INTELLIGENT DECISION SUPPORT SYSTEM FRAMEWORK FOR ENERGY RETROFITS IN EXISTING HOMES

By

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ABSTRACT

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Buildings, particularly residential ones, are one of the major consumers of energy. The majority of the housing stock consists of existing homes, a large number of which are energy inefficient. Retrofitting existing homes to make them energy efficient can contribute immensely to energy savings and associated economic, environmental, and health benefits to homeowners. Despite the established benefits and opportunities of energy retrofitting of homes, its adoption has faced obstacles. The lack of information and the presentation of information in a format not easily understood and used by homeowners for decision-making were identified as major obstacles.

The goal of this research is to support the implementation of home energy retrofits. This goal was supported through the identification of the determinants of home energy retrofit expert knowledge, the development of an energy retrofit expert knowledge elicitation strategy, generating consensus-based energy retrofit knowledge for decision-making, and the development of an intelligent decision support system framework. Specifically, the objectives of the research were to: (1) compile the information barriers to energy retrofits decision process and adoption, (2) analyze the energy retrofit decision process model and its potential implementation as an intelligent decision support system, (3) investigate the process of expertise development with a focus on energy retrofit decision process, (4) develop an expertise elicitation strategy for energy

retrofit knowledge, (5) develop an intelligent decision support system framework for home energy retrofits, and (6) demonstrate the application of the framework with a pilot system.

Seven deliverables were achieved through this research. First, the barriers to home energy retrofit adoption were identified. Second, the protocols followed for decision-making in this domain were appraised and determined to be suitable as a building block for the eventual development of an intelligent decision support system framework. Third, the determinants of home energy retrofit experts were developed. Fourth, a home energy retrofit expertise elicitation strategy was developed and used to elicit the expertise of 19 industry experts, identified based on the determinants of expert knowledge. Fifth, the study was able to identify and achieve consensus on relevant energy retrofit knowledge used in decision-making. Sixth, an intelligent decision support system framework that combines the energy retrofit decision process, quantitative information, and expert knowledge in order to provide suitable information to homeowners to help them with decision-making was developed. Finally, the applicability of the framework was demonstrated using a pilot tool obtained from Exsys Corvid incorporated.

This research proposed an approach that enhances the packaging and delivery of energy retrofit information to homeowners in order to help with decision making. The researcher envisages that the implementation of the findings of this research will remove the information barriers to the uptake of home energy retrofits, leading to an increase in its adoption and hence, reduce energy consumption of buildings to acceptable levels. The researcher further envisages that the determinants of industry expert knowledge and its elicitation, and the intelligent decision support system framework will be accepted and incorporated into industry practices, training, development, and scholarly research.

I dedicate this Ph.D. dissertation to my loving wife and soul mate, the ever-supportive Ama Serwaa Bonsu Duah…

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1

INTRODUCTION

1.1 OVERVIEW

As a result of concerns regarding the inability of the planet to cope with the negative effects of growing human population and practices on the finite resources, there is the need for an intervention to mitigate the fast rate at which the earth's resources are being depleted (LPR 2008, 2010). In recent years, the terms sustainable development and sustainability have been greatly emphasized in our society. The United States Environmental Protection Agency (USEPA) (2011) notes that sustainability is based on a simple principle: our needs for survival and well-being depend, directly or indirectly, on our natural environment. Sustainability, therefore, creates and maintains the conditions under which humans and nature can co-exist in harmony, leading to the achievement of social, economic, and other requirements of present and future generations.

There are two main elements to sustainability: the use of materials, especially those with limited supply or are difficult to recycle, and the use of energy. Material use relates to landscaping, manufacturing, transportation, infrastructure, and building (Lowson 2001). Sustainable building materials include pollution prevention and waste reduction measures in manufacturing, utilizing recycled content, embodied energy reduction, use of natural materials, reduction of construction waste, use of local materials, and energy efficiency (Kim & Rigdon 1998).

From the energy perspective, fossil fuel reserve is one issue that is usually mentioned. Fossil fuels are carbon-based substances formed from the remains of dead animals and plants and used by humans as energy source and includes coal, fuel oil, or natural gas (Jessa 2010; Science Daily 2013). A considerable amount of current energy supply and use is based on limited resources of fossil fuels, which is considered to be environmentally unsustainable. Reducing combustion of fossil fuels as a means of reducing carbon dioxide levels for instance, may lower the levels of harmful air pollutants, like soot (U.S.–GCRP 2012; Lowson 2001; IAEA 2005).

The United States is responsible for nearly one-fifth of all the energy the world consumes (EIA 2011a), or approximately 100 quadrillion Btus of energy, which is the equivalent of over $1 trillion in energy expenditures every year (EIA 2011b). Population growth, and the associated growth in housing, commercial floor space, transportation, goods, and services, is expected to cause a 0.7 percent annual increase in energy demand for years to come (EIA 2011c). Energy consumption must, therefore, be reduced to reach acceptable and sustainable levels. An adequate and affordable energy supply, however, is very important for a number of reasons: it is vital to economic development, central to improved social and economic well-being, and critical to the generation of wealth on industrial and commercial scales (IAEA 2005).

Buildings in general and residential buildings in particular, are one of the major consumers of energy. Compared with other sectors such as transportation and industry, the building sector uses majority of global energy estimated at more than 40%, and a third of global greenhouse gas emissions in developed and developing countries (UNEP 2009). The average household in the United States spends at least $2,000 a year on energy bills, over half of which goes to heating and cooling. Specifically, out of the total energy consumption in an average household, 50% goes to space heating, 27% to run appliances, 19% to heat water, and 4% to air conditioning. The majority of the housing stock, however, consists of existing homes a large number of which are energy inefficient (EIA 2008 cited by USEPA 2009; Energy Star 2012a; United States Census Bureau 2011; USEPA 2009). This research focuses on retrofitting existing homes since older homes far exceed new ones in terms of numbers and are considerably less efficient compared to newly constructed homes.

Energy efficiency means reducing the amount of energy needed to perform a particular task by investing in more effective systems of delivery. Usually, an upfront capital investment in the use or installation of energy saving devices is required and the savings typically pay off the initial expense. For instance, efficiency reduces the demand for electricity without reducing or interfering with the performance of an electrical appliance, and without reducing the comfort or convenience that the appliance provides. Common energy upgrades include the replacement of incandescent light bulbs with compact fluorescent lamps or buying Energy Star rated appliances (IEA 2011; LBNL 2012; Limerick & Geller 2007). Energy efficiency is the most abundant, cheapest, and fastest approach to substantially reducing greenhouse gas emissions. In addition, there is existing technology to implement it on a variety of scales such as homes, cars, large office buildings, and industrial facilities (LBNL 2013).

Retrofitting existing homes to make them energy efficient will greatly lead to energy savings, reduce operating costs and dependence on foreign fuel, improve occupant productivity, and optimize life-cycle economic performance (USEPA 2010c). Increasing investments in energy efficiency in buildings is one of the most constructive, cost-effective ways toward addressing challenges with sustainability due to its economic, social, and environmental benefits (Johnson

Controls 2012; USEPA 2006). Building energy efficiency is the first step toward achieving sustainability in buildings and within organizations (Johnson Controls 2012).

1.1.1 Energy Retrofits in Homes

Refurbishment and retrofit are terms used to describe specific actions done to existing buildings with the intent of upgrading them. Whilst refurbishment work restores a building to its original state, retrofitting a building upgrades it to new requirements (Flourentzou & Routlet 2002). A retrofit is, therefore, the physical and operational upgrade of a building's energy consuming equipment and systems. Retrofits require the replacement or upgrade of old building systems with new energy saving technology and processes. An energy retrofit, by definition, is any improvement made to an existing structure that provides an increase in the overall energy efficiency of the building. Examples of energy-efficient retrofits which can be performed include air-sealing a building's thermal boundary, and installing dense-pack cellulose insulation or loose-fill cellulose insulation (Fulton *et al.* 2012; SME 2012, 2011). Evidence from studies around the world continues to support the assertion that energy efficiency measures and programs result in highly cost-effective investments, even when the narrowest criteria is used (Clinch & Healy 2003). McKinsey and Company, for instance, estimates that increased efficiency would save the United States economy $130 billion per year, while reducing emissions by 1.1 gigatons a year. Moreover, programs dedicated to spur the retrofit of old and inefficient homes or buildings will create jobs and save consumers money (Granade *et al.* 2009).

The building sector has the most potential for providing substantial and economical greenhouse gas emission reductions (UNEP 2009). Since existing buildings consume more than 70% of electricity and produce more than a third of the greenhouse gas pollution in the United States, reducing the energy demand of buildings is vital to promoting a clean energy economy that creates sustainable, quality jobs, and reduces reliance on imported fossil fuels (EERE 2011). Investment in building energy retrofits and other strategies is increasingly becoming a priority in a many cities and states throughout the United States because it simultaneously meets environmental protection, economic development, and social goals (ISC 2009). Though there has been numerous research efforts related to energy efficiency in new home construction in the United States, with over 130 million existing homes compared to an annual addition of about half a million to two million new homes, energy retrofitting existing homes can have a greater impact on saving energy (AHS 2009; BA 2010). Existing techniques and technologies in energy efficiency retrofitting can reduce home energy use by up to 40 percent per home and lower associated greenhouse gas emissions by up to 160 million metric tons annually by the year 2020. Apart from having good payback periods, energy retrofitting homes has the potential to reduce energy bills by $21 billion each year (CEQ 2009).

1.1.2 Cost Effective Energy Retrofit Team Project

This research has been partially conducted as part of a larger project funded by the United States Department of Energy's Building America Program. The Cost Effective Energy Retrofit Team is one of 15 Building America research teams across the United States. Each team was tasked to develop, analyze, and implement strategies to obtain significant and sustainable home energy savings for new and existing homes. The team was grouped under three major research tasks: Tasks 6.1, 6.2, and 6.3 (Cost Effective Energy Retrofit Team, unpublished manuscript, 2011; Duah & Syal 2013a):

- *Task 6.1* was a market characterization project that aimed to identify the dominant archetypes of homes in the Great Lakes Region of the United States. The archetypes were identified by architectural style, vintage, or construction style.
- *Task 6.2* attempted to identify key stakeholders in the value chain of home energy retrofits, and collected information about the needs of those stakeholders. This information can then be used to implement retrofits in a manner that targets the end-user.
- *Task 6.3* proposed a framework of an Intelligent Decision Support System (IDSS) for energy efficiency upgrades. Based on Task 6.3, this research was partially conducted.

1.2 RESEARCH NEED AND JUSTIFICATION

Although the benefits and opportunities of energy efficiency and energy retrofitting of homes are fairly well established, relatively few people are taking advantage of the available retrofit initiatives and cost- and energy-efficient technologies. For instance, in 2007, the approximately 150 energy efficiency-related loan programs in the United States reached less than 0.1% of their potential customers (Fuller *et al.* 2010; Ho & Hays 2010; OTA–U.S. Congress 1993). Generally considered a successful residential energy-efficiency effort, a report by Fuller *et al.* (2010) on findings from a 1980–1992 Bonneville Power Administration Program that provided free audits and highly subsidized retrofits indicates that the program only motivated 5% of eligible customers to have an audit (Palmer *et al.* 2011). Evidence from the Residential Conservation Service, a subsidized audit program established in the late 1970s, suggests that of the audits offered by utilities to their customers at $50 or less, only 3–5% usually responded (Tonn & Berry 1986). Likewise, a review of 85 programs offering audits based on Electric Power Research Institute data found that the average annual participation rate was 3.2% (Berry 1993).

Another estimate of the market penetration for home energy retrofit programs is less than 2% (Neme *et al.* 2011). The United States Department of Energy's Office of Energy Efficiency and Renewable Energy assert that less than 1% of homes have had energy retrofits specifically to save energy (Lee 2010). Under the American Recovery and Reinvestment Act of 2009, about $5 billion was awarded to weatherize modest income homes in the country through the Weatherization Assistance Program. This program authorized grantees to withdraw up to half of the total allocated funds by December 2009. By February 2010, however, only 8% of the total funds had been drawn for the weatherization work (USDOE 2010).

As a result of the above-mentioned reasons, the patronage of energy efficiency and energy retrofits has been low and this has led to what is referred to as the "efficiency gap". This happens when the energy efficiency of buildings, equipment, and appliances in use is far less than what is technically attainable (OTA–U.S. Congress 1993). In the residential sector, many of the traditional building materials and equipment in older homes are known to be energy-inefficient and negatively impact the health of occupants. In order to mitigate these problems and close the efficiency gap, homeowners need to retrofit their homes by switching to innovative and green technologies (Jaffe & Stavins 1994).

In terms of innovations, the construction industry has generally been identified as lagging behind. Existing literature has identified several barriers to technology adoption and energy efficiency in existing homes. These include the lack of access to information about new technology, inadequate training about new products, a lack of information on installation techniques, an inadequate flow of information between manufacturers and industry, and a lack of research flowing from labs in to the field (Koebel *et al.* 2003; Jaffe & Stavins 1994, Listokin *et al.* 2001). To perform effective retrofits, unified and systematic information is required. However, most of this information is scattered and difficult to find (PATH 2002).

In a recent Pan-European survey, on the question of how funds could be targeted in supporting research towards investment in energy efficiency technologies, participants overwhelmingly endorsed spending to demonstrate and validate the potential of current technology with the potential of avoiding good solutions staying in closed boxes without delivering results (European Commission 2005). Respondents agreed that neither cost nor technology was the problem, rather, a lack of information about the available technologies and their benefits to consumers. Bonsall *et al.* (2011) posit that results from the Commission's survey are not atypical, and that of all the market barrier, information is continually cited as most influential to future efficiency adoption.

Getting the right information to the right people in a timely manner and in a more accessible format is important in order to make prudent energy retrofit decisions. A National Renewable Energy Laboratory (NREL) white paper (Bianchi 2011) has noted that Building America Program research is not accessible in a format that is most useful to stakeholders. The Program also identified the importance of information flow in home energy retrofits as one of the key issues. A meeting hosted by Building America in August 2010, in Denver, Colorado, reached a consensus on the necessity of information flow. Some of the facts identified were (NREL 2010b):

- Information is necessary to quantify energy efficiency in appraisal forms
- There is a lack of understanding of energy efficient terminology in the industry
- There is a lack of documentation to remove lead paint from exteriors

- Information is out there, but it is not getting into the hands of the right people
- There is a lack of information to protect trade contractors from liability

Despite the role that information programs play in existing and proposed energy efficiency policy portfolios, very little is known about how participants respond to such programs. Though relatively large literature about various market barriers and market failures in energy efficiency investment exist, limited analyses have focused explicitly on information programs (Newell *et al.* 2006). One of several reasons offered for the efficiency gap is the lack of information about the cost-effective investments that can be made to improve energy efficiency. The lack of information may be particularly important for owners of older existing buildings, who have limited expertise to assess energy retrofit options or customize information to their cases, and may not know how to improve the home's energy efficiency (Palmer *et al.* 2011, Samuel 2011).

Lack of information has been identified as an important reason for low patronage of energy retrofits (Palmer *et al.* 2011) and must be overcome in order to support the implementation of such strategies in the United States. In the following sections, the need for energy efficient homes is highlighted. Specifically, two types of information barriers militating against the adoption of energy retrofits, quantitative information and expert knowledge, are explained. Finally, the need for an integrated and easy-to-use decision support system is discussed.

1.2.1 Need for Energy Efficient Homes

Wasting energy costs money and also affects the planet negatively. As a result of the instability in the oil and gas markets, many people seek ways to cut down on energy costs (Nutt 2009).

Several studies support the assertion that energy efficient homes are comfortable since the additional insulation keeps interior walls at a more comfortable and stable temperature, indoor humidity is better controlled, drafts are reduced, and there are fewer chances of excessive moisture and air seeping through the walls. In addition, such homes are relatively quiet as a result of the extra insulation and tight construction (NREL 2000).

1.2.1.1 Problems with Energy Inefficient Homes

Existing homes are faced with a number of challenges in a bid to make them energy efficient. Common problems with such homes are shown in Table 1.1 (Energy Star 2012b).

Table 1.1: Common Problems in Energy Inefficient Existing Homes

High Energy Bills	Moisture on Windows
Mold, Mildew or Musty Odors	Ice Dams
Damp Basement	Peeling or Cracking Paint
Cold Floors in Winter	Hot or Cold Rooms
Drafty or Uncomfortable Rooms	Dry Indoor Air in winter
Dust Increase	

As a result of building codes, appliance standards, and general technological improvements, new buildings tend to be much more efficient than existing buildings. For instance, a home built in the 1940s consumes, on average, 50.8 thousand British thermal units (mBtu) per square foot, even with previous improvements. This is much lower when compared to an average home built in the 1990s, which only consumes 37.7 mBtu per square foot (Palmer *et al.* 2011; USEIA 2009). The Joint Center for Housing Studies (2009) estimates that 40% of residential energy consumption is attributable to homes built before 1970 and 72% to homes built before 1990. Without retrofitting these existing buildings, it will be difficult to considerably reduce carbon dioxide emissions associated with energy use. Since existing homes consume the majority of energy for residences, and many of them, especially those built before 1970, tend to be energy inefficient, there is the need to significantly reduce energy consumption in homes and reduce energy costs to make homes more affordable (PATH 2002). Retrofitting existing homes to make them energy efficient is beneficial to homeowners, builders, and the environment.

1.2.1.2 Need to Protect Occupant Health and the Environment

Even though homes are typically perceived as not causing pollution, energy sources such as electricity, fossil fuels, etc., contribute to environmental problems such as global warming, acid rain, and smog (SEI 1998). Research shows that indoor air may be more polluted than outside air. Considering that most Americans spend most of their time indoors, in artificially controlled environments of buildings, there is a need to protect occupant health and the environment (DOHW 1999; Klepeis *et al.* 2001). The National Institute for Occupational Safety and Health (2005) has found that indoor environment quality problems are usually caused by ventilation system deficiencies, overcrowding, material off-gassing and mechanical equipment, tobacco smoke, microbiological contamination, and outside air pollutants. It also found that comfort problems are due to improper temperature and relative humidity conditions, poor lighting and unacceptable noise levels, adverse ergonomic conditions, and job related psychosocial stressors. Thus, homes must be energy-retrofitted in order to protect occupant health and the environment.

1.2.2 Need for Quantitative Information for Energy Retrofit Decision Making

Within the energy retrofit industry, quantitative or published information can be obtained from construction and energy efficiency-related information portals and databases currently existing in the United States, energy simulation software, and existing literature/publications (Samuel 2011).

1.2.2.1 Need for Building Energy Simulation Tools

An important tool employed in energy auditing is an energy simulation tool that supports evaluation of demand and supply of building energy technologies. The simulation tool must also support various decision points throughout the life cycle of the design and operation of buildings. These new software tools calculate how building control systems behave and the impact it has on energy use, peak demand, equipment sizing, and the comfort of occupants in order to provide insights into its performance, previously unavailable to the building industry.

The National Residential Energy Laboratory has developed the Building Energy Optimization (BEopt™) software to provide capabilities to evaluate residential building designs, and identify cost-optimal efficiency packages at various levels of whole-house energy savings along the path to zero net energy. BEopt™ can analyze both new construction and existing home retrofits, through evaluation of single building designs, parametric sweeps, and cost-based optimizations. It provides detailed simulation-based analysis based on specific house characteristics, such as size, architecture, occupancy, vintage, location, and utility rates. Discrete envelope and equipment options, reflecting realistic construction materials and practices are evaluated (NREL 2011). Due to the availability of existing energy simulation software and published literature from Building America documents and other literature, there is a need for this information in order to successfully perform energy retrofits.

1.2.2.2 Need for Unified and Central Information (e.g. Cost Database) and Standard Protocol

Despite the relevance of quantitative information in decision-making by homeowners, PATH (2002) assert that homeowners are confused about the varying and conflicting quantitative information that is available in published sources such as cost databases. A major cost database provided by the United States Department of Energy through the Building America program is the National Residential Efficiency Measures (NREM) database. This database was designed as a public, centralized resource of home retrofit measures and costs. It is intended mainly to assist users with deciding upon the most cost-effective retrofit measure(s) for improving the energy efficiency of homes (NREL 2010a). The availability of such a public, centralized, and trusted resource for cost information for energy retrofits is, therefore, pertinent in helping homeowners when making retrofit decisions.

Additionally, unified and systematic information about product availability, cost, manufacturers, potential energy savings, performance certification, and building codes help consumers make the right choices and can accelerate the diffusion of energy efficiency technologies. Most of this information, however, is scattered and difficult to find. The lack of standard protocol to dictate the methods used by home energy retrofits professionals, such as trade contractors and energy auditors, to retrofit a home, has been identified as one of the barriers to the large-scale implementation of energy efficiency in existing homes. The process of overcoming this barrier requires conducting interviews with industry professionals and developing a standard protocol for retrofits (PATH 2002).

1.2.2.3 Need for Standardized Information

There has been a challenge with obtaining standardized industry information. Liz Cocke has posited that, "the problem is not a lack of energy efficient technology, but rather, a lack of information required to implement such technologies" (Liz Cocke, personal communication, December, 2011). One important conclusion drawn at a Building America expert meeting held in October 2010 in New York to optimize condensing boilers with low-temperature distribution and to identify key research and gaps in the condensing boiler industry was that condensing boilers are not being successfully implemented on a large scale due to a clear lack of information on optimum installation strategies and insufficient training for installers and designers. Condensing boilers are 10%-12% more efficient than conventional boilers since they utilize the latent heat of water in addition to its sensible heat. The meeting also set goals to assess current literature and cure the current information vacuum (Aspen Publishers 2010; Samuel 2011).

1.2.2.4 Need for Trustworthy Information

One of the important reasons for the market failure of energy efficient technology is imperfect, or asymmetric, information about such technology (Golove & Eto 1996). Ideally, information is perfect and free (Harris & Carmen 1991 cited by Golove & Eto 1996). Instances of imperfect information include the lack of information, the cost of securing information, the inaccuracy of information, and the ineffective use of information. Regarding the cost of acquiring information, the cost in time, money, or both, when information is available, is usually mentioned (Golove & Eto 1996) and is part of the initial investment related to technology adoption. Any reduction in the cost of information that ensures that adoption costs are reduced will accelerate technology diffusion (Jaffe & Stavins 1994).

Inaccuracy of information has also been recognized in recent times. The self-interests of manufacturers of energy efficiency technologies, which lead to a lot of misinformation in their product advertisements, exist. This has led to mistrust among consumers who may have suffered previously from such misinformation (Golove & Eto 1996; PATH 2002; Samuel 2011). There is, therefore, a need to have trustworthy information.

1.2.3 Need for Expert Knowledge for Energy Retrofit Decision Making

Homeowners may not be aware of the inefficiency of their homes and the availability and benefits of energy retrofits. Specific opportunities for improving the energy efficiency of a building are typically more difficult for homeowners to evaluate on their own. Thus, information provided by experts, such as energy auditors, is not only useful, but has an important role to play in filling the information gap that exists on building energy efficiency (Palmer *et al.* 2011). Apart from quantitative information needed to undertake energy retrofits, homeowners need to draw on the expertise/knowledge of experts within the industry. This section highlights the need for expert knowledge in energy retrofit decision-making and implementation.

1.2.3.1 Lack of Expertise of Homeowners in Energy Retrofits

The average homeowner does not have the capacity to determine the energy efficiency of their home, or the best option to deal with it (EnerGicity 2010). A survey by Komor *et al.* (1989) found that small business owners in energy decision-making positions are neither well informed, nor equipped to make energy efficiency decisions. Palmer *et al.* (2011) assert that the lack of information is problematic for owners of older existing buildings, who do not have the expertise to assess energy retrofit options, and may not know how to improve energy efficiency. For example, homeowners may have challenges determining the right insulation options and the resulting energy savings thereof. They are also unlikely to know the payoffs from other measures applied to make the building envelope tighter, or the heating and cooling systems efficient.

In addition, comparing alternative options and combinations of options can be overwhelming for homeowners; hence the need for expert knowledge. For instance, energy audits of homes performed by a qualified energy auditor can provide important information about current energy use and opportunities for improving energy efficiency. Samuel (2011) posits that homeowners may not have the knowledge to customize all the available published information to their particular case. They may also be confused about the varied and conflicting quantitative and qualitative information available in published sources and from utility companies (PATH 2002).

In a recent survey of 505 United States residents about their perceptions of energy consumption and savings for a variety of household, transportation, and recycling activities, Attari *et al.* (2010) found that the perception of the public about personal energy consumption and the cost savings accrued from increased energy efficiency were widely erroneous and in contrast to recommendations by experts. Palmer *et al.* (2011) assert that one reason why residents have little knowledge of energy efficiency is the current lack of energy auditing in the residential sector. When a person makes a decision to purchase or rent a home, s/he has no way of determining the energy efficiency levels of the available options. Thus, though a person may prefer a more energy efficient building, they are unable to act on such preferences. There is, therefore, the need for expert knowledge to assist in making energy efficiency decisions regarding home upgrades.

1.2.3.2 Need for Energy Retrofit Professionals to Impart Trustworthy Expertise

Expertise is an important asset that must be well-managed in order to make maximum use. At the core of managing expertise, is "getting the right knowledge to the right people at the right time and in the right format" (Epistemics 2003). Expertise, however, is usually so repetitive that experts no longer know what they do or why they do it. As expertise grows, performance of the task becomes automatic, a cognitive phenomenon referred to as automaticity (Armstrong 2003; Shadbolt 2005). In July 2010, a meeting sponsored by the Building America Program was held in Denver, Colorado, to discuss key opportunities and barriers associated with residential energy efficiency. A total of 164 key gaps, barriers and/or issues were identified in the report under the following general themes: challenges with knowledge impartation, lack of consensus on knowledge, need to standardize knowledge, and challenges with knowledge definition or quantification (NREL2010b). These highlight the challenges faced by experts in imparting knowledge to homeowners despite their expertise and the need to develop strategies to assist the impartation of trustworthy expertise.

Results from a survey of home energy auditors related to assessing the energy efficiency gap indicate that energy auditors feel the public knows too little about them or do not trust their advice (Palmer *et al.* 2011). In addition, homeowners may have a perceived distrust of energy auditors, especially those with a contracting interest (NREL 2010a; Palmer *et al.* 2011; Romero 2011; Samuel 2011). There is, therefore, a need to have trustworthy retrofit professionals who will make their expertise available to homeowners devoid of any biases.

1.2.3.3 Need for Framework for Knowledge Elicitation

Knowledge acquisition, which includes the elicitation, collection, analysis, modeling, and validation of knowledge, is a critical and basic task in the management of knowledge (Epistemics 2003). Construction projects are unique and temporary, just as construction project participants and teams. Lessons learned on previous projects are scattered when projects are completed if not recorded or shared properly. Since most construction experiences exist in the minds of people, it is important to elicit their tacit knowledge to be shared and reused in future projects (Hu 2008). The elicitation of tacit knowledge, used in building knowledge-based systems, is one of the most difficult and error-prone tasks faced by knowledge elicitors. During this process, how to capture the knowledge, and how to disseminate the acquired knowledge must be determined. By developing a framework for knowledge acquisition, a consistent method for capturing the knowledge of human experts is assured (Rhem 2001). There have, however, been challenges with the availability and use of expert knowledge for energy retrofits by homeowners. Reasons include confusion about the varied and conflicting quantitative and qualitative information available in published sources, and non-trust of information from utility companies (PATH 2002). There is, therefore, a need to develop a framework for knowledge elicitation from retrofit experts to assist the retrofit decision-making process.

1.2.4 Need for Integrated and Easy-To-Use Decision Support System (DSS)

A Decision Support System (DSS) an interactive computer-based system intended to help users make decisions by retrieving, summarizing, and analyzing relevant decision data. It can improve the effectiveness of decision-making, decrease the need for training, improve management control, facilitate communication, save effort by the user, reduce costs, and allow for more objective decision-making (Power 1998; Turban *et al.* 2005).

In December 2011, Liz Cocke, the director of the Affordable Housing Research Division of the United States Department of Housing and Urban Development noted that “there is too much information out there for building technologies, no one knows what to read and no one knows what/who to believe". Holm (2000) posits that asymmetric information puts residents with inadequate knowledge and experience at disadvantaged situations in a refurbishment process. These assertions bring to the fore two major issues regarding undertaking effective energy retrofits: (1) the need to provide homeowners with comprehensive and reliable *expert knowledge* that is integrated with (2) associated *quantitative information*.

In order to promote energy retrofits among homeowners, there is the need to focus on the packaging and delivery of technological information and expert knowledge. Homeowners can approach experts in this field for clarifications. To realize this, fairly complicated systems involved in the energy retrofit process must be harmonized so that the most appropriate retrofit actions can be selected. At the core of this process is the ability to have unified and systematic information that combines reliable expert knowledge with quantitative information. There is, therefore, the need to capture the quantitative information and expert or experience-based expertise/knowledge of experts. These must be substantiated with building science knowledge and standardized protocols and can be codified into an interactive computer-based tool, or decision support system, to deliver cost effective energy retrofit information to homeowners.

Expert knowledge and quantitative information such as cost databases, energy simulation software, and published information have significant roles in decision making in energy retrofits. Though related, these have not generally been used in an integrated manner. To provide synthesized energy retrofit information in a comprehensive and coordinated fashion, there is a need to integrate all of them in a decision support system. Such an integrated system will provide an overall basis for developing an effective query-based system where the database and expert knowledge will be used to determine the cost-related quantitative parts of the decision, and the simulation program will interpret and help prioritize the measure selection decision. Finally, the published information and expertise of experts will provide the installation and safety related details. This integrated process will support users in reaching decisions with more confidence and will eventually help promote the adoption of home energy retrofits.

1.2.5 Available Decision Support Systems (DSS) in Related Domains

By definition, a decision support system must include three major components: (1) data base management system, (2) model base management system, and (3) dialog generation and management system (Leishman 2005). Though a fourth component, the knowledge-base management system, is optional, it can provide many benefits by providing intelligence to the three major components (Turban *et al.* 2005). Hermez (2012) has argued that many unstructured and semi-structured problems are so complex that they require expertise for their solutions. Such expertise can be provided by a knowledge-based system, such as an expert system. Therefore, the more advanced decision support system are equipped with knowledge-based systems, which can provide the required expertise for solving some aspects of the problem, or provide knowledge that can enhance the operation of the other system components. A decision support system that includes such a component is referred to as an intelligent decision support system (IDSS) or knowledge-based decision support system.

Assessing existing building conditions and retrofitting involves fairly complex systems; hence stakeholders may want to use a decision support system. Though a majority of conventional systems have been created to mainly manage descriptive and procedural knowledge, IDSS are concerned with representation and processing of reasoning knowledge (Holsapple & Whinston 2006). Decision support systems have been used in related domains such as energy auditing, scheduling, estimation, and manufacturing.

An example of a decision support system is one by Doukas *et al.* (2009), who proposed an energy retrofit model that showed the potential for introducing new retrofit actions and new energy efficient standards. It had the following units:

- *Proposals Database:* This contains a set of possible retrofit measures, specifically for building operations, installation and maintenance costs, and energy saving costs attained by the application of measures.
- *Decision Support Unit:* As the core of the model, it provides the sequence of the evaluation processes for the retrofits. Experience data and external parameters are used to implement the unit's evaluation.
- *Experience Database:* This contains the building energy management systems data, relevant external parameters, and experience database.
- *Proposal List:* This includes the final list of proposals for the building.

1.2.6 Summary of Research Need and Justification

Though the benefits and opportunities of energy retrofits are fairly well established, relatively few people are taking advantage of the available retrofit initiatives and cost-effective, energy efficient technologies. Lack of information has been identified as an important reason for the low patronage. This has led to what is referred to as the "efficiency gap". The following needs were identified as the basis of this research:

- *The Need for Energy Efficient Homes*: unlike energy efficient homes, energy inefficient counterparts have negative social, economic, health, and environmental impacts; hence the need to upgrade such homes.
- *Need for Quantitative Information for Energy Retrofit Decision-Making*: there is a need for building energy simulation tools, unified and central information such as a cost database and standard protocol, and a need for standardized and trustworthy information devoid of any biases.
- *Need for Expert Knowledge for Energy Retrofit Decision-Making*: homeowners lack the expertise in energy retrofits and also need industry professionals to impart trustworthy expertise. It is also important to develop a framework for knowledge elicitation.
- *Need for Integrated and Easy-to-Use DSS*: there is a need to focus on the packaging and delivery of quantitative information and expert knowledge using an interactive computer-based tool such as an intelligent decision support system.
- *Available DSS in Related Domains*: decision support systems have been successfully applied in related domains: hence the need to explore its application in the energy retrofit domain.

It is important to understand and integrate the development and elicitation of expert knowledge with quantitative information such as cost databases, energy simulation software, and published information in decision making for energy retrofits (Figure 1.1). This provides synthesized energy retrofit information in a comprehensive and coordinated fashion, thus providing an overall basis for the development of an effective intelligent decision support system.

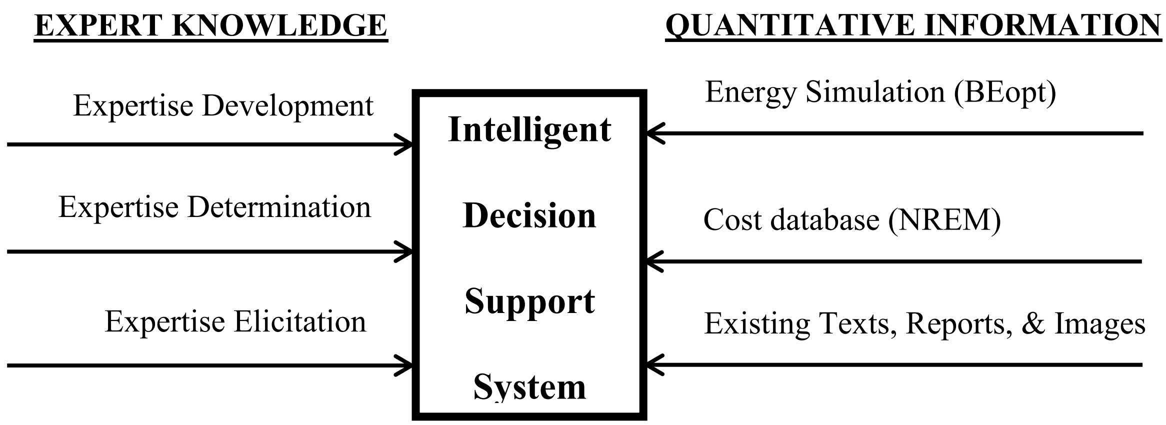


Figure 1.1: Integration of Expert Knowledge with Quantitative Information into IDSS

1.3 RESEARCH QUESTION

Though the benefits and opportunities for home energy retrofits are fairly well established, its adoption has faced huge obstacles. The lack of information, or information in a format not understood and used by homeowners, are major reasons identified from research literature. Therefore, the following research question is proposed:

> Comprehensive and easy to use information is essential to decision making for home energy retrofit. The comprehensiveness of this information includes an integrated approach to expert knowledge coupled with vast amount and varied types of quantitative information. What research approach can be used to identify, capture, and integrate these information types in order to use them as an intelligent decision support system?

1.4 RESEARCH GOAL AND OBJECTIVES

The main goal of this research is to support the implementation of home energy retrofits. This goal is envisioned to be supported through:

1. The development of the determinants of expert knowledge in the energy retrofit domain

2. The development of an energy retrofit expert knowledge elicitation strategy
3. The building of consensus on energy retrofit domain knowledge for decision-making
4. The eventual development of an easy-to-use query-based intelligent decision support system framework

Specifically, the following objectives will be accomplished through this research:

Objective 1 – Energy Efficiency Retrofits

- To compile the information barriers to energy retrofits decision process and adoption

Objective 2 – Energy Retrofit Decision Process

- To analyze the energy retrofit decision process (ERDP) model and its potential implementation as an intelligent decision support system (IDSS)

Objective 3 – Expertise Development

- To investigate the process of expertise development with a focus on energy retrofit decision process

Objective 4 – Expertise Elicitation

- To develop an expertise elicitation strategy for energy retrofit knowledge

Objective 5 – Intelligent Decision Support System for Energy Retrofits

- To develop an intelligent decision support system framework for home energy retrofits

Objective 6 – IDSS Pilot Tool Demonstration

- To demonstrate the application of the IDSS framework with a pilot system

1.5 RESEARCH METHODOLOGY

To solve the research problem, a structured process involving breaking down the objectives using work steps is proposed to be followed. Figure 1.2 shows a structure of the research.

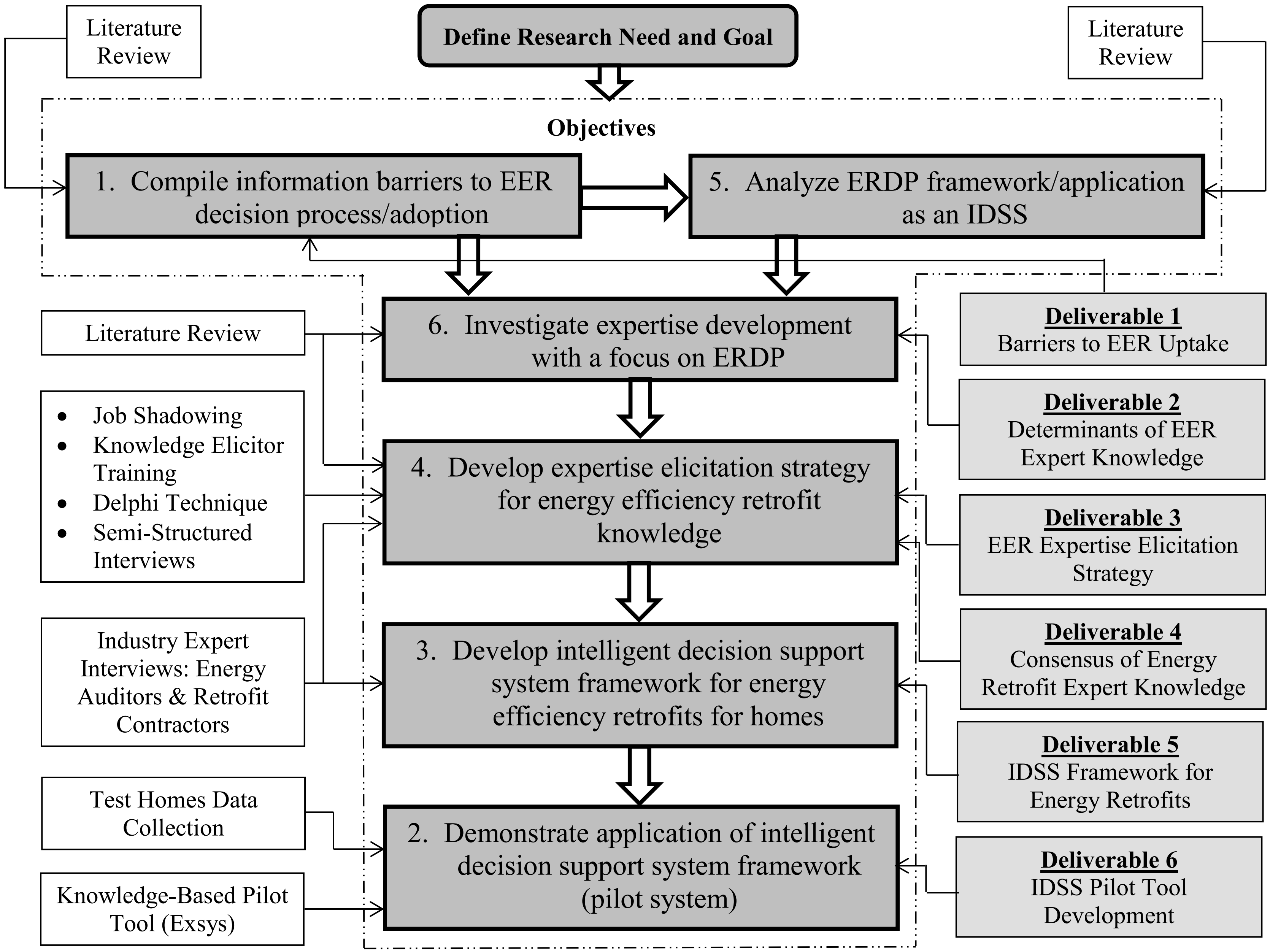


Figure 1.2: Research Structure

1.5.1 Objective 1

To compile the information barriers to energy retrofits decision process and adoption.

Step 1: Describe the energy retrofits decision process and define key information categories required for such decisions

Information available from government documents, research institutions, published literature, energy retrofit experts, and two Master's theses regarding the energy retrofit decision process were compiled. Specifically, information about the following were reviewed: (a) history, need, catalysts, and barriers; (b) energy retrofit process; and (c) programs, initiatives, and available financial incentives. Key information sources for the research were obtained from:

- Government (USDOE websites e.g. Building America program, Building Technologies program, NREM Database, Lawrence Berkley National Laboratory, etc.)
- Energy retrofit experts belonging to the two main nationally recognized professional bodies – Residential Energy Services Network and Building Performance Institute, Inc.
- Industry research and not-for-profit institutions (e.g. DOW, Habitat For Humanity)
- Published literature (mainly from refereed journals and energy efficiency-related books, two Masters theses from the Construction Management Program, Michigan State University)

Finally, information barriers to the adoption of energy retrofits were compiled.

1.5.2 Objective 2

To analyze the energy retrofit decision process (ERDP) model and its potential implementation as an intelligent decision support system (IDSS).

Step 2: Investigate the development of the ERDP model

The ERDP framework developed by the Cost Effective Energy Retrofit team was reviewed by investigating the following three steps in the energy retrofit decision process model:

1. Identify Retrofit Measures
2. Shortlist and Prioritize Measures
3. Provide Expert Advice on Installation

The instances of use of quantitative information showing examples were compiled. Specifically, the model was thoroughly examined to establish the significant role that expert knowledge plays in residential energy retrofit decisions. This information was central to the development of the knowledge-based or intelligent decision support system. It must be noted that the main work related this step has been covered in an MS thesis.

Step 3: Study Intelligent Decision Support Systems and investigate the potential implementation of the energy retrofit decision process model as one

The aim was to understand the development, types, components, and benefits of decision support systems. Specifically, knowledge-driven systems such as intelligent decision support systems were emphasized. Information was obtained mainly from a review of decision support system literature with a focus on knowledge-based/intelligent systems. Two of such systems used as a basis for this research were identified from literature and analyzed. Next, the application of knowledge-based systems in other domains, such as housing assessment and building refurbishments, were explored to understand the decision-making process. This information, and that obtained from the cost effective energy retrofit team report, was used as the basis in exploring the suitability of the energy retrofit decision process model as such a system.

1.5.3 Objective 3

To investigate the process of expertise development with a focus on energy retrofit decision process.

Step 4: Study the theory of the nature and development of expertise

This was obtained mainly from the cognitive psychology literature, specifically, literature relating to the following:

- Nature of Expertise (Defining expertise – cognitive development, knowledge structure, reasoning process)
- Development of Expertise (Expertise development versus skill acquisition; novices versus experts)
- Elicitation of expertise (techniques and methods)
- Application of expertise in the energy retrofit decision process (Experience, automaticity, and learning outcomes)

Step 5: Develop standard criteria for determining an energy retrofit expert

Dominant qualities that differentiate experts from novices were compiled from cognitive psychology with inputs from objectives #1, #2, #3. This was used as the basis for developing preliminary criteria for determining an energy retrofit expert. Using the Delphi technique, 23 industry experts were selected, interviewed, and the protocol generated was analyzed in order to obtain an understanding of the domain and enhance the preliminary criteria that cover the qualities differentiating an expert from a novice. Participants were allowed to modify and expand on the elicited knowledge to ensure they were satisfied with the results. Based on the information from the analysis of the generated protocols, the determinants of energy retrofit expert knowledge were developed and provided the basis for selecting experts whose knowledge was elicited for the development of the proposed intelligent decision support system framework.

The rationale for the sample size was based on a network of 129 independent, Building Performance Institute certified, home performance contractors created by Consumers Energy in 2012. Contractors, who performed only partial energy retrofit work, such as insulation or HVAC only, were not considered since such jobs were subcontracted to them by home performance contractors. Discussions with an expert in the industry who had extensive interaction with utilities and Michigan Saves indicated that, between 40 – 50 contractors out of the total of 129 industry professionals have acceptable competence level and are still in regular business. In a reply to an email on October 16, 2012, the expert had this to say:

> "*Had meetings in Lansing today, with utilities and MI Saves folks. Both reiterated my thoughts that only a portion of the contractor list actually do any work and only a fraction of those are full Home Performance contractors. The consensus thought around the meeting this am was about 40 to 50 companies" (sic).*

Preliminary criteria for selecting 23 industry practitioners for this research was based on intensity of work performed, size of company, experience, and uptake of retrofit advice proffered to homeowners.

1.5.4 Objective 4

To develop an expertise elicitation strategy for energy retrofit knowledge.

Step 6: Develop expertise elicitation strategy for energy retrofits expert knowledge

The methods and techniques for eliciting expertise were obtained by combining inputs from objective #3 and mainly by reviewing literature from cognitive psychology particularly related to the variety of available knowledge elicitation techniques.

Next, an expertise elicitation strategy was developed mainly by combining relevant elicitation techniques from literature and interviews. Protocols generated were analyzed and the results were used to refine the elicitation strategy. This provided the basis for eliciting the knowledge of selected experts from step #5 who qualified based on the expert knowledge determinants developed for this domain.

Step 7: Elicit relevant expert retrofit expertise

Using the elicitation strategy developed in step #6, relevant retrofit expertise was elicited from the identified experts. The aim was to incorporate relevant expert retrofit knowledge into the proposed intelligent decision support system.

1.5.5 Objective 5

To develop an intelligent decision support system framework for home energy retrofits.

Step 8: Analyze expert knowledge obtained in objective #4 and develop a knowledge representation strategy for energy retrofits to be incorporated into proposed IDSS

The expert knowledge elicited was used to identify heuristics they use in their decision-making. Six knowledge-based modules that addressed specific components of homes in energy retrofits were developed to assist with decision making in this domain. The aim of this step was to identify the detailed process of conducting an energy retrofit by experts. Based on this, common sequences employed by experts were identified.

Step 9: Refine energy retrofit decision process model by expanding on the expert knowledge part

The model was refined to align with the requirements of an intelligent decision support system. Omissions from the existing model were included. To understand the role of expert knowledge in the model, the following structure was followed:

- The general structure of the expert energy retrofit decision-making process
- Flow of information and operations used in the process
- Work routines and procedures used by retrofit experts

Step 10: Develop framework for intelligent decision support systems for energy retrofits

Based on step #9, Boolean logic rules that captured the heuristics used by experts were identified mainly through the knowledge elicitation process obtained from objectives #3 and #4. This ensured that factors affecting decision-making in this domain were identified. Using decision trees, a graphical representation of a sequence of interrelated decisions were made. The elicited knowledge formed the basis for the IF-THEN-ELSE rules. For example, if a pattern of determining the need of the homeowner and ensuring that their needs are met is established, the following rule could be used:

IF *the need of the homeowner is known,* THEN *it must be a priority to be achieved.*

Finally, the expert knowledge obtained was integrated with the quantitative or published information using an expert system platform in order to develop the framework for an intelligent decision support system for the energy retrofit industry. The components of the intelligent decision support system framework are:

- Data Management Subsystem (investigate and incorporate relevant published databases such as NREM cost database, BEopt energy simulation software, and published texts)
- Knowledge-based Management Subsystem (develop sub modules for major components of a home by incorporating expert knowledge obtained from the elicitation process)
- Dialog Management Subsystem (identify similar systems such as an expert system that can be used to understand and enhance the user interaction with the framework)

1.5.6 Objective 6

To demonstrate the application of the intelligent decision support system framework with a pilot system

Step 11: Obtain and understand a knowledge-based tool to demonstrate the use of expert knowledge in integration with quantitative information

A knowledge-based tool that can be used to support decision-making was identified and obtained from Exsys Corvid Inc. In order to understand and use it, training programs such as manual review, tutorials, and online training, etc. were completed by the researcher.

Step 12: Develop pilot intelligent decision support system and present to homeowners

Based on objective #5, a pilot intelligent decision support system that combined published information and expert knowledge to help homeowners make energy retrofit decisions was developed. The system was tested on two homes with 2 groups of homeowners each. Each set of homeowners had performed limited retrofit in the past, had a knowledgeable and not-very-knowledgeable partner in this domain, had homes located within the scope of the research, and were willing to participate in the study. The aim was to ascertain the applicability of the research approach used to identify, capture, and integrate home energy retrofit information types its effect on the uptake of home energy retrofit measures by homeowners using the case study approach.

1.6 RESEARCH SCOPE AND LIMITATIONS

1.6.1 Research Scope

This research explores the information barriers to implementing energy retrofit measures in existing homes and suggests the use of an intelligent decision support system that emphasizes greatly the importance of expert knowledge in integration with quantitative information and incorporated into the proposed system. The research scope is as follows:

- This research is part of a bigger body of research performed by the Cost Effective Energy Retrofit team in the area of cost effective energy retrofits. Specifically, it covers Task 6.3, intelligent decision support system for energy efficiency upgrades.
- This research explains the fundamental concept of a decision support system, and the application of an intelligent decision support system using a query-based expert system platform obtained from Exsys Corvid Incorporated.
- Quantitative information for the research is based on that developed by the Cost effective Energy Retrofit team and based on the following sources: NREM database, integration of the XML database with an Expert System, energy simulation software obtained from BEopt, compiled published residential retrofit research and Building America reports, the integration of text and visual information, and uses financial incentive obtained from the Database of State Incentives for Renewables and Efficiency.

- Expert knowledge was obtained from 19 industry experts based on the elicitation strategy developed in this research.

1.6.2 Research Limitations

The limitations of this research are as follows:

- This research is based on the energy retrofit decision process framework developed by the Cost Effective Energy Retrofit team research team for intelligent decision support system for energy retrofit upgrades.
- The emphasis is on the use of expert knowledge as the main knowledge-base of the proposed system.
- The integration of quantitative information is limited to that provided by previous work by the Cost Effective Energy Retrofit team.
- Experts whose expertise was elicited for the research are all based in the Midwest Region of the United States.
- Expert knowledge was obtained from 19 industry experts based on the elicitation strategy developed in this research.

1.7 RESEARCH OUTCOMES AND PROJECTED BENEFITS

The primary outcome of the research is to develop an intelligent decision support system framework that combines quantitative information and expert knowledge to help homeowners make energy retrofit decisions with the view of supporting the implementation of energy retrofit strategies in the United States. Specifically, six sub- outcomes were achieved to support the main research outcome of helping improve the uptake of home energy retrofits and are shown below:

1. Compilation of major barriers to the uptake of energy efficiency retrofits
2. Developing the determinants of energy retrofit expert knowledge
3. Developing of an energy retrofit expertise expert knowledge elicitation strategy
4. Building of consensus on relevant energy retrofit knowledge for decision-making
5. Developing an intelligent decision support system framework for energy retrofit decision making
6. Developing a pilot tool to demonstrate applicability of intelligent decision support system framework

1.8 ORGANIZATION OF DISSERTATION

This dissertation is composed of seven chapters. Chapter one provides a general overview of the energy retrofit domain and the information barriers that militate against the implementation of energy retrofit measures, thus necessitating the need for this research. Chapter one also highlights the goal, objectives, and scope of the research and provides an overview of the methodology employed in this research. Chapter two presents the literature review regarding three broad categories of energy efficiency retrofits, expertise development and elicitation, and decision support systems. Chapter three provides an appraisal of previous work done by the Cost Effective Energy Retrofit team regarding the integration of quantitative information into the energy retrofit decision process model as a building block for the development of an intelligent decision support system.

Chapter four discusses the development of expert knowledge. This resulted in the eventual development of the determinants of energy retrofit expert knowledge. Next, a combination of relevant knowledge elicitation techniques was used as the basis to develop an elicitation strategy that enabled the elicitation and compilation of industry knowledge. Consensus on relevant expert knowledge for decision-making was also reached. Chapter five explains the development of an intelligent decision support system framework based on three building blocks: the energy retrofit decision process model, quantitative or published information, and expert knowledge. This chapter also emphasizes greatly the importance of expert knowledge in integration with the two other building blocks in order to help homeowners make energy retrofit decisions. Chapter six provides a demonstration of the proposed intelligent decision support system framework using a pilot knowledge-based decision support system. It also discusses the results of presenting this tool to homeowners of two test homes. Finally, Chapter seven provides the summary and contributions of the research and outlines recommended areas for future research.

1.9 CHAPTER SUMMARY

This chapter highlighted the background information for this study. The need, goal, objectives, as well as the methodology for achieving the set objectives were also discussed. Finally, the scope and limitations of the research were clarified, and the outcomes, projected benefits, and organization of the research were also provided.

CHAPTER 2

LITERATURE REVIEW AND BACKGROUND INFORMATION

2.1 INTRODUCTION

This chapter presents a review of literature regarding the background of decision making in energy efficiency retrofits and the concepts of the development and elicitation of expertise as well as decision support systems (DSS). Specifically, the literature review has been organized into three broad categories of energy efficiency retrofit, expertise development and elicitation, and decision support systems (see Figure 2.1). It is essential to understand the basic concepts underlying these categories of literature and their related tools in order to understand the decision making process and find ways to assist the process of decision-making in the energy retrofit domain. The aim is to support or increase the implementation of energy retrofit measures.

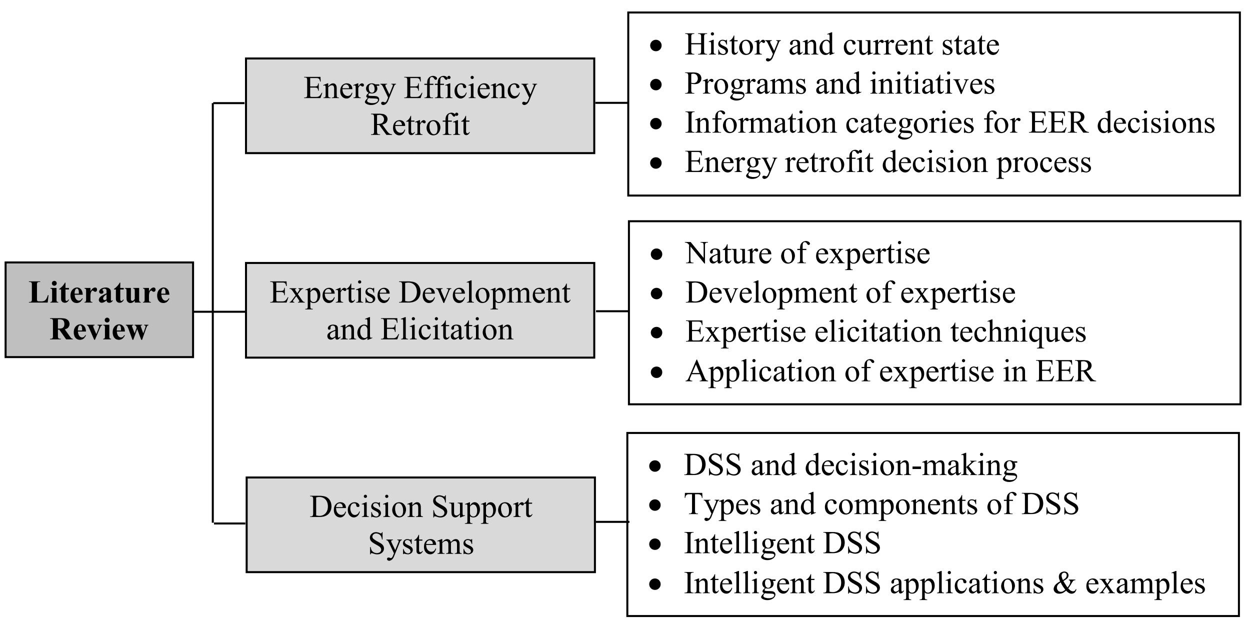


Figure 2.1 Structure of the Literature Review

2.2 ENERGY EFFICIENCY RETROFIT

This section reviews the history and current state of energy retrofits. Literature on programs and initiatives mainly by the government and aimed at encouraging energy retrofit measures implementation were reviewed. Finally, information categories for such decisions were appraised.

2.2.1 History and Current State

Since the energy consciousness of the early 1970s, several agencies including government and non-government, have sought to implement measures to promote energy efficiency in buildings. Such measures include: building energy codes and policies, government programs, and the green building movement. Energy codes and standards set minimum requirements for ensuring that the design and construction of new and renovated buildings are energy-efficient and impacts energy use and emissions for the life of the building. Essentially, they are part of the general building codes critical to the design and construction of buildings (EERE 2011).

The United States Environmental Protection Agency (USEPA 2010a) defines green building as the practice of creating structures and using processes that are environmentally responsible and resource-efficient throughout a building's life-cycle from siting to design, construction, operation, maintenance, renovation, and deconstruction. In the United States, the need for more energy efficient and sustainable construction practices led to the start of the green building movement. According to the USEPA (2010b), sustainable practices, such as using local and renewable materials or passive solar design, started years ago. They note that, the Anasazi in the Southwest of the United States for instance, built entire villages so that all the homes received solar heat in the winter. Syal *et al.* (2009) assert that the green building movement has been a significant contributor to the energy efficiency of buildings in recent times.

The first significant movement toward green buildings can be attributed to the environmentalism movement of the early 1970s. This movement was mainly kindled by a 1962 book authored by Rachel Carson, "Silent Spring," which spoke against the conventional environmental practices of the government. The second major landmark was the oil crisis of the 1970s which only lasted a week, yet had long-term consequences and incited fears of rising fuel costs and the exhaustion of fossil fuels. As a result, several government policies and laws aimed at energy conservation were introduced. For instance, in 1977, the United States Department of Energy was created to address energy usage and conservation. That same year, the Solar Energy Research Institute was established and was later named as the National Renewable Energy Laboratory (NREL) with the mandate to investigate energy efficient technologies such as photovoltaics (Duah *et al.* 2012; Samuel 2011; Syal *et al.* 2009).

In 1987, the UN World Commission on Environment and Development was published. The American Institute of Architects' (AIA) Energy Committee was transformed into a Committee on Environment and in 1992 the AIA Environment Resource Guide was published. Also called the Second Earth Summit, the UN Conference on Environment and Sustainable Development was held in Rio De Janerio in 1992. It had representatives from 172 countries and 2400 non-governmental organizations and Agenda 21 was passed during this summit for achieving global sustainability (Syal *et al.* 2009).

The United States Green Building Council (USGBC), the primary body for certifying green buildings in the United States, was formed in 1993. It launched the Leadership in Energy and Environmental Design for New Construction (LEED-NC) version 1.0 in 1998. The LEED rating system is a third party verification system that rates green buildings (Syal *et al.* 2009). Subsequent upgrades to the rating system have been completed with an increasing emphasis on energy and atmosphere credits, and the inclusion of other building types such as homes (USGBC 2012a, b).

Currently, homeowners are becoming increasingly aware of the need for environmental friendliness and energy conservation. According the United States Department of Labor, though the recent economic recession affected the construction industry, the rising energy costs made "green renovation of buildings" an attractive option (JCHS 2009; Samuel 2011). Consumer spending on home energy efficiency climbed from 32 billion in 1999 to nearly 52 billion (inflation adjusted) in 2009 (USDOE 2010 from JCHS 2009), a spending increase which has led to an improvement in the efficiency of buildings. For instance, in 1980, the average amount of energy consumed by a home built in the 1960s was about 65 British Thermal Units (BTU) per square foot, compared to an increase in energy efficiency of 25% in 2005 (JCHS 2009).

2.2.1.1 Methods for Improving the Energy Efficiency of Existing Buildings

Several methods have been suggested for improving the energy efficiency of homes. The United State Environmental Protection Agency (2009) asserts that, sealing and insulating the building envelope – its outer walls, ceiling, windows, doors, and floors – is often the most cost effective way to improve energy efficiency and comfort. They estimate that up to 20% of heating and cooling costs (or about 10% of total energy bill) can be saved by sealing and insulation. Specific benefits include lower utility bills; improved comfort, especially during summer and winter; reduced noise from outside; less pollen, dust, and insects entering home; and better humidity control. Strategies to increase the energy efficiency of a home include (Maynard 2009): orientation of the house; air sealing and insulating the thermal envelope; installing properly sized and efficient HVAC systems, and hot water heating; and installing energy efficient appliances.

In addition to increasing the efficiency of homes, the industry is becoming increasingly aware of health aspects associated with these retrofits, particularly with respect to air sealing and carbon monoxide production. The indoor environmental quality of a building affects the health of building occupants. Even though air-tight building enclosures improve energy efficiency, occupant comfort, and reliable indoor air quality, such enclosures require a higher level of ventilation performance. Insufficient mechanical systems can have severe ramifications on building performance, occupant comfort, and even health (Finch *et al.* 2009). Singh (2009) proved that occupants in buildings with better indoor environmental quality are healthier.

2.2.2 Programs and Initiatives

In contrast to building new power plants which are expensive and requires years of planning before it can start, energy efficiency is one of the quickest and cheapest ways to increase the amount of energy available for use. The intensity of energy in the United States, that is, the energy consumption per dollar of real gross domestic product, decreased by 46% from 1975 to 2005, mostly due to increasingly energy efficient technologies (REAP 2012). As a result of the existence of a large number of old homes, a majority of which are energy inefficient, reducing energy consumption by these buildings remains a priority.

Government programs are initiated with the aim of decreasing consumption of building-related energy. In order to continually develop innovative, cost-effective energy saving solutions, the Building Technologies Program, one of the national programs of the United States department of energy for instance, conducts work in three key areas – research and development, market stimulation, and building codes and equipment standards activities, with their partners (USDOE 2012a). Three of the programs initiated by the United States government are: Weatherization Assistance Program (WAP), Energy Star Program, and Building America program.

2.2.2.1 Weatherization Assistance Program (WAP)

Officially instituted by the United States Congress in 1976 under Title IV of the Energy Conservation and Production Act, this program started as a means of implementing low cost emergency measures, such as weather stripping and caulking and advanced to more permanent measures like installing storm doors and windows or insulating attics. It received funding of about $5 billion from the American Recovery and Reinvestment Act of 2009 which authorized grantees to withdraw up to half of the allocated funds by December 2009. By February 2010, only 8% of the total funds had been drawn for such work (Duah *et al.* 2012; EERE 2010).

2.2.2.2 Energy Star Program

This is a joint program of the United States Environmental Protection Agency and the United States Department of Energy. Established in 1992 in an effort to voluntarily label energy efficient appliances, especially computers, it was created to protect the environment through energy efficient products and measures. Through 1995, the program expanded to include several other appliances such as space heating and cooling equipment and by the end of 2009, it had sixty product categories. Currently, more than 80% of the American public recognizes this label. Which helped Americans prevent 210 million metric tons of greenhouse gas emissions in 2011 alone (the equivalent of annual emissions from 41 million vehicles) and reduce their utility bills by $23 billion (Energy Star 2012a, b).

2.2.2.3 Building America (BA) Program

The Building America program is an industry driven program, sponsored by the United States department of energy. It comprises industry-driven partners, working to develop technologies that make buildings energy efficient. As a result of the large number of existing buildings in the country, the program has started to stress the importance of existing building energy retrofits and is conducting research targeted at existing homes. One of the important goals of the program is to develop retrofit strategies for existing homes that achieve significant energy savings, and ensure the safety and quality of the homes. Specifically, by the year 2020, Building America aims to reduce energy use in existing homes by 30%-50% (BA 2011a).

2.2.3 Information Categories for Energy Efficiency Retrofit Decisions (Syal *et al.* 2013)

This section reviews the information categories homeowners pursue when they undertake an energy retrofit. Specifically, quantitative information and expert knowledge sources used in energy retrofit decision making by homeowners are discussed.

2.2.3.1 Two Information Categories

In order to undertake an energy retrofit, homeowners pursue information from a variety of sources as shown in Table 2.1.

Table 2.1: Homeowner Information Sources for Energy Retrofits

Word of mouth	Federal and state government sources
Trade contractors	Utility companies
Retrofit contractors	Non-technical newspapers and magazines
Energy auditors	Television and radio shows
Retail and lumberyard employees	Print advertisements
Cost databases	How-to-books and the internet

These information sources can be put into two broad categories of: (1) expert knowledge/expert advice, and (2) quantitative/published information. Both categories are utilized by stakeholders (consumers, energy auditors, retrofit contractors, trade contractors, designers, developers, etc.) in order to make retrofit decisions (See Figure 2.2).

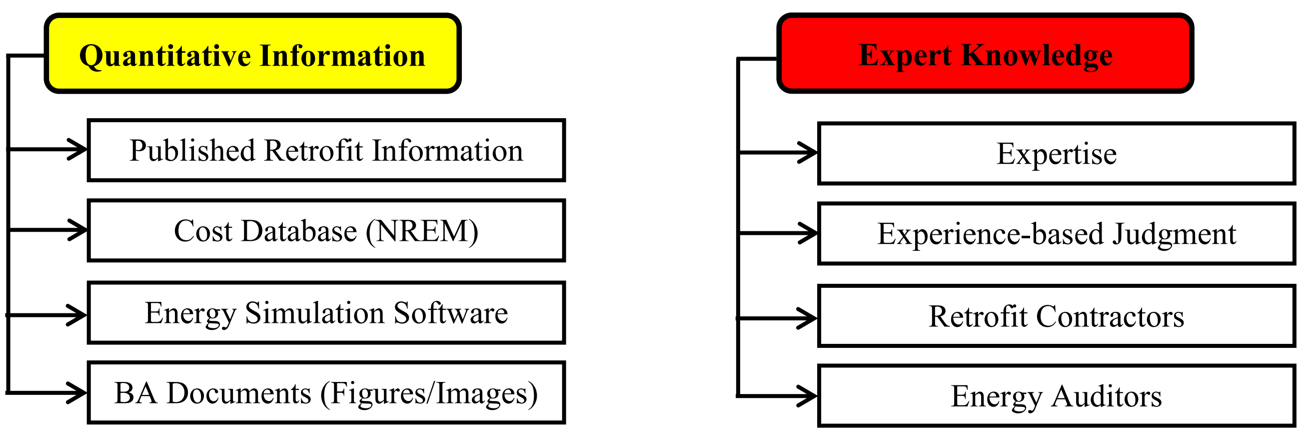


Figure 2.2: Two Key Information Categories/Sources (Modified from Syal *et al.* 2014)

(Note: for interpretation of the references to color in this and all other figures, the reader is referred to the electronic version of this dissertation).

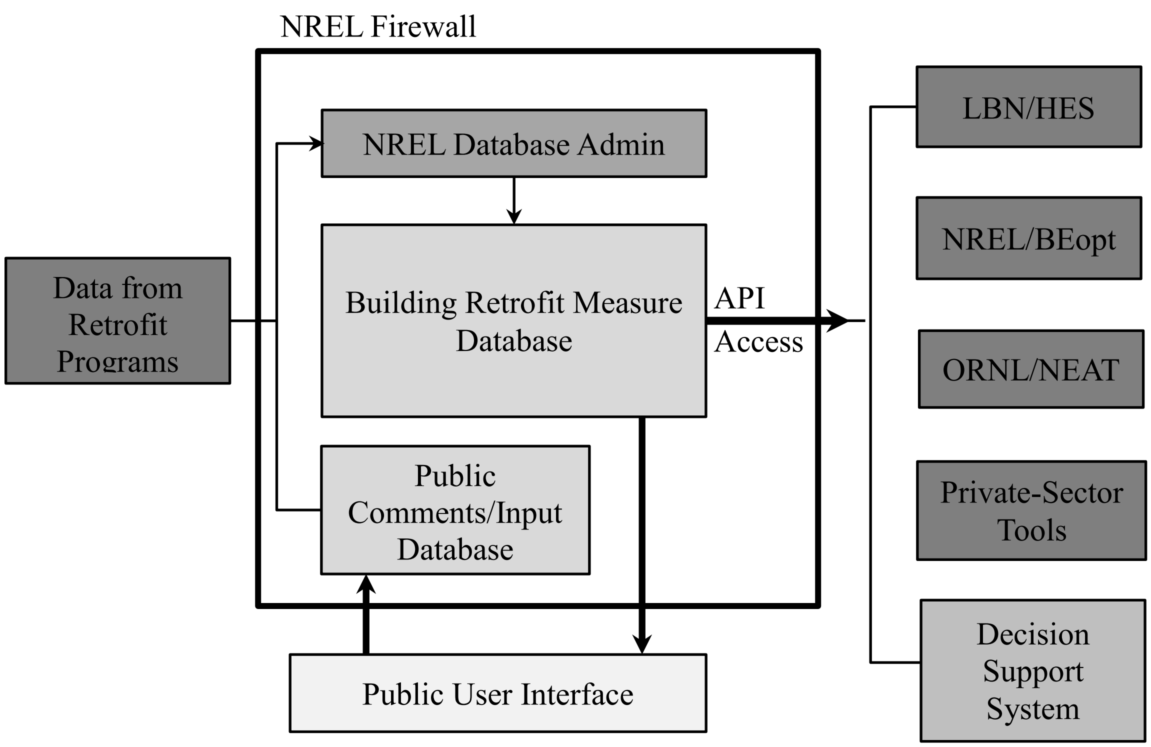
The first category is termed as "quantitative information" and includes information related to the domain, typically found in published sources, and is commonly agreed upon by those knowledgeable in the domain (Palmquist 1996; Syal 2011; Turban 2005; Warszawski 1985). Examples include: published information about retrofit technologies, cost information from databases such as the National Residential Efficiency Measures database, energy simulation reports from simulation software such as Building Energy Optimization, and information available in Building America documents (NREL 2010b, USDOE 2012b).

The second category of information is termed as "expert knowledge" and is also known as expert advice or qualitative information. This category includes information that can be defined as the knowledge of good practice, good judgment, and plausible reasoning in the field (Palmquist 1996; Syal 2011; Turban 2005; Warszawski 1985). Examples include: expertise and experience-based judgment of retrofit contractors and/or energy auditors. Based on the identified information categories, there are certain barriers that work against the broad implementation of energy retrofits, leading to the low adoption rates of energy retrofits (Syal *et al.* 2013). These barriers, known as "information barriers" and "expertise barriers", were discussed in the need section of Chapter one. In order to help remove the barriers, it is important that these two information categories are understood.

2.2.3.2 Sources of Quantitative Information

This section summarizes the existing literature on information portals and databases used in the energy retrofit and other construction-related industries. Several construction and energy retrofit-related information portals and databases for homes currently exist, and a few are presented.

The ***National Residential Efficiency Measures (NREM) database (NREL 2010a)*** is a public, centralized resource of home retrofit measures and costs. Mainly designed to assist users with deciding on the most cost-effective retrofit measure(s) for energy retrofits, it allows constant feedback from users, so it can constantly improve its effectiveness. It was developed by integrating several DOE databases of building retrofit measures into a unified national database. Though mainly intended for software developers of home energy simulation type software such as BEopt, the data is also useful for other participants in the retrofit process, such as designers, trade contractors, and homeowners. The overall structure of the database is shown in Figure 2.3.



Abbr: API – Application Program Interface; LBNL/HES – Lawrence Berkley National Lab/ Home Energy Saver; NREL/BEopt – National Renewable Energy Laboratory/ Building Energy Optimization; ORNL/NEAT – Oak Ridge National Laboratory/National Energy Audit Tool

Figure 2.3: Overall Structure and Working of the NREM Database (Source: Modified from NREL 2010a)

The database was publicly released in February 2010, and the latest version, 2.1.0.0, was released on November 27, 2013 (NREL 2013) (Figure 2.4). Input to the database is from two sources: data from retrofit programs and data from public feedback, both of which are monitored by the database administrator. Once the data is input, various parties can use it for their benefit.

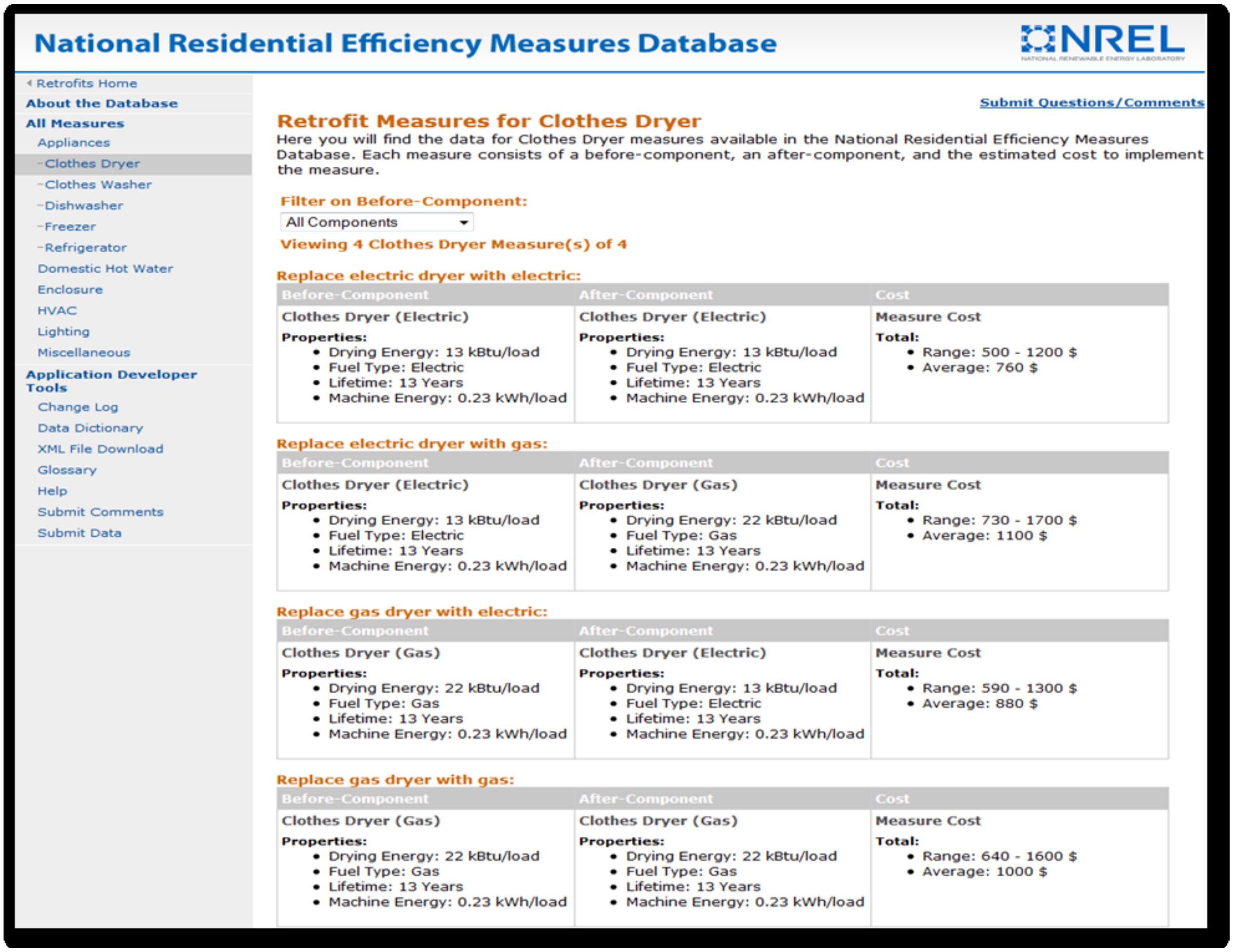


Figure 2.4: Screenshot of NREM Database of Retrofit Measure (Source: NREL 2010a)

(Note: This screenshot highlights all the available measure categories and 4 examples of the "Clothes Dryer" retrofit measure with its associated before component, after component, and cost information)

Developed by the Building America program, the ***Building America Portal*** provides useful information to the public: consumers, researchers, and designers of home energy efficiency technologies and measures (Figure 2.5):

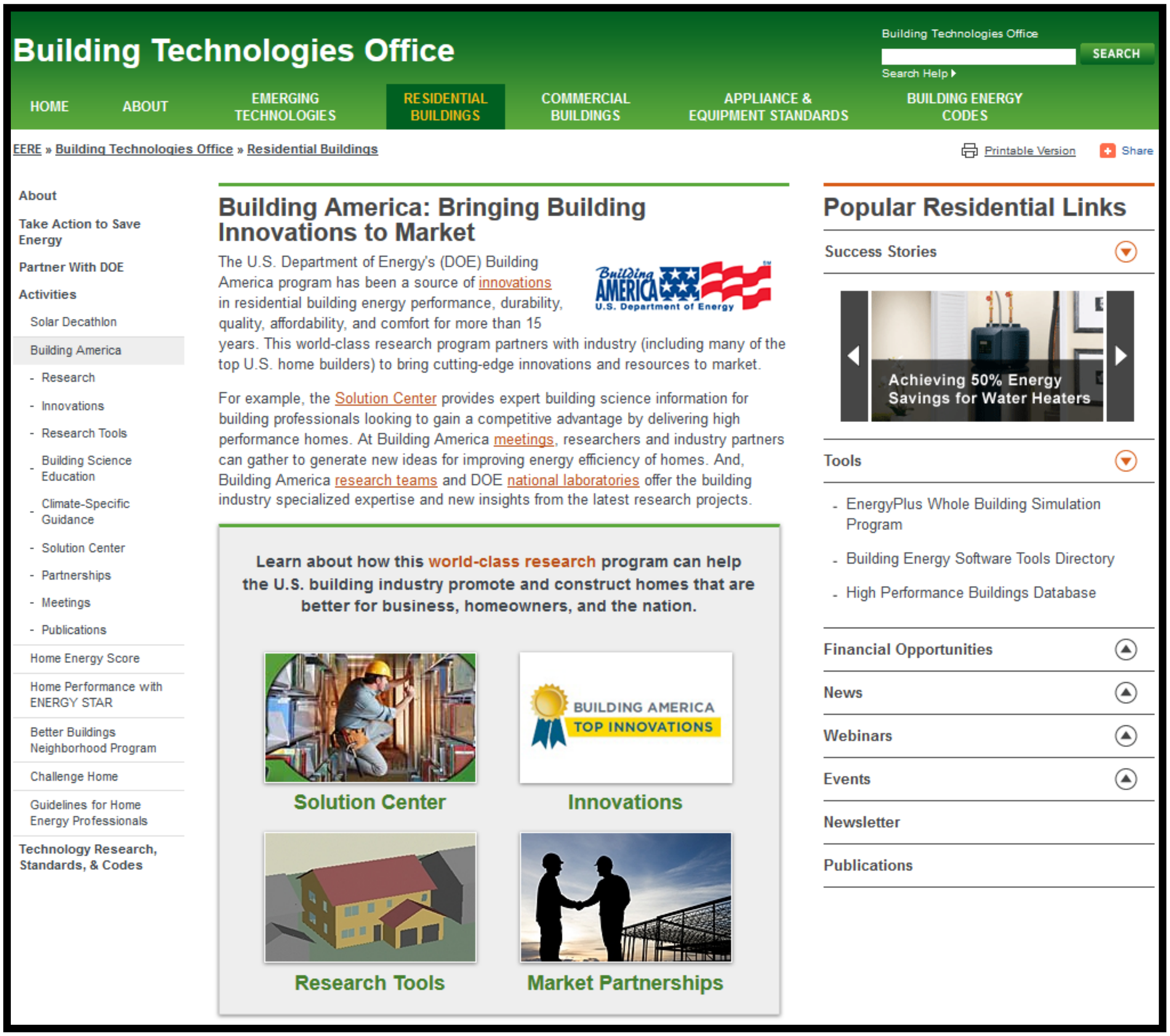


Figure 2.5: Screenshot of the Building America Portal (Source: USDOE 2013a)

(Note: This screenshot highlights information from the "Residential Buildings tab". Other information tabs include Home, About, Emerging Technologies, Commercial Buildings, Appliance and Equipment Standards, and Building Energy Codes)

The layout of the Building America portal mainly includes:

- Information about the program including research teams, current research, future goals, and deployment strategies.
- Technical and scholarly publications related to home energy efficiency.
- Links to building science educational institutions and curricula.
- Information related to energy efficiency technologies, measures, and best practices.
- Sources of energy efficiency incentives and links to similar databases (NREM database).
- Search portal useful for quick retrieval of specific data.

The ***Energy Star Program*** is a joint program of the United States Environmental Protection Agency and the United States Department of Energy and was created to protect the environment through energy efficient products and measures (Energy Star 2010) (Figure 2.6).

The Energy Star program has an information portal that contains the following:

- Products and measures to increase home energy efficiency.
- Tool that assesses home energy performance. Data required to run the tool are "location of the home" and "past energy consumption".
- Tool that suggests retrofit strategies for increased energy performance, based on the location of the home and its typical features.
- Links to other energy efficiency databases.
- Search portal for quick retrieval of specific data, news items, and social media.
- Scholarly and technical publications related to home energy efficiency.

Figure 2.6: Screenshot of the Energy Star Information Portal (Source: Energy Star 2013d)

(Note: This screenshot highlights the main information portal of the Energy Star Program. Major tools for accessing information highlighted include: Energy efficient Products, Energy Savings at Home, Energy Efficient New Homes, Energy Strategies for Buildings & Plants, Tools and Initiatives, Energy Star Social Media, and other information sources)

The ***Database of State Incentives for Renewables and Efficiency (DSIRE 2010) Program*** was established in 1995 as an ongoing project of the North Carolina Solar Center and the Interstate Renewable Energy Council. It is funded by the United States Department of Energy's Office of Energy Efficiency and Renewable Energy and administered by the National Renewable Energy Laboratory. It contains information about renewables, energy efficient technologies, and measures (Figure 2.7).

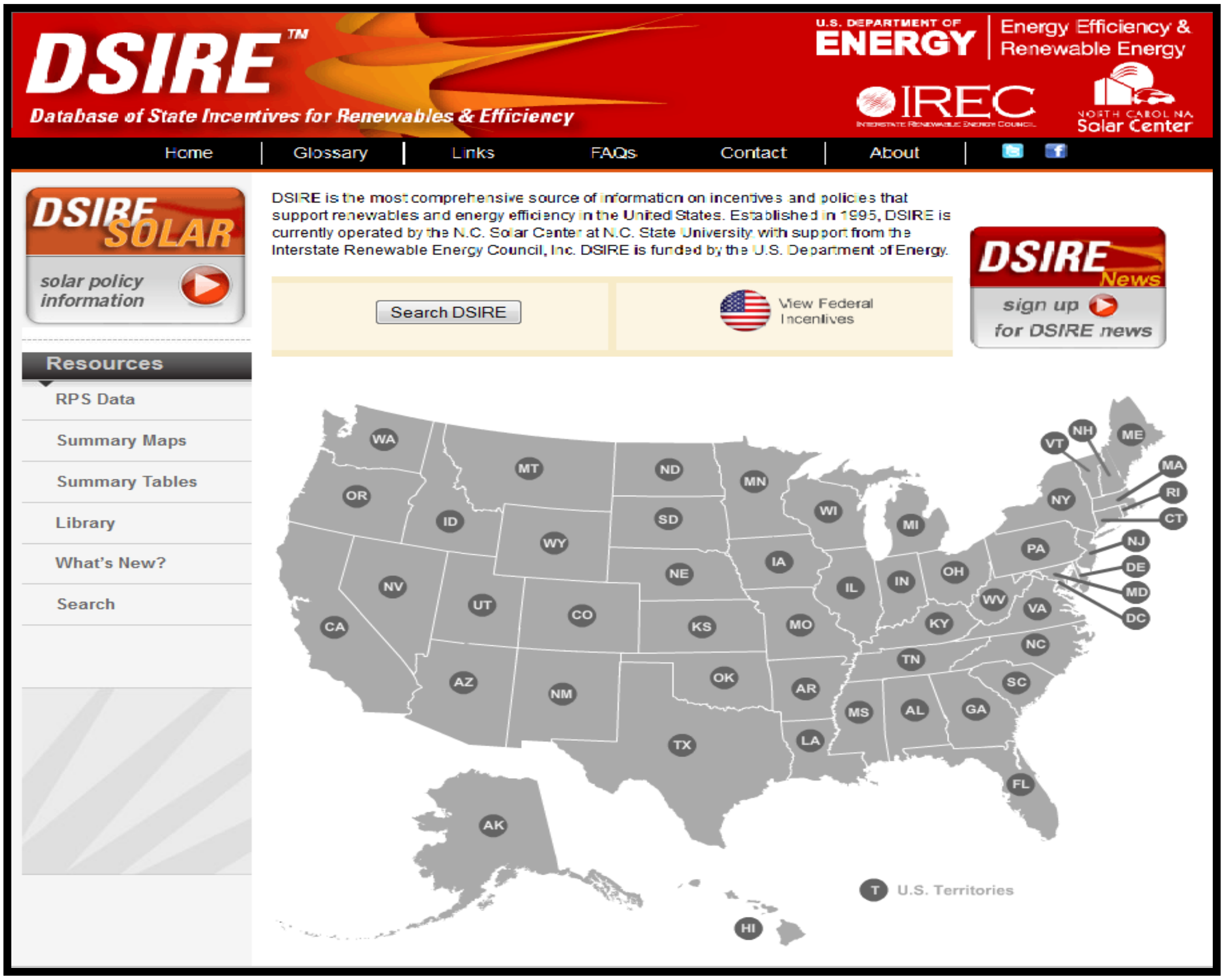


Figure 2.7: Screenshot of Database of State Incentives for Renewables and Efficiency Portal (Source: DSIRE 2013)

(Note: This screenshot highlights information tabs on the home screen such as: Home, Glossary, Links, FAQs, Contact, About, Resources and other information sources)

The database provides three areas of information for both federal and state resources: (1) financial incentives; (2) rules, regulations and policies; and (3) related programs and initiatives.

2.2.3.3 Sources of Expert Knowledge

Within the energy retrofit industry, many sources of expert knowledge are available and pursued by homeowners. Three main sources include: energy retrofit professionals, self-acquired knowledge, and knowledge from a prepackaged source such as an expert system.

The help of competent, trained, and certified ***energy retrofit professionals*** are sought by homeowners in order to make informed decisions about specific energy retrofit measures to select. Such professionals provide accurate, trustworthy, and comprehensive information specific to their home (EnergyARM 2009). One way of obtaining this information is by conducting an energy assessment of the home. Since energy retrofits employed without initial assessment can produce unacceptable results, it is important for energy professionals to estimate a proposed retrofit's energy savings and prioritize the retrofits in descending order of their cost effectiveness (Krigger & Dorsi 2009). A home energy assessment, also known as a home energy audit, is an in-depth examination of a home to determine where and how energy is being lost, identify inefficient systems, and propose cost effective and corrective measures to make the home more comfortable, affordable, and energy efficient. It is the first step to assessing how much energy a home consumes (BPI 2012; Energy Savers 2011; RESNET 2012b).

As a result of the need to have a standardized protocol and harmonized training for energy professionals, guidelines for home energy professionals have been developed by the national renewable energy laboratory and are offered by the Building Performance Institute, Inc. Funded by the United States department of energy, the guidelines foster the growth of a quality residential energy upgrade industry and a skilled and credentialed workforce. It focuses on the most common jobs in the home energy upgrade industry: energy auditor, retrofit contractor, and quality control inspector (EERE 2012).

An *energy auditor* uses specialized tools and equipment such as modeling software, blower doors, and infrared cameras to measure air leaks and reveal hard-to-detect areas of air infiltration and missing insulation. An auditor evaluates the energy efficiency, comfort, health, and safety of a building and identifies areas for saving energy. This information is compiled as a report and includes recommendations to the homeowner (Chuck & Woodley 2011a; RESNET 2012a).

A *retrofit contractor* installs energy efficiency measures to single family, or 2-4 unit-homes, using a variety of building science best practices to improve safety, comfort, durability, indoor air quality, and energy efficiency (Chuck & Woodley 2012). They evaluate a house as a system and take cost-effective steps to improve its overall energy efficiency, lower utility bills, and reduce its carbon footprint (Energy Savvy 2013).

A *quality control inspector* verifies performed work against planned work, specifications, and standards. They also perform building diagnostics, record/report findings and concerns, and specify corrective actions in order to ensure the completion, appropriateness, and quality of work that ensures the safety, and comfort of building occupants as well as and energy savings (Chuck & Woodley 2011c).

Regarding ***homeowner's self-knowledge***, it must be noted that the needs, preferences, and budget of homeowners are major considerations in energy retrofits. However, homeowners who undertake energy retrofits have different levels of expertise ranging from novices to experts. The lack of access to information generally inhibits how much knowledge the homeowner may have. The level of expertise of homeowners ranges from doing simple tasks such as installing energy efficient light bulbs or installing wall insulation, to difficult tasks including blowing insulation into an attic, performing an energy audit, or testing the home to ensure it meets the quality standard. Homeowners generally have limited self-knowledge and usually rely on the expertise of energy retrofit professionals.

Expert systems are a branch of artificial intelligence that can be used to solve problems that generally require human expertise. The basic concept is to capture and organize the enormous task-specific knowledge from experts (expertise) in a computer. Users can recall stored expert knowledge through the computer for specific advice in solving a problem. The computer can arrive at a specific conclusion using inferences and provides advice or necessary logic similar to humans (Liao 2005; Syal et al. 2013; Turban et al. 2005; Warzawski 1985) (Figure 2.8).

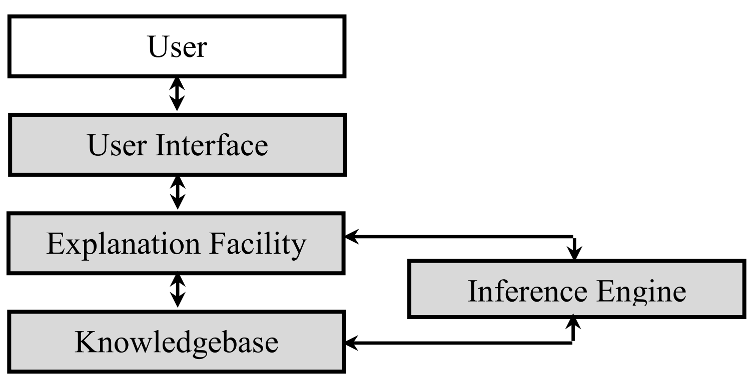


Figure 2.8: Components of an Expert System (Syal *et al.* 2013)

- *User Interface* – this provides the user with an accessible medium for interaction with the system. Information from the user is translated to the system which then provides the user with information in a format that can easily be understood by the user.
- *Knowledgebase* – this stores expertise in the form of heuristic knowledge. The ability of an expert system to be a reliable decision support tool depends on the capacity of the knowledge accumulated in the knowledgebase.
- *Inference Engine* – this is a software system that performs the reasoning process and infers new decision-making options based on the stored expert knowledge. It fortifies the expert system by giving it the ability to infer new knowledge to respond to different situations.
- *Explanation Facility* – this explains the logic used in providing the output. It identifies the steps utilized in the reasoning process and demonstrates them in a format easily understood by the user. Compared to traditional computer systems, it makes the expert system more reliable by explaining the reasons for its decision-making.

2.3 EXPERTISE DEVELOPMENT AND ELICITATION

The study of expertise provides a focus for conducting research into several incidents of cognition, such as, memory limitations and reasoning preconceptions and the theory of cognition, such as, knowledge representations (Hoffman 1996). This section reviews literature on the nature and development of expertise highlighting the key advances and the key elements that distinguish experts from novices in a domain. It also reviews literature on the techniques for eliciting expertise.

2.3.1 Nature of Expertise

The exploration of the nature of expertise and how it develops which has interested scholars, professionals, and laypeople, involves a wide range of theoretical and methodological approaches. Over many years of study, there has been a persistent debate about the development of expertise, focusing on whether such development can mainly be attributed to the rare characteristics of individuals, typically viewed as inherited talents, or of their learning history (Cianciolo *et al.* 2006). The concept of expertise discussed implicitly and explicitly as human factors, includes the analysis of human performance in: task analysis, human reliability analysis, studies of learning and training, interface design, and cognitive modeling (Farrington-Darby & Wilson 2006). Cianciolo *et al.* (2006) have observed that the study of expert performance is directly relevant to the study of typical human development. They emphasize that people are able to use their intellectual capabilities to adapt and succeed in particular environments, and this reflects the outcome of their active engagement in their respective domains.

2.3.1.1 Defining Expertise

The study of expertise basically addresses characteristics of experts, the procedures they follow, and how they differ from non-experts (Johnson 2010). The common psychological definition of expertise relies on the level of performance exceeding that of most others (Cianciolo *et al.* 2006). This definition, however, excludes the recognition of expertise demonstrated by the many individuals and the successes they regularly achieve. Feltovich *et al*. (2006) also define expertise as "a long-term developmental process, resulting from rich instrumental experiences in the world and extensive practice", emphasizing the importance of competence in addition to experience.

Competency has been defined as a set of skills, related knowledge, and attributes that allow an individual to perform a task or an activity within a specific function or job (UNIDO 2002).

The prototype view of expertise, however, maintains that expertise is specific to a domain and that the attributes of experts may be specific to a time and a place. This view maintains the importance of information processing capabilities generally found in domains, such as, problem solving and also recognizes that expertise and its requisite knowledge, skills, and abilities are defined quite differently, depending on the domain. This view recognizes the diversity of skills that lead to successful performance noting that expertise can be thought of as existing in degrees rather than in an all-or-none fashion (Cianciolo *et al.* 2006). In terms of duration, expertise takes considerable time (5-10 years) and investment to be developed (Lindner *et al.,* 2011).

At the cognitive level, expertise can be defined in terms of the following (Hoffman 1996): how it is developed, knowledge structures of experts, and reasoning process of experts.

- *Expertise development* – expertise involves a movement from a superficial and literal understanding of problems (novices) to an articulated, conceptual, and principled understanding (experts). The accumulation of skill based on experience and practice, is not necessarily bound by time, thus, two experts in a domain can be of quite different ages.
- *Experts' knowledge structures* – the knowledge of an expert differs from that of a novice in terms of how it is organized and its extent. Knowledge concepts are interrelated in meaningful ways and memories can be addressed in terms of concept, context, and content (Chi *et al.* 1982; Glaser 1987; Hoffman 1996). The knowledge of an expert is

specific to the domain, extensive (Chase 1983; Glaser 1987; Hoffman 1996), and relies on conceptual categories that are principled or more abstract (Voss *et al*. 1983).

- *Experts' reasoning process* – the flow of expert reasoning is definitely shaped by tasks that are involved in the domain. The special reasoning processes of experts often present themselves as perceptual skill where they usually notice things that novices do not. They often refer to illustrative or prototype examples of past cases when asked to justify or explain their decisions or actions (case based reasoning), appear to possess the ability (flexibility) to generate scenarios or frameworks for reinterpreting novel difficult situations, and experience a declarative-to-procedural shift in expertise reasoning. For instance, whenever a skill such as cycling is highly practiced, knowledge initially taught explicitly becomes tacit or automatic (automaticity of expertise) (Hart 1989; Hoffman 1996; Klein & Hoffman 1993; Lesgold *et al.* 1988; McGraw & Harbison-Briggs 1989; Sanderson 1989).

Samuels and Flor (1993) cite driving an automobile effortlessly through traffic as a good example of automaticity. They note that the beginner driver focuses so much attention on the mechanical aspects of driving that holding a conversation with a passenger while driving is impossible. With practice, the mechanical aspects of driving become less demanding and the skilled driver can simultaneously listen to the radio, hold a conversation, and appreciate the scenery. Evidence from literature support the assertion that skills and knowledge learned to automaticity are better retained in long-term memory (Bahrick 1984; Flor 1995), unlike skills and knowledge developed only to high accuracy which may survive for a short time. In addition, automaticity results in reduced attentional demands needed to perform at that level (Samuels & Flor 1993).

2.3.2 Development of Expertise

In most fields of human endeavor, the performance of experts is outstanding when compared to that of other highly experienced individuals in the field and is usually attributed to a unique, qualitative attribute by most people (Ericsson & Charness 1994). Recent studies of expert performance have questioned the talent-based view that such performances are natural or inborn components and cannot be modified (Biederman & Shiffrar 1987). Analyses of exceptional performance such as exceptional memory have shown how it differs from that of beginners emphasizing how beginners acquire skill through instruction in appropriate general strategy and corresponding training procedures (Howe 1990). A better explanation is that expert performance demonstrates extreme adaptations accomplished through life-long effort, to demands in restricted, well-defined domains (Ericsson & Charness 1994).

2.3.2.1 Stages of Development of Expertise

There appears to be a series of distinct, identifiable stages in the development of expertise. It begins with being a novice, then moves to being an advanced beginner/capable, then on through stages of competence to proficiency, and ultimately to expert as knowledge and skills increase and change both quantitatively and qualitatively (Benner 1984; Cornford & Athanasou 1995; Dreyfus & Dreyfus 1986; Schempp 2011; Trotter 1986). Novices are students or new workers; advanced beginners are in the second or third year of their career. Around the third or fourth year, they may be competent; fewer will become proficient and a smaller number of those who are proficient will develop into experts. Cornford & Athanasou (1995) explain the stages of expertise using Fitts (1964) stages of skill learning, which categorizes them into three stages (Table 2.2):

1. *Cognitive Stage* – learner comes to struggle with the basic factual understandings, the broad outline, the essential nature of the steps, and the order in which these must be performed.
2. *Practice Stage* – repetition of the skill and involvement with reality of this increases the depth of understanding and also establishes the steps and sequences of skill performance clearly in permanent memory.
3. *Autonomous Stage* – skill is performed automatically through practice without the need for a conscious monitoring of the steps and sequences in the skill.

Table 2.2: Stages of Developing Expertise and Skill Acquisition (Benner 1984; Cornford & Athanasou 1995; Dreyfus & Dreyfus 1986; Schempp 2011; Trotter 1986)

Novice • A stage for gaining experience • Responses are relatively inflexible • Rules and procedures govern performance • Skills are "context free" • Have trouble interpreting events **Advanced Beginner** • Similarities across contexts are recognized • Sporadic knowledge is built up • Knowledge about when to ignore rules is developed • No sense of what is important	**Cognitive** • Trainees have to develop an overall plan • Trainees analyze tasks • Trainees verbalize about what is learned • Procedures are described • Information is provided about errors

Table 2.2 (Cont'd)

Competence • Make conscious choices about what they are going to do • Set priorities and decide on plans • Determine what is and what is not important • Know what to attend to and what to ignore • More personally in control • Feel more responsibility for what happens • More vivid memories of their successes and failures **Proficient** • Intuition and know-how become important • No longer think about adjustments • Recognize similarities between events • Able to predict events more precisely • Intuitive options are still analyzed **Expert** • Intuitive grasp of a situation • Reduce variation in a situation • Choose to process less of what they encounter • Performance is fluid and effortless • Seems to know what to do at the right time • Involved in the task in a different way • Not consciously choosing what to do • Personal references and evaluations in performance	**Practice Phase** • Establishment of correct patterns of behavior by practice • Errors gradually eliminated **Autonomous Phase** • Gradually increasing speed of performance • Performance increases beyond the point where errors can be ordinarily detected • Increasing resistance to stress • Increasing resistance to interference from other activities • Available capacity to perform a secondary simultaneous task • Larger and larger units of behavior are programmed

Cornford and Athanasou (1995) note that a combination of the novice-expert stages in development and the stages in skill learning would have the novice positioned at the cognitive stage of skill learning with some movement into the practice fixation stage (see Figure 2.9). The advanced beginner is at the cognitive stage but also very much into the practice fixation stage. The competent performer would appear to be fully into the practice fixation stage, while the proficient individual is at the practice fixation stage and also partially into the process of developing automatic skill performance. The expert would have achieved autonomous level, which produces the characteristic intuitive-type solutions and reactions to problems.

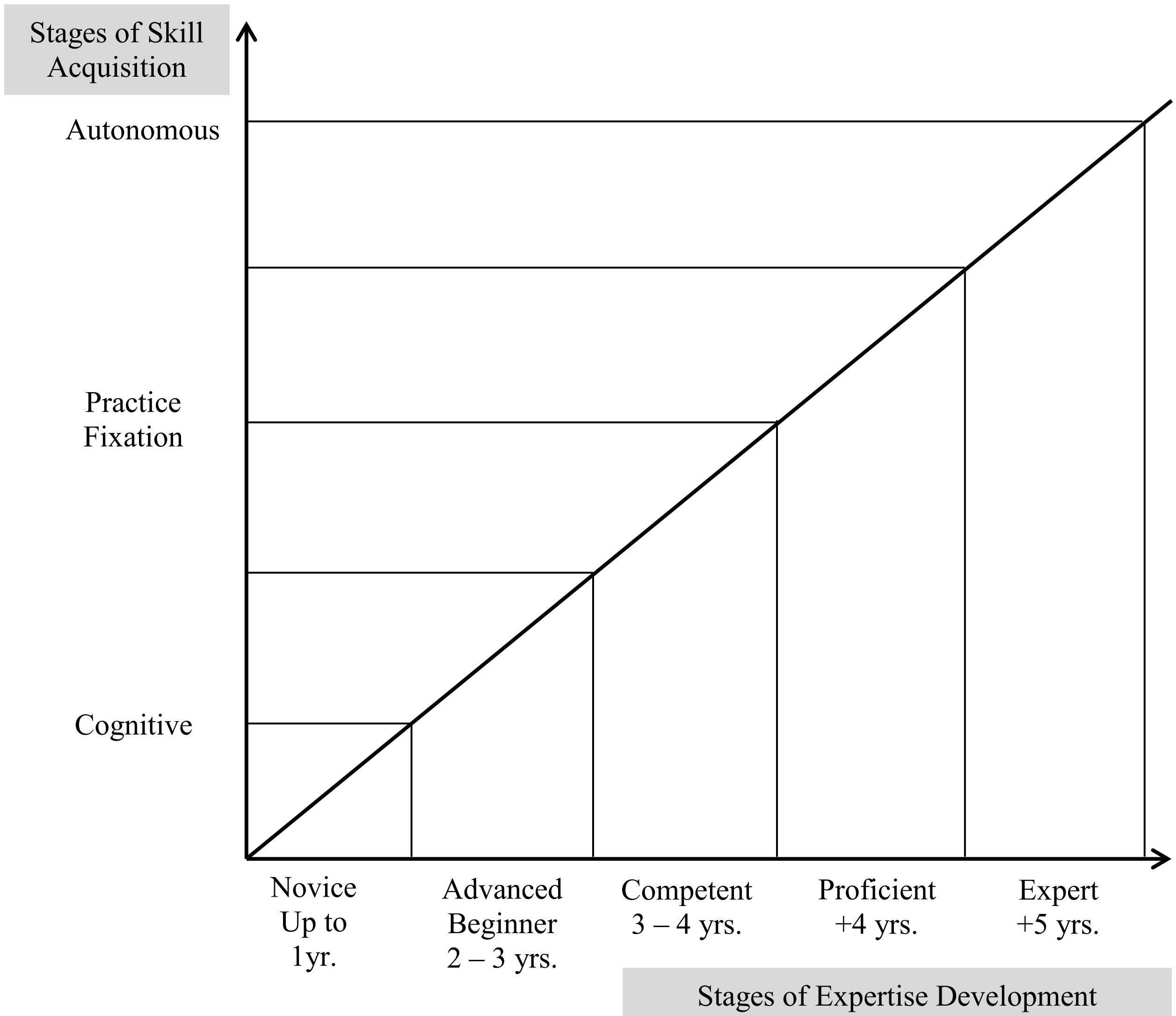


Figure 2.9: Stages of Skill Acquisition and Levels of Expertise (Source: Modified from Cornford & Athanasou 1995)

There are artificial divisions within the stages of expertise development and the stages of skill acquisition, leading to an overlap between the stages. For instance, individual differences, which become obvious in skill learning and the amount of time spent at a particular stage varies greatly from person to person (Cornford & Athanasou 1995). As a result, it is unsuitable to have strict categorizations of the stages of expertise development and skill acquisition. Provision must be made for such overlap in order to incorporate artificial divisions.

2.3.2.2 Key Elements Distinguishing Experts from Novices

An expert is a person particularly skilled in a domain and has the necessary skills and abilities to perform at the highest level. Such people are typically recognized within their profession (Johnson 2010; Shanteau 1992a). Experts have extensive knowledge that affects what they notice and how they organize, represent, and interpret information in their environment. This affects their memory, reasoning, and problem-solving abilities (Bransford *et al.* (2004). The cognitive science view is that experts within their domains are skilled, competent, and think in qualitatively different ways than novices do (Anderson 2000).

Cognitive science literature is replete with distinguishing elements that sets experts apart from novices in terms of their performance. Even though psychologists use the term expert to refer to an individual who is significantly more experienced than others in performing a particular task, the difference between experts and novices cannot be reduced solely to experience (time invested in learning how to perform tasks) but must include qualitative differences between experts and novices (Armstrong 2003). Based on extensive literature review, the following are key elements that experts possess and novices do not, thus distinguishing them from novices (See Table 2.3) (Armstrong 2003; Cellier 1997; Farrington-Darby & Wilson 2006; Glaser & Chi 1988; Shanteau 1992b).

Table 2.3: Key Elements Distinguishing Experts from Novices

High reliance on accumulated experience	Responsible/willing to back recommendations
Automaticity occurs with growth in expertise	Excel in domain
Complete representation of task domains	Perceive large meaningful pattern in domain
Quickly/completely encode new information	More global and functional view of situations
Extensive and up-to-date content knowledge	Fast and solve problems with little error
Highly developed perceptual/attention abilities	Superior short and long term memory
Able to identify and adapt to exceptions	Strong self-monitoring skill
Self-confidence in decision-making	Great anticipation skills

2.3.3 Expertise Elicitation

Knowledge or expertise is an important asset that must be well-managed in order to maximize its use. Knowledge can be found in different places such as: databases, knowledge bases, people's heads, books, journals, etc. Acquiring, documenting, distributing, reusing, and maintaining knowledge are all difficult and time consuming tasks. The task of gathering information, from whatever source, is called knowledge acquisition. The subtask comprising a set of techniques and methods that attempt to elicit an expert's knowledge through some form of direct interaction is called knowledge elicitation (Turban *et al.,* 2013). Three questions dominating knowledge elicitation relate to (Duah and Syal, 2013b; Shadbolt, 2005): (1) How to determine an expert, (2) How to get experts to tell or show us what they do, and (3) How to determine what constitutes their problem solving competence. Often, the expertise has become so routinized or automatic that experts no longer know what they do or why they do it (Shadbolt 2005).

2.3.3.1 Knowledge Engineering

Knowledge engineering is the process of acquiring knowledge from experts, building a knowledge base with the intention of helping experts to articulate what they know, and documenting the knowledge in a reusable format. This process involves the assistance of experts working with the knowledge engineer to codify and make the rules they typically use when they solve problems. Knowledge engineering can be viewed from two perspectives: narrow and broad. While the latter describes the entire process of developing and maintaining intelligent systems, the former deals with knowledge acquisition, representation, validation, inferences, explanation, maintenance, (Turban *et al.* 2005) and is the focus of this research:

- *Knowledge Acquisition* – as explained earlier, this involves the acquisition of knowledge from human experts, books, documents, surveys, or computer files. As a subtask, knowledge elicitation involves collecting relevant knowledge from a human source through some form of direct interaction (Regoczei & Hirst 1992; Shadbolt 2005; Turban *et al.* 2005).
- *Knowledge Representation* – the task of organizing the acquired knowledge from the knowledge acquisition process into a usable format in the knowledge-base.
- *Knowledge Validation* – also known as verification, this involves validating and verifying the knowledge to acceptable levels of quality. For instance, results of test cases can be shown to the experts in order to verify the accuracy of the developed system.
- *Inferencing* – using the stored knowledge in the knowledge base and the details of a problem as the basis, inferences or conclusions can be drawn by the system. Such information can be used to provide advice to users of the system.
- *Explanation and Justification* – this relates to the capacity of the system to explain issues. For instance, explaining why incandescent light bulbs were replaced with more energy efficient and cost effective counterparts.

A major activity of the engineering process, knowledge elicitation, has been shown to be a difficult task. Turban *et al.* (2005) indicate the following as factors that add to the complexity of knowledge acquisition from experts and its transfer to a computer:

- Difficulty or inability of experts to articulate their knowledge.
- Lack of time or unwillingness of experts to cooperate.
- Complication in the testing and refining of knowledge.
- Poorly defined knowledge elicitation methods.
- Scatter of relevant knowledge across several sources.
- Use of incomplete documented information rather than expert knowledge.
- Difficulty in recognizing specific knowledge when mixed with irrelevant data.
- Change in expert behavior when observed or interviewed.
- Problematic relational communication factors affecting knowledge engineer and expert.

2.3.3.2 Knowledge Elicitation from Multiple Experts

Identifying an expert is a very important element in developing a knowledge-based system. There are however benefits of using multiple experts (Turban *et al.* 2005):

- Fewer mistakes, on average, are made compared with a single expert.
- As difficult and expensive it is, there is no need to use a world-class expert.
- Multiple experts handle more complex problems and combine strengths of different reasoning approaches.
- Synergy among experts enhances quality.
- Domain knowledge is better understood.

- The validity, consistency, completeness, accuracy, and relevancy of the knowledge-base are improved.

Challenges with using multiple experts include the following (Turban *et al.* 2005):

- Lack of confidentiality due to the fear by some domain experts of senior experts or supervisor.
- Possibility of compromising solutions generated by a group with conflicting opinions.
- Wasted time in group meetings.
- Difficulties in scheduling the experts.
- Dominating experts who control or do not let others speak.

2.3.3.3 Expertise Elicitation Techniques

Different techniques are required to elicit the different knowledge types. A general principle is that experts should be encouraged to describe their expertise in the most natural way to them. The knowledge elicitor should resist the temptation to anticipate the representation of that knowledge early in the elicitation process (Hart 1985). Knowledge elicitation techniques can be subdivided into natural and contrived methods. A method is described as natural if it is one an expert might informally adopt when expressing or displaying expertise. Such techniques include interviews or observation of actual problem solving. A contrived task elicits expertise in ways that are not usually familiar to an expert (Shadbolt 2005).

Research on the most common elicitation and representation techniques used by human agents include unstructured interviewing techniques, structured interviewing techniques, protocol analysis, psychological scaling, and card sorting. Each technique further requires different abilities from the knowledge elicitor, the domain expert, and allows for a different set of knowledge representation to be used (Wagner *et al.* 2002). Four techniques used for acquiring, analyzing, and modeling knowledge are discussed in this research based on their style, limitations, comprehensiveness, and validity of information typically generated by each (Bechhofer 2006; Epistemics 2003):

- Protocol-generation techniques
- Protocol-Analysis techniques
- Hierarchy generation techniques
- Diagram-Based Techniques

The aim of ***Protocol Generation Techniques*** is to produce a record of behavior (or protocol), whether in audio, video, or electronic media. Audio recording is the usual method, which is then transcribed to produce a transcript. Examples of groups of techniques that produce protocols include interviews, commentary, teach back, and observation (Epistemics 2003).

- *Interviews* – as the most frequently employed of all elicitation methods (Cullen & Bryman 1988), it is the most direct way to find out what someone knows. It involves asking the domain expert questions about the domain of interest and how they perform their tasks (Burge 2001). Three major types of interviews are: unstructured, semi-structured, and structured (Table 2.4).

  Compared to other knowledge elicitation methods, interviews, whether structured or unstructured, are relatively easy to administer. However, the compromise occurs at the data analysis and interpretation phases where, for instance, the tasks of summarizing and drawing conclusions from open-ended interview responses are challenging. Depending on the degree of structure inherent in the interview and the amount of preplanning about questions that are asked, the analysis of the responses may be quite straightforward (i.e., frequencies of responses, similarities of diagrams, lists of features) (Cooke 1992).

Table 2.4: Major Interview Types

Unstructured Interviews (Burton *et al*. 1987; Cooke 1992; Cooke & McDonald 1987; Epistemics 2003; Hoffman 1987)	
Process	• No predefined structure, only a rough idea • Knowledge elicitor is free to explore domain
Pros	• Useful for initial interviews when there is little domain information • Helps establish rapport between expert and elicitor • Style is free-flowing
Cons	• An inefficient/time consuming way of gathering detailed information • Can offend experts as a waste of time
Semi-structured Interviews (Cooke 1992; Shadbolt 2005)	
Process	• Combines a highly structured agenda with the flexibility to ask subsequent questions • Questions are constructed prior to interview • Not too many prepared questions asked to allow for subsequent questions
Pros	• Less amount of structure imposed • Helps experts focus on key questions • Avoids unnecessary information • Allows elicitor to be prepared and competent during interview • Provides reliable, comparable, and qualitative data
Cons	• An inefficient/time consuming way of gathering detailed information • Can offend experts as a waste of time
Structured Interviews (Cooke 1992; Epistemics 2003; Hoffman *et al.* 1995)	
Process	• Formal interview where knowledge elicitor plans and directs sessions
Pros	• Knowledge elicitor training not as valuable compared to unstructured interviews
Cons	• No flexibility for knowledge elicitor since questions are pre-prepared • There are more constraints on responses of expert

Table 2.4 (Cont'd)

	• More preparation time is needed • Compared to the unstructured interview, the knowledge elicitor must be more knowledgeable of the domain

- *Verbal Protocols/Commentary* – these are the recorded articulations of experts via video, audio tape recorder, or direct notes etc., about how experts perform their tasks and the problems they face. Since the articulation occurs during task performance, the unavoidable distortion or forgetting that could occur if the reporting were left until afterwards is avoided. These protocols are particularly useful for gaining information about the psychological or cognitive process for the actions of persons whose knowledge are being elicited but cannot be directly observed, such as the knowledge requirements or mental processing. The disadvantage of this technique is the think-aloud protocol during task performance can impose an additional burden on the expert, especially significant when the task is difficult and this may alter the way the task is performed (CEET 2002).
- *Teach Back* – in this technique, the knowledge elicitor describes part of the knowledge that has been acquired during previous sessions or from other sources. The expert then comments on what the knowledge elicitor is describing to reveal misinterpretations or verify information, a process which continues till the expert is satisfied with the elicitor's explanation. This method seeks to bring the elicitor up-to-date with the information in the knowledge-base and how it is presented (Burge 2001; Cooke 1992; Epistemics 2003; Johnson & Johnson 1987).
- *Observation* – in order to maintain a broader perspective of the domain, knowledge elicitation often begins with observations of task performance within the domain of interest (Cooke 1992). Though time consuming, this technique involves the knowledge

elicitor observing and making notes as the expert performs their daily activities. A combination of task performance videotaping and retrospective reporting techniques can be useful (Burge 2001; Epistemics 2003). Though observations occurring in the natural setting provide insights of actual behavior, not all tasks can be observed this way, thus, the need to observe performance in a simulated context (Hoffman *et al.* 1995). Aside from where they occur, observational methods also vary in terms of what is observed, the observer's role, and the method of recording. Like other knowledge elicitation methods, observation has cost-benefit tradeoffs. For instance, though they tend to interfere minimally with task performance, the observer must avoid intruding the process in order to obtain reliable and valid data (Cooke 1992). Generally, since they are less efficient in capturing the required knowledge or providing any insight into why decisions are made, they are rarely used (Burge 2001; Epistemics 2003).

The central assumption of ***Protocol Analysis Techniques*** is that it is possible to instruct subjects to express their thoughts such that it does not change the sequence and content of thoughts hindering the completion of a task and hence reflecting immediately available information during thinking (Ericsson 2006). Such techniques are used with transcripts of interviews or other text-based information to identify various types of knowledge, such as goals, decisions, relationships, and attributes. It actually acts as a bridge between the use of protocol-based techniques and knowledge modeling techniques (Bechhofer 2006). For most projects, categories of fundamental knowledge such as concepts, attributes, values, tasks, and relationships are used for this technique. So, for example, an interview transcript would be analyzed by highlighting all project-relevant concepts. This would be repeated for all the relevant attributes, values, tasks, and relationships (Burge 2001; Epistemics 2003; Shadbolt 2005).

The main advantage of protocol analysis is that the decision-making process of a domain expert at work is described. Analyzing such transcripts requires a systematic breakdown of the information to produce a structured model of the expert's knowledge. Experts find it much easier to talk about specific examples of problems rather than in abstract terms. For instance, they can more easily answer a question relating to: *explaining how they know that a design would not work* rather than *explaining how they know what makes a poor design* (Hart 1985).

Two general types of protocol analysis are *on-line* and *off-line*. In *on-line* protocol analysis, the domain expert is being recorded solving a problem and concurrently a comment is made. The nature of the commentary specifies two sub-types of online methods – self report and shadowing. In *self-report*, the expert performing the task may be describing what they are doing as problem solving proceeds whereas in *shadowing*, a running commentary on what the expert performing the task is doing is done by another expert. *Off-line* protocol analysis allows the expert(s) to comment with hindsight on the problem solving session which is typically shown to them via an audio-visual record. This may take the form of a reflective self-report by the problem-solving expert, a critical reflective report by other experts, or a group discussion of the protocol by a number of experts including its originator (Shadbolt 2005).

In a study to compare four knowledge elicitation techniques – structured interview, protocol analysis, card sort, and laddered grid – reported across two classification domains using eight experts in each, Burton *et al.* (1989) found that protocol analysis is the most commonly used technique. Its popularity is driven by the fact that experts are very comfortable in its use and is familiar to them in some way. This assertion is corroborated by Hart (1985), who notes a general principle in knowledge elicitation to be that the expert should be encouraged to describe his/her expertise in the way which is most natural to him/her.

Hierarchy-Generation Techniques involve the creation, reviewing, and modification of tiered knowledge, often in the form of ladders, that is, tree diagrams (Epistemics 2003). Clinical psychologists first introduced the laddering technique in the 1960s, as a method of understanding the core values and beliefs of people (Hawley 2009). In the knowledge elicitation context, laddering refers to a structural questioning strategy, using a restricted number of probes, designed to reveal the relationship between concepts. It may also be used as a method of task analysis to break down a task into its component subtasks probing the routine expertise employed (Corbridge *et al.* 1994). The expert and elicitor construct a graphical representation of the domain by negotiation and based on the relations between the domain and problem solving elements (Shadbolt 2005).

Diagram-Based Techniques include the generation and use of concept maps, state transition networks, event diagrams, and process maps to capture relevant details of tasks and events (Bechhofer 2006). The knowledge elicitor elicits knowledge from the expert by mutual reference to a diagram on a paper or computer screen. Concept maps have been strongly advocated as a comprehensive technique for eliciting many types of knowledge, which has been demonstrated with experimental evidence showing that people understand and apply knowledge more easily and readily when concept maps are used rather than predicate logic (Epistemics 2003).

2.3.4 Delphi Technique

Most research studies are motivated by the need to answer research questions. To do this however, a suitable research design, thought of as the structure of the research, must be used (Keeney *et al.* 2011; Trochim 2006a). Three types of research designs are: experimental, case study, and survey designs (Parahoo 2006). Even though experimental designs are considered the most rigorous of all research designs in scientific studies (Hall 2013; Trochim 2006b) due to their reliance on random assignment and laboratory controls that ensure the most valid and reliable results, they are usually not practical for many social science, educational, or business research studies since in many cases, researchers cannot exercise laboratory controls in natural-world settings or randomly assign subjects (Hall 2013).

A case study is a qualitative research approach where a case(s) is explored by a researcher over time. It involves detailed and in-depth data collection techniques from multiple sources. In the end, a description of the case(s) and case-based themes are reported on (Creswell 2007). Survey design and implementation is the process of systematically collecting data in order to address an issue. Specifically, individuals are asked questions and the results of the analysis are generalized to groups represented by the respondents (Keeney 2011; Thayer-Hart *et al.* 2010).

One type of survey that is becoming gradually popular, and gaining recognition and use across a wide range of research disciplines, is the Delphi technique (Keeney *et al.* 2011). Originally developed by the Rand Corporation to study the impact of technology on warfare, the Delphi technique allows researchers to maintain significant control over bias in a well-structured academically demanding process using the judgment of qualified experts (Hallowell & Gambatese 2010). The main premise is based on the assumption that group opinion is more valid than individual opinion (Keeney *et al.* 2011). The Delphi technique can be defined as an iterative process designed to combine expert opinion into group consensus using surveys (Lynn *et al.* 1998; Yousuf 2007). Delphi is useful where opinions and judgments of experts and practitioners are necessary, but it is not possible to convene experts in one meeting (Yousuf 2007).

Delphi is cost-effective and widely used for consensus building using specific rounds of questionnaires to collect data from a panel of selected participants. In contrast to other data gathering and analysis techniques, Delphi employs multiple iterations designed to develop a consensus of opinion concerning a specific topic. The feedback process employed in Delphi allows and encourages the selected participants to reassess their initial judgments about the information provided in earlier iterations (Hsu & Sandford 2007; Keeney *et al.* 2011). The Delphi method works especially well when the goal is to improve the understanding of problems, opportunities, solutions, or to develop forecasts (Skulmoski *et al.* 2007).

2.3.4.1 Types of Delphi Techniques

Two common types of Delphi techniques are the classical and modified. The classical Delphi uses an open first round to facilitate idea generation in order to elicit opinion and gain consensus. It uses three or more postal rounds but can be administered by email. The modified Delphi usually takes the form of replacing the first postal round with face-to-face interviews or focus groups (Keeney *et al.* 2011).

The following provisions are made in order to accomplish the objectives of Delphi: feedback of individual contributions of information and knowledge, some assessment of the group judgment or view, some opportunity for individuals to revise views, and some degree of anonymity for the individual responses (Hsu & Sandford 2007; Linstone & Turoff 2002). One important component of the Delphi technique is that a large number of individuals across diverse locations and areas of expertise can be included anonymously, thus avoiding domination of the consensus process by one or a few experts, manipulation, or group pressure for conformity (Hsu & Sandford 2007; Jairath & Weienstein 1994; Keeney *et al.* 2011). The use of statistical tools in the analysis of data in the Delphi technique allows for an objective and impartial analysis and summarization of the collected data (Hsu & Sandford 2007).

2.3.4.2 Delphi Process

Theoretically, the Delphi process can be continuously iterated until consensus is determined to have been achieved (Hsu & Sandford 2007). Typically three rounds of questionnaires are sent to a preselected expert panel, although the decision over the number of rounds is largely practical (Jones *et al.* 1992). The first round usually seeks an open response and allows the participants relatively free scope to elaborate on the topic under investigation (Rowe 1994 cited by Powell 2003). Using a qualitative analysis of the results, the responses are then converted into a well-structured survey instrument for the second round of data collection (Hsu & Sandford 2007; Powell 2003). Alternative approaches such as the use of semi-structured questionnaire can be used especially when extensive review of literature is performed (Hsu & Sandford 2007; Powell 2003). Though optional, pilot testing of questionnaires can help identify ambiguities and improve the feasibility of administration of questionnaires. Next, the participant responses are collated into a single anonymous easily readable list (Jairath & Weinstein 1994).

The second and subsequent rounds are more specific, and seek the quantification of earlier findings, usually through rating or ranking techniques (Powell 2003). The collation of the results from the previous rounds presented to the participants tends to lead to the convergence to a consensus of opinion (Jairath & Weinstein 1994). This process can be iterated until there is a convergence of consensus.

2.3.4.3 Consensus Building

Two common types of criteria used in achieving consensus are: the *statistical approach* and *percentage levels*. The main statistics used are the measures of central tendency (mean, median, and mode) and level of dispersion (standard deviation and inter-quartile range) (Hasson *et al.* 2000). Generally, the uses of median and mode are favored, the former, based on Likert-type scale, is strongly favored in order to provide feedback to the expert panel (Keeney *et al.* 2011). For percentage level criteria, consensus is deemed to have been reached when a certain percentage of the opinion of the expert falls within a prescribed range adopted prior to data collection (Keeney *et al.* 2011). Keeney (2011) highlights the lack of a standard threshold for an acceptable percentage level and cites varying thresholds for different authors to buttress this assertion: 51%, 66%, 70%, 75%, 80% (Boyce *et al.* 1993, Green 1982; Keeney *et al.* 2006, Loughlin & Moore 1979, McKenna 1994, Mitchell 1991, Ulschak 1983, cited by Keeney 2011).

2.3.4.4 Delphi Participant Selection

Powell (2003) has argued that the success of a Delphi study hinges on the combined expertise of the participants who make up the expert panel, of which two major aspects are: panel size and qualifications of expert.

- *Panel Size* – even though the reliability of the consensus reached improves with the increase in participants, there is limited empirical evidence supporting the effect of this increase on the reliability or validity of consensus reached (Murphy *et al.* 1998). Though most Delphi studies have used between 15 and 20 respondents (Ludwig 1994), or even a wider range of 10 to 100 experts (Akins *et al.* 2005), Skulmoski *et al.* (2007) argue that when the sample is homogenous in nature, then smaller sample sizes, such as 10–15 participants may be sufficient since an inference could be made about the generalizability and representativeness to the larger population. Hallowell and Gambatese (2010) add that panel sizes of between 12 and 15 can be easily managed by a full-time facilitator.
- *Qualifications of Expert* – though the most important aspect of an expert panel member in a Delphi process is their level of expertise, the characteristics required to define an individual as an "expert" are ambiguous (Hallowell & Gambatese 2010). This assertion points to a correlation between the quality of the research findings and the quality of the expert panel. Delphi does not always use random sample which is representative of the target population, rather, it employs experts (Keeney *et al.* 2011).

For a successful implementation of the Delphi technique, it is important that expert panel members have the following traits:

- Willing and able to make a valid contribution (Powell 2003).

- Must reflect current knowledge, perceptions, and relatively impartial to findings (Jairath & Weinstein 1994).
- Diverse panel to ensure better performance through the consideration of different perspectives and a range of alternatives (Murphy *et al.* 1998).
- Highly trained and competent within the specialized area of knowledge related to the target issue (Hsu & Sandford 2007).
- Nominated from members within the target groups of experts (Ludwig 1994).
- Primary stakeholders with various interests related to the target issue or research effort (Hsu & Sandford 2007).
- Identified through literature searches and/or recommendation from other recognized experts in the field (Gordon 1992).

2.3.4.5 Reliability and Validity of Delphi

In terms of ***Reliability***, Delphi ensures methodological rigor which is vital to the integrity of research (Keeney *et al.* 2011). Reliability is the certainty that the research is true enough to be trustworthy, gives consistent results in different applications when solving research problems, or yield the same results when used repeatedly in a situation that did not change (Ahmad 2012; Kelly 1996; Ziesel 2006).

Unlike objective methods where bias is mainly introduced by the research, the success of the Delphi process depends on the unbiased judgment of experts (Hallowell & Gambatese 2010). It enhances reliability by two main ways: (1) bias is avoided due to the anonymity of participants which avoids domination of the consensus process by one or a few experts, manipulation, or group pressure for conformity; and (2) increase in panel size enhances the reliability of the respondent group, though panel quality is more important than its quantity (Keeney *et al.* 2011).

Validity refers to the ability to measure the attributes of the construct (DeVon *et al.* 2007), enhanced when primary data is used (Ahmad 2012). Two ways of measuring validity include (Keeney *et al.* 2011): content and criterion-related validity.

- *Content validity* – this estimates if the item in the tool samples the complete range of study attributes (DeVon *et al.* 2007). Content validity in Delphi is based on the assumptions that (Keeney *et al.* 2011; Spencer-Cooke 1989): (1) results are based on group and expert opinion which is more valid than individual opinion and (2) experts are afforded the opportunity to scale items during the qualitative round whilst the iteration allows for an opportunity to review and judge suitability of scale.
- *Criterion-related validity* – the rounds, iteration, and achieving consensus establishes that a test can effectively predict criterion or indicators of a construct (Keeney *et al.* 2011).

2.4 DECISION SUPPORT SYSTEMS (DSS)

This section reviews literature on the concept of decision making, definitions, types, and components of decision support systems with an emphasis on knowledge-based/intelligent systems and its applications as well as application examples with potential for this research.

2.4.1 Decision-Making

A simple view of decision-making is that it is a problem of choice among several alternatives for the purpose of attaining a goal(s) (Druzdzel & Flynn 2002; Turban *et al.* 2005). A more sophisticated view includes the process of constructing the alternatives (i.e., given a problem statement, developing choice options). A complete picture includes a search for opportunities for decisions (discovering that there is a decision to be made) (Druzdzel & Flynn 2002).

Decision support systems exist to help people make decisions. To understand it, one needs to appreciate the decision-making process (DeKock 2003), a process of choosing among alternative courses of action for the purpose of attaining a goal(s) (Turban *et al.* 2005). Three types of decisions are: structured, semi-structured, and unstructured (Finlay 1994; Mallach 1994; Turban 1993, 1995, 2001). In structured decisions, a well-defined decision-making procedure exists, thus, all inputs, outputs, and internal procedures are known and can be specified. Semi-structured decisions have some structured elements but cannot be completely structured and are difficult to specify at least one of the components. Unstructured decisions, have unstructured decision components since the decision may be new, complex, or rare that it would not have been studied completely (Bohanec 2009).

2.4.2 Definition and Types of Decision Support Systems

A decision support system can be defined as an interactive computer-based system intended to help users make semi-structured and unstructured decisions by retrieving, summarizing, and analyzing decision relevant data (Arnott 2004; Bidgoli 1993; Druzdel & Flynn 2002; Power 1998). It can improve the effectiveness of decision-making, decrease the need for training, improve management control, facilitate communication, save effort by the user, reduce costs, and allow for more objective decision-making (Turban *et al.* 2005).

Decision support systems can be divided into several types based on their dominant architecture component. The five major types include: communications-driven, data-driven, document-driven, knowledge-driven, and model-driven systems (Power 2009). Of these types, the knowledge-driven system fits the scope of the intelligent decision support system envisioned for this research. These are person-computer systems with specialized problem-solving expertise that suggest or recommend actions to managers (Fedorowics 1993; ISAI 2003; Power 2009).

2.4.3 Components of Knowledge-Driven Decision Support Systems (DSS)

The three fundamental components of a decision support system are: database management system which stores raw data, model-base management system which converts the raw data into useful information, and dialog generation and management system or user interface. A decision support system that requires expert knowledge in decision-making has an optional component called knowledge-based management system (Druzdzel & Flynn 2002; Leishman 2005). Though optional, this system can act as an independent subsystem or support for other systems and can also provide many benefits by providing intelligence for the three major components (Turban *et al.* 2005). A decision support system that includes such a component is referred to as an intelligent decision support system (IDSS) many of which are implemented based on expert systems (Vohra & Das 2011).

The basic concept of an expert system is to capture and organize the task-specific knowledge derived from the experts (expertise) in a computer program. Users can recall the stored expert knowledge for specific advice in solving a problem. The system arrives at a particular conclusion by means of inferences and then provides advice or necessary logic in the same way a human expert would (Liao 2005; Syal *et al.* 2013; Turban *et al.* 2005; Warzawski 1985). The intelligent decision support system envisaged for this research had a knowledge-based management system that incorporated the model base features into an expert system shell obtained from Exsys Corvid (Basen & Dutta 1984 cited by Turban & Watkins 1986; Özbayrak & Bell 2003; Shannon 1985 cited by Turban & Watkins 1986; Turban & Watkins 1986) (Figure 2.10).

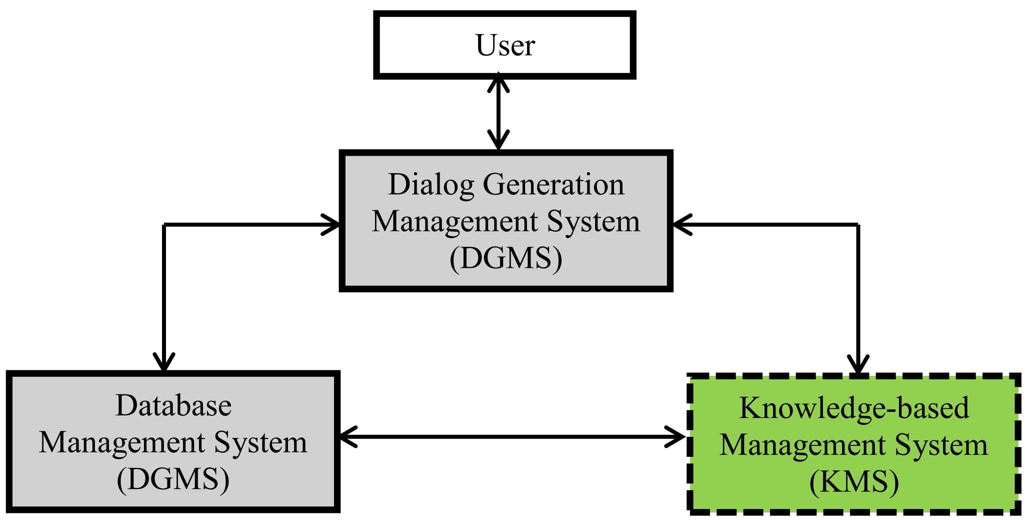


Figure 2.10: Schematic View of Envisaged Intelligent Decision Support System

2.4.4 Decision Support Systems Applications in Related Fields

The most frequently used techniques for developing knowledge-based systems are rules-based systems, case-based systems, model-based system, artificial neural networks, and genetic algorithms, applicable to many different kinds of decision-making scenarios (Yang & Skitmore 1996). Specifically, there has been increasing focus on decision support system applications in the Architectural, Engineering, and Construction industry in the last decade (Juan *et al.* 2009; Kolokotsa *et al.* 2009; Yang & Peng 2001; Zavadskas *et al.* 2006). Two specific examples of the application of such systems in related fields are discussed below:

2.4.4.1 Genetic Algorithm-Based Decision Support System for Housing Condition Assessment and Refurbishment Strategies (Juan et. al. 2009)

This study focused on residents facing refurbishment decisions and proposed a concept for developing resident-friendly, on-line, housing condition assessment, and refurbishment decision support system (Figure 2.11).

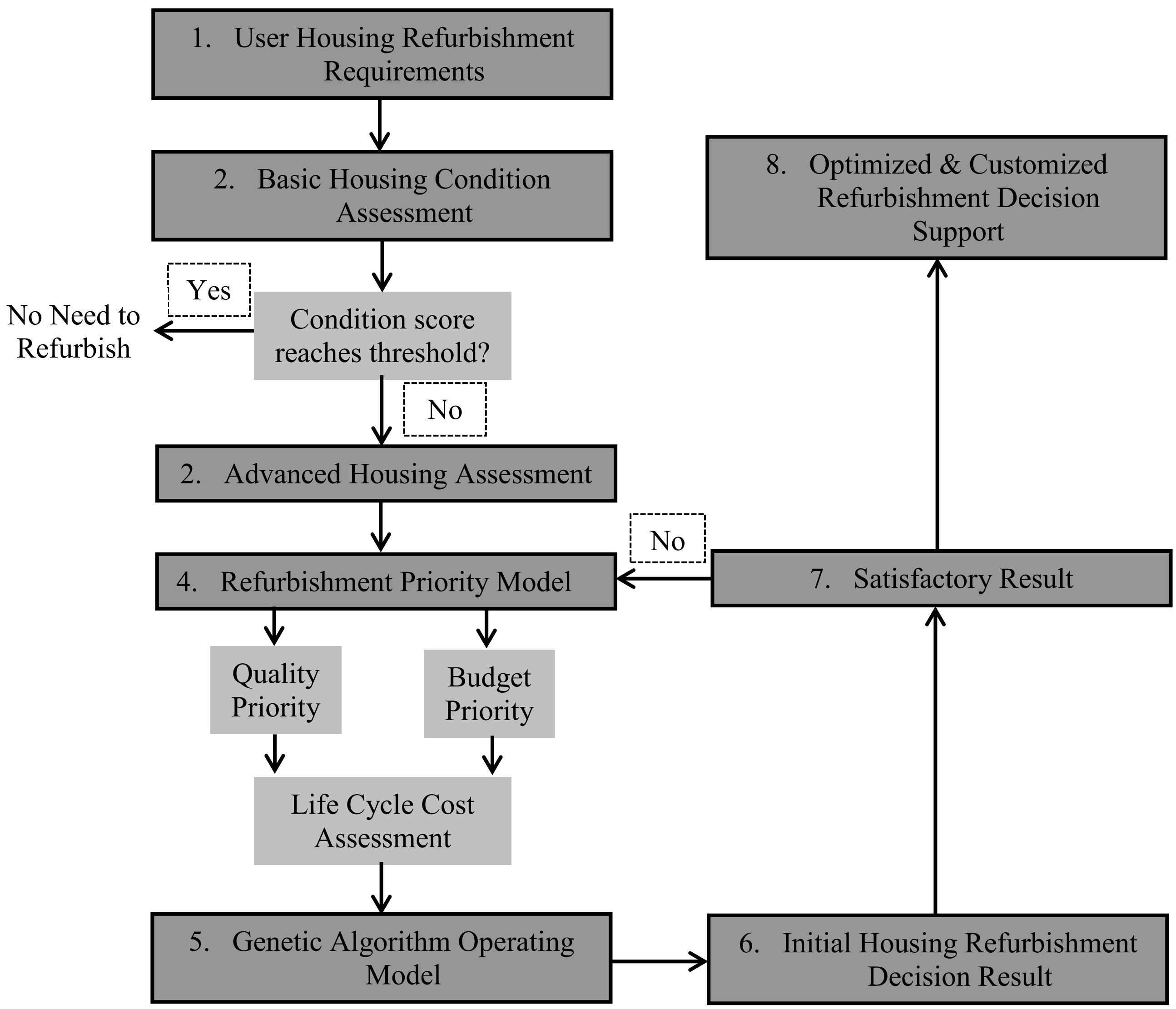


Figure 2.11: Decision Support Process Diagram

Three procedures contained in developing the decision support system are:

1. Evaluate the online mechanism for condition assessment, including the physical and functional states of housing;
2. Implement an optimization algorithm model based on the genetic algorithm approach in two scenarios, quality priority and budget priority, to figure out satisfactory refurbishment strategies; and
3. Map the interface of decision support information to users who may plan to perform refurbishment work.

Based on the existing evaluation systems, the authors selected six criteria for refurbishment application based on the frequency in the literature review: safety, usage, convenience, comfort, utility, and health. The trade-off between cost and quality for refurbishment work was mainly determined through prior interviews with participants considering conducting housing refurbishment within the year. Two priority decision models were developed: budget-based restriction (Budget Priority) where residents usually determine their refurbishment budget, and quality-based restriction (Quality Priority), where residents may determine their expected (fixed) refurbishment quality.

- *Budget Priority* – Though residents usually have a pre-determined retrofit budget, it is difficult for them to successfully perform the retrofit work to meet optimum quality standards without sufficient knowledge and experience. The budget prioritization system allows residents to determine their refurbishment budget by providing the optimal quality of retrofit actions that are within the resident's fixed budget.

- *Quality Priority* – Several simplified scoring rules for defining the quality of each item were developed. The quality score system was developed by interviewing contractors and refurbishment experts. The decision support system architecture consisted of three modules: interface, analysis, and database. The interface module provides expert knowledge in a user-friendly way to improve the quality of communication among the residents, the retrofit designers, and contractors. The analysis module helps make the complex operation process more efficient and effective, and the database module provides updates on cost data and on new retrofit action skills available.

2.4.4.2 Knowledge-based Decision Support System Quality Function Deployment Tool for Assessment of Building Envelopes (Singhaputtangkul et al. 2013)

When assessing building envelope materials and designs for a private high-rise residential building in the early design stage, a building design team may face several decision-making problems. These include inadequate consideration of requirements and possible materials and designs, lack of communication and integration between team members, subjective and uncertain requirements, and disagreement between members of the team. As a result, this study developed an automated knowledge-based decision support system quality function deployment tool to help the team to ease such problems (Figure 2.12). Four major parts of the tool are:

- House of quality
- Knowledge management system
- Fuzzy inference engine
- User interface

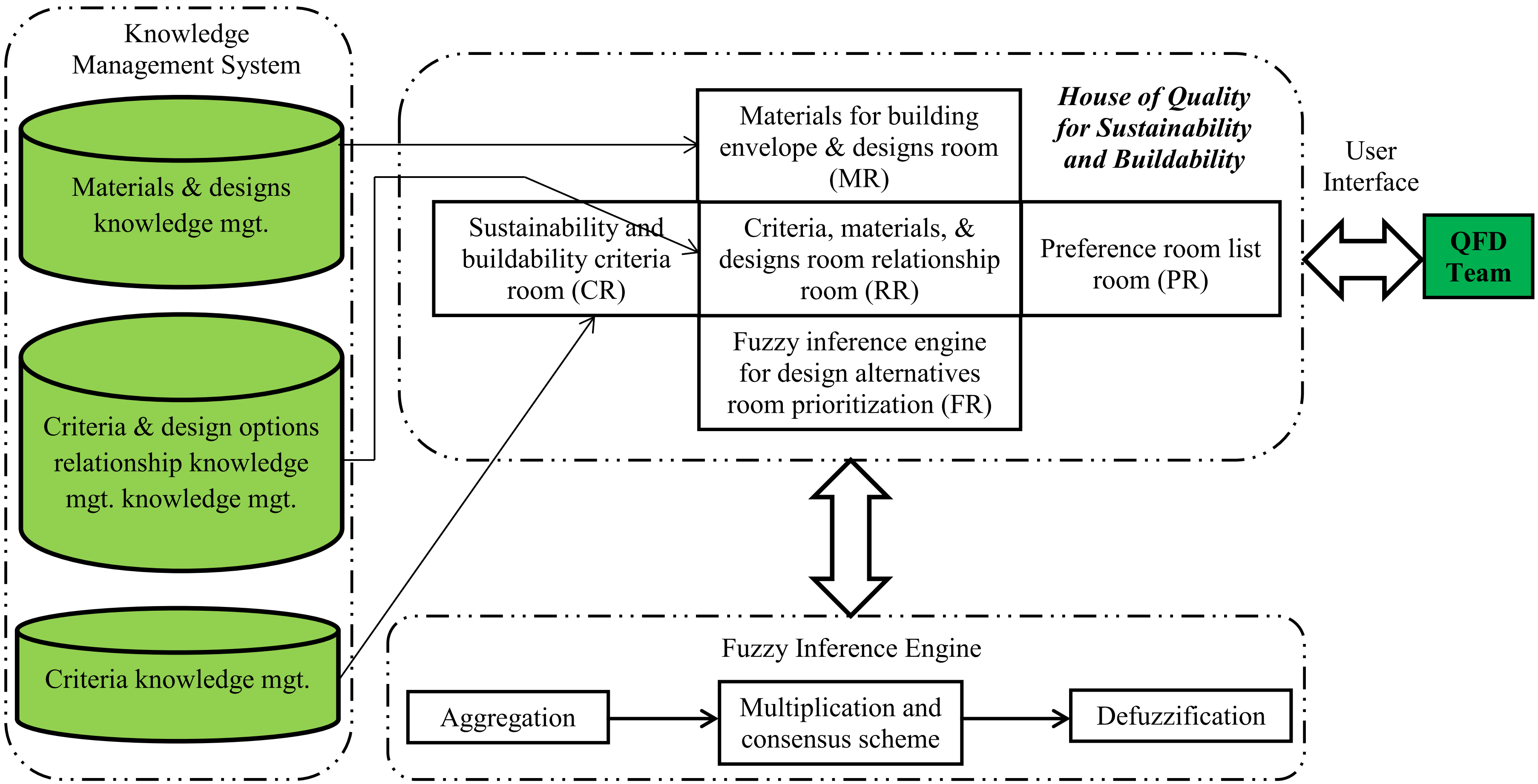


Figure 2.12: Architecture of the Knowledge-Based Decision Support System Quality Function Deployment Tool

(Modified from Singhaputtangkul *et al.* 2013)

The *house of quality* is the central element and functions to structure the decision making process and integrate other elements together. It has the following sub-components:

- Criteria for sustainability and buildability.
- Building envelope materials and designs.
- Relationships between criteria and materials and designs.
- Fuzzy inference engine for prioritizing design alternatives.
- Preference list.

The *knowledge management system* serves as the database for the first three sub-components of the house of quality for sustainability and buildability, and is made up of three parts:

- Knowledge management of the criteria system grouped into 4 categories: environmental, economic, social, and buildability.
- Knowledge management of the materials and designs system.
- Knowledge management of relationships between the criteria and design alternatives system presented using Boolean logic, e.g. IF *the design alternative supports aesthetics, trend and image of a building project,* THEN *the performance satisfaction of the design increases.*

The *fuzzy inference engine* evaluates preferences of decision makers for the assessment of the building envelope materials and designs by translating subjective information, incomplete information, and partially ignorant facts into the decision model.

The *user interface* – this provides an interaction platform between the user and the tool.

Using a case study of the design team comprising an architect, a civil and structural engineer, and a mechanical and electrical engineer, the results showed the following:

- Decision makers can be reminded about key criteria and possible building envelope materials and designs for the assessment of building envelopes.
- There was increased efficiency and consistency in assessment decision-making.
- There was enhanced communication and integration among decision makers.
- Fuzzy inference engine can provide assistance to the team in translating subjective and uncertain requirements into a more useful format.
- The consensus scheme helps in the reduction of disagreements in opinions among members.

2.5 CHAPTER SUMMARY

This chapter identified and reviewed literature under the three broad categories of energy efficiency retrofit, expertise development and elicitation, and decision support systems. In the first category, specific areas of literature reviewed included the history and current state, programs and initiatives, information categories for energy efficiency retrofits, and energy retrofit decision process. The second category looked at the nature, development, and strategies for eliciting expert knowledge with an emphasis on the Delphi technique. The final category reviewed specific literature relating to decision-making, types and components of decision support systems with an emphasis on intelligent systems and its relevant applications.

CHAPTER 3

PROCESS AND QUANTITATIVE INFORMATION FOR ENERGY RETROFIT DSS

3.1 INTRODUCTION

The energy retrofit industry and the important role played by information in the decision-making process were highlighted in Chapter two. In addition, decision support systems were reviewed in detail with specific emphasis on such systems that incorporate knowledge-based systems, also known as intelligent decision support systems. Finally, due to the integral role of the expertise of experts or expert judgments in knowledge-based systems, the development and elicitation of expertise was thoroughly discussed.

It has been established that homeowners pursue information from a variety of sources in order to undertake energy retrofits. These information sources were put into two broad categories of quantitative information and expert knowledge. A critical aspect of the energy retrofit decision process involves the integration of quantitative information with expert knowledge. Such synthesized information serves as a good basis for the development of an intelligent decision support system. However, there are problems with information obtained from these two sources, particularly expert knowledge from experts such as energy auditors and retrofit contractors. The problems include comprehensiveness, inaccuracy, cost, and perception of bias. It is vital that these two information categories are understood in order to solve the information barrier in the adoption of energy retrofits in existing homes. Chapter one of this dissertation mentioned the importance of focusing on the packaging and delivery of quantitative information and expert knowledge in order to promote energy retrofits among homeowners.

To develop an intelligent decision support system for energy retrofits, however, it is important to understand the energy retrofit decision process. The researcher was part of a team that developed the energy retrofit decision process model. The team comprised researchers from the Sustainable Construction Management Research Group of Michigan State University, The Dow Chemical Company – Building Solutions Group, Habitat for Humanity, and Ferris State University. Two graduate dissertations (Samuel 2011; Mo 2012) are outputs of this research.

3.1.1 Glossary

In this chapter, the frequently used terms quantitative information and expert knowledge may be interchanged with other terms as indicated below:

- Quantitative Information/ Published Information/ Databases/ Simulation Reports/ Documents, Figures, Pictures etc.
- Expert Knowledge/ Expertise/ Experience-Based Judgment/ Retrofit Contractors' Advice/ Energy Auditors' Advice.
- Homeowner/User.

3.1.2 Chapter Objectives

A major step identified in the implementation process of an energy retrofit decision support system is the integration of quantitative information with expert knowledge in the decision process in order to help users with decision-making. To implement this, however, in the energy retrofit domain, there is a need to understand the energy retrofit decision process. This chapter has a three-fold objective and is shown below:

1. To analyze the energy retrofit decision process model.

2. To analyze the available quantitative information that must be integrated into the energy retrofit decision support system.
3. To demonstrate how the understanding of the energy retrofit decision process model and compilation of the quantitative information can be integrated into an energy retrofit decision support system.

3.2 ENERGY RETROFIT DECISION PROCESS (Syal *et al*. 2014; Samuel 2011)

Based on the general understanding of the energy retrofit decision making process by energy auditors, retrofit contractors, and homeowners, the researchers developed the energy retrofit decision process model. Specifically, data was collected from three sources: literature review, energy auditor and retrofit contractor interviews, and job shadowing of energy retrofit professionals.

3.2.1 Preliminary Knowledge-Base for Energy Retrofit Decision Process Model

Since the energy retrofit decision process model integrates quantitative information with expert knowledge, there was a need to develop a preliminary knowledgebase to be used as the initial expert knowledge for the model. Chapter four of this dissertation discusses the development of a comprehensive energy retrofit elicitation strategy. It is on the basis of this elicitation strategy that relevant energy retrofit information is eventually elicited and compiled.

For the preliminary knowledgebase however, a total of six home energy auditors and retrofit contractors were the main source. The compilation involved detailed interviews and job shadowing of the identified energy retrofit professionals. The aim of the process was to understand and compile the protocol followed for decision making in energy retrofits. All the retrofit professionals were certified by two nationally recognized certification groups Residential Energy Services Network and/or Building Performance Institute. While three of the retrofit professionals were both energy auditors and retrofit contractors, two were both energy auditors and HVAC contractors, and one was solely an energy auditor.

3.2.1.1 General Section

There were two sections to the interview: a general section and a retrofit specific section. The general section sought to identify information regarding the retrofit professional, including area of expertise, period of time involved in the area, and size and method of business operations. In addition, this section was used to eliminate any biases in the opinion of the retrofit professionals. This was achieved by asking questions related to personal likes and dislikes in the retrofit process/industry. In instances where it was determined that an opinion in the retrofit-specific section substantiated the bias expressed in the general section, that opinion was considered biased and eliminated. For example, if their area of expertise is in window replacement, and they promoted an opinion that upgrading existing windows to higher efficient counterparts was the best energy efficiency strategy contrary to existing knowledge, this opinion was considered biased and removed.

3.2.1.2 Retrofit Specific Section

In the retrofit specific section of the interviews, the goal was to query the retrofit professionals on the specifics of the retrofit process in order to identify and elicit energy retrofit execution strategies that can be employed in the proposed system. Thus, a standard protocol for the retrofit process was identified based on the following: identification of methods for selecting retrofit measures, shortlisting and prioritizing measures, and identifying categories of information to be provided for the installation of shortlisted measures. The questions in this section sought to elicit the techniques they use when they encounter practical retrofit situations and included the following:

- Approach taken to identify measures.
- Methods used to shortlist and prioritize measures.
- Technology and equipment they would use to audit a home.
- Measures considered unsafe and cannot be installed by the homeowners themselves.
- Building science aspects to be considered while selecting measures.
- Homeowner motivations in deciding to energy retrofit their home.
- Categories of information necessary to install a measure properly.

The job shadowing of these retrofit professionals when they performed practical energy retrofit work was used to complement the information elicited from the above-noted questions.

3.2.2 Energy Retrofit Decision Process Model

On the basis of the information obtained from the preliminary knowledgebase, the reasoning of these professionals when performing retrofit tasks, as well as the sequence in which these tasks were performed, were identified and documented. This information was used to compile a common protocol for the energy retrofit decision process. Using the protocol and associated information inputs at various decision points, the energy retrofit decision process model was developed (Figure 3.1).

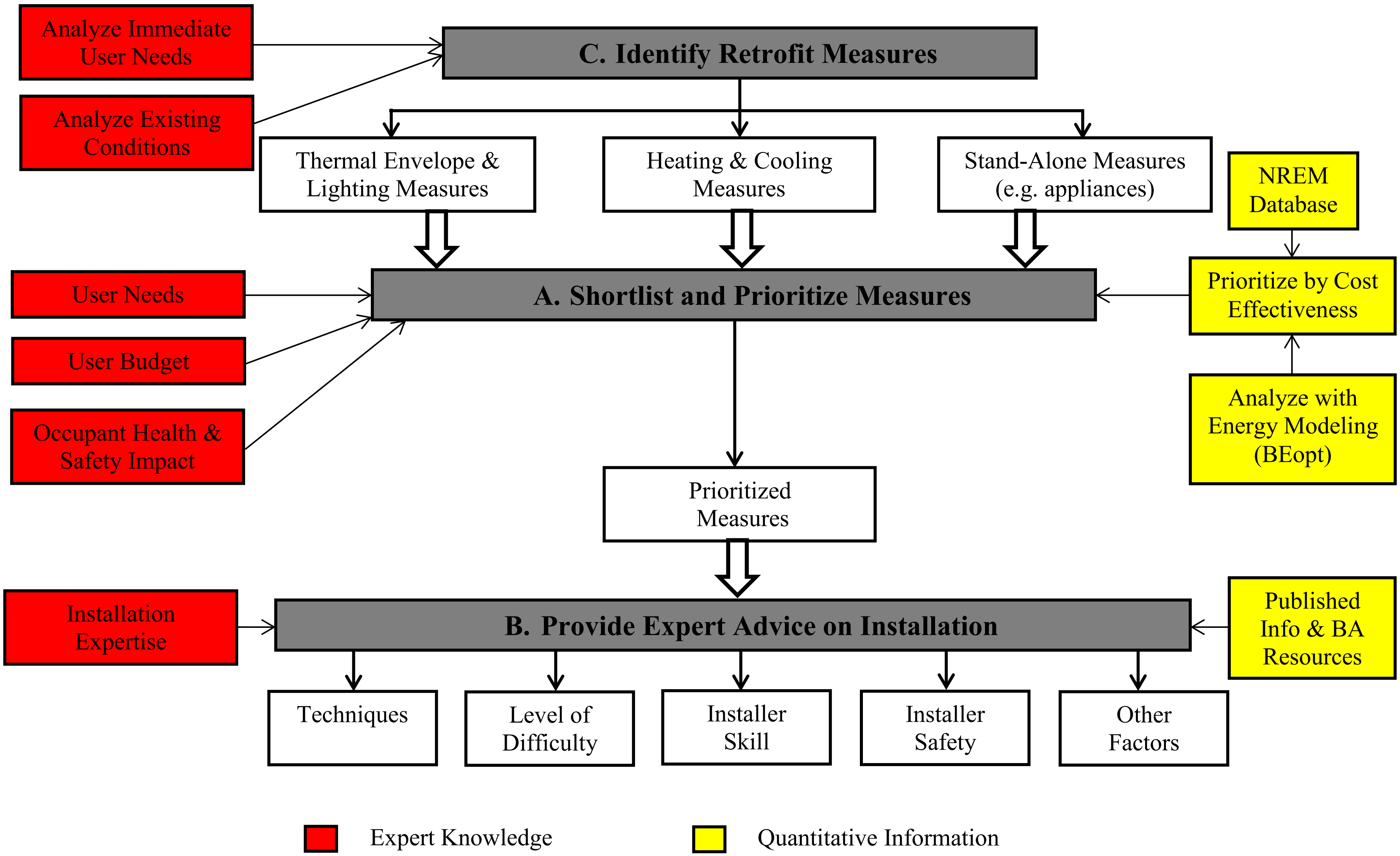


Figure 3.1: Energy Retrofit Decision Process (ERDP) Model (Modified from Syal *et al.* 2013, 2014)

The energy retrofit decision process model outlines the steps, and information output for each step, for the implementation of residential energy retrofit measures. There is a clear distinction between information inputs using the two key categories of information: quantitative information and expert knowledge. The three principal steps involved are as follows:

A. Identify Retrofit Measures.
B. Shortlist and Prioritize Measures.
C. Provide Expert Advice on Installation.

The main sources of quantitative information used for the model are shown below:

- Cost information – national residential efficiency measures (NREM) database.
- Energy Simulation – building energy optimization (BEopt) software.
- Financial Incentives – database of state incentives for renewable energy.
- Others – published literature.

The main sources of the preliminary knowledgebase in the model are shown below:

- Literature review.
- Interviews with energy auditors and retrofit contractors.
- Job shadowing of energy auditors and retrofit contractors.

The next section discusses in detail the three principal steps of the model.

3.2.2.1 Identify Retrofit Measures

The first step in the retrofit decision making process mimics the function of an energy auditor who assesses the energy performance of a home. The user provides information regarding existing home efficiency levels. The model employs a dual approach by analyzing homeowner and home upgrade needs, and then considers retrofit measure possibilities for upgrading the existing inefficiencies. Using the national residential efficiency measures database, the retrofit measures are grouped based on the measure types available: major appliances, domestic hot water, enclosure, HVAC equipment, lighting, and miscellaneous. The basis for recommending that a building component or system be upgraded to higher efficiency standards, such as Energy Star or Building America Benchmark, is when it is identified as inefficient. Finally these measures are put into three broad categories: thermal envelope and lighting measures, heating and cooling measures, and stand-alone measures (such as appliances).

3.2.2.2 Shortlist and Prioritize Measures

At the end of the first step, a number of retrofit measures are identified, which are then shortlisted in the second step based, on the budget of the homeowner. For maximum return on the retrofit investment by user, shortlisting also includes prioritization based on the cost effectiveness of the measures. To achieve these, the following process is followed:

1. The first priority is given to the needs of the homeowner, even if it is less cost effective.
2. Measures are prioritized based on the budget of the homeowner and the cost effectiveness of the measure. Energy savings is determined using an energy simulation tool and cost information is from the national residential efficiency measures cost database.
3. Major energy-related interactions occur between the components of the home such as thermal envelope and lighting measures and in heating and cooling measures. The system incorporates this phenomenon in order to obtain optimal results.
4. Measures, such as non-HVAC appliances, with limited or no interactions with other components regarding energy performance, otherwise regarded as stand-alone measures, are determined independent of the other measures.

5. Finally, strategies for improving occupant health and safety issues are proposed.

3.2.2.3 Energy Retrofit Installation Advice

Once the measures have been shortlisted and prioritized, the final step of the model involves the provision of energy retrofit advice on the installation of the measures determined. This advice is provided under the following categories:

- Installation techniques
- Level of installation difficulty
- Installer skill level
- Installer safety
- Material selection and procurement
- Other factors

The main sources of energy retrofit advice are from both quantitative information sources, such as published information, and existing BA resources. The published information can be provided as images, text, files, and web links.

3.3 ENERGY RETROFIT DECISION PROCESS MODEL AS A BUILDING BLOCK FOR INTELLIGENT DECISION SUPPORT SYSTEM FRAMEWORK

As discussed in Chapter two of this dissertation, of the five major types of decision support systems, the knowledge-driven type, otherwise known as an intelligent decision support system, has specialized problem-solving expertise and suggests or recommends actions (Power 2009; Fedorowicz 1993; ISAI 2003). Though a number of such systems have been developed in the architectural, engineering, construction and construction management industry in the last 10-15 years, many of these are dominated by building remodeling, refurbishment, and energy retrofit types (Juan *et al*. 2009; Kingsman & De Souza 1997; Kolokotsa *et al*. 2009; Singhaputtangkul *et al.* 2013; Yang & Peng 2001; Zavadskas *et al*. 2006).

In order to develop a framework for an intelligent decision support system for the energy retrofit industry, a number of building blocks have been identified. These building blocks were identified based on the understanding of the energy retrofit decision process (ERDP) model and the development of an intelligent decision support system. The following three building blocks will be employed in the eventual development of the framework for the energy retrofit industry (Figure 3.2): (1) ERDP model, (2) quantitative information, and (3) expert Knowledge.

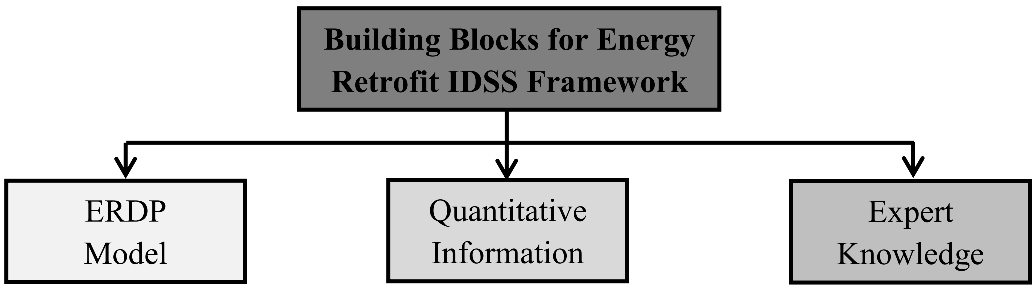


Figure 3.2: Building Blocks for Intelligent Decision Support System Framework

3.3.1 Quantitative Information for Energy Retrofit Decision Support System Framework

Having understood the model, this section explores the use of one of the three building blocks, the development of comprehensive quantitative information and its components, in the energy retrofit DSS. It is made up of three distinct components (Figure 3.3):

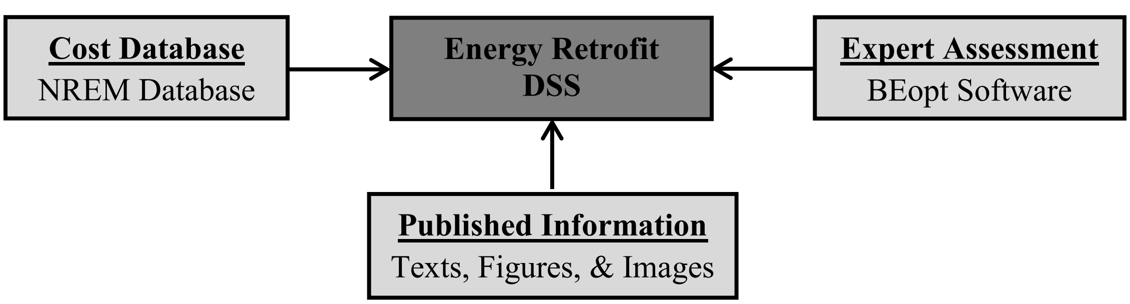


Figure 3.3: Components of the Energy Retrofit Decision Support System

In the next sections, each of the components is discussed in detail, and their working and integration into the energy retrofit decision process model is highlighted.

3.3.1.1 Cost Database (NREM) (NREL 2010a)

The cost database used in this research is the National Residential Efficiency Measures database. It provided the cost and technology information input for the retrofit decision process. As discussed in Chapter two, the database is the nationally recognized source of retrofit technology and cost information, and is developed by the National Renewable Energy laboratory of the United States Department of Energy (NREL 2010a; Syal *et al.* 2014). The research team performed a detailed analysis of the architecture of the database. Next, input and output information was compiled. The intent was to explore the possibility of integrating the database into an expert system shell for the eventual inclusion as part of the development of the proposed IDSS framework demonstration.

In the ***Database Structure***, the available retrofit measures and data in the database are organized in a hierarchical structure as follows (Figure 3.4) (NREL 2010a; Syal *et al.* 2014):

- *Group*: as the highest level of classification of major house systems, it currently contains six measure types (appliance, domestic hot water, lighting, enclosure, HVAC, miscellaneous).
- *Category*: this is the sub-classification of a Group (for example, “HVAC” is a group, and “Cooling” and “Heating” are the categories of “HVAC”).

- *Component type*: this is the sub-classification of a *category* and is more specific (for example, "Central Air Conditioner" and "Room Air Conditioner" (AC) are more specific methods of "Cooling," and these are defined as Component Types in the database).
- *Component*: the lowest level of the hierarchical structure representing the most detailed retrofit measures with distinctive properties (for example, "Central Air Conditioner SEER 13 or SEER 15" are distinctive properties of specific types of central AC).

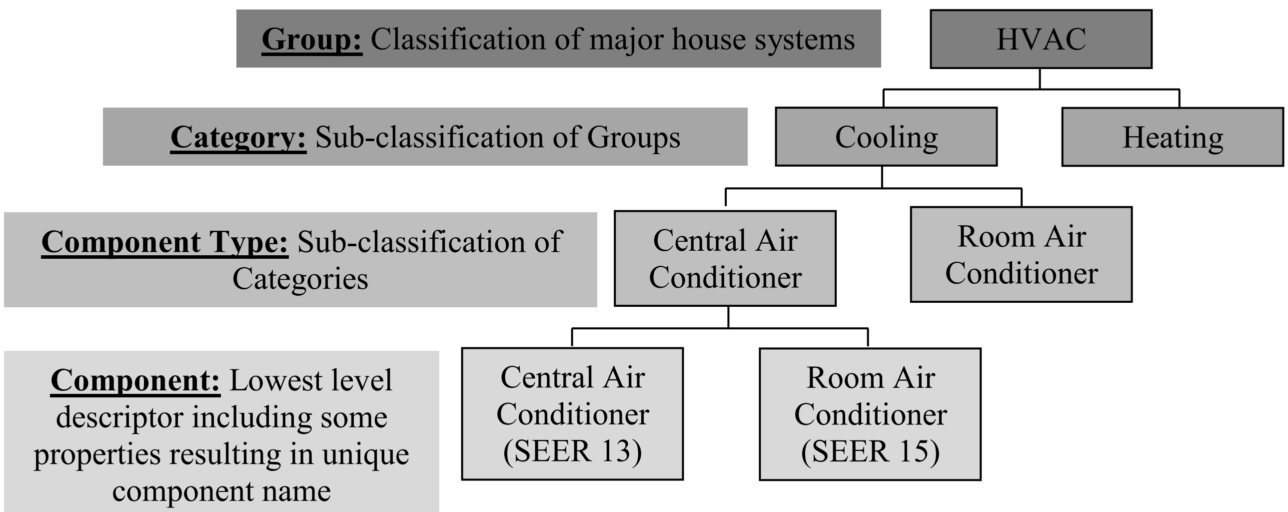


Figure 3.4: Database Structure and Hierarchy (Modified from NREL 2010a)

In terms of ***measure construction***, the national residential energy laboratory has developed a rule set that evaluates the energy efficiency of component properties. These rules are used at the point of measure construction. The overarching principle of the rule set is that the after-component must be more energy efficient than the before-component. For example, when the before-component is an incandescent light bulb, the after-component must be one with better energy efficiency properties such as compact fluorescent lights or light-emitting diode lights. Apart from the practical improvement inherent in the rules, the after component must provide the same level of service as the before-component. This is in conformity with the principle of energy retrofits, where renovations done must improve the overall energy efficiency of the home. Finally, the system suggests the value-added energy efficiency practices for users (NREL 2010; Syal *et al.* 2014).

For the ***types of retrofit measures***, there are six types of retrofit measures in the database as mentioned earlier. The hierarchy of data in the database corresponds with the types of retrofit measures in each Group (Figure 3.4). Each retrofit measure comprises component types, and each component type has several measures (Figure 3.5).

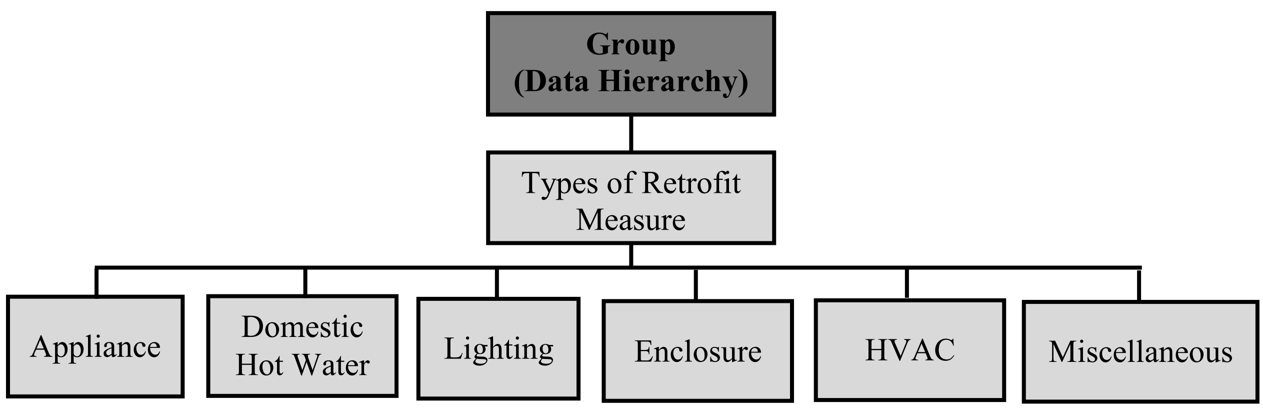


Figure 3.5: Types of Retrofit Measures (Group Level)

In total, there are forty-seven component types corresponding to each of the six retrofit measure types. For each component type, the corresponding number of retrofit measures is indicated in parentheses. For example, there are 190 different clothes washers under the appliances measure. Mo (2012) posits that data for each retrofit measure is collected from various sources and the amount of data depends on the reasons for the retrofit, such as market variety for the measure product, the complexity of the installation, etc.

Actions are specific labor operation methods, and explain how the after-component must be implemented by the database. The actions are put into five different categories (NREL 2010; Mo 2012):

- *Replace*: exchange a before-component for a more energy efficient after-component of the same type, when the homeowner wishes to retain the existing function.
- *Install*: initiate an energy efficient after-component from none (installation upgrades the existing condition of a home, though the homeowner does not usually require it).
- *Remove*: exchange a before-component for none (can be combined with the Install action when the users wish to use different component types).
- *Insulate*: related to the installation of additional insulation into existing measure components.
- *Seal*: related to leakage reductions for either the whole house or ducts.

Regarding the ***database construction and integration (Mo 2012)***, the database was constructed using Extensible Markup Language (XML), can be downloaded to local computers of users as a form of XML file, and has universal access using a web user interface. Within the XML files, data objects such as measure components, actions, and costs are stored as table structures. These can be accessed using queries. In order to select specific data from the XML database, an XML Path Language, XPath, was selected. It is the main method through which the database, which is in an XML format, is connected to the expert system shell program of the proposed intelligent decision support system.

In order to fully integrate the database to the proposed intelligent decision support system, a number of software applications were used. Two challenges encountered were: the determination of the structure and data context of the XML code, and gaining a comprehensive understanding of the XML database. As a result of these two challenges, various software applications including Microsoft Office Access (Microsoft Corporation 2012), BaseX (BaseX 2012), and XML spy, were employed.

3.3.1.2 Energy Assessment (BEopt Software)

In Chapter two, the importance of energy assessment in the energy retrofit process was highlighted. Various energy assessment tools are available on the market. The Building Energy Optimization (BEopt) software is one such tool that aids in the prioritization of energy retrofit measures. It is used to obtain the optimal conditions for a building design by providing the cost and energy consumption information of each of the selected measures. First of all, the software identifies the existing condition of the house by allowing the homeowner to select from a list of predefined input options. Based on the options selected, it calculates the energy savings cost. This is compared with an ideal, or reference case, built into the system. Next, reports related to the input options and output results are provided for further analysis. There are three different input types (geometry, options, and site) that must be applied to the homes by users during the energy assessment process and are discussed below.

The ***geometry input*** is divided into the drawing area, rendering area, and general inputs (NREL 2012a) (Figure 3.6).

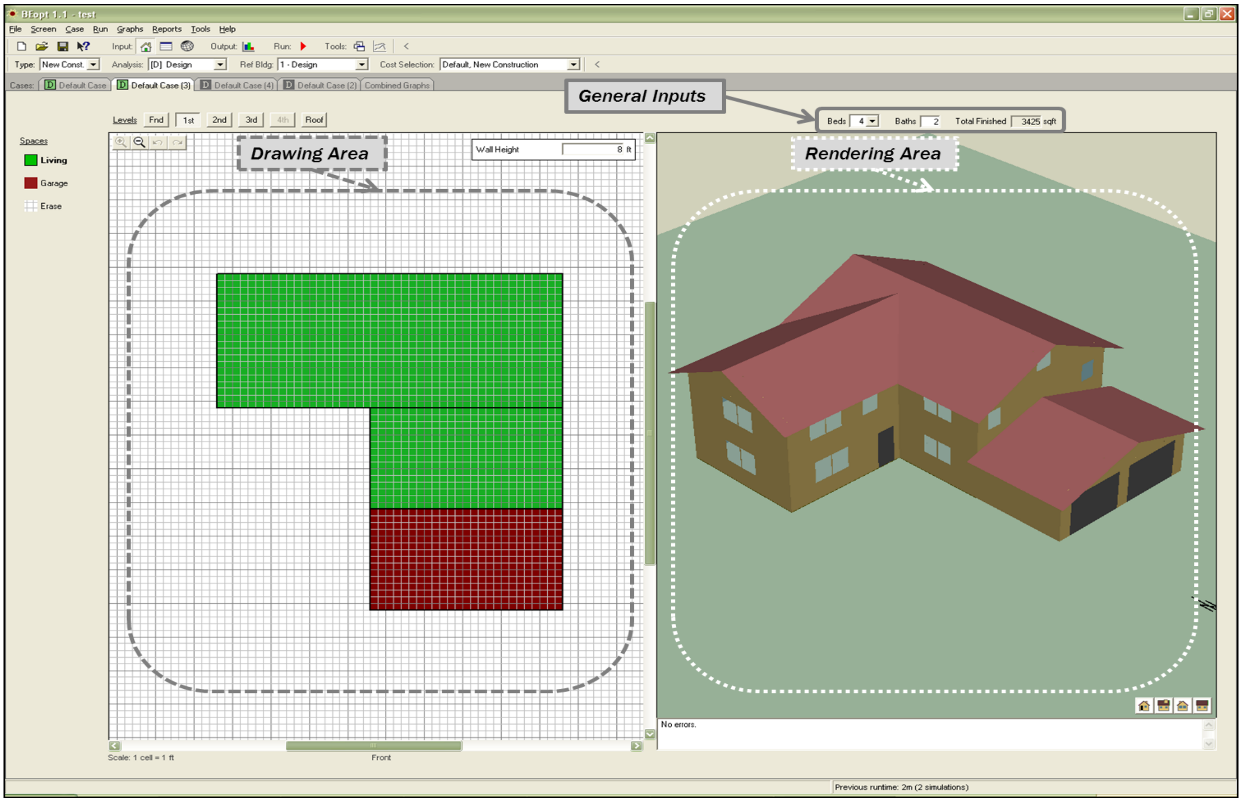


Figure 3.6: Screenshot of Geometry Input in BEopt

(Note: the floor plan is indicated on the left and reflected in the rendering area on the right as a three dimensional model with openings for windows and a roof. Different space types such as the number of bedrooms, bathrooms, etc. can be indicated in the general inputs section)

For the ***options input,*** users can select corresponding retrofit information that reflects the existing condition of their home based on predefined options in specified categories (Figure 3.7). Currently, fourteen retrofit measure groups are provided by, and are indicated below (NREL 2012a) (Table 3.1):

Table 3.1: Retrofit Measure Groups

Building	Foundation/Floors	Major Appliances	Power Generation
Operation	Thermal Mass	Lighting	Include Combinations
Walls	Windows/Shading	Space Conditioning	
Ceiling/Roofs	Airflow	Water Heating	

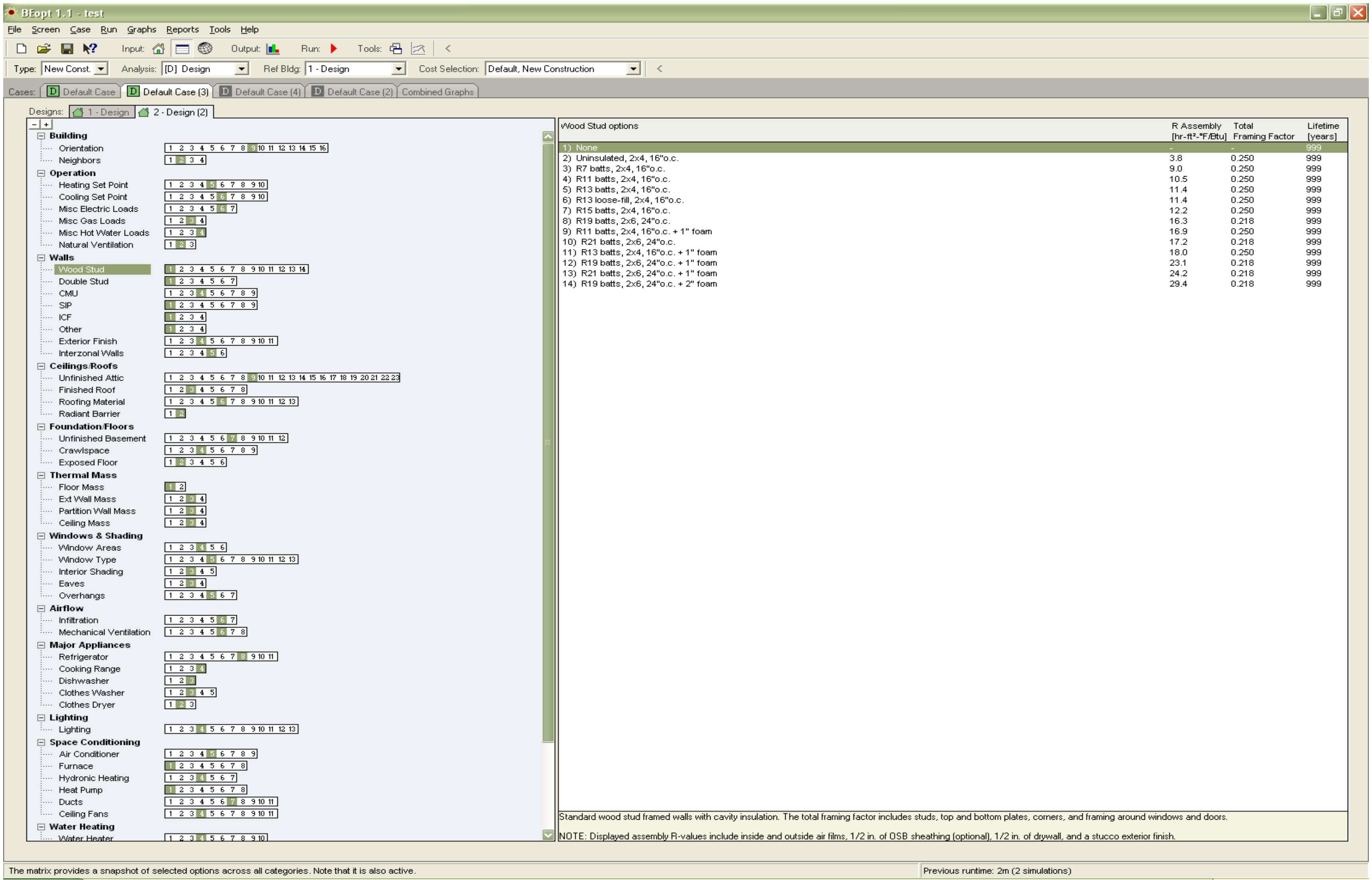


Figure 3.7: Screenshot of Options Input in BEopt (Mo 2012)

(Note: All fourteen retrofit measure groups are indicated on the left and the options for each selected retrofit measure, on the right)

For the ***site input*** information regarding the location of the home, economics, mortgage payment, fuel type, utility rates, energy factors, etc. is obtained here. Based on the data entered in the three input types (geometry, options, and site), BEopt calculates the energy savings costs and other energy outputs to generate three graphs: Cost and Energy, End Use, and Input Option Graphs (Figure 3.8).

- *Cost and Energy Graph* – shows in percentage terms, energy savings source and amount of annual energy savings costs for each case when compared to the reference case.
- *End Use Graph* – provides segments of annual energy costs. Different energy-consuming components can be used to generate different graphs such as: source energy, utility bills, site energy – propane, carbon dioxide emissions, and loads not met.
- *Input Option Graph* – provides a summary of input options selected by homeowners for each case. In order to note the input feature of each case, the different input options for other cases are indicated with green bars. It must be noted that this is being compared with the input options of the reference case.

At the end of the energy simulation output, the software creates input reports which details full account of the input options. These are grouped by geometry, site, and input options. In addition, it generates detailed reports which include specific energy savings information such as option information, cost multipliers, unit costs, lifetimes, annual simulation results, monthly simulation results, cash flow, and economics. Most of the cost data in are derived from the national residential efficiency measures database version 2.0 and the RS Means (2009). In addition, the measure groups are similar to those provided in the database. These compatible features were part of the reason for selecting BEopt as the simulation software for the proposed system.

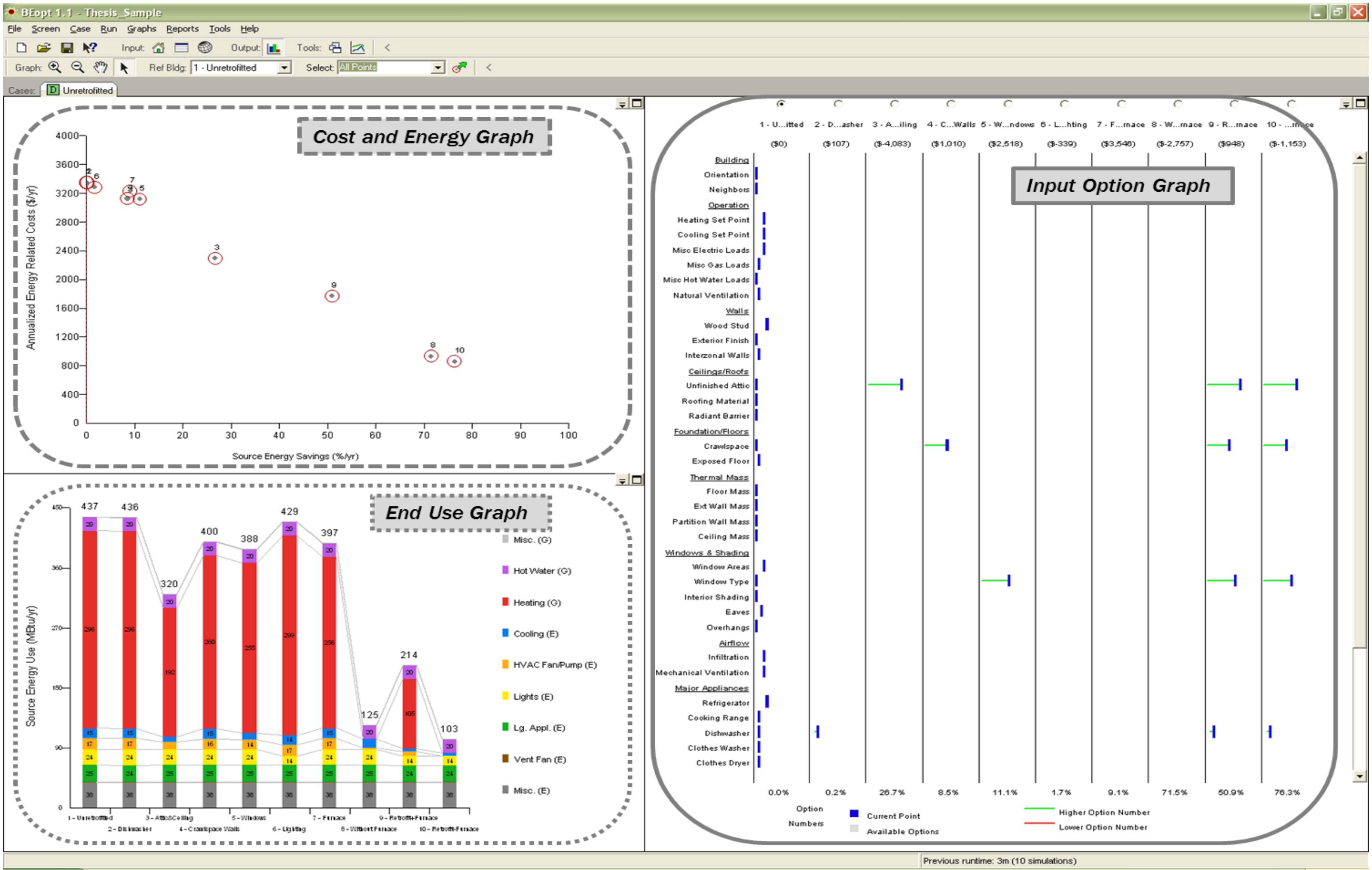


Figure 3.8: Screenshot of Output Graphs (Mo 2012)

(Note: this highlights the following graphs: Cost and Energy on the top left, End Use on the bottom left, and Input Option on the right)

3.3.1.3 Published Information: Text, Figures, and Images

The importance of focusing on the packaging and delivery of quantitative information and expert knowledge in order to promote energy retrofits among homeowners has been mentioned. This third component provides various explanations regarding the identified retrofit measures and the corresponding installation advice. Such information is obtained from published reports, mainly produced by governmental programs, such as Building America, and other United States Department of Energy national laboratory reports. Typically, users are provided available quantitative information, expert knowledge, and advice on the selected measures. This is achieved by using report files, images, and web links. For instance, if the dishwasher needs to be replaced, additional information for decision-making can be provided to the user (Figure 3.9).

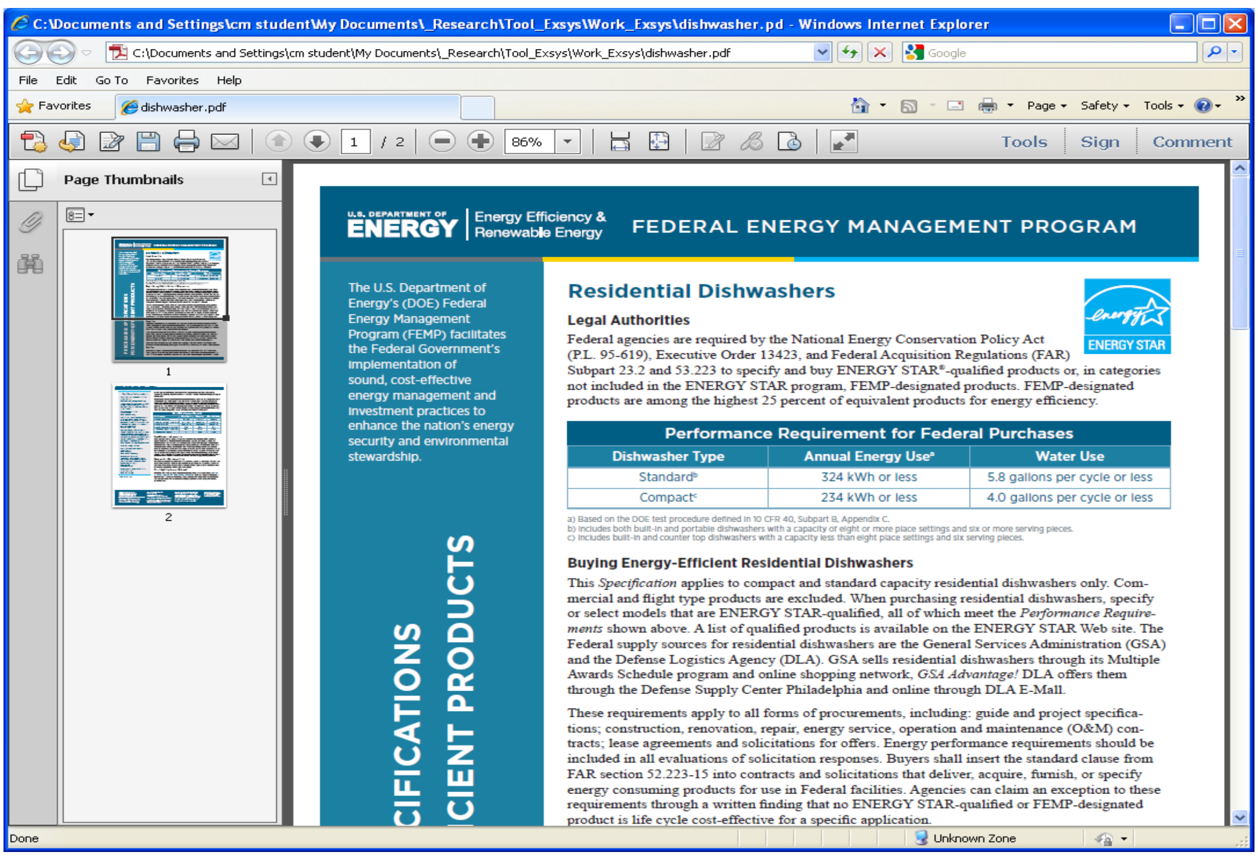


Figure 3.9: Additional Document from the Result Screen (Dishwasher) (Mo 2012)

(Note: highlights United States Department of Energy information for Residential Dishwashers)

3.3.2 Energy Retrofit Decision Support System Framework

The importance of integrating quantitative information with expert knowledge in the energy retrofit decision process model has been established. This integration was achieved by incorporating the cost and technology product information from the national residential efficiency measures database, energy assessment using results from the BEopt simulation software, and installation-related information obtained mainly from Building America documents, with the framework. Since the emphasis of this chapter is on the integration of the complied quantitative information into the framework, the expert knowledge incorporated in this chapter is a preliminary attempt at eliciting the expertise of experts. A comprehensive energy retrofit expertise development and elicitation strategy, which can be used in selecting industry experts whose knowledge will be compiled, is discussed in detail in Chapter four.

Primarily, the following summarizes the information sources that were incorporated into the proposed energy retrofit decision support system framework:

- Quantitative Information
    - Cost and technology product information from the national residential efficiency measures database
    - Energy assessment and simulation results from BEopt software
    - Existing published information from Building America and other literature
- Preliminary Knowledgebase
    - Expert knowledge in the energy retrofit domain elicited from retrofit contractors and energy auditors during the development of the preliminary knowledgebase for the energy retrofit decision process model

3.4 CHAPTER SUMMARY

Homeowners generally pursue information from a variety of sources in energy retrofit decision making. Such information, categorized as expert knowledge/advice and quantitative/published information can lack comprehensiveness and accuracy. This can impede the uptake of energy retrofits, hence the need to understand and solve this information barrier. The energy retrofit decision process model was appraised and determined to be suitable to be used as an intelligent decision support system.

Specifically, two of the three building blocks suitable for the eventual development of an intelligent decision support system for energy retrofits were analyzed: energy retrofit decision process model and quantitative information. The energy retrofit decision process model provides a good basis since it captures the decision-making protocol of the industry. The quantitative information was also deemed useful since it can provide the available published information. This was obtained from three sources: the national residential efficiency measures database, BEopt energy simulation software, and existing published information (text, images, and videos).

The last building block, the expert knowledge, was explored by developing a preliminary knowledgebase. A demonstration was provided to show how the energy retrofit decision process model and the compilation of the two information categories can be integrated in order to develop a decision support system for energy retrofits. Since expert knowledge provides intelligence to traditional decision support systems, its development and elicitation is the focus of a detailed discussion in Chapter four.

CHAPTER 4

ENERGY RETROFIT EXPERT AND EXPERTISE ELICITATION

4.1 INTRODUCTION

A major step in the development of an intelligent decision support system involves the integration of quantitative information with expert knowledge. Chapter three provided a comprehensive analysis of the energy retrofit decision process framework, and described preliminary efforts made to demonstrate its applicability as an intelligent decision support system using Exsys, an expert system platform. Finally, using a hypothetical example, the functioning of the energy retrofit decision process model as a preliminary energy retrofit decision support system framework was demonstrated.

In Chapter three, the focus was on the integration of quantitative knowledge into an intelligent decision support system. This chapter focuses on the integration of expert knowledge by first identifying the determinants of expert knowledge in this industry. Next, an expertise elicitation strategy is developed and used to elicit expert knowledge from industry experts selected based on the determinants of expert knowledge. This knowledge is then compiled and used as the core component of the knowledge base for the development of the knowledge-base management system of the proposed intelligent decision support system.

4.1.1 Chapter Objectives

As mentioned in Chapter 2, three questions dominating knowledge elicitation relate to (Duah & Syal 2013b; Shadbolt 2005): (1) how to determine an expert, (2) how to get experts to tell or show what they do, and (3) how to determine what constitutes their problem solving competence. This chapter describes the overall industry-specific strategy for expertise elicitation. The overall goal of this chapter is to develop an expertise elicitation strategy that can be used to elicit tacit or implicit knowledge available in the industry. This elicited knowledge will then form the knowledge-base for the knowledge-based system. The objectives of this chapter are to:

1. Develop an energy retrofit expertise identification system to help determine the level of expertise of an energy retrofit professional;
2. Determine the problem-solving competencies of retrofit professionals; and
3. On the basis of 1 and 2, develop an overall strategy for eliciting expertise from experts in the energy retrofit industry.

4.1.2 Components of an Intelligent Decision Support System

The intelligent decision support system envisaged for this research and discussed in Chapter two, had a knowledge-based management system that incorporated the model base features into an expert system shell obtained from Exsys Corvid (Basen & Dutta 1984 cited by Turban & Watkins 1986; Özbayrak & Bell 2003; Shannon 1985 cited by Turban & Watkins 1986; Turban & Watkins 1986). Additionally, two information sources for decision making in the energy retrofit domain were put into two broad categories of quantitative information and expert knowledge. This chapter focuses on expert identification and knowledge elicitation.

In Chapter three, the components of the energy retrofit decision support system were discussed. This mainly comprised quantitative information sources such as cost information from the national efficiency measures database, energy assessment from an energy simulation tool called

BEopt, published texts, images, and videos. The proposed intelligent decision support system for the energy retrofit domain discussed in this chapter, however, incorporates expert knowledge as the knowledge-base in order to make it an intelligent system (See Figure 4.1).

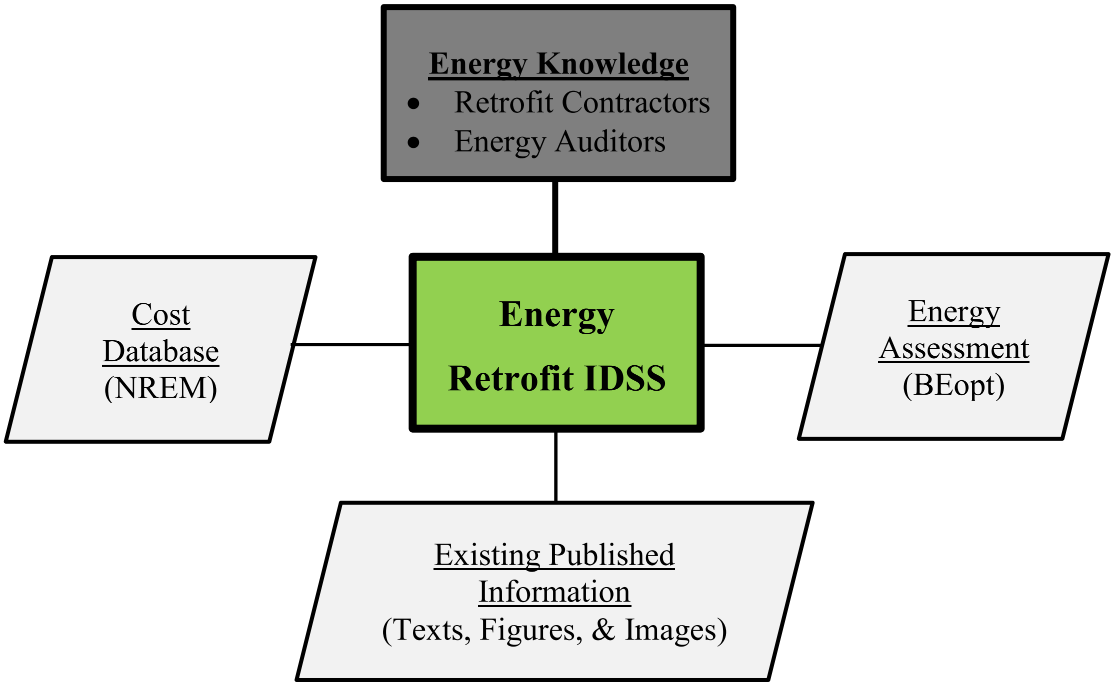


Figure 4.1: Components of the Energy Retrofit Intelligent Decision Support System

4.1.3 Knowledge Elicitation versus Knowledge Acquisition

There has been a growing importance of the need to define and document expert knowledge. Cooke (1994) gives a number of reasons for this growing trend: (1) cognitive psychologists and researchers have been concerned about what constitutes knowledge, especially in the domain of artificial intelligence, (2) the need to increase content knowledge by training other people, especially when experts retire, and (3) the use of expertise in knowledge-dependent computer applications such as Decision Support Systems and expert systems, has increased. Knowledge elicitation, part of a larger process of knowledge acquisition, is the process of collecting information from a human source, thought to be relevant to that knowledge through some form of direct interaction. Such knowledge is used in building an expert system or knowledge-based system through a process called knowledge engineering (Regoczei & Hirst 1992; Shadbolt 2005, Turban *et al.* 2005). Specifically, however, the process of eliciting, acquiring, and representing knowledge involving descriptions, relationships, and procedures in a specialized domain is called knowledge acquisition (Dhaliwal & Benbasat 1989; Shadbolt 2005). Figure 4.2 shows the structure of the knowledge acquisition process and the role played by knowledge elicitation within the overall framework of knowledge engineering.

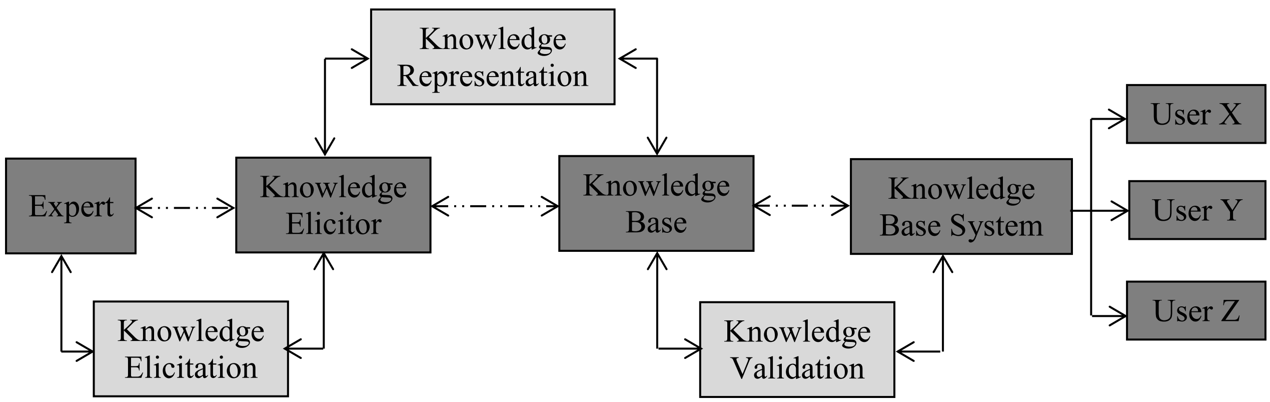


Figure 4.2: Structure of the Knowledge Acquisition Process

In order to develop an intelligent decision support system, however, expert knowledge obtained through the expertise elicitation process is not the only component. Syal *et al.* (2013a) posit that, quantitative information obtained from available written and published information must be included. Available quantitative information in this domain was discussed in Chapter two, and its role in the energy retrofit decision process model and the energy retrofit decision support system was also discussed in Chapter three.

4.1.4 Problem of Defining and Eliciting Expert Knowledge

Expertise can be defined as expert opinion/knowledge, or the state of being an expert (Cornford & Athanasou 1995). As a result of significant practical problems, there are challenges with defining expertise. Specifically within the cognitive domain, there is a challenge to evolve an operational definition of expertise that focuses on cognitive factors to identify experts (Hoffman 1996). A recurring debate about expertise development has two schools of thought: (1) that it is mainly attributable to rare characteristics of individuals often thought of in terms of largely inherited talents, or (2) that is mainly based on their learning history (Cianciolo *et al*. 2006). Thus, various approaches about the nature of expertise and how it is developed continue to address whether there are born or made experts.

Even though expert knowledge plays an important role in the development of an intelligent decision support system, its elicitation has been fraught with several problems. Like all forms of development, the development of expertise is subject to individual differences in psychological and behavioral characteristics. In terms of development, however, expertise is not the same thing as intelligence, since an expert may have low general intelligence or ability outside their domain of expertise (Hoffman 1996).

4.1.4.1 Problem of Knowledge Elicitation

The challenge usually cited in the development of knowledge-based systems and applications is the process of eliciting expert knowledge (Feigenbaum & McCorduck 1984 cited by Cooke 1994; Turban *et al.* 2005). The expertise of experts is usually tacit or implicit. Tacit knowledge is practical, action-oriented knowledge based on practice. Though acquired by personal experience, it is rarely expressed openly and often resembles intuition. Persons with such knowledge may be unaware of having it, and it is very difficult for them to articulate (Smith 2001; Taylor 2007). Tacit knowledge in any domain is very important. Ninety percent of knowledge in any organization is embedded and synthesized in peoples' heads (Wah 1999; Bonner 2000; Lee 2000 cited by Smith 2001; Smith 2001).

Another difficulty with knowledge acquisition is that most experts perform various tasks automatically or intuitively. Automaticity occurs when there is a declarative-to-procedural shift in the reasoning of experts where, for instance, highly practiced knowledge such as reading or cycling, initially taught explicitly becomes tacit or automatic (Hart 1989; Hoffman 1996; Klein & Hoffman 1993; Lesgold *et al*. 1988; McGraw & Harbison-Briggs 1989; Sanderson 1989). Such knowledge is difficult to elicit since experts find it difficult to tell or show what they do. Even in instances where the knowledge or expertise can be articulated, experts are usually unavailable or have a difficulty in explaining what they do. Finally, in some instances where the knowledge elicitor is not well trained, or is a non-expert, or has limited knowledge, the expert may simplify or distort their knowledge when explaining what they do (Cooke 1994).

Turban et *al.* (2005) summarizes the difficulty in knowledge elicitation, particularly tacit knowledge, by identifying the following factors that add to the complexity of knowledge elicitation from experts and its transfer to a computer:

- Difficulty of experts in articulating their knowledge
- Experts lack of time or unwillingness to cooperate
- Difficulty in testing and refining knowledge
- Poor definition of knowledge elicitation methods
- Relevant knowledge scattered across several sources
- Need to combine quantitative information and expert knowledge

- Specific knowledge may be mixed up with irrelevant data
- Expert behavioral change when interviewed or observed
- Problematic interpersonal communication factors

The role of knowledge elicitation within the general framework of processing knowledge through the knowledge acquisition process in order to be used in developing knowledge-based system or expert system is important. The effectiveness of the developed system is a direct result of the quality of the knowledge that was gathered during the elicitation process. This makes the elicitation of expert knowledge in the construction industry critical since it is unique and complex, mainly due the dynamic and transient nature of projects involved.

4.1.4.2 Problem of Defining Energy Retrofit Expertise

In the energy retrofit industry, the lack of information, or the lack of information in a format that homeowners can understand and use, in order to make retrofit decisions has been identified as a key impediment to the uptake of energy retrofits. Homeowners traditionally depend on experts in the field of energy retrofit, such as energy auditors and trade contractors, for information. There are, however, several problems with such information including comprehensiveness, inaccuracy, cost, and perception of bias (Syal *et al.* 2014).

Since the industry is an emerging one, there is a need for all the necessary regulations, training, and development to clearly identify the available expertise in this industry. For instance, there has been a growing effort at developing a standardized protocol and harmonized training for energy professionals. A standard protocol basically provides consistency in the means and methods used by energy retrofit professionals, such as trade contractors and energy auditors (PATH 2002; EERE 2012b; NREL 2012b). In 2012, the Building Performance Institute, Inc. announced four new home energy professional certifications to the nation's weatherization and home performance workforce. Designed for experienced home performance professionals only, the four new certifications focus on common jobs in the home energy upgrade industry: energy auditor, retrofit installer, crew leader, and quality control inspector. The new certifications are funded by the United States department of energy, developed by the National Renewable Energy Laboratory and offered by the Building Performance Institute, Inc. (EERE 2012b).

4.1.5 Development of Energy Retrofit Expertise

An extensive literature review in Chapter two established the differences in performance between novices and experts. The expertise of experts can be defined in terms of the following:

1. *Experience* – experts perform better due to real world experience and extensive practice leading to long-term developmental processes (Cianciolo *et al.,* 2006; Ericsson & Charness 1994; Feltovich *et al.* 2006).
2. *Extent* – expertise exists in degrees and not as a whole (Cianciolo *et al.* 2006).
3. *Development* – expertise progresses from literal understanding (novices) to expert reasoning (experts) (Hoffman 1996).
4. *Knowledge structures* – experts have extensive and well-organized domain knowledge (Glaser 1987; Lesgold 1984; Hoffman 1996).
5. *Reasoning process* – qualities include using prototype examples of past cases, generating scenarios, moving from declarative to procedural shift in reasoning in order to explain

decisions, actions, or novel difficult situations (Hoffman 1996; Klein & Hoffman 1993; Hart 1989; McGraw & Harbison-Briggs 1989; Sanderson 1989).

In terms of development of expertise, a series of distinct, identifiable stages are: novice, advanced beginner, competence, proficiency, and expert (Benner, 1984; Cornford and Athanasou, 1995; Dreyfus and Dreyfus, 1986; Schempp, 2011; Trotter, 1986). Three dominating traits or qualities of experts in the energy retrofit industry can be put into three broad categories: experience, automaticity or intuitive decisions, and learning outcomes/competence.

- ***Experience*** – based on the series of distinct, identifiable stages of the development of expertise and the review of literature in Chapter two, the following preliminary categorizations are made for the energy retrofit industry:
    1. *Novice* – new workers in the energy retrofit industry
    2. *Advanced beginner* – second or third year of career
    3. *Competence* – third or fourth year of career
    4. *Proficiency* – beyond four years
    5. *Expert* – a smaller number of those deemed proficient become experts typically after 5 years

    It generally takes a minimum of five years to attain a level of expertise in highly skilled professions. Based on research from fields like the trades, teaching, chess, and radiology, overall competence in most occupations can be achieved in three years, but the mastery of complex skills will be achieved in more than 5,000 hours. Over 100,000 diverse problems will have to be encountered, however, for variable situations (Cornford and Athanasou 1995).

- ***Automaticity/Intuitive Decisions*** – As expertise grows, performance of the task becomes automatic, a cognitive phenomenon called "*automaticity*" (Armstrong 2003). Within the energy retrofit domain, preliminary issues to determine automaticity include:
  - Number of audits typically performed annually by an energy auditor,
  - Number of retrofits to be performed annually for industry proficiency, and
  - Good range of strategies and appropriate mechanisms for assessing them which is backed by appropriate organization of knowledge. For instance, frequency of updating industry knowledge, knowledge of incentives, rebates, and tax benefits etc.

- ***Learning Outcomes/Competence*** – preliminary domain learning outcomes include the following:
  - Ability to translate energy savings into dollars, and compare projected savings with the cost of each energy retrofit measure,
  - Ability to assess building performance before and after energy retrofit improvements,
  - Ability to explain industry procedures and goals,
  - Education of homeowners about efficient use of energy, and
  - Awareness of health and safety concerns pre- and post-retrofit.

4.2 ENERGY RETROFIT EXPERTISE IDENTIFICATION SYSTEM

As a result of the inherent differences in implicit knowledge in different domains, having a generic system for selecting expert participants is unsuitable. The development of suitable and rigorous expertise identification systems for specific domains is therefore proposed.

4.2.1 Application of the Delphi Technique to the Energy Retrofit Industry

The selection of an appropriate research methodology is an essential decision to make in any research since this directly affects the success of the entire research. When a problem does not lend itself to precise analytical techniques, and there are questions to be answered by intuitive judgment, which supersedes questions to be answered by concrete measurement, and there are existing disagreements among experts to the extent that a refereed communication process is desirable, the Delphi has been found to be the favored research method (Linstone & Turoff 1975 cited by Hallowell & Gambatese 2010; Pill 1971; Yousuf 2007). The specific objectives of the Delphi Method are as follows (Gambatese 2010):

1. Gain insight from a group of certified experts (accuracy);
2. Establish a degree of consensus (precision);
3. Maintain anonymity of diverse expert panel members during the process (unbiased); and
4. Answer a question that cannot be addressed using standard statistical procedures because of the nature of the question, or lack of objective data (judgment).

4.2.1.1 Delphi Participant Selection

A major drawback of the Delphi technique is that there is a low level of reliability of judgments among experts and, therefore, dependency of forecasts on the particular judges selected (Yousuf 2007). Powell (2003), however, asserts that the success of a Delphi study clearly rests on the combined expertise of the participants who make up the expert panel. Jairath and Weinstein (1994) propose that participants should be experts who reflect current knowledge and perceptions yet are relatively impartial to the findings. Hsu and Sandford (2007) argue that situations where subjects have less in-depth knowledge of certain topics, and hence are unable to specify the most important statements identified by participants who possess in-depth knowledge concerning the target issue, must be avoided. Murphy *et al*. (1998) posit that diversity of expert panel membership leads to better performance as this may allow for the consideration of different perspectives and a wider range of alternatives.

For statistical purposes, rather than calling for expert panels to be representative samples, the Delphi technique suggests that the qualities of the expert panel are a better criterion than the number of participants (Powell (2003). The research addressed the foregoing in three ways:

1. There was extensive literature review in order to identify the existing body of knowledge. This helped in developing the initial framework for the questions during the focus group interaction, and also to identify any biases thereof.

2. The Modified Delphi Technique was chosen for this research where a focus group of 5 energy retrofit professionals, considered to have in-depth knowledge in this domain was selected. This replaced the open first round that is typical with the Classical Delphi Technique and helped in identifying the ambiguities and improving the feasibility of administering the questions. There were a total of 23 participants in all. The focus panel members had varied backgrounds, competencies, and experiences. For instance, while their combined year of practice was 40.5 years, the average year of practice for the group was 8.1 years. They were knowledgeable in this domain and were registered with the two main nationally recognized trade organizations (Residential Energy Services Network or Building Performance Institute), had been in current practice for minimum of two years, and reflected current knowledge (Jairath & Weinstein 1994). In order to

improve the performance, divergent opinion through the consideration of different perspectives from a wide range of alternatives (Murphy 1998) was encouraged. For instance, both energy auditors and retrofit contractors were included. In addition, professionals working for non-profit organizations, who have fewer biases due to the nature of the work of their organizations, as well as those with an association with academia, were also included in the focus group participation list.

The focus group represented the thoughts from a retrofit contractor, an energy auditor, a not-for-profit organization, an energy retrofit business practitioner, and an academic and industry practice professional. Thus, the questions developed for the second round had good theoretical basis, which was combined with opinions of the focus group and was devoid of obvious inaccuracies and biases.

3. Since the thrust of this section of the research is to identify the determinants of energy retrofit expert knowledge using specific attributes, it was important that the opinions included in this section were judged to be of a high quality. For instance, while consensus in the opinion of the panel members was sought, the determination of their proficiency level was based on a combination of expert opinion, extensive literature review and available quantitative information.

4.2.1.2 Reaching Consensus in Delphi

The basis of the Delphi technique is the reaching of consensus among experts in a given domain. A two round Delphi questionnaire study was carried out to investigate reaching consensus regarding the proficiency levels of experts in the energy retrofit industry. The first round was preceded by a focus group interaction, which was then given to the rest of the panel members. On issues where no consensus was reached, there was a second round of the Delphi survey. Statistical parameters commonly employed in Delphi studies to either individually or in combination indicate when consensus has been reached are: percentage of agreement, mean, standard deviation, median, and or mode (Hasson *et al.* 2000; Jacobs 1996; Keeney *et al*. 2010; McIlfatrick & Keeney 2003). For this study, one of the most commonly reported parameters – percentage of agreement – was used. A predetermined percentage agreement of 70% or more was used as an indicator of consensus.

4.2.2 Steps to Develop Energy Retrofit Expertise Identification System

In order to develop the energy retrofit expertise identification system, 7 major steps, designed based on the Delphi technique, were followed. As a result, a Delphi procedure for the identification system was developed (Figure 4.3). The major steps in the development of a Delphi-based procedure for this system are discussed below:

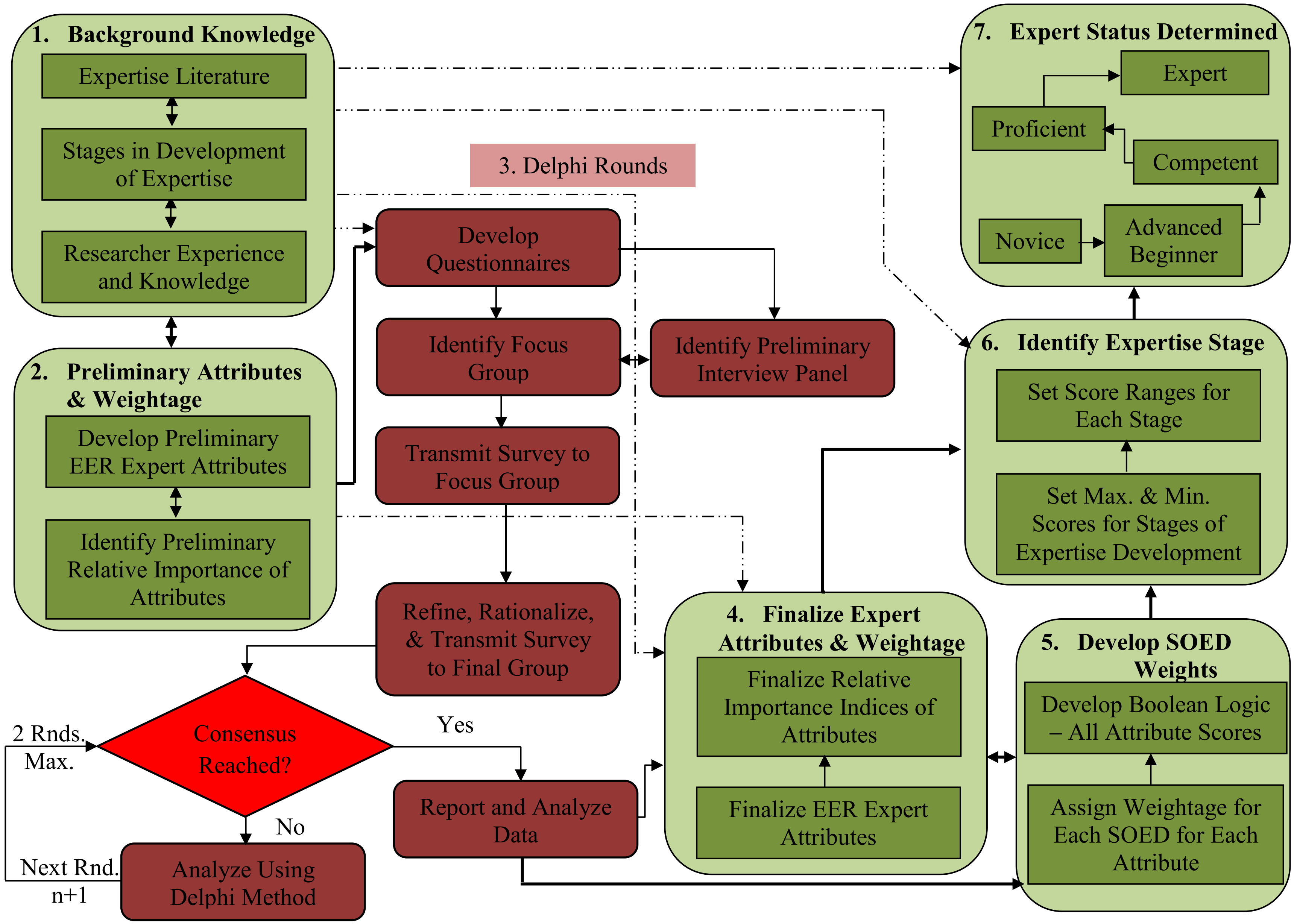


Figure 4.3: Delphi Procedure for Energy Retrofit Expertise Identification System

- Step 1 – Compile background knowledge
- Step 2 – Identify preliminary energy retrofit expert attributes and weightage
- Step 3 – Conduct Delphi rounds
- Step 4 – Finalize energy retrofit expert attributes
- Step 5 – Finalize stage of energy retrofit expertise development weights
- Step 6 – Identify expertise stage
- Step 7 – Determine expertise status

4.2.2.1 Compile Background Knowledge (Step 1)

The background knowledge compiled for the development of the identification system was mainly from 3 sources: literature on expertise in general, literature on the development of expertise, and the experience and knowledge of the researcher. The first two sources were discussed in section 4.1.

The experience and knowledge of the researcher was mainly developed based on the interaction of the researcher with energy retrofit professionals and researchers. For instance, the researcher was part of the Cost Effective Energy Retrofit team, part of a larger project funded by the United States Department of Energy's Building America program. The team was one of 15 Building America research teams across the United States. Each team was tasked to develop, analyze, and implement strategies to obtain significant and sustainable home energy savings for new and existing homes (CEER 2011; Duah & Syal 2013a). In addition the researcher is a co-author of a paper published in an academic journal for this industry. The researcher has also presented two domain-based research papers at two academic conferences, and has been involved in the work leading to the completion of two domain-based Master's dissertations (Samuel 2011; Mo 2012).

4.2.2.2 Identify Preliminary Energy Retrofit Expert Attributes and Weightage (Step 2)

A total of seventeen questions were developed under the three categories that distinguish an expert from a novice: experience, automaticity or intuitive decisions, and competence. These questions, in combination with the background knowledge, formed the basis for the development of the preliminary energy retrofit attributes and weightage. As a result of the unavailability of experts due to the lack of time or unwillingness to cooperate (Cooke 1994; Turban *et al* 2005), two separate interviews for the energy retrofit expertise identification system and the energy retrofit expertise elicitation strategy were combined into one interview. Some of the questions for specific attributes employed in the identification system were also usable in the elicitation strategy. After the initial round with the focus group, some of the questions were deleted and others were modified.

(Preliminary questionnaire for developing the EREIS and EREES is provided as Appendix A.1).

Tables 4.1 – 4.3 indicate the preliminary attributes developed for each of the three categories. For each category, the supporting literature and background knowledge is indicated. Finally, relative importance scores (RIS), signifying the importance of each attribute based on the background knowledge were developed and included. The relative importance scores ranged from 0.1 – 0.6 with 0.1 being the least important and 0.6, the most important. It must be noted that the relative importance scores were provided based on the view of the importance of each attribute to the energy retrofit expert. Assuming it was viewed from the homeowner perspective, different scores would have been applied to the various attributes necessary to identify the determinants of energy retrofit expert knowledge.

Table 4.1: Preliminary Attributes – Energy Retrofit Experience Questions

Attribute	Literature	RIS
1. Number of Years in Energy Retrofit Industry	Baker 2003; Benner 1984; Cianciolo *et al.* 2006; Feltovich *et al.* 2006; Cornford & Athanasou 1995; Dreyfus & Dreyfus 1986; Schempp 2011; Trotter 1986; Ericsson & Charness 1994	0.4
2. Number of Audits/ Retrofits	Cianciolo *et al.* 2006; Feltovich *et al.* 2006	0.4
3. Period Away From Industry	Cianciolo *et al.* 2006; Feltovich *et al.* 2006	0.1

Table 4.2: Preliminary Attributes – Automaticity/Intuitive Decision Questions

Attribute	Literature	RIS
4. Frequency of Seeking Second Opinion	Armstrong 2003; Cellier 1997; Glaser & Chi 1988; Farrington-Darby & Wilson 2006; Hart 1989; Hoffman 1996; Klein & Hoffman 1993; Lesgold *et al.* 1988; McGraw & Harbison-Briggs 1989; Sanderson 1989; Shanteau 1992b	0.2
5. Awareness of Financial Aid in Industry	Bransford *et al.* 2004; Farrington-Darby & Wilson 2006	0.2
6. Justification of Decisions or Actions	Armstrong 2003; Cellier 1997; Glaser & Chi 1988; Farrington-Darby & Wilson 2006; Hart 1989; Hoffman 1996; Klein & Hoffman 1993; Lesgold *et al.* 1988; McGraw & Harbison-Briggs 1989; Sanderson 1989; Shanteau 1992b	0.6
7. Knowledge of Retrofit Measures	Armstrong 2003; Cellier 1997; Farrington-Darby & Wilson 2006; ; Glaser & Chi 1988; Shanteau 1992b	0.3

Table 4.3: Preliminary Attributes – Competence Questions

Attribute	Literature	RIS
8. Building and Building Science Knowledge	Anderson 2000; Armstrong 2003; Cellier 1997; Farrington-Darby & Wilson 2006; Glaser & Chi 1988; Shanteau 1992b	0.6

Table 4.3 (Cont'd)

9. Knowledge of Identification of Retrofit Needs – Example	Building science and construction knowledge is useful in identifying energy retrofit needs. A clear understanding of this principle allows the energy retrofit professional to offer easy-to-understand examples or illustrations	0.6
10. Knowledge of Energy Assessment	BPI 2010; Energy Savers 2011; RESNET 2012	0.6
11. Knowledge of Retrofit Benefits	Doris *et al*. 2009; Energy Star 2012b; NREL 2000; Nutt 2009	0.3
12. Knowledge of Measure with Most Return on Investment	Hart 1989; Hoffman 1996; Klein & Hoffman 1993; Lesgold *et al.* 1988; McGraw & Harbison-Briggs 1989; Sanderson 1989;	0.4
13. Knowledge of External Factors Affecting Retrofit Cost	Hart 1989; Hoffman 1996; Klein & Hoffman 1993; Lesgold *et al.* 1988; McGraw & Harbison-Briggs 1989; Sanderson 1989	0.5
14. Building Science Knowledge – Post Occupancy Health Issues	Building science knowledge is very important in this industry. Post occupancy health issues are so dangerous they can lead to deaths.	0.5
15. Building Science Knowledge – Whole House System	In order to prescribe effective energy retrofit measures for ma home, an expert must be aware that the home works as a system. Changing one part of the system affects the energy performance of the rest of the components.	0.6
16. Installation Knowledge – Do it Yourself Advice	An expert must understand the science behind the installation of various retrofit measures and on that basis give good advice on installation	0.6
17. Installation Knowledge – Professional Advice	An expert must understand the science behind the installation of various retrofit measures and on that basis give good advice on installation.	0.6

4.2.2.3 Conduct Delphi Rounds (Step 3)

During this step, questions were developed for each of the 17 preliminary attributes identified in step 2. Since the questionnaire developed were a combination of the development for the identification system and elicitation strategy, there were 7 sections in all: general, energy retrofit experience, habitual or intuitive decisions, identifying energy retrofit measures, shortlisting and prioritizing energy retrofit measures, installation advice, and final comments. Questions regarding the 17 preliminary attributes cut across all 7 sections.

In the ***general section for Delphi rounds***, questions in this section were used to gather information about the expert, including area of expertise, duration involved in the area, geographic region of operation, professional affiliations, and the size and method of business operations. This section was also used to exclude biases in opinion by asking questions related to personal likes and dislikes in the energy retrofit industry. If a certain opinion proffered by an expert in the competence questions supported a bias expressed in the general questions, that opinion was considered biased and eliminated. For example, if the expert's area of expertise is in high efficiency windows, and s/he tries to promote an opinion that upgrading existing windows to higher efficiency windows is the best energy efficiency strategy, even though this is not supported by building science knowledge, this opinion was considered biased and eliminated.

The purpose for the ***energy retrofit experience section for Delphi rounds*** was twofold. First, the experience of the experts in the industry was sought through questions regarding their years of practice and the number of audits and retrofits they have performed. Secondly, it sought the opinion of experts to determine the proficiency levels of an expert through practice based on their experiences. The aim was to help enhance the preliminary attributes developed.

In the ***habitual or intuitive decisions for Delphi rounds***, the questionnaire sought to identify common practices in the energy retrofit domain, and how energy retrofit professionals make decisions that come to them naturally or intuitively. A total of 4 questions were asked in this section.

In the ***identifying energy retrofit measures section for Delphi rounds***, the energy retrofit decision process model, which was discussed in-depth in Chapter three, was considered. It follows three basic steps: identify measures, shortlist and prioritize, and provide expert advice on installation. The next three sections of the questionnaire were based on the energy retrofit decision process model. In this section, there are queries about steps taken by energy retrofit professionals in identifying general measures. In addition, questions about building construction and science knowledge, considered very important in this industry, are asked.

The next section was the ***shortlisting and prioritizing energy retrofit measures for the Delphi rounds.*** Having identified some measures (in section 4), there is a need to shortlist and prioritize the measures based on a number of the following parameters: cost effectiveness, needs of the homeowner, health and safety issues, user budget, etc. Questions in this section sought to elicit such information from the energy retrofit professionals.

The penultimate section was ***installation advice for Delphi rounds***. Here, the last step in the energy retrofit decision process model is the offer of installation advice for the identified energy retrofit measures. Since this section involved actual installation work, construction and building science knowledge played a dominant role. As a result of the negative effects of do-it-yourself work by homeowners, especially on the health and safety of occupants of homes, this section sought to identify measures that could be performed by homeowners themselves and those that they could not. It also included specific installation advice for different components of a home such as the walls, attic, foundation, and HVAC equipment.

The last section was for ***final comments for the Delphi rounds***. This was mainly unstructured, where an opportunity was given for participants to provide any final comments, or mention any issues that were missed, to be included in the main questionnaire. After developing the questionnaire, the participants were identified based on the preliminary criteria mentioned earlier. The first group, the focus group, were selected based on the criteria spelled out in section 4.2.1 regarding participant selection. They were encouraged to make recommendations for additional energy retrofit professionals to be included in the panel. Interestingly, seven of the panel members identified were eventually recommended by multiple colleagues. This trend reinforced the competence of the membership of the panel.

Next, the preliminary survey was transmitted to the 5 member focus group. Based on their responses and the available background knowledge, the questionnaire was refined and finalized. For instance, there were two questions related to a similar issue:

1. The first question sought to identify the number of retrofits or audits completed by each professional annually and the second sought to identify the same information completed by each professional in their careers. Since information from the latter could be used in the former, the former question was deleted.
2. Another example sought to identify important building regulations at the local, state, and federal levels that are applicable in this domain. Based on the responses from the focus group, it was found that there were no specially designed building regulations for this

industry except for those used for the general building industry. Thus, this question was also removed.

(A detailed description of the finalized questions is provided as Appendix A.2)

The refined and finalized questionnaire was then transmitted to the larger participant panel. Based on the responses received from this panel, the data was analyzed for consensus using the predetermined percentage for consensus of 70%. At the end of this first round, which included the aggregation of the data received from the focus group, there was consensus reached on 13 (76.47%) of the 17 attribute-based questions. Consensus was not reached on 3 (17.64%) of the questions, and 1 (5.89%) question did not require consensus since it was purely informational.

Feedback for questions with no consensus was developed. It included a summary of participant responses, refined with further options, and was anonymously transmitted to the panel in the second round. At the end of the second round consensus was achieved for the rest of the questions, at which point the Delphi process was terminated (Table 4.4). This provided the basic data for this section of the research and comprised observations and conversations of what was said by participants, reproduced using audio recordings which were transcribed, and field notes.

Table 4.4: Consensus Status of Questions after Round 1 of Delphi Process

No.	Attribute	Consensus
1	Number of Years in Energy Retrofit Industry	N/A
2	Number of Audits/ Retrofits	No
3	Period Away From Industry	Yes
4	Frequency of Seeking Second Opinion	Yes
5	Awareness of Financial Aid in Industry	Yes
6	Justification of Decisions or Actions	Yes
7	Knowledge of Retrofit Measures	Yes

Table 4.4 (Cont'd)

8	Building and Building Science Knowledge	No
9	Knowledge of Identification of Retrofit Needs – Example	Yes
10	Knowledge of Energy Assessment	Yes
11	Knowledge of Retrofit Benefits	Yes
12	Knowledge of Measure with Most Return on Investment	Yes
13	Knowledge of External Factors Affecting Retrofit Cost	Yes
14	Building Science Knowledge – Post Occupancy Health Issues	Yes
15	Building Science Knowledge – Whole House System	Yes
16	Installation Knowledge – Do it Yourself Advice	Yes
17	Installation Knowledge – Professional Advice	No

Each recording was listened to at least two times, then transcribed, and read a minimum of two times. When the information was not clear, or difficult to understand, respondents were contacted again for clarification. Additionally, frequent notes were made in order to identify important statements and identify patterns based on the content of the data.

(A detailed analysis of all the data obtained for the identification system and elicitation strategy after the first Delphi round is provided in this dissertation as Appendix B.1).

4.2.2.4 Finalize Energy Retrofit Expert Attributes and Weightage (Step 4)

Based on the analysis of the data that was generated in the Delphi rounds, the energy retrofit expert attributes were finalized. A key component in the finalization of these attributes was the integration of expert knowledge generated from the Delphi rounds. For instance, the "Frequency in Seeking Second Opinion" attribute, identified from quantitative information emphasized that experts rely to a greater degree on their accumulated experience, have greater skill in anticipating (Farrington-Darby & Wilson 2006; Shanteau 1992b; Glaser & Chi 1988; Cellier 1997; Armstrong 2003), and experience a declarative-to-procedural shift in expertise reasoning during intuitive or automatic decisions (Hart 1989; Hoffman 1996; Klein & Hoffman 1993; Lesgold *et al.* 1988; McGraw & Harbison-Briggs 1989). An analysis of the data generated from the interviews, however, contradicted this assertion. The participants emphasized the need to constantly refer to books, internet, etc. in order to reinforce the information they gave to homeowners. One of the key reasons was that the industry was emerging and evolving. They also indicated that as a result of the skepticism that homeowners have about energy retrofit professionals, relying on these information sources frequently was ideal. Finally, the names of some of the attributes were changed to reflect the new insights obtained by combining the quantitative information and expert knowledge. For instance, the "Frequency in Seeking Second Opinion" attribute discussed above was refined to "Knowledge Update Frequency" to reflect the information elicited during the data analysis stage.

The ***rationale for weightage*** was an important component of the identification system. The accumulation of skill based on experience and practice is not necessarily bound by time, hence, two experts in a given domain can be of quite different ages. Thus, it makes sense to speak of expertise in development levels rather than stages (Hoffman 1996). Based on the quantitative information that was used to develop the preliminary attributes and the knowledge obtained through the analysis of data from the Delphi process, the energy retrofit expert attributes were finalized. Emphasis was put on competency of experts and their building science knowledge due to the dominant role such knowledge plays in the industry. This was consistently highlighted by participants throughout the Delphi rounds. Panel members emphasized that such knowledge helps one to understand the dynamics of a building, as well as help prescribe measures that are effective and do not affect the health and safety of building occupants. Such knowledge was therefore rated highest compared to return on investment knowledge which could be viewed very high from the homeowner perspective and yet is common knowledge in the practice of energy retrofits.

On the basis of the aforementioned, even though experience is a major factor to consider when determining an expert, it cannot be the sole factor. There has to be demonstrable competence, reinforcing the existence of a correlation between experience and competence. As a result, the responses obtained from the expert panel about the question regarding the competencies needed to be successful in this domain were incorporated in the development of the weightage for the attributes. Consequently, based on the knowledge obtained from the Delphi process, literature review, and the experience of the researchers, each attribute was assigned a relative importance score (RIS) based on the perspective of an energy retrofit expert, ranging from 0.1 to 0.6 where 0.1 was the least important and 0.6 was the most important.

Table 4.5: Final Energy Retrofit Expert Attributes and Respective RIS Score

No.	Name of Attribute	RIS
1	Construction and Building Science Knowledge	0.6
2	Construction and Building Science Knowledge – Example	0.6
3	Building Science Knowledge – Post Occupancy Health Issues	0.6
4	Building Science Knowledge – Whole House System	0.6
5	Construction Knowledge – Installation Advice (Do-it-Yourself)	0.6
6	Construction Knowledge – Installation Advice (Professional Work)	0.6
7	Energy Assessment Knowledge	0.5
8	Number of Years in Energy Retrofit Industry	0.4
9	Number of Audits/Retrofits	0.4
10	Justifying/Explaining Decisions/Actions	0.4
11	Construction and Financial Knowledge	0.4
12	Break From Industry	0.3
13	Knowledge Update Frequency	0.3
14	Available Financial Aid Knowledge	0.3
15	Return on Investment Knowledge	0.3
16	Retrofit Benefits Knowledge	0.2
17	Retrofit Measures Knowledge	0.1

For the ***relative importance scores for attributes***, questions for attributes that tested the building science and construction knowledge of an industry professional were assigned a score of 0.6. Additionally, questions that tested the application of experience and use of previous examples by participants when they perform work were also rated highly (0.6). Questions that tested the general competencies of participants, especially, related to their experience were assigned a 0.4/ 0.5 score. Finally, questions regarding general knowledge expected of industry practitioners, and testing of industry processes or basic information had RIS of 0.2/0.3 and 0.1 respectively. All the scores were based on the perspective of the energy retrofit professional practice.

In terms of ***number of audits/retrofits attribute scoring***, the type of energy retrofit work performed by the participants was identified as not homogeneous. In order to have a comparative and representative attribute that clearly identified the energy retrofit expertise of each participant, there was the need to clearly develop a scoring system that compensated for the expertise inherent in each participant. Most of the participants were either energy auditors, or performed both energy auditing and retrofit contracting. In instances where the participant was only an energy auditor, the data for number of audits was used to compute scores for this attribute. When a participant performed both energy audits and energy retrofit work, either the number of audits or retrofits performed was used. An analysis of the protocol generated, however, indicated that though most of them claimed they did energy audits and retrofit contracting, they mainly performed energy assessments and some minimal retrofit work like air sealing and insulation. Hence, in all such instances, data for the number of energy audits performed was used. Next, those who did mainly energy retrofit work and some minimal number of energy assessments had data for the number of retrofits performed used. Finally, for those who had performed energy audits in the past but not currently (mainly educational and advocacy), based on their experience and obtained background information, an assumed number of energy audits was assigned and was used as the energy retrofit expertise identification system score for this attribute.

The ***ranking of attributes*** was based on the relative importance scores assigned each attribute. A ranking was developed to indicate the importance of each attribute in determining the stage of expertise development of participants (Table 4.6). The data analysis showed that participants who achieved expert status obtained very high scores on all highly ranked attributes (Table 4.7), thus, establishing a correlation between the level of expertise and the determinants of industry expert knowledge. Compared to the attribute weightage and ranking developed for the identification system (Table 4.6), it can be seen from Table 4.7 that most of the experts, obtained high scores for the stages of expertise development (5–Expert; 4–Proficient) on a majority of the attributes. This reinforces the robustness of the weightage and expertise identification systems.

Table 4.6: Ranking of Attributes for Energy Retrofit Expertise Identification System

No.	Name of Attribute	RIS	Rank
8	Construction and Building Science Knowledge	0.6	1
9	Construction and Building Science Knowledge – Example	0.6	1
14	Building Science Knowledge – Post Occupancy Health Issues	0.6	1
15	Building Science Knowledge – Whole House System	0.6	1
16	Construction Knowledge – Installation Advice (Do-it-Yourself)	0.6	1
17	Construction Knowledge – Installation Advice (Professional Work)	0.6	1
10	Energy Assessment Knowledge	0.5	7
1	Number of Years in Energy Retrofit Industry	0.4	8
2	Number of Audits/Retrofits	0.4	8
6	Justifying/Explaining Decisions/Actions	0.4	8
13	Construction and Financial Knowledge	0.4	8
3	Break From Industry	0.3	12
4	Update Frequency	0.3	12
5	Available Financial Aid Knowledge	0.3	12
12	Return on Investment Knowledge	0.3	12
11	Retrofit Benefits Knowledge	0.2	16
7	Retrofit Measures Knowledge	0.1	17

Table 4.7: Stage of Expertise Development Scores for Participants after Delphi Round One

Attributes	ATRIBUTE-BASED SCORES 5 – Expert [Ex], 4 – Proficient [Pr], 3 – Competent [Co], 2 – Advanced Beginner [Ab], 1 – Novice [No]																
Expertise	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**
Res 1 (Pr)	4	4	5	3	4	4	5	5	3	4	3	4	4	5	5	5	4
Res 2 (Ex)	5	5	5	4	5	5	5	3	5	4	5	2	3	5	5	5	5
Res 3 (Ex)	5	5	5	5	4	5	5	5	3	5	5	4	5	5	4	3	5
Res 4 (Pr)	5	5	5	5	3	2	5	2	3	3	5	5	5	5	5	5	4
Res 5 (Ex)	5	5	5	3	5	4	5	5	5	4	4	4	5	5	5	5	4
Res 6 (Ex)	5	5	5	5	5	4	4	5	5	4	2	4	4	5	5	5	5
Res 7 (Ex)	3	5	5	3	5	5	5	5	5	5	5	4	4	5	5	5	5
Res 8 (Ex)	5	5	5	5	5	5	5	5	4	5	5	5	5	5	5	5	5
Res 9 (Ex)	3	5	5	5	5	4	5	5	5	4	5	5	5	5	5	5	5
Res 10 (Ex)	5	5	5	3	5	5	5	5	3	4	3	5	5	5	5	5	5
Res 11 (Pr)	2	5	3	5	3	4	5	5	3	4	3	2	5	3	4	4	2
Res 12 (Ex)	5	5	5	3	5	5	4	5	3	5	2	4	5	5	5	5	5
Res 13 (Ex)	4	5	5	5	3	5	5	5	4	4	3	3	5	5	5	5	5
Res 14 (Pr)	1	5	5	5	2	4	5	5	5	4	5	4	5	5	5	5	5
Res 15 (Pr)	4	4	5	5	3	2	1	3	3	3	3	4	3	3	5	4	5
Res 16 (Pr)	5	5	3	2	2	4	5	4	2	4	4	3	5	4	5	5	5
Res 17 (Ex)	3	5	5	5	5	5	5	5	3	4	5	5	5	4	5	5	5
Res 18 (Pr)	3	5	5	4	3	5	5	5	3	4	5	4	4	5	5	5	5
Res19 (Ex)	5	3	5	5	5	4	5	5	4	4	4	5	5	5	5	5	5
Res 20 (Ex)	5	5	5	5	5	4	5	5	5	4	3	5	5	4	5	4	5
Res 21 (Pr)	5	3	5	5	3	4	5	5	5	5	5	3	4	5	5	4	5
Res 22 (Ex)	5	4	4	5	3	4	5	5	5	5	5	5	5	4	4	5	4
Res 23 (Pr)	5	5	5	4	4	3	5	5	4	3	5	2	5	4	4	5	5

4.2.2.5Develop Stage of Energy Retrofit Expertise Development Weights (Step 5)

In order to differentiate the significance attached to the stages of development of expertise and the stages of skill acquisition of energy retrofit professionals from the weightage for each attribute (relative importance score), the responses for each of the stages of expertise development were weighted. On a scale of 10–50, the following indicates the specific weights assigned to each stage for all 17 attribute-based questions: Novice – 10, Advanced Beginner – 20, Competent – 30, Proficient – 40, and Expert – 50. Boolean logic made up of IF-THEN-ELSE statements was developed for each of the responses provided by each participant for each attribute-based question. The objective was to determine for each attribute-based question, the corresponding stage of expertise development: novice, advanced beginner, competent, proficient, or expert. The first attribute-based question is used as an illustration and shown in Figure 4.4: *How long have you been working in energy efficiency retrofits for existing homes?*

	EXPERT							
	RESPONDENT #7		Expertise ID					
Number	ATTRIBUTE-BASED QUESTIONS	RIS	Novice	Advanced Beginner	Competent	Proficient	Expert	Selected Option
1	*How long have you been working in energy efficiency retrofits for existing homes?*	0.4	10	20	30	40	50	
	IF up to a year, **THEN Novice**		4					
	IF more than 1 year but up to 2 years, **THEN Advanced Beginner**			8				
	IF more than 2 years but up to 3 years, **THEN Competent**				12			**12**
	IF more than 3 years but up to 4 years, **THEN Proficient**					16		
	IF more than 4 years, **THEN Expert**						20	

Figure 4.4: Screenshot Showing Part of EREIS for Respondent #7

(Note: screenshot shows the following 5 columns: Number, Attribute-based Questions, Relative Importance Scores, Expertise Identification, and Selected Option)

As can be seen from Figure 4.4, there are If-Then-Else statements corresponding to each stage of expertise development. For instance "IF more than 4 years, THEN Expert" means that the energy retrofit expertise identification system will score any participant who has worked in the industry for more than 4 years as an expert for this specific attribute-based question.

4.2.2.6 Identify Energy Retrofit Expertise Stage (Step 6)

In order to identify the energy retrofit expertise stage, the relative importance score for each question is multiplied by each of the stage of expertise development weights. In the example shown in Figure 4.4 above, the score for this question was determined to be 0.4. This was multiplied by 10 for novice, 20 for advanced beginner, 30 for competent, 40 for proficient, and 50 for expert stages. This resulted in 4, 8, 12, 16, and 20 respectively for each of the stages. In Figure 4.4, the response elicited from Respondent #7 showed that the respondent had worked for between 2 and 3 years in the industry. Thus, the score in the selected option for this attribute-based question was entered as 12 (competent). This process was repeated for each of the 17 attribute-based questions.

Next, assuming that a respondent could obtain the minimum (novice) or maximum (expert) scores for each attribute-based question, the minimum and maximum attainable scores were compiled and aggregated for all 17 attribute-based questions: Novice – 72, Advanced Beginner – 140, Competent – 216, Proficient – 288, and Expert – 360. As a result of the artificial divisions existing in the novice-expert continuum and skill development, there is an expectation of some overlap between the stages. For instance, individual differences, which become obvious in skill learning and the amount of time spent at a particular stage varies greatly from person to person

(Cornford & Athanasou 1995). Since the energy retrofit domain is an evolving industry and is developing standard protocols for the industry (BPI 2013), there was a need to further enhance the overlap. Thus, the following score ranges set for each stage of expertise development (Table 4.8) were computed:

[(B – A) 3] + B, where B, A = maximum and minimum scores for stage of expertise development

Table 4.8: Score Ranges for Identifying Stage of Expertise Development

Stage of Expertise	Score Range		Stage of Expertise	Score Range
Novice	72 – 94		Upper Competent	202 – 239
Lower Advanced Beginner	95 – 127		Lower Proficient	240 – 273
Upper Advanced Beginner	128 – 164		Upper Proficient	274 – 311
Lower Competent	165 – 201		Expert	312 – 360

4.2.2.7 Determine Energy Retrofit Expertise Status (Step 7)

Finally, to determine expertise status, responses for each of the questions were put into the energy retrofit expertise identification system where scores for each stage of expertise development was aggregated leading to the determination of the expertise status of each participant. As shown in Figure 4.5, Respondent 7 obtained a total energy retrofit expertise identification system score of 339 and, hence, was designated as an expert.

Only participants with designations of “Upper Proficient” or “Expert” were included in the next round of the Delphi process. This led to the exclusion of 2 of the participants in the next round, as shown in Table 4.9. Respondents 11 and 15 obtained scores corresponding to the expertise designation of “Lower Proficiency” (260 and 263 respectively). Since they did not meet the predetermined expertise criteria for inclusion, they were excluded from the subsequent rounds of the study.

	EXPERT							
	RESPONDENT #7		Expertise ID					
Number	ATTRIBUTE-BASED QUESTIONS	RIS	Novice	Advanced Beginner	Competent	Proficient	Expert	Selected Option
1	***How long have you been working in energy efficiency retrofits for existing homes?***	0.4	10	20	30	40	50	
	IF up to a year, THEN Novice		4					
	IF more than 1 year but up to 2 years, THEN Advanced Beginner			8				
	IF more than 2 years but up to 3 years, THEN Competent				12			12
	IF more than 3 years but up to 4 years, THEN Proficient					16		
	IF more than 4 years, THEN Expert						20	
17	***What measures do you think must be installed by a licensed retrofit professional? Kindly give reasons.***	0.6	10	20	30	40	50	
	IF none, THEN Novice		6					
	IF mentions 1 measure, THEN Advanced Beginner			12				
	IF mentions 1 measure/provides reasons, THEN Competent				18			
	IF mentions 2 measures/provides reasons, THEN Proficient					24		
	IF mentions 3 measures/provides reasons, THEN Expert						30	30
			72	140	216	288	360	339

Figure 4.5: Identifying Energy Retrofit Expertise Stage

(Note: screenshot shows the following 5 columns: Number, Attribute-based Questions, Relative Importance Scores, Expertise Identification, and Selected Option. It also highlights the total score obtained by Respondent #7, 339, and the expertise designation of an "Expert")

Table 4.9: Panel Member Expertise Designation Based on Expert Determinants

Panel Member #	Expertise Designation	Score (Max – 360)	Inclusion in Next Round
1	Upper Proficient	305	Yes
2	Expert	327	Yes
3	Expert	324	Yes
4	Upper Proficient	296	Yes
5	Expert	334	Yes
6	Expert	331	Yes
7	Expert	339	Yes
8	Expert	354	Yes

Table 4.9 (Cont'd)

9	Expert	337	Yes
10	Expert	333	Yes
11	Lower Proficient	260	No
12	Expert	326	Yes
13	Expert	329	Yes
14	Expert	323	Yes
15	Lower Proficient	263	No
16	Upper Proficient	295	Yes
17	Expert	323	Yes
18	Expert	319	Yes
19	Expert	335	Yes
20	Expert	321	Yes
21	Upper Proficient	308	Yes
22	Expert	331	Yes
23	Upper Proficient	309	Yes

(Detailed energy retrofit expertise identification system scores for participants are provided in this dissertation as Appendix D.1 – D.23).

4.2.3 Discussion and Inferences

The data obtained was analyzed based on the following: elicited knowledge, knowledge elicitor training, quantitative information, and inferences and emerging patterns. The following discussion demonstrates how the only question with no consensus in the second round of the Delphi process was analyzed and reported (Table 4.10):

Question: *Based on your experience, how many audits do you think must be performed by a retrofit professional in a year in order to make them proficient?*

a. 10 – 20/year
b. 21 – 30/year
c. 31 – 40/year
d. 41 – 50/year
e. More than 50/year

Table 4.10: Initial Reported Data for Annual Number of Audits

Annual Number of Audits	Percentage of Experts (%)
10 – 20	27.78
21 – 30	50.00
31 – 40	11.11
41 – 50	0
51 or more	11.11
Total	**100**

Detailed analysis of the transcript of the interview revealed an interesting pattern. It emerged that even though there was no consensus on the exact number of audits to be completed annually by the experts, so long as an energy retrofit professional was doing about a couple of energy audits a month, it was good enough for them to maintain their proficiency level. As a result, a new categorization was provided with only three options for the annual number of audits: 10–30, 31–50, and 51 or more, on the basis of which further analysis was completed. Consensus was reached (77.78%) for this question in the subsequent round and is shown in Table 4.11.

Table 4.11: Modified Categories for Annual Number of Audits

Annual Number of Audits	Percentage of Experts (%)
10 – 30	77.78
31 – 50	11.11
51 or more	11.11
Total	**100**

Analyses for all the responses were completed in a similar fashion, at the end of which the results and findings were compiled and discussed in the next section. This provided a good basis for the development of the determinants of expert knowledge in the energy retrofit domain.

Key findings of this section of the research are discussed. Through the development and implementation of the energy retrofit expertise identification system using qualitative methods, the determinants of expert knowledge were identified for this domain. Using a data collection technique dominated by the Delphi process, data was collected and analyzed from 19 industry experts. The following highlights the key findings:

1. The success of the industry practice is heavily influenced by the knowledge type of industry practitioners. The type of knowledge depends on specific attributes needed to succeed in the industry, some of which are of relative importance, primarily due to its role in the industry. In a hierarchical order starting from the most important, the following are attributes needed for success in this domain:
    a. Building science and construction knowledge
    b. Certification and continuing education
    c. Field experience and expert collaboration
    d. Computer and diagnostic equipment knowledge
    e. Professional ethics
2. The identifiable stages in the development of expertise (Benner 1984; Cornford & Athanasou 1995; Dreyfus & Dreyfus 1986; Schempp 2011; Trotter 1986): Novice, Advanced Beginner, Competent, Proficient, and Expert, are implementable in the energy retrofit industry and can be used as a good metric to gauge the level of expertise of industry practitioners.
3. Three distinguishing traits between novices and experts in the energy retrofit industry are experience, automaticity or intuitive decisions, and competence. These traits were embedded in the energy retrofit decision process model (Syal *et al.* 2014) and were specifically considered under each of the three main steps: identify energy retrofit measures, shortlist and prioritize the measures, and provide expert advice on installation.

4. In terms of energy retrofit experience, the study identified the following:
    a. The number of years spent in the industry alone is not enough to determine an expert in this industry. The study found no correlation between the number of years spent in the industry and the expert knowledge score. For instance, two participants with differing years of practice, 3 years and 38 years, both obtained similar designations of "Upper Proficient".
    b. Experience (number of years) indicators, commensurate with the stage of expertise development in this domain are: *Novice (*up to a year), *Advanced Beginner (*1–1.99 years), *Competent (*2–2.99 years), *Proficient (*3–3.99 years), *and Expert* (4 or more years).
    c. To maintain acceptable proficiency, an industry professional must perform 12–30 energy audits, and 6–15 energy retrofits, annually.
    d. As a result of the changing and evolving nature of the energy retrofit industry, being away for more than a year negatively affects proficiency.
5. In terms of energy retrofit intuitive decision-making, the following were observed:
    a. In order to maintain/improve levels of proficiency, industry practitioners must regularly update their knowledge and make reference to information sources.
    b. The knowledge of available financial incentives in the industry by practitioners is very important for the success and growth of the industry. Common sources for such information are: trade organizations, utility companies, colleagues in the industry, government sources, and not-for-profits like Habitat for Humanity.
    c. Industry experts employ the following traits to justify or explain decisions or actions: case based reasoning, self-confidence in decision-making, reliance on accumulated

experience, flexibility to generate scenarios in order to explain difficult or new scenarios, and provision of relevant information sources.

d. Industry experts are knowledgeable in 4 or more energy retrofit measure categories: (a) tightening of envelope measures (e.g. air sealing and insulation); (b) heating and cooling measures (e.g. furnaces, ventilation systems, air conditioners); (c) stand-alone measures (e.g. lighting and appliances); and (d) energy saving measures (e.g. water heater pipe insulation, water saving showerheads and faucet aerators).

6. Expertise of experts can be defined in terms of:

    a. *Experience* – better performance due to real world experience and extensive practice leading to long-term developmental processes.

    b. *Extent* – expertise exists in degrees and not in an all-or-none fashion.

    c. *Development* – progresses from literal understanding (novices) to expert reasoning (experts).

    d. *Knowledge structures* – very extensive and well organized domain knowledge.

    e. *Reasoning process* – possess qualities such as using prototype examples of past cases, generating scenarios, and moving from declarative to procedural shift in reasoning in order to explain decisions, actions, or novel difficult situations.

4.3 ENERGY RETROFIT EXPERTISE ELICITATION STRATEGY

As a result of the critical role played by the elicitation of expertise within the overall knowledge acquisition process, it is important that a comprehensive elicitation strategy is developed for the energy retrofit domain. The elicited knowledge can then be used in the development of a knowledge-based system implementable in an intelligent decision support system framework. The next section discusses the components of the energy retrofit expertise elicitation strategy.

4.3.1 Components of the Elicitation Strategy

As mentioned in Chapter two, the narrow perspective of knowledge engineering, which deals with the acquisition, representation, validation, inferencing, explanation, and maintenance of knowledge, is the focus of this research. This section describes the first component, knowledge acquisition. Specifically, the subtask of involving collecting relevant knowledge from a human source through some form of direct interaction, also known as knowledge elicitation, is highlighted. The knowledge elicitation strategy envisioned for this study sought to address the three problems of knowledge acquisition (section 4.1.4): (1) eliciting tacit or intuitive knowledge (2) solving the problem of unavailable experts, and (3) knowledge elicitor with limited domain knowledge. The following sections discuss the components of the strategy.

4.3.1.1 Knowledge Elicitor Training

As a result of the unstructured and tacit nature of expert knowledge, a major goal of the knowledge elicitation process is to help experts articulate their knowledge in order for it to be documented in a reusable format. Knowledge elicitors/engineers are humans who are able to communicate with experts and combine knowledge from several sources to build a valid knowledge-base (Regoczei & Hirst 1992; Turban *et al.* 2005). The researcher played the role of a knowledge elicitor in this research. This section emphasizes the importance of comprehensive training of the knowledge elicitor in developing an effective knowledge elicitation strategy. Specifically, the role of the researcher in the development of this strategy is highlighted.

The role of the knowledge elicitor is critical in the development of any knowledge-based system. Rolston (1988) asserts that even though the knowledge of an expert is what is being modeled, it is the knowledge elicitor (acting as an intermediary whose duty is to activate the process of moving expert knowledge into the knowledge-based system) who actually builds the system. This process is particularly critical due to the following reasons (Rolston 1988):

1. Knowledge in the knowledge-based system is that of the elicitor rather than the expert.
2. The knowledge elicitor must ensure continual personal work relationship with the expert.
3. Experts must not be asked basic information easily obtainable from background reading.
4. Frequent use of domain language by knowledge elicitor when working with an expert.
5. Experts do not follow linear reasoning lines typically found in textbooks.
6. Expert knowledge is tacit.
7. Compared with novices, experts find it more difficult to explain their actions.
8. Retrieval of expert knowledge is difficult without a problem solving context.
9. Need for probing questions by knowledge elicitor until a suitable detail level is obtained.
10. Need for protocol generation such as tape recording for future use.

Published literature from various sources was extensively reviewed and presented in Chapter two. It included information on the three broad categories of energy efficiency retrofit industry, knowledge development and elicitation, and decision support systems.

Academic publications have been completed as a result of the training of the knowledge elicitor for this research. This includes publications, presentations, and a major industry report by the researcher who was part of a larger research team. Academic publications were concluded before the knowledge elicitation stage was completed and comprised the following:

- *Journal Publication Titled*: Information Framework for an Intelligent DSS for Home Energy Retrofits (Syal *et al.* 2014).
- *Out-Of-State Conference Presentation Titled:* Information Barriers in Home Energy Retrofit Adoption: Research in Progress (Duah & Syal 2013a).
- *In-State Conference Presentation Titled*: Knowledge Elicitation from Home Energy Retrofit Experts: A Delphi Approach (Duah & Syal 2013b).
- *International Conference Presentation Titled:* Developing a Decision Support System for Cost Effective Energy Retrofits (Duah *et. al* 2012).
- *Major Industry Report for the United States Department of Energy Titled:* Information Framework Development for Retrofit Technology Measures (Syal *et al.* 2013).

As mentioned in section 4.2.2, ***industry interactions*** by the researcher with professionals and researchers were completed. The researcher was part of the team, which included representations from the Sustainable Construction Management Research Group, School of Planning, Design and Construction at Michigan State University; DOW Chemical Company; Habitat for Humanity; and Ferris State University. The researcher also had regular interaction with industry professionals in cities across the state of Michigan whilst working with two graduate students of the Construction Management Program at Michigan State University. This led to the completion of two graduate level theses.

4.3.1.2 Relevant Knowledge Elicitation Techniques

The choice of knowledge elicitation techniques may depend on the characteristics of the domain, the expert, and the required system. To efficiently acquire knowledge in a domain, a range of techniques is necessary (Shadbolt 2005). An important technique that must be integrated during knowledge elicitation is to encourage the expert to describe his/her expertise in the way most natural to him/her. Additionally, experts find it easier to talk about specific examples of problems due to the autonomy of expertise (Hart 1985).

Several techniques for eliciting expertise of experts are available and have been discussed in Chapter two. A critical aspect of these elicitation techniques relates to their reliability and validity. In order to ensure that the elicitation strategy developed for this study was adequate, effective, and accurate, there was a need to have a combination of suitable elicitation techniques for each domain. Hence, the elicitation strategy developed in this chapter is a combination of relevant techniques including having a knowledgeable elicitor. This allows the expert to freely express themselves in a suitable environment. This section describes the three techniques employed: semi-structured interviews, job shadowing, and the Delphi technique.

Even though ***semi-structured interviews*** were used, the structure was very loose during the development of the preliminary questionnaire, which was sent to the focus group. Based on the responses of the focus group, the questions were refined and finalized by incorporating the ten reasons proffered by Rolston (1988) about the criticality of the role of the elicitor in developing a knowledge-based system. For instance, as a result of extensive literature review and background reading, there was no need for the researcher to pose basic questions, such as "who an energy auditor is" or "what an energy assessment process involves", to the experts. Additionally, since it is difficult for an expert to retrieve knowledge without a problem solving context, questions based on problem solving contexts were incorporated into the questionnaire, an example of which is indicated below:

> *Comment on the following scenario – you have to recommend energy retrofit measures for a home but you have no means of performing a test on the home. Explain in a step-by-step manner, what methods you will use to make that decision. Note that the homeowner is highly informed about the home and is able to give you relevant information regarding equipment efficiencies, insulation types and levels, age of home, and building system, etc.*

Finally, a protocol, which is a record of behavior, whether in audio, video, or electronic media (Epistemics 2003), was generated for each knowledge elicitation session.

In terms of ***job shadowing*** and as explained in Chapter three, a total of six home energy auditors and retrofit contractors were used as the main source of expert knowledge for the preliminary knowledgebase. Three of them, primarily energy auditors and retrofit contractors, were job shadowed. The objective was to observe them in order to gaining insights and experience how they perform their job, understand and compile decision-making protocols, and improve communication with industry practitioners. During the process, there was minimal interference from the researcher who mainly observed the experts performed their work and took notes. In order to understand the rationale behind some of the decisions and actions taken, the researcher asked few questions so as to avoid interrupting them. This was, however, not a huge concern since knowledge learnt to automaticity are better retained in long-term memory (Bahrick 1994; Flor 1995) and demand less cognitive and attentional energy (Samuels & Flor 1993).

The ***Delphi technique***, according to Hallowell and Gambatese (2010), is a cost-effective and widely used method for consensus building which involves the use of specific rounds of questionnaires to collect data from a panel of selected participants and allows researchers to maintain significant control over bias in a well-structured academically rigorous process using the judgment of qualified experts. Hermez (2012) has suggested that unstructured and semi-structured problems are complex and require expertise for their solutions. The Delphi technique was identified as the preferred research method for problems hardly studied using precise analytical techniques, answerable by intuitive judgment rather than concrete measurement, and with disagreements among experts needing a refereed communication process (Pill 1971; Linstone & Turoff 1975 cited by Hallowell & Gambatese 2010).

Based on the foregoing analysis, a combination of elicitation techniques that emphasized the importance of knowledge elicitor training and employed the Delphi technique as the dominant elicitation technique was developed for this domain and used in this research (Figure 4.6).

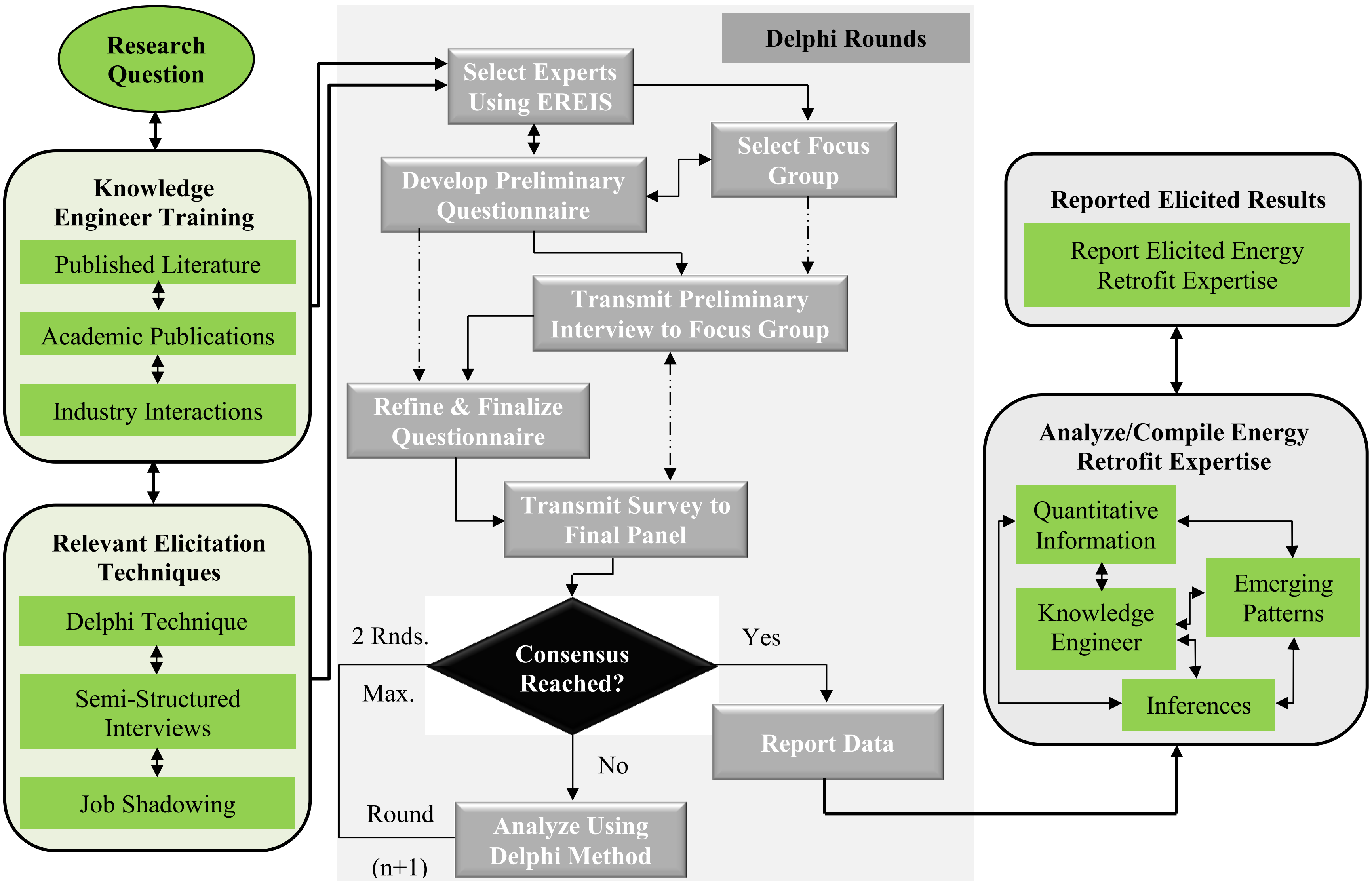


Figure 4.6: Energy Retrofit Expertise Elicitation Process Model

4.3.2 Data Collection

Participants whose expertise was to be elicited and compiled were selected based on the energy retrofit expertise elicitation strategy developed in section 4.2. In total, 19 participants (14 Expert- and 5 Upper Proficient-scoring) were included in the Delphi rounds. As explained in section 4.2.2, questionnaires for the identification system and elicitation strategy were combined into one survey. Out of a total of 25 questions developed, 9 were exclusively identification system type questions, 5 were exclusively elicitation strategy type questions, and 11 were for both question types. At the end of the first round of Delphi study, it was established that whilst there was no need for consensus to be reached on 4 (11.76%) of the questions, consensus was reached on 23 (67.66%) of the questions. There was no consensus reached on 7 (20.58%) of the questions and, hence, were included in the next round of the Delphi survey. Thus, no need for consensus and consensus reached accounted for 79.42% of the questions (Table 4.12).

Table 4.12: Summary of Consensus Status Questions after First Round of Delphi

Question Number	Expert Criteria Only	Knowledge Elicitation Only	Expert Criteria & Knowledge Elicitation	Consensus Status
1	Yes	N/A	N/A	Not Needed
2	Yes	N/A	N/A	Not Needed
3a	Yes	N/A	N/A	No
3b	Yes	N/A	N/A	No
4	Yes	N/A	N/A	Yes
5	Yes	N/A	N/A	Yes
6	Yes	N/A	N/A	Not Needed
7	Yes	N/A	N/A	Yes
8a	Yes	N/A	N/A	Yes
8b	Yes	N/A	N/A	Not Needed
8c	Yes	N/A	N/A	No
9	Yes	N/A	N/A	Yes
10	N/A	N/A	Yes	Yes
11	N/A	N/A	Yes	No
12	N/A	Yes	N/A	No
13	N/A	N/A	Yes	Yes
14	N/A	N/A	Yes	Yes
15	N/A	N/A	Yes	Yes

Table 4.12 (Cont'd)

16	N/A	Yes	N/A	Yes
17	N/A	Yes	N/A	Yes
18	N/A	N/A	Yes	Yes
19	N/A	N/A	Yes	Yes
20	N/A	N/A	Yes	Yes
21	N/A	N/A	Yes	Yes
22	N/A	Yes	N/A	No
23a	N/A	Yes	N/A	Yes
23b	N/A	Yes	N/A	Yes
23c	N/A	Yes	N/A	Yes
23d	N/A	Yes	N/A	Yes
23e	N/A	Yes	N/A	Yes
24a	N/A	N/A	Yes	No
24b	N/A	N/A	Yes	Yes
25a	N/A	N/A	Yes	Yes
25b	N/A	N/A	Yes	Yes

The 7 questions with no consensus at the end of the first round were identified. Anonymous feedback based on the responses was provided to the expert panel in the second round at the end of which consensus was reached on 6 out of the 7 questions. Based on the background knowledge obtained in this study, inferences were drawn for the question with no consensus reached on the basis of which a suitable consensus was determined by the researcher. Finally, the data obtained from the Delphi rounds was reported, analyzed, and is indicated in the next section.

(A detailed analysis of data obtained for the identification system and elicitation strategy after the last Delphi round including the results is provided in this dissertation as Appendix B.2).

4.3.3 Discussion and Inferences

Based on the comprehensive elicitation strategy developed and the analysis of the data obtained, there was consensus reached by the experts regarding suitable expert knowledge for making energy retrofit decisions. This knowledge was mutually acceptable by participants and is applicable to industry practice and usable by homeowners for decision-making. This section reports on such knowledge used in decision-making. Analysis of the elicited expert knowledge was completed in a similar fashion outlined in section 4.2.3. This section discusses the results of the analysis and is reported under based on the three principal stages of the energy retrofit decision process model (Syal *et al.* 2014) highlighted in Chapter three: (1) identify retrofit measures, (2) shortlist/prioritize retrofit measures, and (3) provide expert advice on installation.

4.3.3.1 Reported Data: Identify Energy Retrofit Measures

Table 4.13 reports on the consensus reached by experts regarding what they described as important in identifying energy retrofit measures and are put under 5 knowledge categories.

Table 4.13: Elicited Knowledge: Identify Energy Retrofit Measures

Knowledge Category	Elicited Knowledge
Building components and user features used for assessing home energy performance when there is no means of testing	• Building envelope features/ages (wall insulation, windows, doors) • HVAC equipment types, ages, and characteristics • Comfort complaints • Visible moisture issues • Visible health and safety issues • Appliance and lighting characteristics • Review of utility use and billing history
Limited instances for using energy inefficient products or appliances	• Where cost is prohibitive • If cost ineffective (e.g. using an AC 2 weeks each year) • Unavailability (e.g. range microwave) • If emphasis is on health and safety and not energy efficiency (e.g. basic power vent water heater that passes combustion appliance zone test)
Importance of the whole-house system of energy retrofitting	• Dominant relationship exists among housing characteristics that affect the energy performance of other components, hence, the home must be viewed as a whole and not in parts: o Construction type (balloon vs. platform framing, materials, number of stories) o Vintage (archetype – Cape Cod vs. Ranch, complexity of form) o Age (some walls with no insulation till mid-1970's)

Table 4.14 (Cont'd)

Key issues for home energy assessment	• Determining where and how energy is lost
	• Identifying energy inefficient systems
	• Prescribing energy retrofit measures to enhance the following:
	  o Occupant health and safety
	  o Occupant comfort
	  o Home durability
	  o Improve energy efficiency of home
	  o Lower financial burden

Major HER benefits	• Financial, comfort, and health

4.3.3.2 Reported Data: Shortlist/Prioritize Energy Retrofit Measures

Table 4.14 reports on the consensus reached by experts regarding what they described as important knowledge when shortlisting or prioritizing energy retrofit measures.

Table 4.14: Elicited Knowledge: Shortlist/Prioritize Energy Retrofit Measures

Knowledge Category	Elicited Knowledge
Typical homeowner concerns prior to energy retrofits	• Financial benefits • Comfort issues • Impact of work on homeowner • Health issues
Key homeowner reasons for performing energy retrofits	• Financial • Comfort • Health
Measures with greatest paybacks (return on investment)	• Air sealing • Insulation • Lighting
Major traits industry experts must have for effective homeowner advice	• Building science knowledge • Financial knowledge • Knowledge of available financial incentives • Experience
External issues that affects cost of home energy retrofit work being performed	• Health and safety remediation (e.g. lead) • Access to work areas (air sealing attics with low pitched roofs) • Weather conditions (working in attics during peak summer months) • Existing content of space (remove items, perform work, rearrange)
Major post-occupancy health and safety issues	• Air quality (backdrafting of carbon monoxide) • Material off-gassing • Moisture issues

Table 4.14 (Cont'd)

Whole-house system interactions of building components affecting energy performance	• Reduction in infiltration and exfiltration through thermal envelope affects sizing of heating system • Installing energy efficiency lights like compact fluorescent lights instead of incandescent light bulbs can reduce heat load
Expert competencies	• Building science and construction knowledge • Computer and diagnostic equipment knowledge • Certification and continuing education • Field experience and expert collaboration • Professional ethics

4.3.3.3 Reported Data: Provide Expert Advice on Installation

Table 4.15 reports on the consensus reached by experts regarding what they described as useful expert advice for the installation of energy retrofit measures:

Table 4.15: Elicited Knowledge: Provide Expert Advice on Installation

Knowledge Category	Elicited Knowledge
Crawlspace air sealing and insulation	• Treat crawlspaces as conditioned spaces • Look out for health and safety issues • Check for latest fire code • Wear personal protective equipment
Above grade wall insulation	• Treat space as conditioned • Ensure remediation of health and safety hazards
Attic air sealing and insulation	• Ensure air sealing is performed before insulation • Ensure proper ventilation • Ensure health and safety remediation, if any
HVAC equipment upgrade and duct improvement	• Equipment specification (efficiency, age, and size) • Air sealing and insulating equipment and ducts • Ensure an adequate distribution system • Ensure combustion safety
Do-it-yourself installation measures	• Energy saving measures such as: o Furnace filter change o Adjusting hot water heater o Installing faucet aerators o Dryer vent or hose change o Pipe insulation o Programmable thermostat install (education needed) • Lighting • Minor air sealing (window or door caulking) • Appliance replacement (e.g. refrigerator)

Table 4.15 (Cont'd)

Reasons for allowing do-it-yourself measures	• No safety issues involved • Require minimal aptitude • Easy to install • Installation information obtainable from published sources
Professional-only-install measures	• Major air sealing (e.g. sealing the whole attic) • Heating, cooling, and air condition measures • Insulation installation • Electrical work • Hanging doors and windows
Reasons for professional-only-install measures	• Required by law • Involve health and safety issues • Requires expert installation • Involves expensive measure-specific tools

4.4 CHAPTER SUMMARY

A major step in the development of an intelligent decision support system involves the integration of quantitative information with expert knowledge. This chapter focused on the elicitation of expert knowledge. As a result of the lack of standard protocol and the difficulty in determining the level of expertise in this industry, a comprehensive tool known as the energy retrofit expertise identification system was developed for this domain. It provides a comprehensive basis for defining expertise in this domain through the development of the determinants of expert knowledge.

Next, as a result of the commonly acknowledged problem of knowledge elicitation in knowledge-based system development, an energy retrofit expertise elicitation strategy that emphasized comprehensive knowledge elicitor training and a combination of relevant elicitation techniques was developed and used to elicit and compile the knowledge of 19 industry experts. Chapter five discusses the last component of the expert knowledge building block, knowledge modeling, and the development of an intelligent decision support system framework.

CHAPTER FIVE

INTELLIGENT DECISION SUPPORT SYSTEM FRAMEWORK

5.1 INTRODUCTION

A key barrier to home energy retrofits, as identified in existing literature and discussed in earlier chapters, is the lack of information, or the lack of information in a format that can be understood and used by homeowners to make retrofit decisions. Regarding information for energy retrofitting their homes, homeowners traditionally depend on experts in the field of energy efficiency, such as energy auditors and trade contractors. This information has, however, been fraught with several problems such as comprehensiveness, accuracy, cost, and perception of bias. Two types of information identified in the home energy retrofit industry are quantitative information and expert knowledge. The integration of the former into an Intelligent Decision Support System was the focus of Chapter three.

Despite the critical role of expert knowledge in the development of an intelligent decision support system, there have been varied problems regarding its elicitation, often cited as a major barrier in the development of knowledge-based systems and applications (Feigenbaum & McCorduck 1984 cited by Cooke 1994; Turban *et al.* 2005). Chapter four focused on the integration of expert knowledge, where energy retrofit expert knowledge was identified and elicited. The focus of this Chapter is to highlight the key components of an intelligent decision support system and to develop the system framework for the energy retrofit industry.

5.1.1 Knowledge Modeling

In order to use the expert knowledge, elicited and compiled in Chapter four, in an intelligent decision support system platform, it has to be represented in a proper format. The different ways of representing it by knowledge engineers for knowledge-based systems is referred to as knowledge models. Since a knowledge model must involve constructing the problem-solving behavior of an expert, it must be in terms of knowledge instead of representations (Epistemics 2003; Turban *et al.* 2005).

Knowledge modeling methods can be classified into three categories (Turban *et al.* 2005): manual, semiautomatic, and automatic.

- *Manual methods* are basically interview-based, and knowledge is elicited from the expert or other sources and coded in the knowledge-base. Interviewing, tracking the reasoning process, and observing are three major manual methods. Manual methods are regarded as slow, expensive, and less accurate, and there is a shift toward automating the process.
- *The semiautomatic method* has two categories: expert-based and knowledge engineer-based. Whilst in the former, experts are allowed to build knowledge bases with little or no help from the knowledge engineer, in the latter, knowledge engineers are allowed to complete the required tasks in a more efficient or effective manner (sometimes with minimal participation by an expert).
- *Automatic methods* have little or no role for both the expert and knowledge engineer. For instance, the induction method, which generates rules from a set of previous cases, can be used to build a knowledge-base. The term automatic is a relative one and is used to compare the involvement of a knowledge engineer and an expert in the other methods.

This research employed a combination of the manual and automatic methods. First, the primary manual methods used for this research were the Delphi process, observations, and protocol analysis. Protocol analysis mainly involved job shadowing of experts where protocols were generated and then analyzed and interpreted in order to structure the protocol into knowledge representation using rules. Next, the automatic method involved the extraction of knowledge automatically from existing data, primarily energy assessment reports. The major reasons for the combination of these two methods are indicated below:

- Though the manual method was suitable for the domain under study and has its advantages, the associated problems such as slowness of the process, high cost involved, and issues with accuracy had to be minimized.
- It was very difficult to find domain experts out of the limited numbers available. Some were busy, sometimes uncooperative, and/or wanted to be compensated financially for their extended time expended for this research.
- Since good knowledge engineers are highly paid and difficult to find (Turban *et al.* 2005), the researcher acted as one and undertook training, hence had an increased capability of interpreting data using the automatic method.
- As a result of the innate difficulty of some experts explaining what they do and how they do it due to the cognitive principle of automaticity, there was a need to complement the knowledge obtained via manual means with that gained through the automatic process.

Inductive learning, a typical method for knowledge discovery using the automatic method of knowledge modeling, was used in this research. In this method, rules are induced from existing cases whose results are known. The rules that are induced are then stored in the knowledge base for future reference (Turban *et al.* 2005). For this research, however, inferences made from the induction were combined with those obtained through the manual process, and available published or quantitative information, in order to generate a comprehensive rule system to be employed in the proposed intelligent decision support system.

5.1.2 Chapter Objectives

A knowledge-based system is significant because it must be incorporated into traditional decision support system components to make it intelligent. In order to develop an intelligent decision support system to help users with decision making in the energy retrofit industry, there is a need to integrate all the components of the intelligent system. The overall objective of this chapter is to develop an intelligent decision support system (IDSS) framework that can be used for decision-making in the energy retrofit domain. The following sub-objectives were defined:

1. Identify the key components or building blocks of the proposed IDSS framework
2. Refine the energy retrofit decision process model by expanding the knowledge part
3. Develop rules for various knowledge parts of the energy retrofit decision process model to be employed in the knowledge-based system of the proposed intelligent system

5.2 INTELLIGENT DECISION SUPPORT SYSTEM BUILDING BLOCKS

The building blocks for the development of the proposed intelligent decision support system framework include the compiled quantitative information and expert knowledge. Quantitative information was discussed in Chapter three and includes cost database information obtained from the national residential efficiency measures database, energy simulation or assessment software obtained from BEopt, and existing published information in the form of texts, images and videos.

The expert knowledge, discussed in Chapter four, highlighted two of the three parts needed for the framework: energy efficiency retrofit knowledge definition and energy efficiency retrofit knowledge elicitation. This chapter discusses the third part, energy efficiency retrofit knowledge modeling by developing suitable rules for an intelligent decision support system (Figure 5.1).

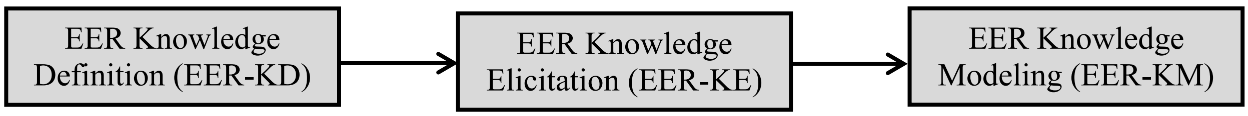


Figure 5.1: Energy Retrofit Expert Knowledge Modeling Process

5.2.1 Components of Proposed Intelligent Decision Support System

The energy retrofit decision process model, discussed in Chapter three, was a key component in identifying quantitative information and expert knowledge, and also the basis for identifying the major building blocks for developing the proposed intelligent system framework (Figure 5.2).

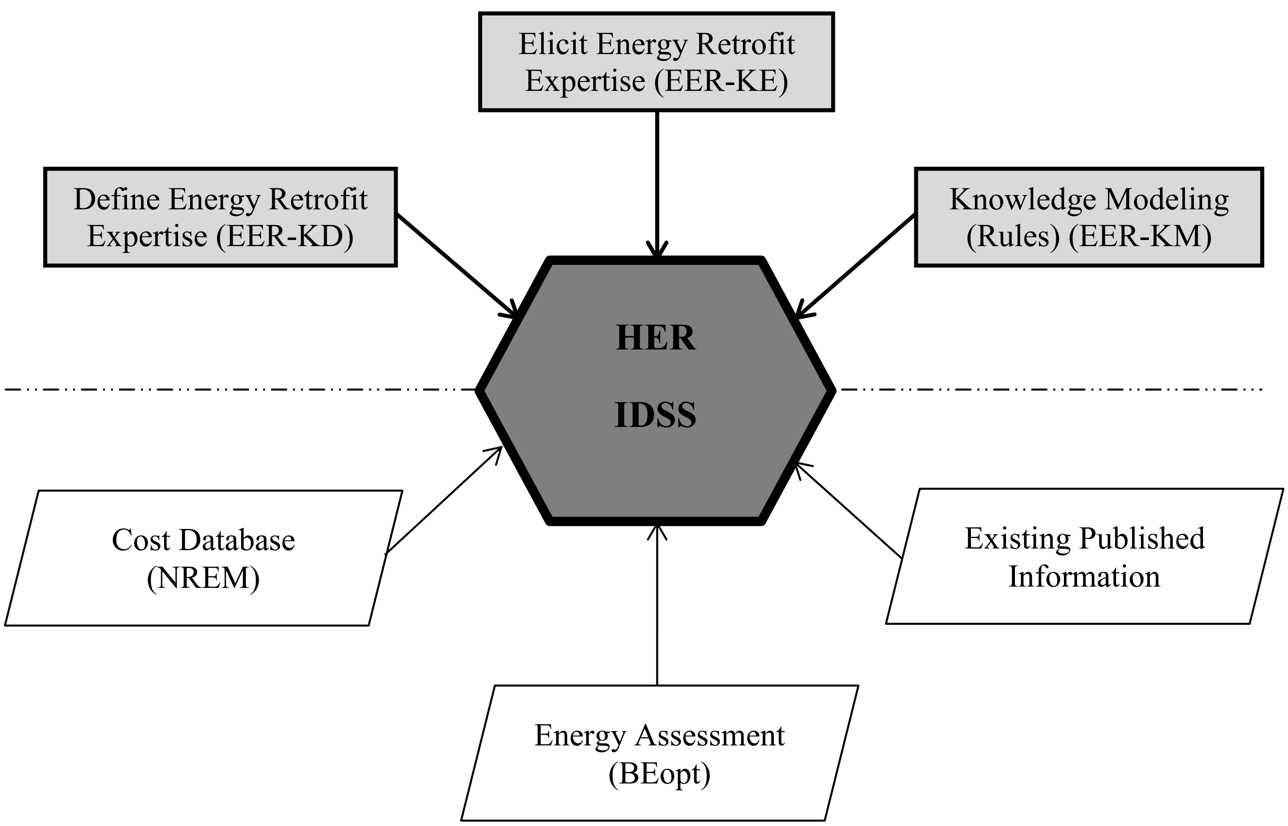


Figure 5.2: Building Blocks for Proposed Intelligent Decision Support System Framework

Figure 5.2 highlights the three key sources for the quantitative information (cost database, energy assessment, and existing published information) as well as the three available energy retrofit expert knowledge components (EER-KD, EER-KE, and EER-KM).

5.2.2 Development of Rules

In order to use energy retrofit expert knowledge in an intelligent system platform, the elicited knowledge from the experts, or obtained from a data set, must be represented in a format understood by humans and executed on computers. The development of rules is the most popular in representing knowledge in a suitable format (Turban *et al.* 2005). As discussed in section 5.1.1, a combination of manual and automatic knowledge modeling methods was used in the rule development. The energy retrofit rule development process involved 3 main stages: manual knowledge modeling, automatic knowledge modeling, and the integrated knowledge modeling (Figure 5.3).

5.2.2.1 Manual Knowledge Modeling

The energy retrofit expertise elicitation strategy developed and discussed in Chapter four, was the manual knowledge modeling technique used in this research. The protocol generated through the process was then analyzed, and the knowledge interpreted. For instance, analyses of the protocols identified the need for a hierarchy for installing two major energy retrofit measures: thermal envelope measures and HVAC measures. It was established that thermal envelope measures had to be performed first since they directly affect the type of HVAC upgrades that will be prescribed.

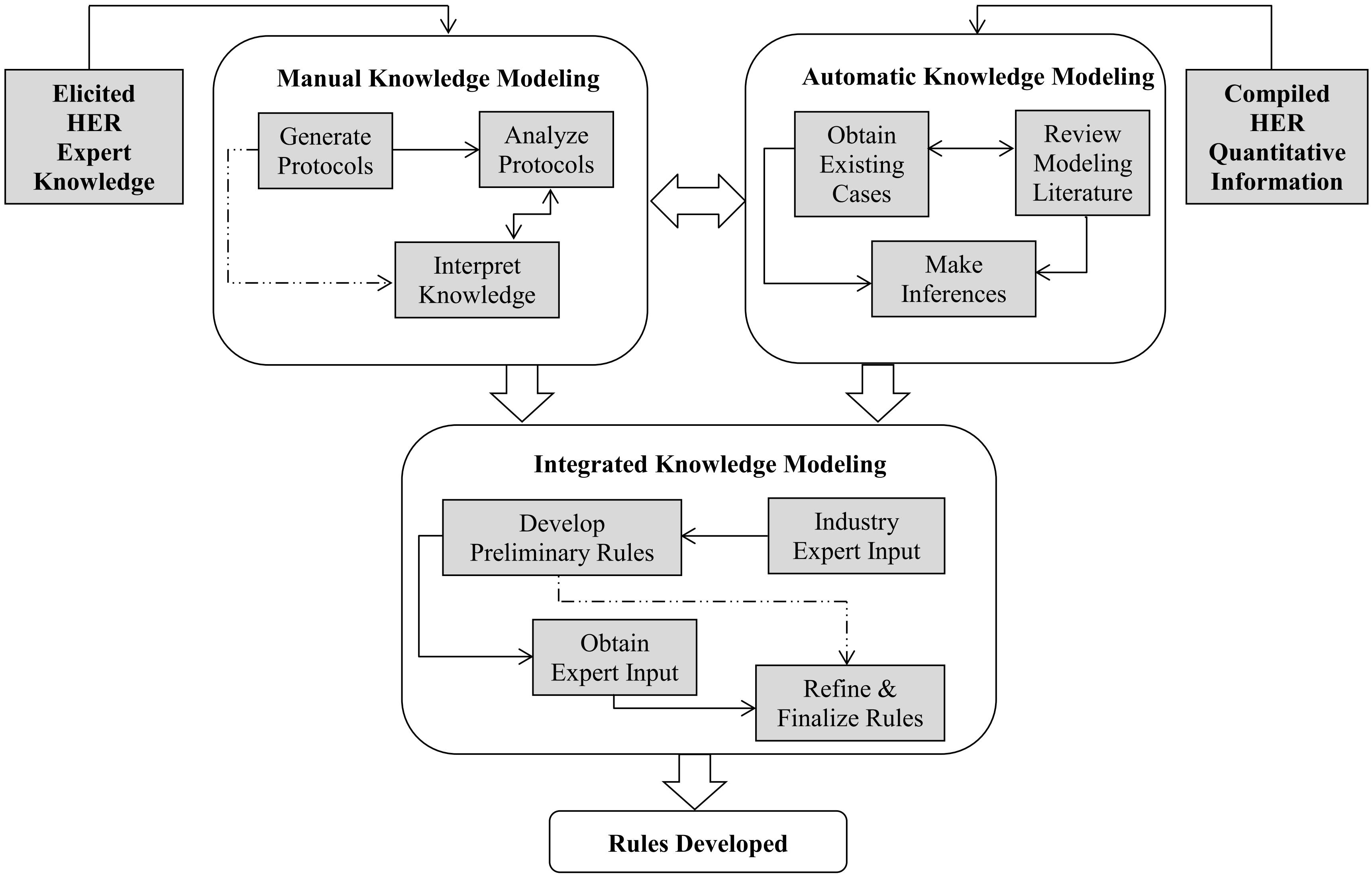


Figure 5.3: Energy Efficiency Retrofit Rule Development Process

5.2.2.2 Automatic Knowledge Modeling

Data for the automatic method of knowledge modeling was obtained from the Alternative Energy Engineering Technologies Program of Lansing Community College. As one of the first colleges in the United States to incorporate alternative energy into its curricula and also offer an Associate Degree, this program offers two classrooms devoted to alternative energy, hands on practice with commercial alternative energy systems equipment, sophisticated high power hydrogen fuel cell systems with computer-aided diagnostics, and highly skilled faculty who are dedicated to student success (LCC 2013).

At the end of each year, students in the program are required to perform an energy audit on a residential home. Typically done in groups (on average) of three students, 20 reports spanning a period of five years were obtained for analysis using the automatic method of knowledge modeling. Internet-based housing information and data gathering sources such as Michigan Housing Locator, zillow.com, realtor.com, and trulia.com were used to complement the information about the homes obtained from the energy assessment reports. Of all the upgrades recommended for energy retrofitting the identified homes, a consistent hierarchy was identified from the automatic knowledge modeling stage. Thermal envelope measures were always applied first, before HVAC measures, an assertion corroborated by other published information (ACEE 2012; Gellings & Parmenter 2004; Hershfield 2013; Krigger & Dorsi 2009; Lstiburek 2006).

5.2.2.3 Integrated Knowledge Modeling

During the integrated modeling stage, rules were developed based on the interaction of expert knowledge and quantitative information obtained from both the manual and quantitative modeling techniques. This led to the preliminary development of rules with an input from an industry expert (based on scores obtained from the identification system developed in Chapter four of this dissertation). The rules were then refined and finalized in a format suitable for use in the proposed intelligent system. The next section discusses the development of the rule logic.

5.2.2.4 Developing Rule Logic

In the development of rules, knowledge is typically represented in the form of condition-action pairs: IF this condition (or premise or antecedent) occurs, THEN come action (or result or conclusion or consequence) will (or should) occur (Leishman 2005; Singhaputtangkul *et al.* 2013; Turban *et al.* 2005; Vohra & Das 2011). For instance:

IF *the home has incandescent lights,* THEN *replace them with compact fluorescent lights*.

The conclusion from this rule is that energy inefficient incandescent light bulbs must be replaced with energy efficient compact fluorescent lights in order to contribute to increasing the energy efficiency of the home. Turban *et al.* (2005) posits that the IF side of rules can include a lot of Ifs, in which case the THEN side can also include several parts. In order to have majority of IF parts, the introduction of an AND part is ideal. An example is indicated below:

IF *the home has a balloon system of construction,*

AND *the home is very drafty,*

AND *the heating system is oversized,*

AND *the dishwasher requires replacement,*

AND *all the lights in the home are incandescent light bulbs,*

THEN *air seal and insulate the house.*

THEN *resize and install an appropriate heating system.*

THEN *install an energy star rated dishwasher.*

THEN *remove all incandescent lights and install compact fluorescent lights.*

The THEN parts, for convenience, can all be lumped into one comprehensive action part as indicated below:

THEN *(1) Air seal and insulate the house*

(2) Resize and install an appropriate heating system

(3) Install an energy star rated dishwasher

(4) Remove all incandescent lights and install compact fluorescent lights

For this research, the logic used in the rule development was based on the energy retrofit decision process model (Figures 3.1 and 5.4). The overarching logic was based on the energy retrofit expert knowledge elicited and corroborated by quantitative information, thus the following hierarchy is suggested:

1. Thermal envelope measures
2. HVAC measures
3. How water heating measures
4. Lighting measures
5. Stand-alone and energy saving measures

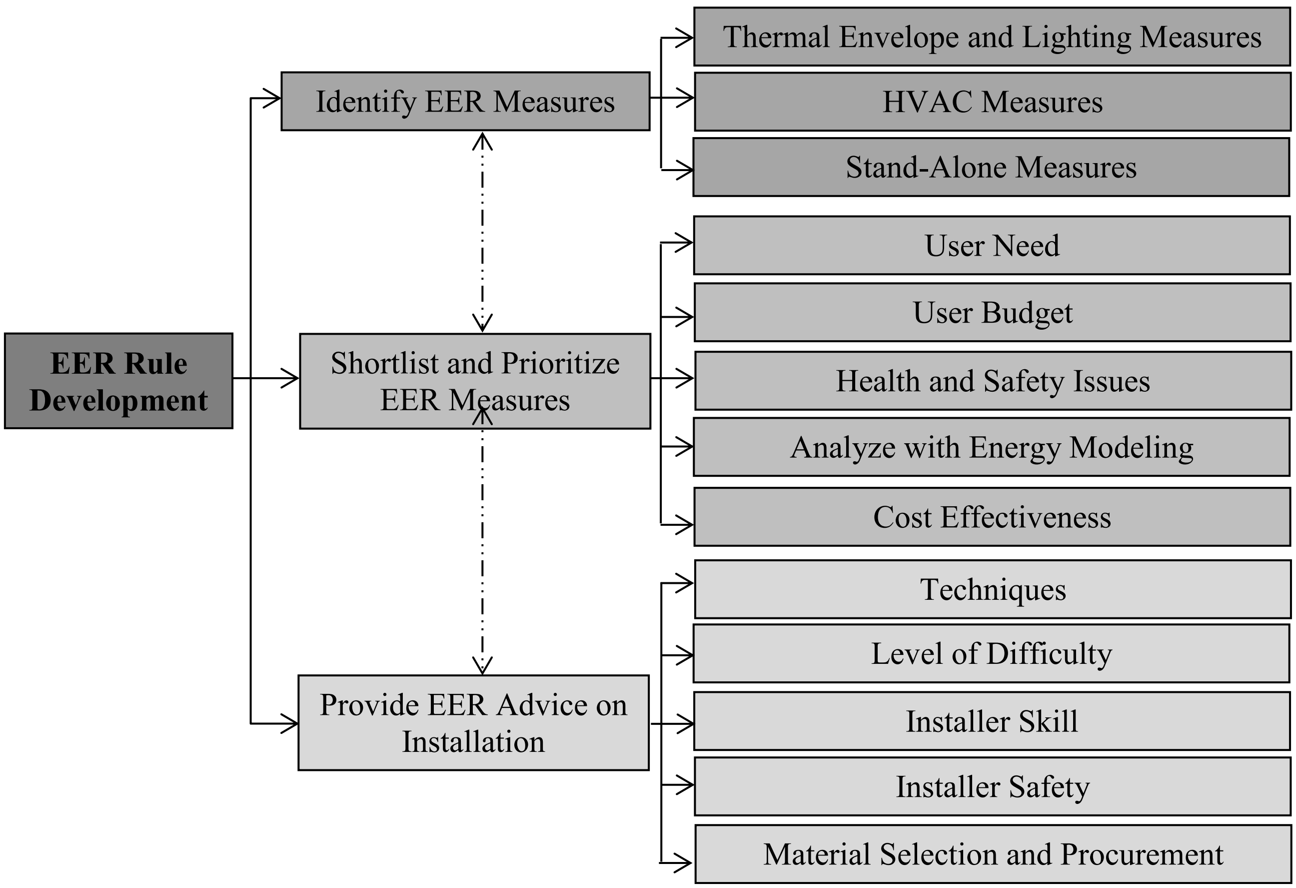


Figure 5.4: Rule Development Process Based on Energy Retrofit Decision Process Model

The basis for the order is that after the thermal envelope measures (air sealing and insulation) have been performed, the rate at which conditioned air leaves the home (exfiltration) or unconditioned air enters the home (infiltration) is reduced, thus, greatly improving its tightness. As a result of this improvement, the heating and cooling loads will have to be recalculated in order to properly size them. For instance, the existing furnace can be upgraded from a 150 kBtu/hr at 80% annual fuel utilization efficiency (AFUE) forced air central furnace to a 90 kBtu/hr at 95% (AFUE) system at a cost of $2,500 with a payback of 6 years. Energy Star labeled heating systems are energy efficient systems and must be considered when upgrading the heating system. Proper sizing requires a calculation and analysis developed by the Air Conditioning Contractors of America (ACCA 1995, 2005, 2009 cited by Baechler *et al.* 2011).

The guidelines are published in Manuals J, S, and D. The procedures necessary to estimate the heat loss and gain of residential structures is outlined in the Manual J, guidance on equipment selection based on load calculations in Manual S, and proper sizing of ducts and its design is described in Manual D (Baechler *et al.* 2011).

This order is important (thermal envelope before HVAC measures) since the sizing of the HVAC system has a direct effect on its performance. For instance, a home with an oversized furnace will perform inefficiently, make the home uncomfortable, and costs more to purchase and run. In rare cases where there is an immediate need to replace a broken down heating system before the winter conditions set in, the order can be reversed after a simulation of the home using an energy simulation software has been used to determine the effect of proposed upgrades on the thermal envelope. On the basis of this projection, air conditioning contractors of America guidelines on heating and load calculation will be made and a suitable sizing and efficiency for the new heating system will be installed. Due to the precarious nature of installing HVAC measures, which must only be completed by qualified energy retrofit experts or professionals, the researcher recommends that homeowners consult qualified professionals such as energy auditors or retrofit contractors. Such experts will perform an energy assessment of the home, determine proper system sizing, and conduct tests to ensure the health and safety of the occupants of the home.

Next since hot water heating systems account for 15–25% of energy costs in a home (Energy Saver 2012a), it is important that energy efficient upgrades of these systems are performed. This is performed in a higher hierarchy than lighting because, unlike commercial properties, lighting in residential homes does not account for a huge proportion of the energy costs, even though they have shorter payback periods. Finally, stand-alone measures can be applied at any time of the retrofit process and do not have a direct effect on the other measures. Examples include the installation of appliances such as dishwashers, clothes washers and dryers, and refrigerators.

5.3 INTELLIGENT DECISION SUPPORT SYSTEM FRAMEWORK DEVELOPMENT

Figure 5.5 represents the architecture of the proposed energy retrofit intelligent decision support system framework. It has three major components, which are the knowledge-based management, data management and the user interface subsystems.

The knowledge-based management subsystem is the central element of the energy retrofit intelligent decision support system, and basically functions to provide the heuristic or implicit knowledge elicited from the energy retrofit experts complemented by quantitative information from the data management subsystem in order to help with energy retrofit decision making. The three parts of the knowledge-based management subsystem development process, described in earlier sections, are: (1) the energy efficiency retrofit knowledge definition, which was identified through the development of the energy retrofit expertise identification system, (2) the energy efficiency retrofit knowledge elicitation, which was obtained through the development of the energy retrofit expertise elicitation system, and (3) the energy efficiency retrofit knowledge modeling, where a suitable format for representing knowledge in an intelligent decision support system platform, using rules, were developed.

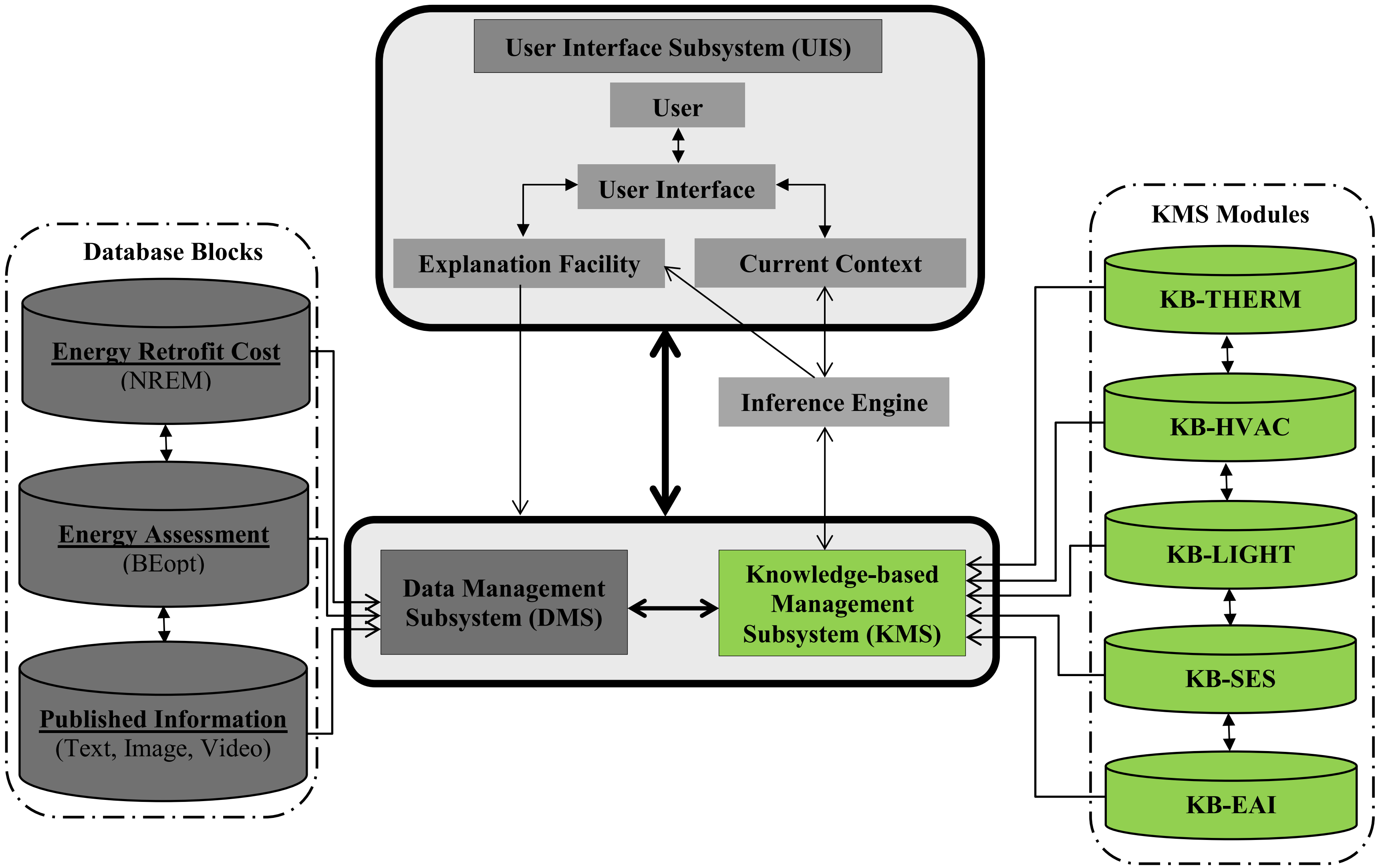


Figure 5.5: Home Energy Retrofit Intelligent Decision Support System Framework

5.3.1 Knowledge-based Management Subsystem

The energy retrofit decision process model developed for the energy retrofit industry and discussed in detail in Chapter three has three main components: (1) identify retrofit measures, (2) shortlist and prioritize measures, and (3) provide expert advice on installation. Based on the model, the proper definition of energy retrofit expert knowledge and its subsequent elicitation in Chapter four, the researcher developed six knowledge-based modules for the proposed intelligent decision support system:

1. Knowledge-based thermal envelope measures (KB-Therm) module
2. Knowledge-based heating, cooling, and air conditioning measures (KB-HVAC) module
3. Knowledge-based hot water heating measures (KB-HWH) module
4. Knowledge-based lighting measures (KB-Light) module
5. Knowledge-based stand-alone and energy saving measures (KB-SES) module
6. Knowledge-based expert advice on installation (KB-EAI) module

5.3.1.1 Knowledge-Based Thermal Envelope Measures (KB-Therm) Module

The elements of a building that separate the controlled interior environment from the uncontrolled exterior environment are referred to as the building or thermal envelope. This includes elements such as: walls, windows, doors, roofs, foundations, and ceilings. When carefully designed and well maintained, the thermal envelope minimizes energy used by the heating, ventilation, and air conditioning (HVAC), and lighting systems. For optimum efficiency when a building is being heated, cold exterior air should not leak into conditioned spaces (infiltration) and conditioned air should not leak from the conditioned space inside to the exterior (exfiltration). The reverse is also true when the building is being cooled. The exception is when natural ventilation is needed for ventilation, cooling, or heating. For lighting, the thermal envelope can be designed to maximize the use of natural daylighting in order to reduce the energy load (ACEE 2012; Gellings & Parmenter 2004; Krigger & Dorsi 2009). These reinforce the correlation between the thermal envelope and other building systems highlighted in whole house systems of buildings. It is, therefore, important to address thermal envelope measures first in most energy retrofits.

Based on the knowledge elicited and compiled from energy retrofit experts using the Energy retrofit Expertise Elicitation Strategy combined with the compiled quantitative information particularly, the work completed by the Cost Effective Energy Retrofit team on market characterization (Hendron & Engebrecht 2010; Kim *et al.* 2014), influential architectural variables in determining high energy consuming buildings which makes them candidates for energy efficient retrofits are (Table 5.1):

Table 5.1: Influential Architectural Variables for High Energy Consuming Buildings (Hendron & Engebrecht 2010; Kim *et al.* 2014)

Size of house	Presence of a fireplace unit	Main heating/cooling system
Number of stories	Visible moisture issues	Visible health and safety issues
Age of house	Attached garage or carport	Appliances and lighting characteristics
Presence of basement	Comfort complaints	

Energy codes and standards set minimum efficiency requirements for new and renovated buildings, assuring reductions in energy use and emissions over the life of the building, increases building energy efficiency, and results in significant cost savings in private and public sectors of the United States economy (USDOE 2013b). Energy codes were, however, established in the late

1990s, thus a majority of housing in the Great Lakes region of the United States does not have modern energy efficient features, since they were built prior to the 1970s and have undergone limited upgrades (Kim *et al.* 2014). In addition, Kim *et al.* (2014) posit that housing types that have high energy consumption rates based on monthly energy bills in the Midwest region of the United States fall into the following categories:

1. 3 or more stories, 2500 square feet or larger, and built since 1970
2. 3 or more stories, 900 – 2500 square feet, and built between 1930 and 1949

Since energy codes were established in the late 1990s, houses built prior to this era and have had no upgrades will be energy inefficient. Other features that indicate that a house needs an energy efficient retrofit are shown below (Kim *et al.* 2014):

1. Presence of a fireplace
2. If there is a basement
3. If home has air conditioning
4. If asbestos roofing shingles are used
5. If siding material is aluminum, asbestos, or vinyl
6. If foundation is exposed concrete blocks or stucco

One and a half story homes, such as Cape Cod homes, constructed between 1930 and 1960 have particular insulation challenges across the Midwest region of the United States (Kim *et al.* 2014). Since houses built before 1970 did not have to conform to energy codes anyway, Cape Cods built before 1970 with limited or no energy retrofits completed will have this problem.

Based on the classification of houses into types that could be related to energy consumption (Kim *et al.* 2014), three criteria pertaining to historical factors and physical features of the homes were adopted for this study: year of construction, number of stories, and size of house. The various classifications for each of the criterion are shown below:

1. *Year of Construction* – 1929 or before, 1930 – 1969, 1970 and beyond
2. *Number of Stories* – 1 story, 2 stories, 3 or more stories
3. *Size of House* – 900 sq. ft. or less, 901 sq. ft. – 2500 sq. ft., 2501 sq. ft. or more

All house types that are dominant in the Midwest have basements irrespective of the year they were built, and approximately 90.10% of high energy consuming housing types have a basement (Kim et al. 2014). While houses built before 1930 have an energy-inefficient balloon frame system of construction, those built beyond this period have a more energy efficient platform frame construction system. Other considerations for the development of the logic for the rules for thermal envelope measures include: air leakage/flow/drafts of the home, window type, external appearance of home, condition of basement/crawlspace, performed upgrades, condition of lower level of home, and if home is occupied all year round.

In terms of the condition of the lower level, especially regarding performed upgrades below grade level, Lstiburek (2004) has noted that existing vented crawl spaces are experiencing serious moisture and mold problems, and involve significant resources to repair. As a result, he proposes conditioned crawl spaces, which perform better regarding cost, safety, health, comfort, durability and energy consumption, over vented crawl spaces. The problem with vented crawlspaces is that when outside air with a dew point higher than the interior crawl space surface temperature is permitted to enter it, there are obvious moisture problems. Conditioned crawl spaces are designed and constructed as mini-basements or part of the conditioned space of the house. There must be perimeter insulation, a continuous sealed ground cover–such as taped polyethylene, and perimeter drainage similar to a basement when the ground level of the crawlspace is below that of the surrounding grade (Lstiburek 2004).

Based on the foregoing discussion and elicited energy retrofit knowledge, an example rule is:

IF *the house was built before 1970,*

AND *is a Cape Cod style home,*

AND *has had no thermal envelope upgrades,*

AND *has a vented crawlspace*

THEN *perform the following upgrades*

1. *Air seal and insulate the house in the following order: (attic, crawlspace, conditioned space)*
2. *Upgrade vented crawlspace to a conditioned crawlspace*

(Note: A detailed description of all the questions and available options to the user, used as the basis for the rules for the thermal envelope, is provided as Appendix C.1).

5.3.1.2 Knowledge-Based Heating, Cooling, and Air Conditioning Measures (KB-HVAC) Module

This section is a demonstration of the rule development for the heating, cooling, and air conditioning (HVAC) systems. The components are discussed separately as sub-modules.

This section discusses the ***<u>"Heating Measures Sub-Module"</u>***. There are a variety of technologies that can be used to heat a home. Based on the frequency of use in the United States, the following show the order of available heating systems: (1) furnaces and boilers, (2) electric resistance heating, (3) heat pumps, (4) boilers, (5) wood and pellet-fuel stoves, and (6) solar. With 65% of single-family homes in the United States having a central forced-air furnace that distributes heated air throughout the house using ducts, furnaces are the most common way to heat a home, about two-thirds of which, are fueled by natural gas. Next, excluding heat pumps, 14% of single-family homes are heated with electric resistance heat, most of which are central forced-air, while many others use electric space heating–which are either wall-mounted or baseboard–as their main heating system (Baechler *et al.* 2011; Energy saver 2012b).

With 10% of United States homes using heat pumps, they are the third most used heating system. Heat pumps can either be air-source or ground-source (geothermal) and can be with or without ducts. Wood and pellet-fuel stoves account for 3.5% of heating systems for United States single-family homes using biomass or waste sources. Finally, active solar heating, which basically uses the energy from the sun to heat the air which is then used to warm the house accounts for less than 0.4% of heating systems in the United States (Baechler *et al.* 2011).

The efficiency of a furnace or boiler is measured by annual fuel utilization efficiency (AFUE), a measurement of how efficient the appliance is in changing the energy in its fuel to heat over a typical year. For instance, an AFUE of 90% means that 90% of the energy in the fuel is changed into heat for the home and the other 10% escapes (e.g. chimney) (USDOE 2012c). While low efficiency furnaces have AFUEs of less than 78%, mid-efficiency furnaces have AFUEs of 80%

- 82%, and high-efficiency furnaces have 90% – 98% AFUE (Baechler *et al.* 2011). Replacing an old furnace with a new energy efficient one makes economic sense since money is saved on heating and air conditioning, fuel is conserved, and consistent warm winter and cool summer conditions in a home are maintained. Apart from the fuel type, other considerations for selecting the right furnaces for homes are the unit size and unit efficiency.

Ducts channel conditioned air to warm conditioned spaces. If this air is lost or cooled before reaching the conditioned space, money will be lost. It is, therefore, important to have ducts installed inside conditioned the space and also seal and insulate leaks in order to minimize conductive heat loss. It must be noted, however, that ducts can be upgraded only in forced-air systems. A general rule of thumb in the justification for investing in higher efficiency furnaces is that the higher the heating load and fuel price, the better the justification for this investment (Baechler *et al.* 2011).

In terms of age, furnaces older than 15 to 20 years must be replaced. A furnace less than this age can have its distribution system (ducts) and the unit itself repaired. Krigger & Dorsi (2009) assert that if the cost to repair the furnace is more than half the cost of replacement, it makes more economic sense to upgrade to a new energy efficient system than investing in the old system.

Based on the foregoing discussion and elicited energy retrofit knowledge, an example rule is:

IF *the current heating system is a central forced-air natural gas system*

AND *it is 30 years old*

AND *has an AFUE of 72%*

AND *has a size of 150kBtuh*

THEN *perform the following upgrades:*

1. *Upgrade current 30 year old system with a new energy star labeled central forced-air heating system with an AFUE of more than 90%.*
2. *In order to determine the proper sizing for the heating system and to perform a health and safety test before and after the installation of a new system, consult an energy retrofit professional.*

The basis for the THEN part of the logic is that since there are health and safety hazards associated with the installation of heating systems, such as backdrafting of carbon monoxide which can cause death, the advice would be for the user to contact an expert. The system will, however, provide the financial, health, and safety benefits.

This section discusses the "***Cooling Measures Sub-Module***". In order to cool homes, a variety of air conditioning and other cooling systems are used in most homes. Typical cooling systems include air conditioning, heat pumps, evaporative cooling, radiant floor cooling, and dehumidifiers. In the Mid-West region of the United States, compared to the heating load, the cooling load is minimal. Evaporative coolers and radiant cooling are suitable only for dry climates. Since the focus of the research is in this region, air conditioning and the different types, which are the main systems of cooling used, are discussed in this section. Additionally, as a result of the installation of thermal envelope measures such as air sealing and insulation, natural ventilation is also considered as a cooling measure.

Four types of cooling systems employed in this research are central air conditioning (AC), ductless mini-split air conditioners, room air conditioners, and natural ventilation or cooling. The majority of homes, however, use central ACs where cooled air is provided throughout the home typically by combining it with central furnaces in order to use the same ducts and blower. Generally, central AC systems are better than room ACs and can save energy, money, are very quiet, and convenient to operate. The choice of installing a central AC depends on the availability of ductwork. For instance, replacing a 10 year old air conditioner with a newer, more efficient model may save 20% to 40% of cooling energy costs (Energy Saver 2012c).

Central ACs are rated according to their seasonal energy efficiency ratio (SEER), which basically specifies the relative amount of energy needed to provide a specific cooling output. Several older systems have SEER ratings of 6 or less, but the minimum SEER allowed today is 13. If manufactured after January 23, 2006, ACs must achieve a SEER of 13 or higher. A central AC typically lasts for about 15 to 20 years though replacement parts are available to meet new standards (Energy Saver 2012c).

In order to help with the decision for replacing a cooling system, Baechler *et al.* (2011) have developed a basic decision tree for replacing a cooling system. Based on responses to questions about details of currently installed cooling system, it helps users make decisions about specific upgrades. Questions relate to the type of system installed, age, condition, repair cost, increased heating load, and climate (Figure 5.6.). This is particularly important since the decision tree can be converted into Boolean logic comprising If-Then-Else rules. Such information can be combined with expert knowledge to generate an appropriate logic that will lead to the provision of appropriate information to the user of the proposed framework.

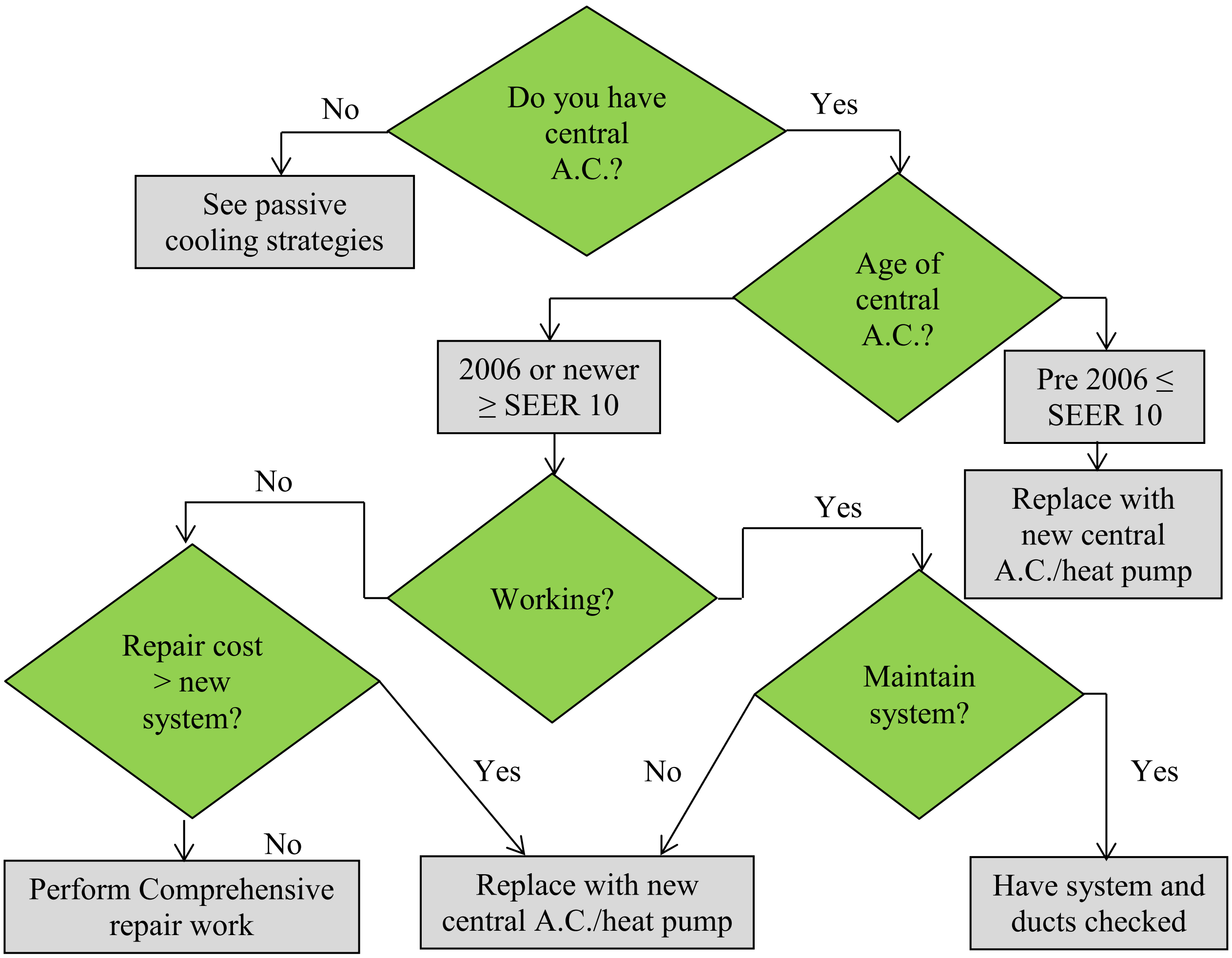


Figure 5.6: Basic Decisions for Replacing Air Conditioning System (Modified from Baechler *et al.* 2011)

Based on the foregoing discussion and elicited energy retrofit knowledge, an example rule is:

IF *the current cooling system is a central air conditioning system*

AND *the AC system is more than 16 years old*

AND *has a SEER rating of 10*

AND *AC is used regularly*

THEN *perform the following upgrades:*

1. *Upgrade current system to a new Energy Star labeled central air conditioning system with SEER rating of 13 or more.*
2. *In order to ensure that the system is properly installed, there are no issues with the ducting system, and the precise sizes have been chosen, consult an energy retrofit professional.*

The basis for the THEN part of the logic is that since a prerequisite for central AC is a central heating system, it is assumed that there is a ducting system in place. Based on the discussion above and the decision tree by Baechler *et al.* (2011), it was determined that a pre-2006 AC with a SEER rating of less than or equal to 10 had to be replaced with a more energy efficient counterpart, such as one with an Energy Star label. The trigger response which led to the prescription of this energy efficient upgrade was the frequency of use of the AC system. Based on the energy retrofit expert knowledge elicited, it was identified that some systems such as ACs might be maintained entirely if the frequency of use is low (e.g. 2 weeks in a year). In this instance, however, the AC was used regularly hence the trigger for the energy efficient upgrade.

(Note: A detailed description of all the questions and available options to the user, used as the basis for the rules for the HVAC systems, is provided as Appendix C.2).

This section discusses the ***"Ventilation Measures Sub-Module"***. In order to ensure good air quality in a home, there is a need for ventilation. Ventilation essentially brings fresh air inside the home and also removes stale air, including indoor contaminants (house cleaning chemicals, off-gassing paints, and plastics), excess moisture (showering and cooking), and pollutants (carbon monoxide). Air infiltration and exfiltration through air leaks around doors and windows, or naturally through open windows and doors can be classified as ventilation. Mechanical means of maintaining a good air quality is also another means of properly ventilating a house (Baechler *et al.* 2011; Metoyer 2013). Even though most home heating and cooling equipment, including forced-air heating equipment, is not manufactured to be used for ventilation, it can be combined with a ventilation system or a separate ventilation system can be installed. In this research, it was assumed that either the heating and cooling systems employed in the homes were combined with a ventilation system or the home used natural means of ventilation.

5.3.1.3 Knowledge-Based Hot Water Heating Measures (KB-HWH) Module

Based on responses from the experts and the available quantitative information primarily from federal documents, such as Energy Savers, the following five types of water heating systems and their fuel types were identified: conventional storage, tankless or demand-type, heat pump, solar, and tankless coil and indirect water heaters. Available fuel types depending on location in the United States are: natural gas, electricity, propane, fuel oil, geothermal energy, and solar. Heating water for domestic use accounts for between 15–25 percent of the energy consumed in homes and storage-type water heaters are the most common domestic hot water heating system in the United States. Cost effective measures for hot water heating systems include lowering the thermostat (ideally 120°F) so that it lessens safety fears, such as scalding, yet high enough for activities such as dish and clothes washing and bathing (EERE 2001).

An analysis of the elicited expert knowledge and the inferences made indicated that the installation of water heater insulating "jackets" of R-11 or higher can be cost effective in reducing standby losses on units with storage, particularly older or poorly insulated ones, by slowing down the rate of heat loss from the tank. The payback on such an investment is about 3 months and may be lower and more beneficial when the hot water tank is installed outside of conditioned space (e.g., garage). The installation of pipe insulation, especially in unconditioned spaces such as garages, attics, crawlspaces, and for a distance of at least six feet from the tank, is also an effective energy saving and cost effective measure. In terms of age, conventional storage water heaters only last about 10 years and eventually leak due to rustiness and holes.

Based on the foregoing discussion and elicited energy retrofit knowledge, an example rule is:

IF *home is heated with a condensing boiler*

AND *the water heating system is the conventional water heater (natural gas)*

AND *it has no insulation blanket*

AND *it is more than 30 years old*

THEN *upgrade to energy efficient tankless or demand type water heater*

The THEN part of the rule is based on the logic that since conventional water heaters last about 10 years, a 30 year old system must be replaced, thus, there would be no need for the provision of an insulating blanket. Rather, a more energy efficient tankless or demand type water heater is recommended for the home. Alternatively if it was an 8 year old conventional water heater, then the recommendation would be the installation of an insulating blanket to the current system.

(Note: A detailed description of all the questions and available options to the user, used as the basis for the rules for the water heating systems, is provided as Appendix C.3).

5.3.1.4 Knowledge-Based Lighting Measures (KB-Light) Module

Traditional incandescent lights are known to be energy inefficient compared to their energy efficient counterparts such as energy-saving incandescent lights, compact fluorescent lamps, and light emitting diodes, all of which typically use about 25%-80% less energy thus economically beneficial and last 3 – 25 times longer. Even though the initial cost of energy efficient bulbs is higher than traditional incandescent lights, energy efficient bulbs have lower operating costs and last longer, thus saving money over the life of the bulb (Energy Saver 2012d).

Compared to commercial buildings, lighting in residential homes does not consume that much energy. Payback on lighting upgrades is short and is relatively inexpensive compared to other energy upgrades in a home, such as heating or cooling system installation. To demonstrate how the logic for the rule was developed for lighting, the following example is used:

IF *all the light bulbs in your home are traditional incandescent*

THEN *upgrade all lights to compact fluorescent light bulbs. Consider installing dimming switches, timers, or sensors.*

The THEN part of the rule is based on the logic that traditional incandescent light bulbs are energy inefficient. By upgrading to energy efficient compact fluorescent lamps, there will be financial gains, energy will be saved, and they will last longer.

(Note: A detailed description of all the questions and available options to the user, used as the basis for the rules for the lighting systems, is provided as Appendix C.4).

5.3.1.5 Knowledge-Based Stand-Alone and Energy Saving Measures (KB-SES) Module

When performing energy efficiency upgrades it is important to use the whole-house approach, which basically operates on the understanding that there is interaction of all systems in a home that affects the energy performance of the home. Baechler *et al.* (2011) posit that energy upgrading using the whole-house approach ensures the health and safety of the homeowner and also leads to cost-effective energy savings. On the contrary, as the name suggests, stand-alone measures are those that have limited or no interaction with the energy performance of other systems. Examples of stand-alone measures include major non-HVAC appliances or appliances such as refrigerators, clothes washers and dryers, and dishwashers. In addition, there are some measures that do not have a huge effect on reducing the energy consumption of buildings. Such measures, referred to as energy saving measures, include water heater pipe insulation, water saving showerheads, furnace filter change, and faucet aerators.

A key determinant of the efficiency of appliances is the ENERGY STAR labeling. Every appliance has the purchase price, and the operation and maintenance costs. Compared to standard rated appliances, ENERGY STAR qualified appliances use 10–50 percent less energy, thus saving energy, money, and helping reduce emissions of greenhouse gases and air pollutants. Available appliances from ENERGY STAR include refrigerators, clothes washers, clothes dryers, dishwashers etc. (Energy Star 2013a). Fridges and freezers made before 1993 are inefficient since the units cost more than $100 per year in electricity, which is twice as much as a new ENERGY STAR qualified models. In addition, fridges and freezers from the 1970s cost four times more to operate (Energy star 2013b). It is estimated that there are 170 million refrigerators and refrigerator-freezers currently being used in the United States. About a third of this number is over 10 years old and costs consumers $4.4 billion a year in energy costs. Consumers can save from $200–$1,100 on energy costs over the lifetime of a refrigerator if it is replaced with a new ENERGY STAR certified refrigerator (Energy Star 2013c). Hence, the threshold for old refrigerators was set at more than 10 years old.

As a result of the discussion above and the energy retrofit expert knowledge elicited, the following rule was developed as a demonstration for the stand-alone measures:

IF *the refrigerator has a standard rating*

AND *is 15 years old*

THEN *upgrade to an Energy Star rated refrigerator*

The THEN part of the rule is based on the logic that financial and environmental benefits will be obtained by upgrading to an energy efficient refrigerator. These benefits are reinforced by the knowledge elicited from the expert panel which asserted that the three main reasons why homeowners undertake energy efficient retrofits to be: financial, health, and environmental.

(Note: A detailed description of all the questions and available options to the user, used as the basis for the rules for the energy saving measures, is provided as Appendix C.5).

5.3.1.6 Knowledge-Based Expert Advice on Installation (KB-EAI) Module

In addition to the five modules discussed above, a sixth module was developed based on the last part of the energy retrofit decision process model and this involved the provision of expert advice on installation. Apart from the available quantitative information, a key component of the knowledge elicitation process developed in this research was the identification of possible installation challenges during the energy retrofit process and the subsequent advice proffered by the experts. For each of the modules developed, corresponding expert advice for installation was developed and combined to create a separate module. In most instances, however, the expert advice provided is directly integrated with available industry advice from published databases and literature provided to the user.

For example, under the hot water heating module, IF the home has a hot water heating system which can be maintained, the information about actions to have an efficient system running will be provided. A demonstration of the information is indicated below:

> *In order to improve the efficiency of your hot water heating system, it is important to install an insulating blanket in order to slow down the rate of heat loss from the tank. Insulating blankets have very fast payback periods (2 or 3 months).*
>
> *It is advisable to set the water heater thermostat at 120^{o}F in order to slow mineral buildup and corrosion in your water heater and pipes, reducing standby losses and consumption losses from water demand or use in your home. Water heated at 140^{o}F also poses a safety hazard, such as scalding, and can waste between $36 and $61 annually in standby heat losses and over $400 in demand losses. For more information go to:*
> *http://energy.gov/energysaver/projects/savings-project-lower-water-heating-temperature.*

All of the modules are integrated with each other and also linked to the data management subsystem through the knowledge-based management subsystem, thus, allowing the interaction of expert knowledge (all modules in knowledge-based system) and existing quantitative information (data management system), to assist users with energy retrofit decision-making.

5.3.2 Data Management Subsystem

A database is the organization of files into related units which are viewed as one storage concept. The data can then be made available to a wide range of users. Software used in establishing, updating, and questioning (e.g. managing) a database are, however, referred to as database management systems (Turban *et al.* 2005). The database used in the energy retrofit intelligent decision support system was that which was incorporated into the expert system shell obtained from Corvid Exsys. This database was used to store energy retrofit data relevant for this study and was also used to support the other knowledge-based modules.

The key database information was that obtained and configured into 3 database blocks: an energy assessment software from Building Energy Optimization (BEopt), an energy retrofit cost database from the national renewable efficiency measures (NREM) database, and other published text, images, and videos primarily from government and additional scholarly documents. Depending on the information needed to be processed based on the logic generated from any of the modules either individually or in conjunction with any of the modules in the knowledge-based management subsystem, all the blocks can be run in any sequence or period. Data entered into the published texts, images, and videos and expert advice on installation blocks in the data management system can be edited individually with no need for the whole data record. However, data entered in the energy assessment software and energy retrofit cost database blocks are edited based on the master edits from the system administrators of those databases.

5.3.3 User Interface Subsystem

The user interface subsystem developed for the energy retrofit intelligent decision support system framework incorporated the functions of the user interface of an expert system: user, user interface, explanation facility, and current context.

5.3.3.1 User Interface Subsystem – User

The user refers to the individual who will be seeking advice on energy retrofit decision making. The proposed energy retrofit intelligent decision support system is intended to be used by homeowners, and energy retrofit professionals such as energy auditors and certified energy retrofit contractors, among others.

5.3.3.2 User Interface Subsystem – User Interface

This provides the user with an accessible medium for interaction with the system. It has two functions; first, information from the user is received here and then translated into the system. Second, information is provided to the user from the system in a format that the user can easily understand, usually in texts, images, and videos.

5.3.3.3 User Interface Subsystem – Explanation Facility

The logic behind any output that is typically provided as rules in the knowledge-based management subsystem is explained here. Basically, the steps used in the reasoning process are identified and demonstrated in an easily understandable format to the user, thus increasing reliability through the explanation for reasons for its decision-making. In the expert system shell obtained from Corvid, the explanation facility is provided by a tool known as the rule view which basically shows all the IF-THEN- ELSE rules employed before a decision was reached.

5.3.3.4 User Interface Subsystem – Current Context

Without integration between the quantitative information and the expert knowledge, it is not possible to produce an appropriate decision or solution. Typically, since the knowledge of the user about their existing situation may be limited, they are unable to provide specific information to the system. In such instances, the current context function of the user interface subsystem will attempt to develop a decision/solution based on the available information.

5.3.4 Inference Engine

Data from the data management subsystem is integrated with knowledge from the knowledge-based management subsystem in order to provide information that will help users with decision making, which is provided through the user interface subsystem. The software system that performs the reasoning process and infers new decision-making options based on the stored expert knowledge is the *inference engine.* The inference engine fortifies the system by giving it the ability to infer new knowledge with which it can respond to different situations. Without the inference engine, the data in the data management subsystem and knowledge in the knowledge-based management subsystem is not useful.

5.3.5 Intelligent Decision Support System Framework Capability

The intelligent decision support system for home energy retrofits will provide a comprehensive decision support package to ease the decision making process by homeowners. Three key components developed were the knowledge-based management, data management, and the user interface subsystems. The data management subsystem provides all the explicit or quantitative information basically from three key sources: energy assessment (BEopt energy simulation software), cost database (NREM), and published information (text, image, and video). The user interface subsystem is the system that ensures the interaction between the user (homeowner) and the system using an accessible medium. Two functions of this system are receiving user information and translating into the system, and the user receiving information from the system in an easily understandable format. The knowledge-based management subsystem, which is a major aspect of this research and also a key component of such an intelligent system, provides all the implicit or tacit knowledge. Six sub-modules were developed for this subsystem: knowledge-based thermal envelope measures; knowledge-based heating, cooling, and air conditioning measures; knowledge-based hot water heating measures; knowledge-based lighting measures; knowledge-based stand-alone and energy saving measures; and knowledge-based expert advice on installation.

The knowledge-based sub-modules were synchronized with the energy retrofit decision process model developed earlier as part of the research. Thus, standardized protocols followed in energy retrofit decision making was employed in the organization of the knowledge-based sub-module. For instance, it was determined that the thermal enveloped plays a dominant role in the energy efficiency of a home and also has a direct effect of the HVAC measures. As a result, the first sub-module (thermal) basically identifies the infiltration and exfiltration of the home and makes recommendations to improve the tightness of the envelope. The HVAC sub-module provides knowledge to enhance the efficiency of the heating, cooling, and air conditioning systems. A major problem in the decision making process in this area involves the decision whether to replace, retrofit, or maintain any of these systems. Any of these decisions are, however, tied to how effective the thermal envelope is since it can affect the sizing of the system and the efficiency. The HVAC, connected with the thermal and other sub-modules, is able to offer advice based on implicit and explicit knowledge inherent in the energy retrofit intelligent decision support system.

Since domestic water heating accounts for between 15 and 25 percent of the energy consumed in homes, it is important to manage water-heating energy costs. In addition, storage-type water heaters, which are inefficient when compared with other water heating systems, are the most common systems in most homes. The hot water heating sub-module provides advice on managing water heating costs, selecting an appropriate system, and offers advice on reducing hot water consumption. Next, even though the impact of using energy inefficient lighting is not as high in residential homes as in commercial buildings, they offer a quick return on investment, definite energy savings, and can be easily installed by homeowners. The light sub-module has the capability to offer advice to improve the efficiency of lighting systems in a cost-effective and efficient manner.

Apart from the four sub-modules mentioned above, which cover the standard protocol used in the energy retrofit decision process model, it was identified that there are some measures that can greatly improve the energy efficiency of homes, even though minor. Such measures are addressed in the standalone or energy saving measures sub-module. This sub-module offers advice on measures such as furnace filter change, pipe wrap, thermostat change, etc. The final sub-module, expert advice on installation, provides all the installation advice for all the other five sub-modules. Each sub-module has implicit as well as explicit advice for installation. Whilst the explicit advice and data is embedded in the data management subsystem, this sub-module provides all the implicit advice in order to support the other five sub-modules and compliment the explicit information provided in the data management subsystem.

5.3.5.1 Benefits of Using the Energy Retrofit Intelligent Decision Support System

As a result of the information barrier to the adoption of energy retrofit, the energy retrofit intelligent decision support system framework developed has an aim of offering decision support in the energy retrofit domain in order to help homeowners with energy retrofit decision making. It has been established that expert knowledge is implicit, the expertise of experts is difficult to elicit, and has been described as the bottleneck of the knowledge elicitation process. The energy retrofit intelligent system offers a hitherto unavailable expert knowledge to homeowners and users through the expertise definition and elicitation strategies developed and incorporated into the system. The expert knowledge provided in combination with the explicit knowledge will ease the decision making process by homeowners. A limited number of knowledge-based decision support system has been developed for the construction industry. In the energy retrofit domain, however, the researcher asserts that the energy retrofit intelligent decision support system is the first such tool developed and contributes to the body of knowledge in this domain.

By making such a tool available, the mistrust between homeowners and industry practitioners as well as other challenges with information such as bias, and incompleteness will be greatly reduced. Industry practitioners will benefit greatly from this tool since the advice they provide to homeowners can be reinforced using the tool. Homeowners will also have a higher trust of the information provided by industry professionals since the tool can corroborate some of the information provided. They can also improve on their skill and knowledge based on the information provided by the tool.

The extensive use of the tool will lead to an improvement in the uptake of energy retrofits since the information barrier will be reduced greatly or removed. Homeowners will become more conscious and knowledgeable and will push the boundaries of the existing knowledge and research in this domain. This can lead to groundbreaking research and innovations aimed at improving the industry.

5.4 CHAPTER SUMMARY

In this chapter, the significant role of a knowledge-based system in an intelligent decision support system has been emphasized. In order to operate fully, the knowledge based system and the data management systems must be integrated in order to provide relevant information to help homeowners with decision making in the energy retrofit industry. An intelligent decision support system framework for the energy retrofit industry was also developed. The three main components of the system developed were a knowledge-based management subsystem, a data management subsystem, and a user interface subsystem.

Based on the understanding of the information barrier to energy retrofits, the proposed energy retrofit intelligent decision support system framework attempts to decompose the decision making process in this industry by incorporating expert knowledge, the major barrier of knowledge acquisition with published or quantitative information with the view to helping homeowners in the energy retrofit decision making. The energy retrofit system developed consists of 6 interconnected knowledge-based systems linked to a database that aims to help users make energy retrofit decisions by:

1. Identifying possible energy retrofit measures of a home
2. Shortlisting and prioritizing the measures using expert knowledge integrated with published or quantitative information.
3. Providing expert advice on the installation of recommended energy retrofit measures

This contributes to decision support system research in two ways. First, the proper definition of energy retrofit expertise has been a challenging task. This has been compounded by the inability to elicit expert knowledge since it is implicit in nature and is developed to automaticity, hence, is difficult to elicit. The energy retrofit industry is an evolving industry which has issues with the availability of standardized protocols and training. Thus, decision-making information in this industry has been fraught with problems related to accuracy, comprehensiveness, bias, etc. The challenges associated with the definition of expert knowledge and its elicitation in the home energy retrofit domain makes it a good candidate for the development of an intelligent decision support system. Second, the construction industry is transient and complex. In order to make decisions in this industry, it is important to combine the available quantitative information with the tacit or implicit expert knowledge into a system that can help users with decision-making. One such system that has the capacity to combine these categories of information in a suitable platform in order to help users with decision-making is an intelligent decision support system.

CHAPTER SIX

APLICATION OF IDSS FRAMEWORK ON AN EXPERT SYSTEM PLATFORM

6.1 INTRODUCTION

Two information categories that are useful in the decision-making process of the energy retrofit industry have been highlighted as quantitative information and expert knowledge. The lack of information, or the availability of information in a format that can be understood and used by homeowners, were identified as major barriers to the uptake of energy retrofit in Chapter one. Based on extensive literature review in Chapter two, decision support systems were identified as computer interactive systems that have the potential to help users make decisions. The incorporation of a knowledge-based system into traditional decision support system was identified to be the component that makes the system intelligent. Such systems are referred to as intelligent decision support systems.

At the heart of a knowledge-based system is the availability and elicitation of expert knowledge. In Chapter four, the researcher developed a research approach that can be used to properly identify industry experts, as well as a knowledge elicitation strategy to elicit and document expert knowledge. This resulted in the identification of 19 industry experts whose knowledge was elicited and compiled. On the basis of the elicited expert knowledge, and the available quantitative information highlighted in Chapter three, an intelligent decision support system framework for the energy retrofit industry was developed in Chapter five where both information sources were integrated. The goal of this framework development was to enable the packaging and delivery of both information categories by synthesizing and integrating them. Such information is then provided to homeowners in an easy-to-use fashion. It is anticipated that homeowners will understand the information and, hence, afford them better opportunities for making such decisions.

This Chapter focuses on the applicability and use of the framework using an expert system platform. It also demonstrates the suitability and practicability of the intelligent decision support system framework.

6.1.1 Chapter Objectives

The intelligent decision support system framework developed for the energy retrofit industry in Chapter five was aimed at providing a decision support package to ease the decision process for users. In order to understand how the framework can be used by users and industry practitioners for energy retrofit decisions, this Chapter has a goal of demonstrating the applicability of the energy retrofit intelligent decision support system tool using an expert system shell. In order to achieve this goal, the following objectives were set to be accomplished:

1. Understand the functioning capability of an expert system shell
2. Demonstrate the functioning of energy retrofit intelligent decision support system on the expert system platform and test on two homes
3. Based on objective 2, gauge the functioning capability of the tool and finalize the system

6.1.2 Exsys Corvid: Expert System Shell Software

A system that attempts to mimic the decision-making ability of a human expert by capturing human expertise and applying it to problem-solving is referred to as an expert system. The core idea behind it is based on transferring human expertise from an expert to a computer. This knowledge is then stored in the computer, and users run the computer for a specific advice as needed. The inherent knowledge possessed by an expert system determines its power, not the knowledge representation and inference engine scheme it uses (Turban *et al*. 2005).

Of the many expert system shells available, Exsys Corvid knowledge automation expert system was chosen for this research primarily based on the over 28 years of enhancement, refinement, and application of their systems to real-world problems, capabilities, powerful but easy-to-use tools able to handle most demanding tasks, numerous case studies, and the use of the system by nonprogrammers (Exsys 2011). The development of the decision-making logic of an expert system is fundamental to its success. Exsys Corvid has suggested three main roles for the development of an expert system:

- Fully capturing the decision-making logic and process of the domain expert
- Designing the system in a user interface with the desired outlook for online deployment (interaction of the system with the user through knowledge delivery such as the design and organization of questions and the results screen is determined)
- Integrating with other information technology sources (supports the integration of external quantitative data sources and other information, such as images, text files, and web links, into the intelligent decision support system)

6.1.2.1 Capturing the Decision-Making Logic (Exsys 2010)

At the heart of the development of expert system is the ability to capture the decision-making logic and processes of expert knowledge in order to provide advice to users, comparable to that of an expert. The logic used by the system follows the thought processes of an expert and this is fundamental to capturing expert knowledge. The process includes a procedure to identify the decision steps of an individual expert, and then converting that into a format usable in a computer and easily readable and understandable by humans. Exsys Corvid provides Boolean logics in the form of IF-THEN rules to describe the decision-making process, as described in Chapter five. The first step to developing a rule in Exsys Corvid is the development of suitable variables which simplifies the process of building the system. The rules typically represent a section in a decision, a combination of which may be used to build a complex system.

This section discusses the ***Variables (Exsys 2010)***. A problem can be broken down into rational pieces, each of which can be represented as a variable. These variables are used to develop the rules based on the decision-making logic and is employed in the system (Figure 6.1). When the system is run, users are asked to provide specific responses which are used to assign values to the variables, derive values from other rules, or use external sources such as another application or database. For instance, if the decision-making logic for determining energy retrofit measures includes identifying the age of the home, a suitable variable that can be generated in the system is [Age_of_Home]. Suitable values such as 1900–1970, 1971–2000, and 2001–2013, will be provided for the user to make a choice. On this basis, a value will be assigned to the variable, and used in building the logic of the system.

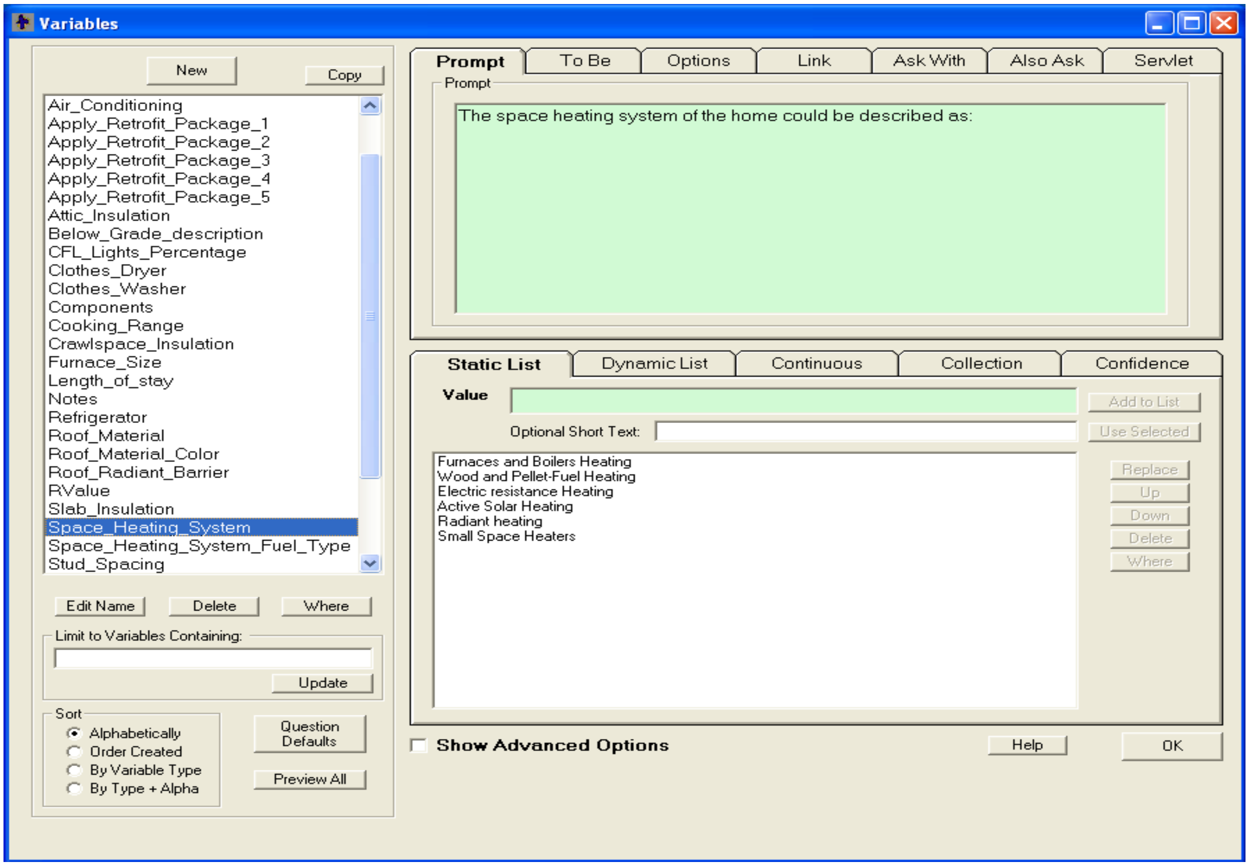


Figure 6.1: Variable Types in Exsys Corvid

(Note: Screenshot highlights three main variable functions: the pane for creating new variables on the left, the space for typing the prompt on the top right, and the space for typing the list of responses for the user of the system on the bottom right)

There are seven types of variables provided in Exsys Corvid and each has a special function or capability: static list, dynamic list, numeric, string, date, collection, and confidence.

1. *Static list* – as one of the most common variables in Exsys Corvid, it is a simple multiple choice list that has values which are defined when developing the system. For example, a Static List Variable [Heating_System_Type] can have “Furnace and Boilers,” “Active Solar Heating,” “Electric Resistance Heating,” “Heat Pump,” “Wood and Pellet Heating,” and “Space Heaters” as options from which the user can choose from.

2. *Dynamic list* – though similar to static lists with simple multiple choice lists, variables are not fixed during the development of the system. Rather, it changes dynamically during runtime. For instance, selection of specific type of dishwasher during runtime.
3. *Numeric* – Numeric Variables, String Variables, and Date Variables are all Continuous Variables. Numeric variables can have numeric values usable in formulas/algebraic expressions/calculations. For example, an energy bill in order to determine heating costs.
4. *String* – string value that can hold any text string such as a social security number.
5. *Date* – used to express date values, such as date for the installation of the heating system.
6. *Collection* – list of string values built during a run and not asked directly of the system user. System content such as other variable values, additional text information, images, or web links can be added to the Collection Value List, either in a sorted or unsorted manner and can be used to develop a report and shown on the result screen (Mo 2012).
7. *Confidence* – a variable that can be assigned a confidence value to reflect a certainty degree for a user's input for a specific situation. For instance, the likelihood of product or appliance appropriateness for the user.

Even though all seven variables can be useful in developing a system, most systems are built using only three variables: static list, numeric, and confidence. The other types of variables are very powerful for developing certain systems and are used occasionally (Exsys 2007).

This section discusses the ***Logic Block.*** The logic for the expert system is developed in the Logic Blocks and provides a unique way of defining, organizing, and structuring rules into logically related blocks. The rules are organized using a tree structure and this allows related rules in the system to be grouped appropriately. The creation or editing of a Logic Block can only be done by opening the Logic Block Window (Figure 6.2). Even though Logic Blocks do not have any specific form, they can also handle more advanced functions such as backward chaining or Meta Blocks when the logic is complicated.

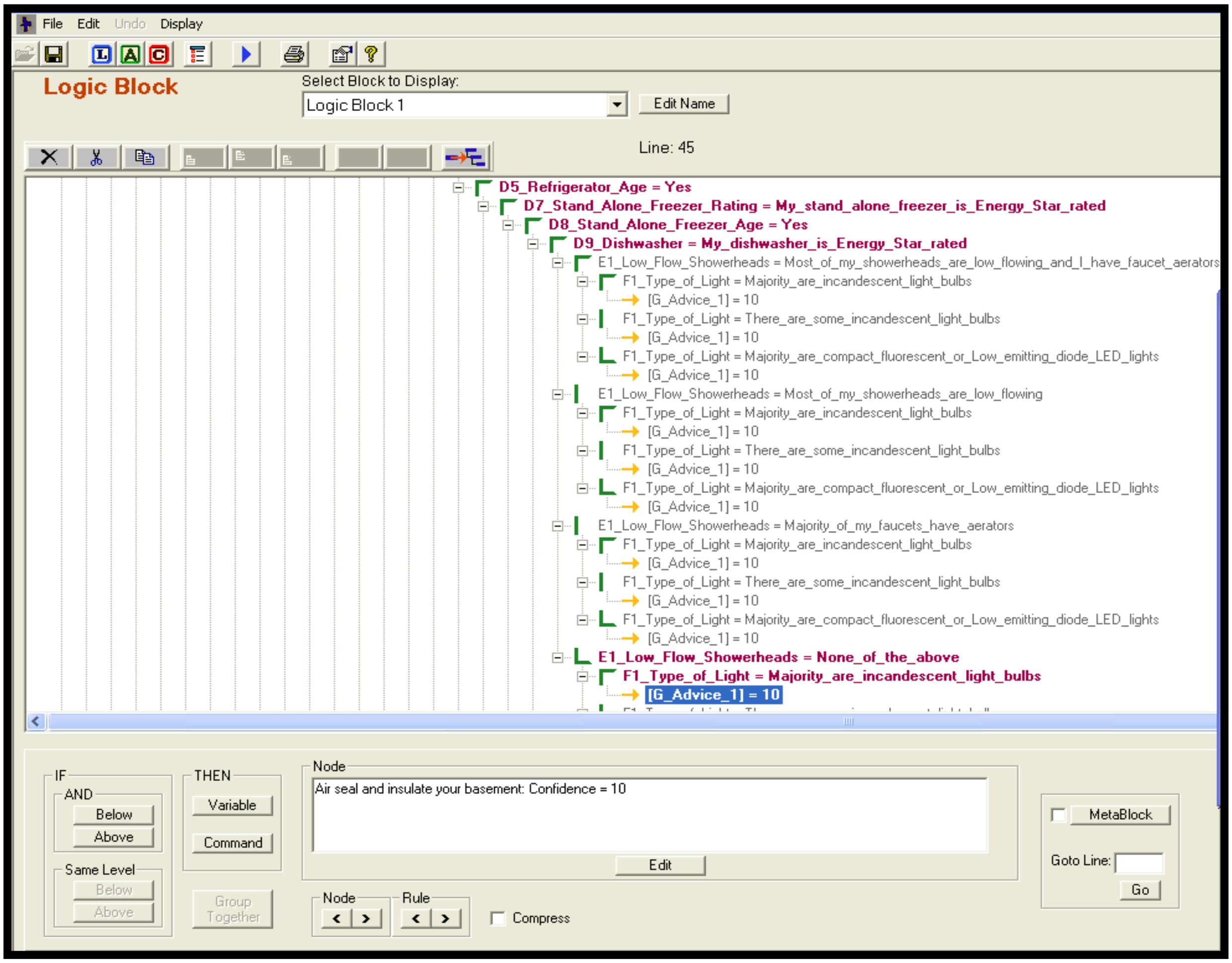


Figure 6.2: Screenshot of Logic Block Window

(Note: Screenshot highlights decision tree-like structure of the logic block. Each green square bracket indicates the IF part of the logic and the right pointing arrow shows the THEN part)

This section discusses the ***Command Block.*** The Command Block can be described as the "trigger block". It controls how the system operates, what actions to perform, and the order of performing the actions. Thus, even though the Logic Block will have details about the logic in the decision making, the "trigger" is obtained from the Command Block (Figure 6.3).

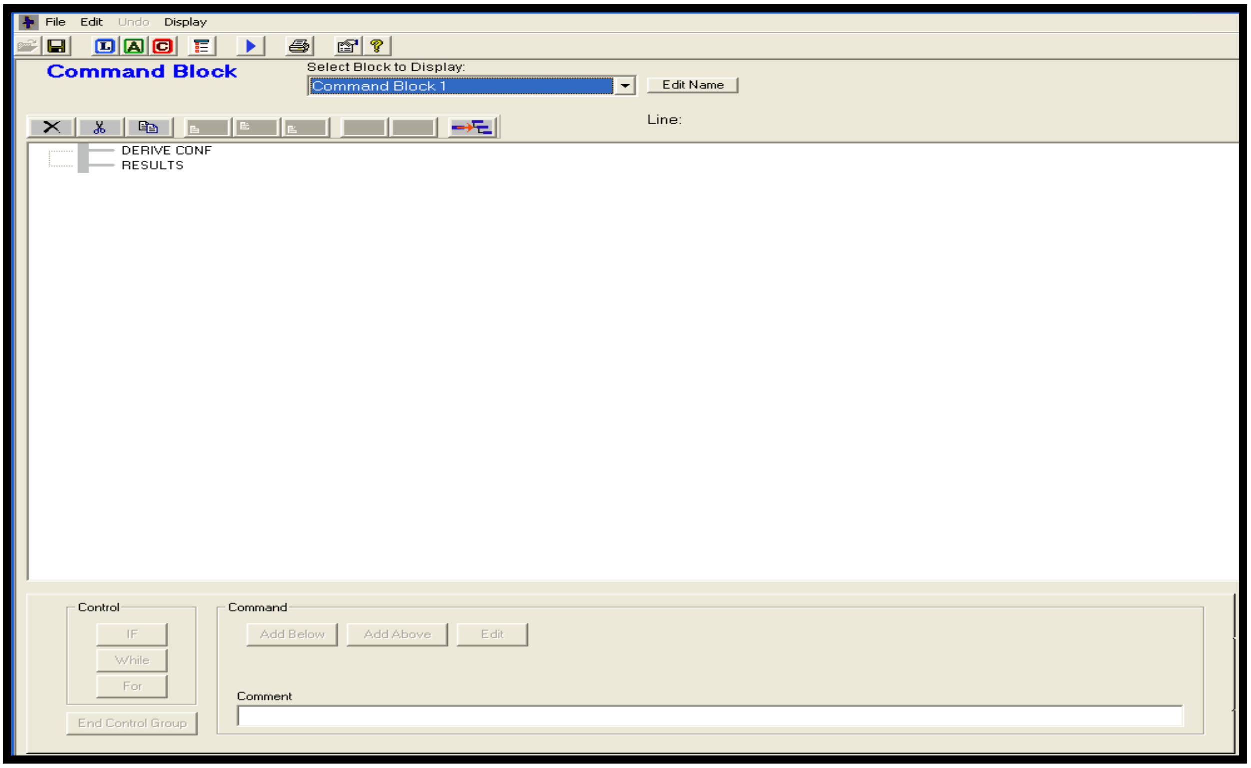


Figure 6.3: Screenshot of the Command Block

(Note: Screenshot shows an example of building a command where "Derive Confidence" variables and show "Results" are indicated)

Three typical sections in the Command Blocks are (Exsys 2011):

- *Starting Commands*: commands that provide the title and brief explanation of the system to the users. They relate to executing a user-interface and not the decision-making logic.
- *Logic Commands*: vital part of the Command Block, that prompts the system about what to do with rules in the Logic Blocks and rules are run using Variable Corvid commands.

- *Result Commands*: commands that display results to users by prompting the order for delivering specific information to the result screen. Additional information such as images, text files, and web links can be also provided.

6.1.2.2 System Configuration in User Interface (Exsys 2010)

The structure of the system to make it user friendly and allow for interaction of the user with the system can be done after the logic is working. Exsys Corvid can be run either using the Exsys Inference Engine as a Java Applet, or as a Java Servlet Runtime program. Appearance features such as fonts, colors, positions, images, etc., similar to formatting a Word document, are set in the default Applet mode. The system designer is able to control how questions will be asked and how results will be presented using the Corvid Runtime. Complex user interfaces can, however, be integrated into Corvid systems with Adobe Flash using the Corvid Servlet Runtime.

6.1.2.3 Integrating Other Information Technology Sources (Exsys 2010)

Exsys Corvid allows for easy integration with other resources in order to get data, save results, or monitor processes by providing connection to databases. The system is able to read data files, or streams, and can also send information to a wide range of programs. Since rules are produced in a simple readable syntax, the system can be easily built. As a result of the ease and flexibility of setting up interfaces to external resources, the three components of the data management subsystem found in the energy retrofit intelligent decision support system were incorporated into the system: energy assessment of homes software called Building Energy Optimization (BEopt), a national energy retrofit cost database obtained from the National Renewal Energy Laboratory called the National Residential Efficiency Measures database, and from published information in the form of text, images, and videos.

6.2 DEMONSTRATION OF FUNCTIONING OF ENERGY RETROFIT IDSS

As demonstrated in Chapter five, the decision-making logic of an expert integrated with published information can be represented in an intelligent decision support system, using series of IF-THEN rules. The expert knowledge component of the intelligent system was embedded in the knowledge-based system which had six modules. Five of the six modules were used in the demonstration of the applicability of the framework: (1) knowledge-based thermal envelope, (2) knowledge-based heating, ventilation, and air conditioning, (3) knowledge-based hot water heater, (4) knowledge-based lighting, and (5) knowledge-based energy saving measures. The succeeding sections describe how the Variables, Logic block, and Command blocks of the energy retrofit IDSS were developed on the Exsys Corvid platform.

6.2.1 Development of Energy Retrofit Intelligent Decision Support System Variables

As mentioned earlier, the development of variables is the first step in making the rules since a problem can be decomposed into rational pieces. Two major variables used in the comprehensive reasoning system, eventually provided in the Logic Block, were the Static and Confidence Variables. The Static Variables helped simplify the system since a number of options were provided for each variable in order for the user to make a choice. It is on the basis of the choice and a collection of choices, that the reasoning of the system is modeled in the Logic Block, thus, reducing ambiguities associated with decision-making. The Confidence Variables helped in identifying a suitable preference for the user. In all, over 50 variables were developed comprising mainly Static and Confidence Variables (Table 6.1).

Table 6.1: Variable Types Developed for the System

ID	Name of Variable	Variable Type
	Thermal Envelope	
A1	Home Description	Static
A2	Architectural Characteristics	Static
A3	Age of Home	Static
A4	Performed Upgrades	Static
A5	Condition of Lower Level	Static
A6	Duration of Home Occupation	Static
A7	Basement or Crawlspace Features	Static
A8	External Appearance of Home	Static
A9	Window Condition	Static
A10	Draftiness of Home	Static
A11	Main Heating System	Static
	Heating, Ventilation, and Air Conditioning System	
B1	Main Heating System	Static
B2	Type of Furnace or Boiler	Static
B3	Furnace or Boiler Fuel Type	Static
B4	Electric Resistance Heating Type	Static
B5	Wood and Pellet Heating Type	Static
B6	Space Heater Type	Static
B6A	Heat Pump Type	Static
B7A	Age of Heating System	Static
B8	Efficiency of Main Heating System	Static
B9	Size of Main Heating System	Static
BB1	Furnace Filter Change	Static
BB2	Main Heating Control System	Static
BB3	Cooling System	Static
BB4	Age of Cooling System	Static
BB5	SEER Rating of AC	Static
BB6	Cooling System Use	Static
	Hot Water Heating Variables	
C1	Water Heating System	Static
C2	Age of Water Heating System	Static
C3	Water Heater Insulating Blanket	Static
	Energy Saving Measures (Appliances and Water Saving)	
D1	Clothes Washer	Static
D2	Clothes Dryer	Static
D3	Refrigerators	Static
D4	Refrigerator Rating	Static

Table 6.1 (Cont'd)

D5	Refrigerator Age	Static
D6	Stand Alone Freezers	Static
D7	Stand Alone Freezer Rating	Static
D8	Stand Alone Freezer Age	Static
D9	Dishwasher	Static
E1	Low Flow Showerheads	Static
Lighting		
F1	Type of Light	Static
Energy Retrofit Advice		
G	Advice 1	Confidence
G	Advice 2	Confidence
G	Advice 3	Confidence
G	Advice 4	Confidence
G	Advice 5	Confidence
G	Advice 6	Confidence

For each of the static variables, a suitable prompt or question for the user was inserted accompanied by a list of corresponding responses from which the user could make a choice(s). The Confidence Variables were assigned values that were used to complete the "THEN" part of the logic. Since the tool developed was supposed to help users make decisions, a list of prioritized measures was always provided in order to help users with decision making. As a result, for each logic to be complete, a number of Confidence Variables based on the nature of the "IF" and "AND" parts of the logic, were provided. This is discussed further in the next section where the development of the logic is highlighted. Figure 6.4 is a screen shot of the Variable window in Exsys Corvid.

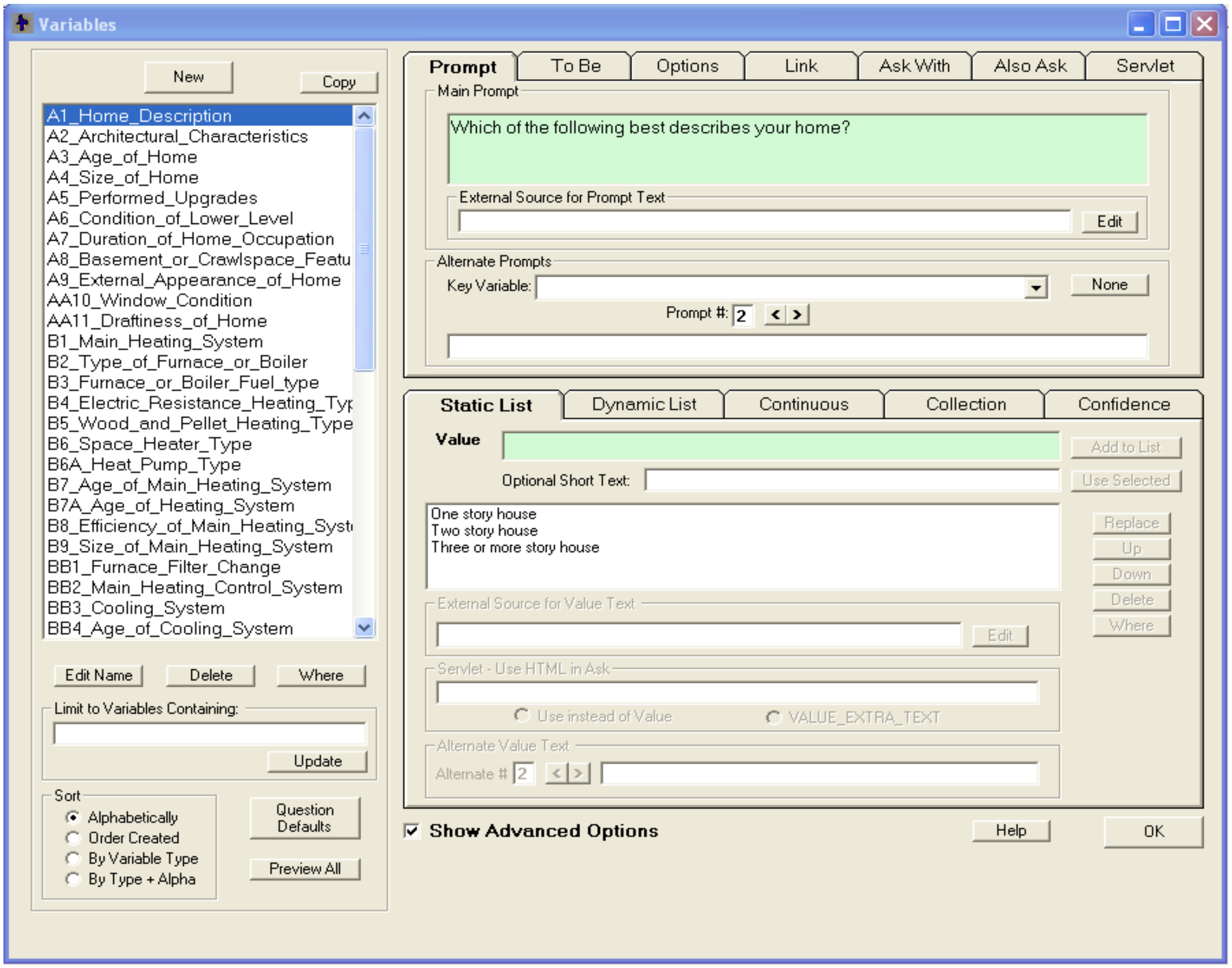


Figure 6.4: Screenshot of the Variable Window

(Note: This shows the variables used on the left, prompt for the A1 variable on the top right, and the list of options available to the user for this variable on the bottom left)

In the development of the Logic Block, however, not all the variables were used. Thus, the choice of the specific variable was a function of the response chosen by the user for each variable used in the logic. For instance, for the variable "type of main heating system", the following six prompts are provided: (1) furnaces and boilers, (2) active solar heating, (3) electric resistance heating, (4) wood and pellet heating, (5) space heaters, and (6) heat pump. Based on the choice of the user to this prompt, a specific line of the decision tree diagram used in the Logic Block is followed and, hence, not all variables are used.

6.2.2 Development of Energy Retrofit Intelligent Decision Support System Logic Block

Based on the series of logic developed for the framework in Chapter five, rules were developed in Exsys Corvid using the appropriate variables. As mentioned earlier, the rules are developed in the Logic Block. In order to add nodes in a Logic Block window, denoted by an "L" in a blue line colored box, the "IF AND Below" tab is selected (Figure 6.5).

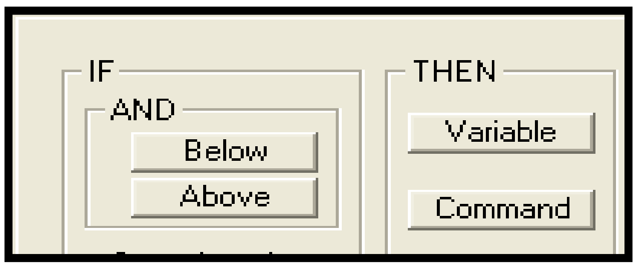


Figure 6.5: Screenshot of Logic Block Building Buttons

This tab opens up the variable window where the relevant variable is selected (Figure 6.4). Once selected, the variable shows up in the Logic Block. Series of related variables can then be added in order to complete the "IF" part of the logic by selecting the "IF AND Below" button. In instances where it is appropriate to have a desired variable above a line, the "IF AND Above" button is used. When the "IF" part of the logic is complete, the "THEN" part can be completed by using the "THEN" Variable button. Like the "IF" part, the variable window is opened and the appropriate confidence variable(s) can be selected to complete the logic. Figure 6.6 shows a screen shot of part of the Logic Block.

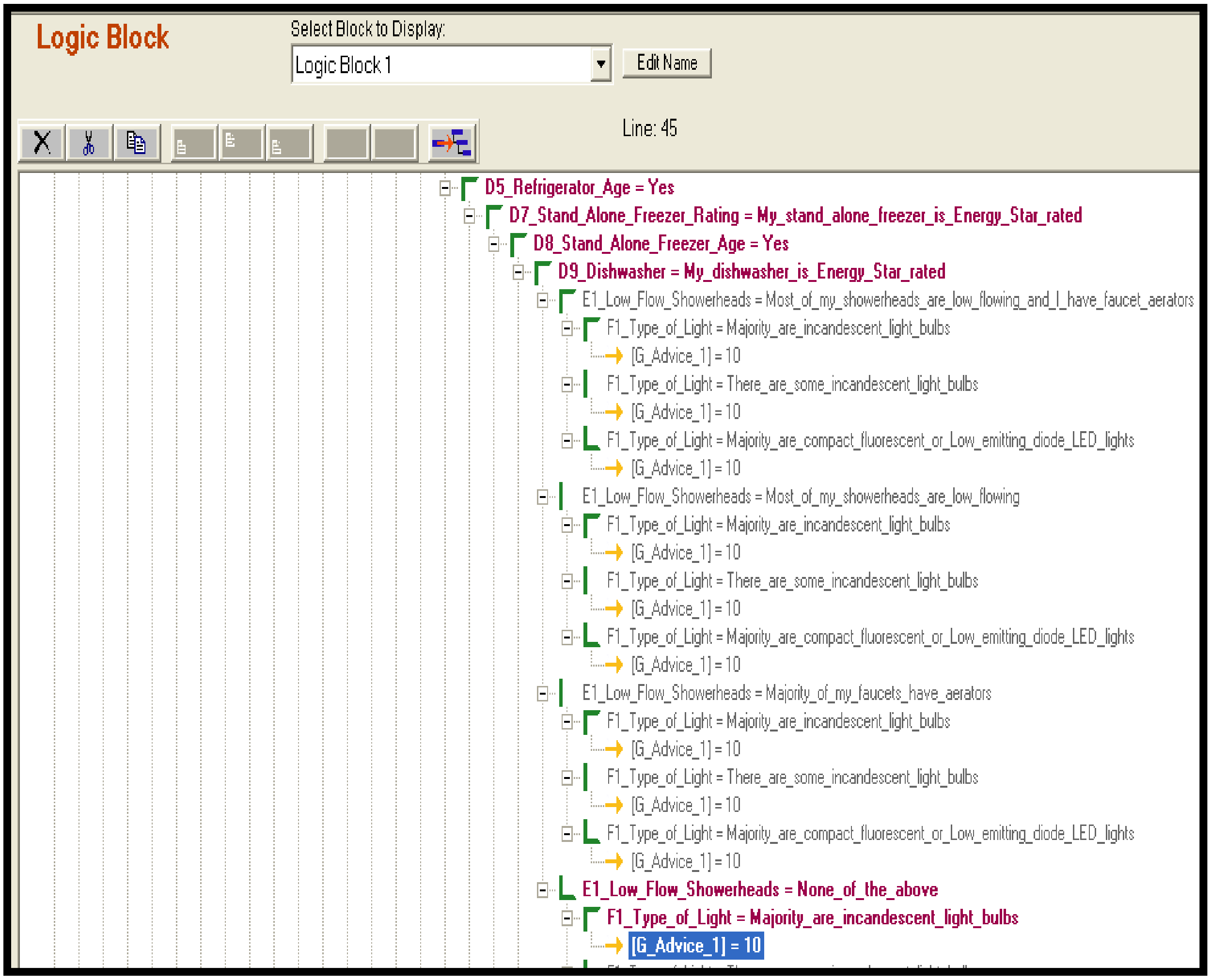


Figure 6.6: Screenshot of the Energy Retrofit Logic Block

(Note: Screenshot highlights decision tree-like structure of the logic block. Each green square bracket indicates the IF part of the logic and the right pointing arrow shows the THEN part)

Each green square bracket indicates the IF part of the logic. The brackets indicate a group of logics that use the same variable in the system even though they have different values. The "THEN" part of the logic is indicated by the yellow arrow pointed to the right. When there are two "IF" parts of a logic, where one is indented under the other, they are combined with a logical "AND" indicating that both parts of the logic must be true. For the "THEN" part of the logic, denoted by an arrow to be true, the IF parts of the logic under which the “THEN” part falls must also be true. “IF” parts of the logic that are associated with the “THEN” part of the logic are shown in the bold magenta color. For ease of understanding the symbols and logic used, there is a separate window called the “Rule View” which combines the “IF-AND-THEN" part of the logic. This shows the full text of the rule associated with the logic. This is very significant since it allows the system developer to obtain a good understanding of the decision tree path chosen by a user and, hence, provide relevant advice to the user. It is also useful for comparative analyses of the various lines in the logic since each is captured in the rule view. Figure 6.7 is a screen shot of the rule view showing an example of an IF part and a series of “AND” parts.

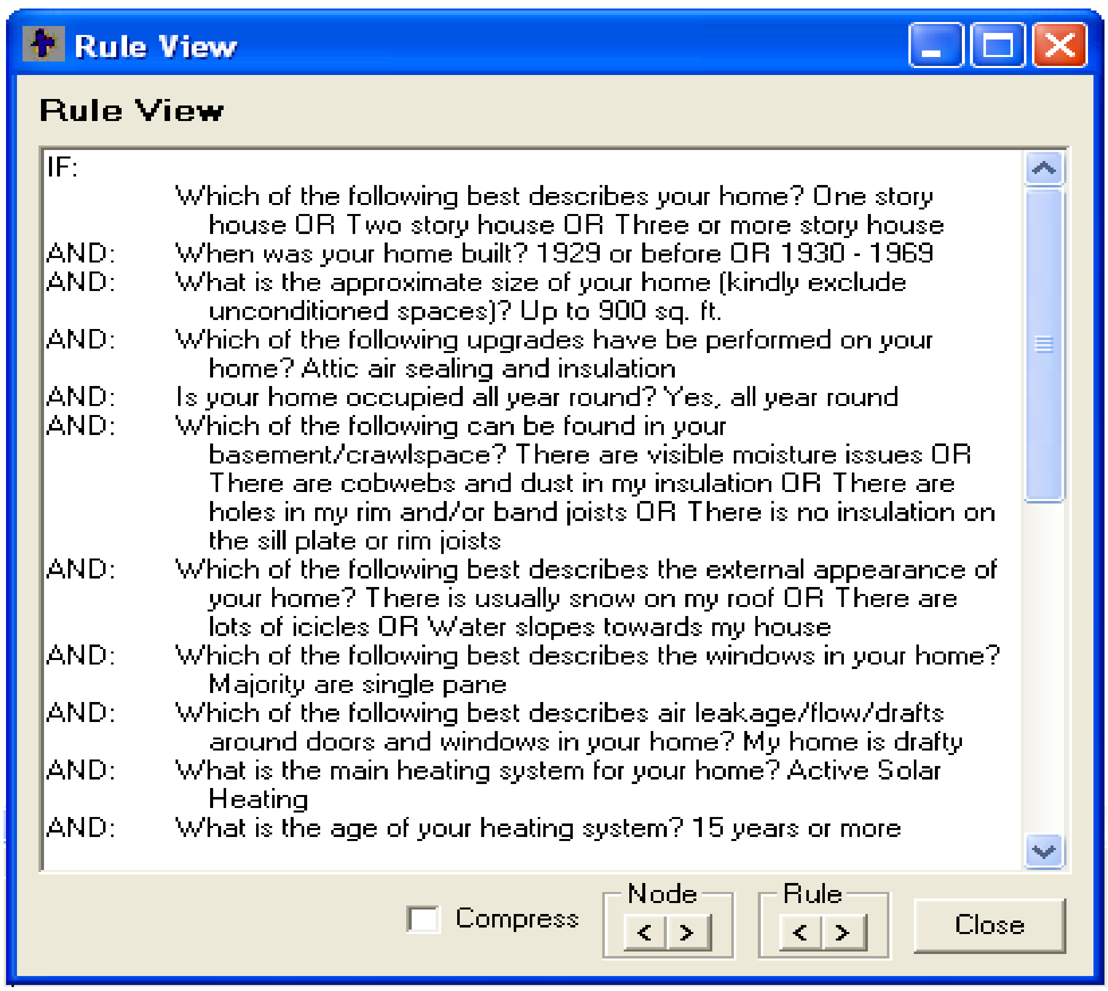


Figure 6.7: Screenshot of a Rule View

Since the framework was developed as an intelligent decision support system, it is important that all possible measures are provided to the user in a prioritized fashion in order to help with the decision-making process. This action is performed in the Logic Block by including a number of confidence variables in the appropriate order in the "THEN" part of the logic (See Figure 6.8). The red square brackets in Figure 6.8 denote the incomplete "IF" parts of the logic whilst the green ones denote complete "IF" parts of the logic.

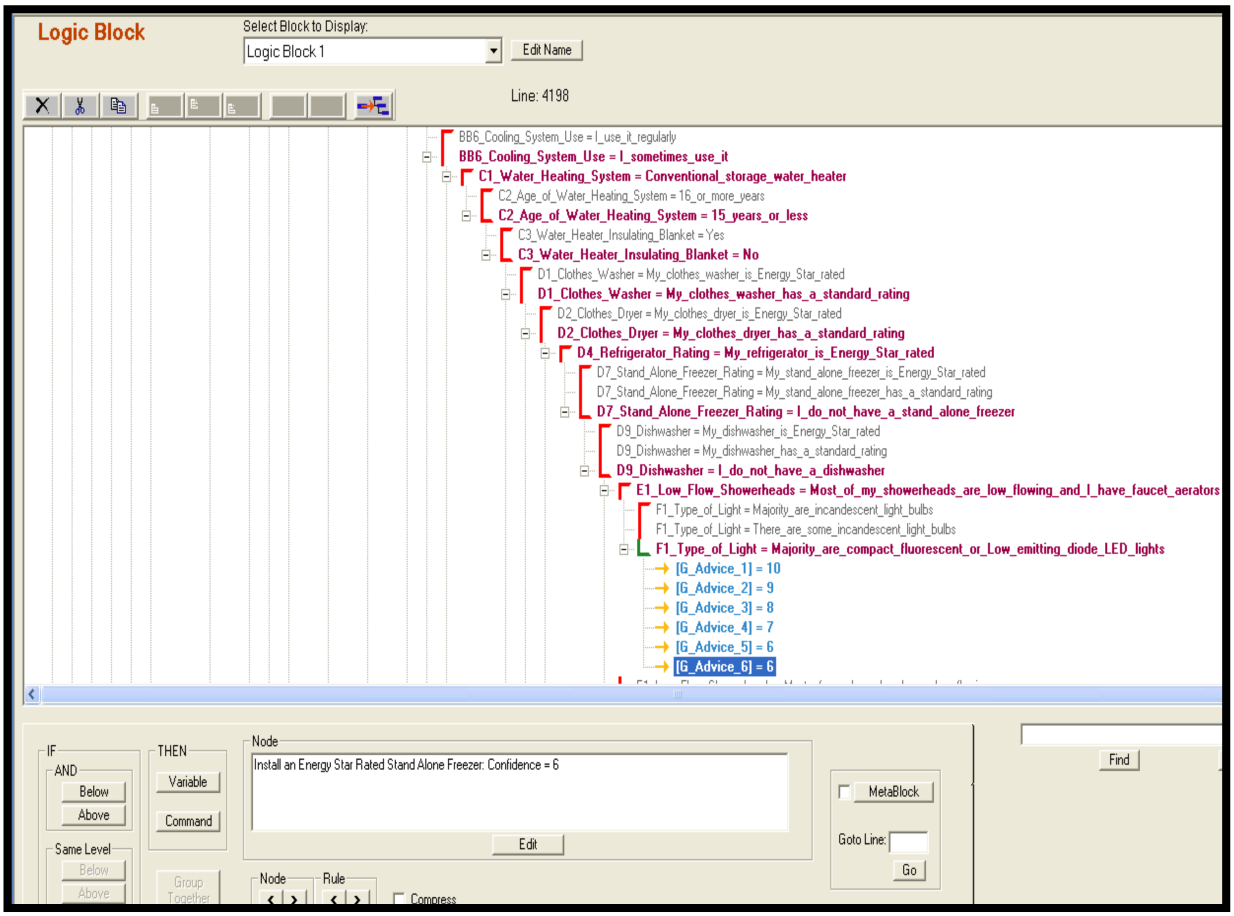


Figure 6.8: Screenshot of Multiple Variables for the THEN Part of Logic

(Note: Screenshot highlights decision tree-like structure of the logic block. Each green square bracket indicates the completed IF part of the logic and the red square brackets, the uncompleted IF part. The 6 right pointing arrows shows the THEN parts of the logic)

The Logic Block for the intelligent decision support system framework was built in a similar fashion. In all, over 7,200 lines of the logic were developed by the researcher for demonstration purposes on the Exsys Corvid platform and captured the decision-making logic of the system.

6.2.3 Development of Energy Retrofit Intelligent Decision Support System Command Block

Every Exsys Corvid system must have a Command Block in order for it to function. Described as the "trigger block", the operational commands used for this system instructs Corvid to perform specific operations (Exsys 2007). The Command Block window is opened by selecting the command button denoted by a "C" in a red line colored box. By selecting the "Add" button to add an operation command, the Command Builder window is opened (Figure 6.9).

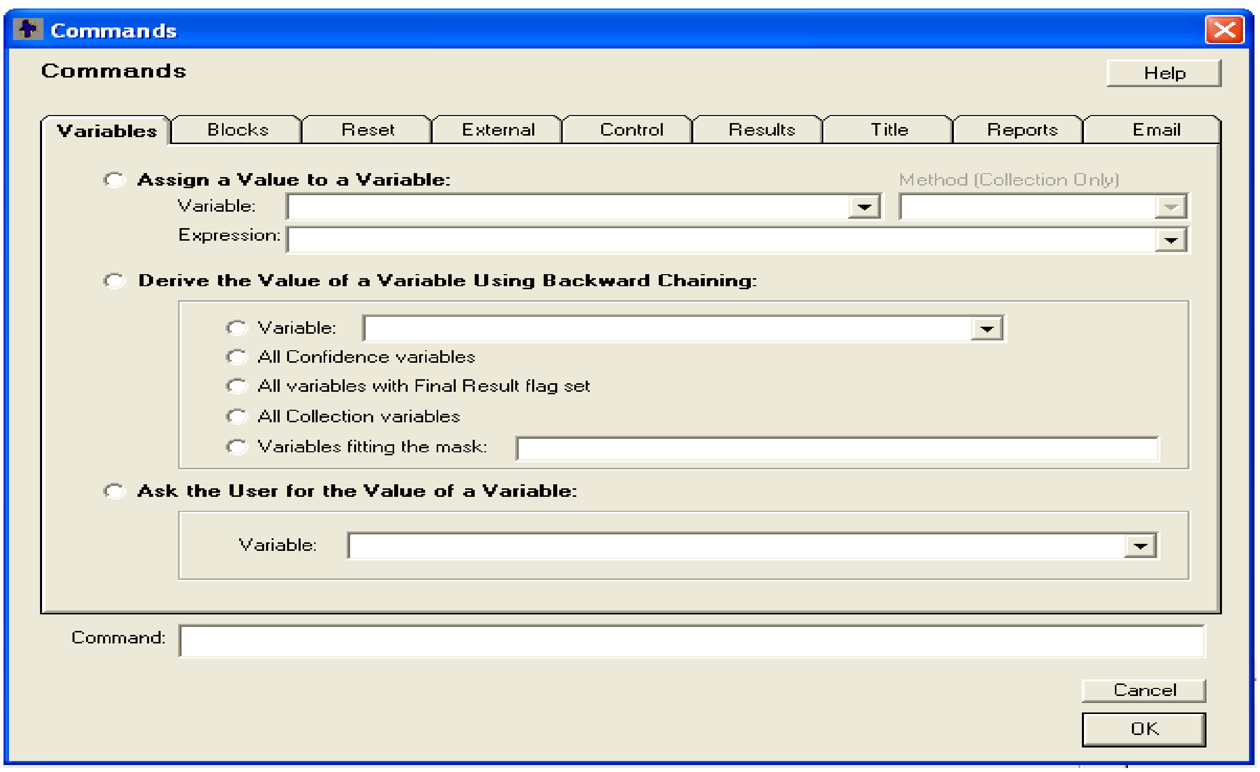


Figure 6.9: Screenshot of the Command Builder Window

(Note: Screenshot shows 3 options for the variable tab: Assign a Value to a Variable, Derive the Value of a Variable Using Backward Chaining, and Ask the User for the Value of a Variable)

This window has many tabs and options for building the commands for the system. The first tab, Variables, is the most used tab and allows three types of commands for variables to be built (Exsys 2007):

- SET – this assigns a value to a variable but is typically done in the Logic Blocks.
- DERIVE – as the section usually used to run systems, this uses mainly the Logic Blocks to find the value for a variable. It performs this function by instructing the inference engine to use all Logic Blocks to derive the value of a variable(s).
- ASK – the end user is asked the value of a variable, irrespective of the logic of the system. The user is automatically asked variables in an order determined by the system logic.

The system developed for the purposes of demonstration of the intelligent decision support system framework used a single "DERIVE" command to run the rules. The "All Confidence Variables" radio button was selected in the "DERIVE" section to build the command "DERIVE CONF" as indicated in Figure 6.3. By this action, the rules developed in the Logic Block that set values for the Confidence Variables are tested. In instances where values of the variables are needed, such information is requested from the user. The "DERIVE CONF", thus, tells the system what to do and when to it, except that it does not display the results.

Another command needed to display the results, the "RESULTS" command, was added by selecting the "Add Below" button. This instructs the system to follow the "DERIVE CONF" command first and then execute the "RESULTS" command next. When selected, the Command Builder window is opened again. Next, the "Results" tab which has options to control and design the layout of the result screen was selected. In order to show the values when the system is run, the default "RESULTS" command was used. This tab also affords the opportunity for the results screen to be designed. As a result, the following title was provided “Energy Retrofit Advice” (Figure 6.10).

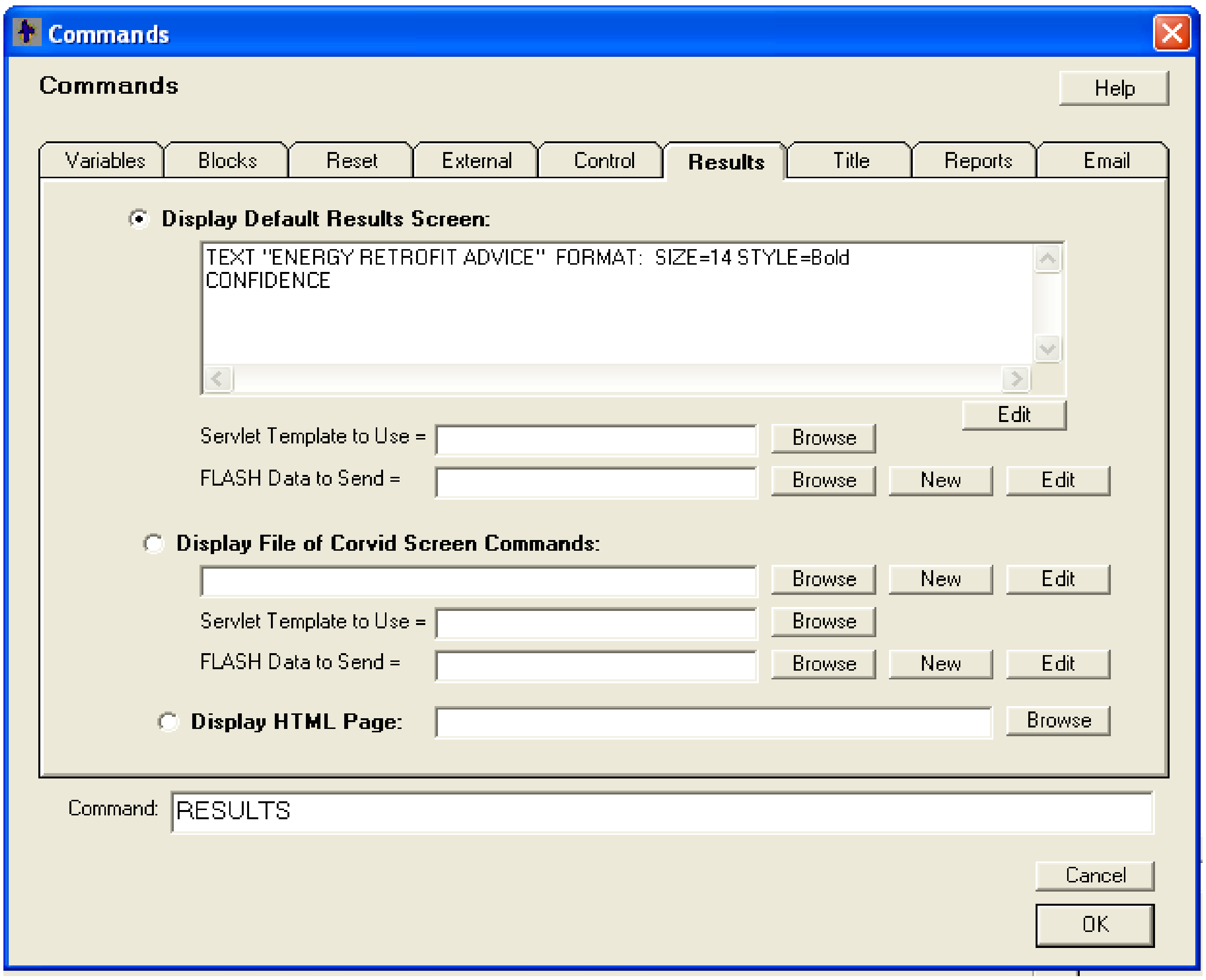


Figure 6.10: Screenshot of the Results Tab

(Note: Screenshot shows the three available options in the Results tab of the Command Block: Display Default Results Screen, Display File of Corvid Screen Commands, and Display HTML Page)

The “Results” tab can be edited by selecting the edit button on the “Display Default Results Screen” work space to open the “Screen Commands” window (Figure 6.11).

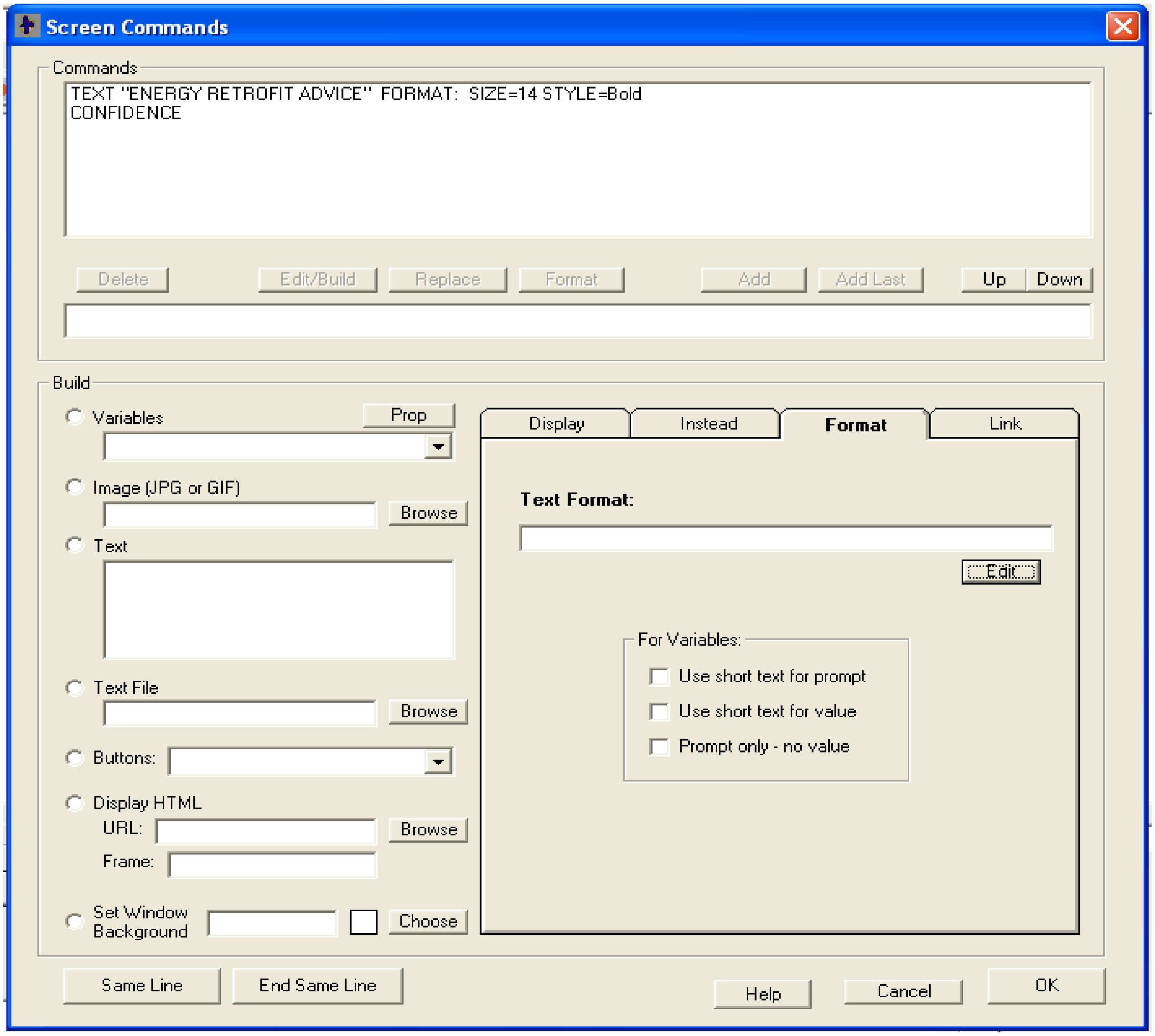


Figure 6.11: Screenshot of the Screen Commands Window

(Note: Screenshot shows two main panes: Command text work space at the top and build work space at the bottom. The build pane has two sections: (1) variables, image, text, text file, buttons, display html, and set window background to the left and (2) edit pane: display, instead, format, and link, to the right)

Relevant text can be included in the "Text" work space. The text can then be edited in the "Edit Format" window. Here, the name, style, and size of the font can be edited. Other formats that can be edited are foreground and background color, position of text, indent, etc. (Figure 6.12).

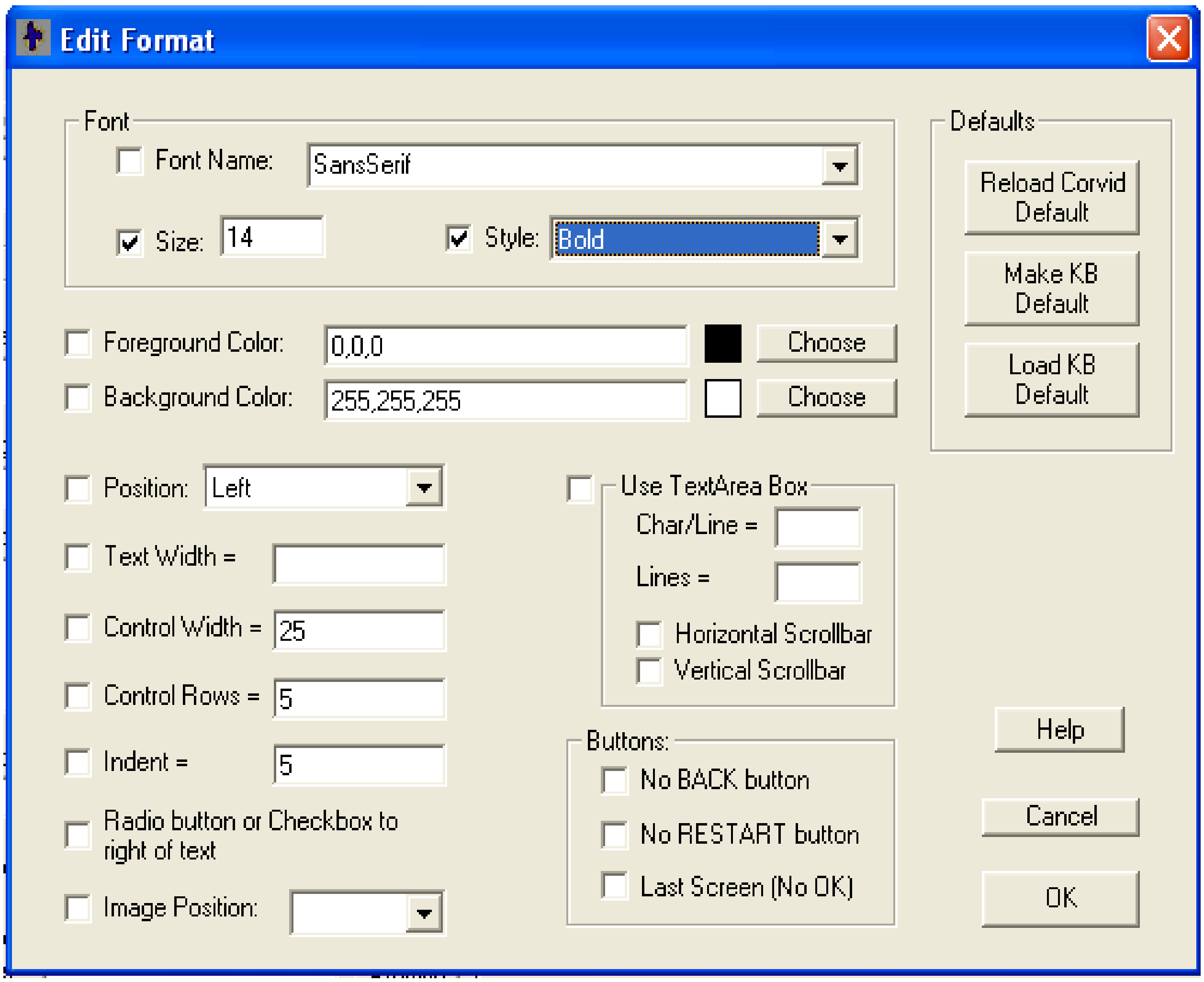


Figure 6.12: Screenshot of the Edit Format Window

(Note: Screenshot highlights the options for editing text: font, size, foreground color, buttons etc.)

Finally, the "Foreground Color" and "Background Color" can be edited in the "Color" window. This offers different types of colors including tints and shades that can be used to design the text and appearance of the "Results" screen (Figure 6.13).

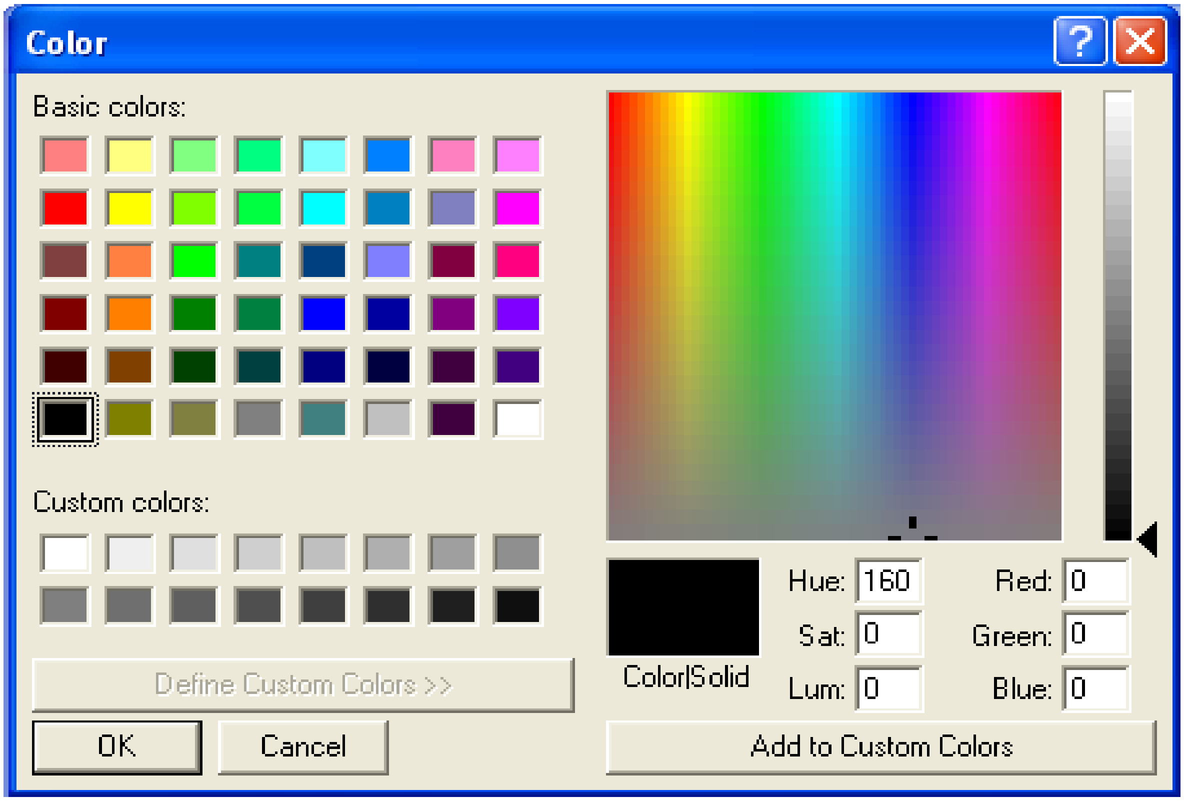


Figure 6.13: Screenshot of the Color Window

6.2.4 Running Energy Retrofit Intelligent Decision Support System Using Inference Engine

Having developed the Variables, Logic and Command Blocks, the system can now be run. The "Run the System" button, shown as a blue right-pointing triangle is selected (Figure 6.14).

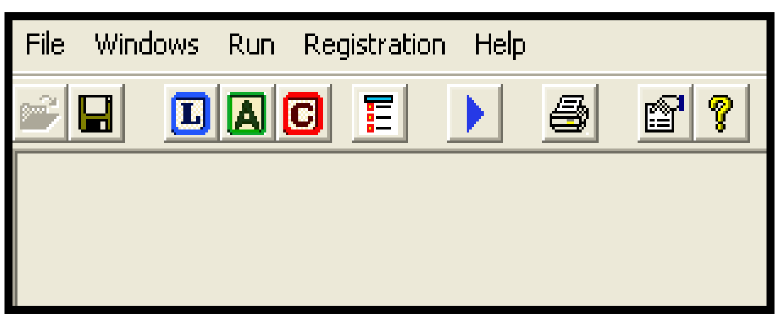


Figure 6.14: Screenshot of Run the System Button

The system is run in Exsys Corvid using the Corvid Runtime Applet, displayed in the Corvid Browser window. Even though the window uses the core of Microsoft Internet Explorer, it does not have the common navigation controls. The Inference Engine is contained in its Runtime Applet where it ensures that actions designed in the Command Block are adhered to using the Logic Blocks that were developed based on the Variables, thus serving as the “reasoning capacity” of the system (Exsys 2007).When the “Run the System” button is selected, the logic that was developed and ordered in the Command Block is followed. Thus, based on the hierarchy of the energy retrofit decision process model which requires that the thermal envelope measures are addressed first, rules were developed. Questions requesting information from the user on subsequent sections of the model are then requested. Figure 6.15 shows part of the “Thermal Envelope Features” prompts a user must assign a value to, and the available options.

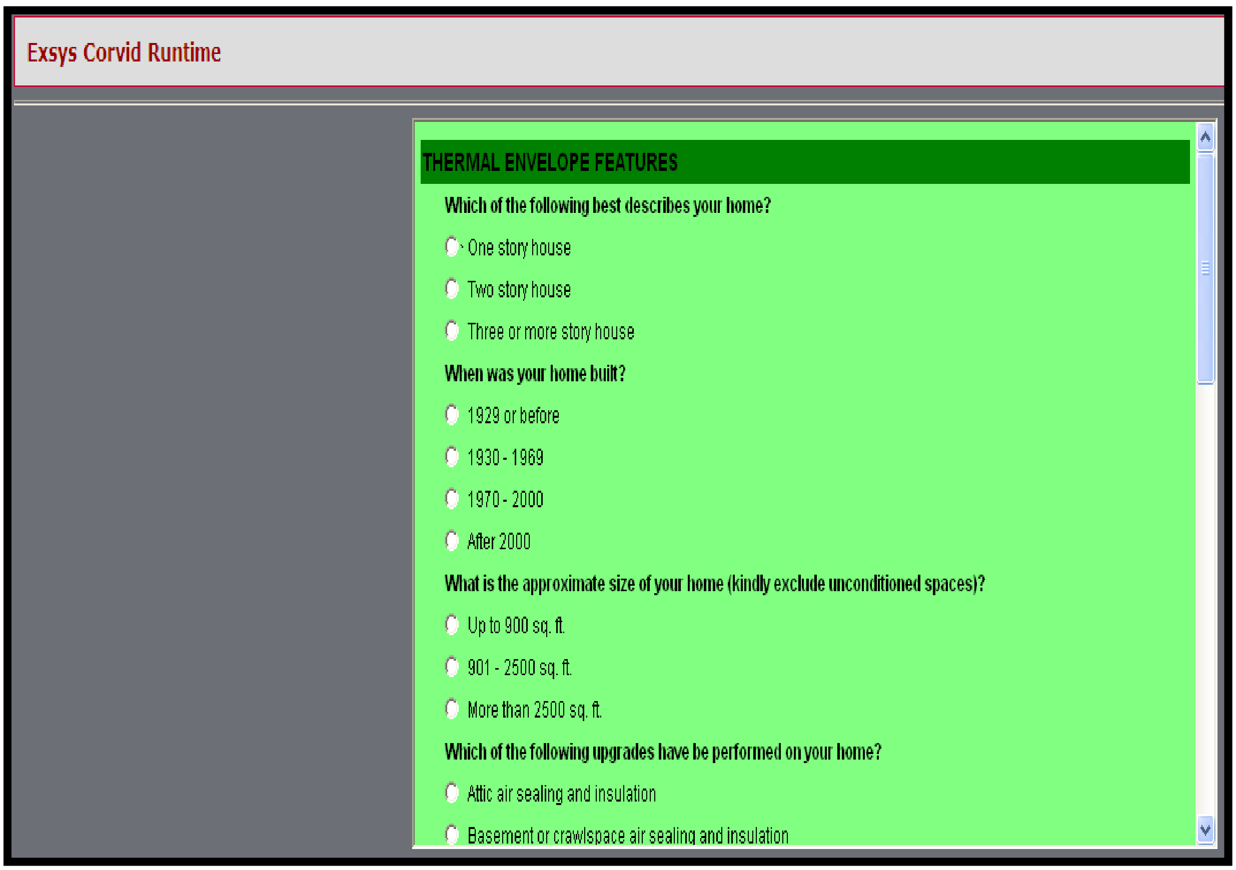


Figure 6.15: Screenshot of Exsys Corvid Runtime

(Note: Screenshot shows 4 prompts for “Thermal Envelope Features” and available user options)

6.2.5 Test Homes Details and Homeowners Characteristics

The final part of the demonstration of the functioning of the energy retrofit IDSS on the Exsys Corvid platform involved the use of test homes within the study area. In the next two sections, the basis for selecting the test homes and the data that was obtained are discussed. Using the data, the applicability of the IDSS framework is then demonstrated on the Exsys Corvid ES platform to provide energy retrofit advice to homeowners of the test homes.

6.2.5.1 Choosing the Test Homes

The purposive sampling technique was used to select two test homes. Unlike probability sampling where units are selected from a population to create a sample in order to make generalizations, the main goal of purposive sampling is to focus on particular characteristics of a population with knowledgeable experts, in order to enable the research questions to be answered. As a form of a non-probability sampling technique, the decision to include specific sample participants in purposive sampling is based on a variety of criteria such as specialist knowledge of research issue, capacity and willingness to participate in the research, and reliability and competence of participants (Lund Research 2012; Oliver 2013; Tongco 2007).

Specifically, the following reasons are adduced for selecting two test homes for the demonstration of the applicability of the intelligent decision support system framework developed in Chapter five:

1. Capacity, availability, and willingness of homeowners to participate in the study.
2. Unique homeowner characteristics – one of two homeowners had to be knowledgeable and could provide relevant details about the home construction, systems, and appliances

and the other, a novice who knew basic information about the home. This criterion was useful in gauging the reaction of homeowners after energy retrofit advice is proffered.

3. Location of test home (within study area).
4. Since it was only for demonstration of functionality and use purposes, two test homes with unique homeowner characteristics were suitable for the objective.

The steps for testing the energy retrofit intelligent decision support system tool using the expert system platform process are:

1. Identify two Test Homes
2. Visit Test Home #1 and collect data
3. Collect data for Test Home #2 without visiting home
4. Check for completeness of data from Test Homes
5. Input data into energy retrofit intelligent decision support system
6. Run system and obtain energy retrofit advice
7. Provide advice to homeowners
8. Gauge functioning capability of tool and finalize the system

The researcher visited the Test Home #1 and collected data from the Knowledgeable Homeowner. The data collection for the second home was, however, through an interview at a location in a different city. This was to simulate the functioning of the system which does not require a home visit. The information obtained from both homes was then checked for completeness before there was input into the system. In Test Home #1 (Figure 6.16), the researcher conducted a visual inspection of the internal and external components, appliances, and other relevant features of the home.

Figure 6.16: Image of Test Home #1

In addition, there was extended interaction with the Knowledgeable Homeowner regarding specific information about the home, such as performed upgrades, efficiency of systems, comfort issues, and showing the researcher around the home. Data obtained was mainly documented by taking notes and photographs. In Test Home #2 (Figure 6.17), data was obtained by asking specific questions to the Knowledgeable Homeowner in the hierarchy designed in the system. Based on the responses received, the data was recorded and input into the energy retrofit intelligent decision support system tool on the Exsys Corvid platform.

Figure 6.17: Image of Test Home #2

6.2.5.2 Test Homes Data

Having visited Test Home #1, data obtained by the researcher after interaction with the Knowledgeable Homeowner and inspection of the home is indicated in Table 6.2 based on the order each section was designed in the system. Data for Test Home #2 was obtained based on the responses from the knowledgeable homeowner and is shown (Table 6.3).

Table 6.2: Data Obtained for Test Home #1

No.	Data Requested	Data Obtained
Thermal Envelope		
1	Number of stories	One
2	Year home was built	1970 – 2000
3	Approximate size of home	901 – 2500 sq. ft.
4	Performed upgrades	Crawlspace and basement air sealing and insulation
5	Lower level of home description	Unconditioned basement and crawlspace
6	Period of occupying the home	All year round
7	Basement/crawlspace description	Crawlspace has no insulation/has moisture issues
8	External appearance of home	Usually snow on roof in the winter
9	Type of windows	Majority are single pane storm windows
10	Air leakage of doors/windows	A lot of draft

Table 6.2 (Cont'd)

Heating and Cooling System		
1	Main heating system	Central forced-air furnace
2	Fuel type	Natural gas
3	Age of heating system	10 years or less
4	Efficiency of heating system	90% AFUE (Annual Fuel utilization efficiency)
5	Size of heating system	90–119 kBtu/hr
6	Changing furnace filter	Regularly changed
7	Control system for heating	Vary temperature on programmable thermostat
8	Main cooling system	Central air conditioning
9	Age of cooling system	8–15 years
10	SEER rating of cooling system	SEER 13 or more
11	Frequency of use–cooling system	Rarely or never
Hot Water Heating System		
1	Main hot water heating system	Conventional storage water heating system
2	Age of hot water heating system	15 years or less
3	Insulating blanket installation	No
Appliance Use		
1	Efficiency of clothes washer	Energy star rated
2	Efficiency of clothes dryer	Energy star rated
3	Number of refrigerators	1
4	Efficiency of refrigerator	Energy star rated
5	Refrigerator more than 10 years	No
6	Number of stand-alone freezers	None
7	Efficiency of dishwasher	Energy star rated
Water Use		
1	Energy saving features installed	Low flow energy saving showerheads and water saving aerators
Lighting		
1	Type of lights used in home	Majority compact fluorescent or LED light bulbs

Table 6.3: Data Obtained for Test Home #2

No.	Data Requested	Data Obtained
Thermal Envelope		
1	Number of stories	One
2	Year home was built	1929 or before
3	Approximate size of home	901 – 2500 sq. ft.
4	Performed upgrades	Crawlspace air sealing and insulation
5	Lower level of home description	Conditioned basement/unconditioned crawlspace
6	Period of occupying the home	All year round
7	Basement/crawlspace description	Basement has visible moisture issues
8	External appearance of home	Usually snow on roof in the winter

Table 6.3 (Cont'd)

9	Type of windows	Majority are double pane
10	Air leakage of doors/windows	Little or no draft
Heating and Cooling System		
1	Main heating system	Central forced-air furnace
2	Fuel type	Natural gas
3	Age of heating system	11–29 years
4	Efficiency of heating system	81%–89% AFUE (Annual Fuel utilization efficiency)
5	Size of heating system	89 kBtu/hr or less
6	Changing furnace filter	Regularly changed
7	Control system for heating	Vary temperature on programmable thermostat
8	Main cooling system	Central air conditioning
9	Age of cooling system	7 years or less
10	SEER rating of cooling system	SEER 13 or more
11	Frequency of use–cooling system	Sometimes
Hot Water Heating System		
1	Main hot water heating system	Conventional storage water heating system
2	Age of hot water heating system	15 years or less
3	Insulating blanket installation	No
Appliance Use		
1	Efficiency of clothes washer	Standard rating
2	Efficiency of clothes dryer	Standard rating
3	Number of refrigerators	1
4	Efficiency of refrigerator	Energy star rated
5	Refrigerator more than 10 years	No
6	Number of stand-alone freezers	None
7	Efficiency of dishwasher	None
Water Use		
1	Energy saving features installed	Low flow energy saving showerheads and water saving aerators
Lighting		
1	Type of lights used in home	Majority compact fluorescent or LED light bulbs

6.2.5.3 Home Energy Retrofit Advice for Test Homes

On the basis of the data obtained for both test homes which was entered into the system, the following retrofit advice was offered for each of the homes (Table 6.4, 6.5):

Table 6.4: Home Energy Retrofit Advice for Test Home #1

Test Home # 1	
Thermal Envelope	
Retrofit Advice 1a	Upgrade energy inefficient main entrance door and window with energy efficient counterpart.
Retrofit Advice 2a	Air seal door leading to garage
Retrofit Advice 3a	Air seal door leading to crawlspace
Retrofit Advice 4a	Air seal single-pane windows
Heating, Cooling, and Air Conditioning System	
Retrofit Advice 5a	Insulate heating ducts in basement
Windows	
Retrofit Advice 6a	Upgrade windows to double-pane counterparts or better (note that the performance of this measure has very long payback periods)

Table 6.5: Home Energy Retrofit Advice for Test Homes #2

Test Home # 2	
Thermal Envelope	
Retrofit Advice 1b	Perform remedial action to solve moisture issues in basement walls. Consult an industry expert for detailed cost information.
Heating, Ventilation, and Air Condition System	
Retrofit Advice 2b	Upgrade existing furnace to energy efficient counterpart at $1100 with a lifetime of 20 years (See Figure 6.16). More information: http://www.nrel.gov/ap/retrofits/measures.cfm?gId=2&ctId=308
Appliances	
Retrofit Advice 3b	Upgrade Standard Clothes Washer to Energy Efficient Counterpart at $880 with a lifetime of 14 years (See Figure 6.17). More information: http://www.nrel.gov/ap/retrofits/measures.cfm?gId=4&ctId=293
Retrofit Advice 4b	Upgrade Standard Clothes Washer to Energy Efficient Counterpart at an average cost of $1,000 with a lifetime of 13 years (See Figure 6.18). More information: http://www.nrel.gov/ap/retrofits/measures.cfm?gId=4&ctId=374

For demonstration purposes, the details of the energy retrofit measures for Test Home #2 which were input into Exsys Corvid, are discussed in the succeeding paragraphs. Information regarding cost information was obtained from the National Residential Efficiency Measures (NREM) database (Figures 6.18, 6.19, and 6.20), a sub-component of the knowledge management database of the intelligent decision support system framework developed in Chapter five.

Replace Furnace:

Before-Component

Gas, 80% AFUE

Properties:
- AFUE: 0.8 Btu/Btu
- Fuel Type: gas
- Max Supply Temp: 120.0 degrees F

Performance Standards:
- Exceeds Federal Standard 1992
- Meets Federal Standard 2015

Lifetime:
- 20 Years

After-Component

Gas, 90% AFUE

Properties:
- AFUE: 0.9 Btu/Btu
- Fuel Type: gas
- Max Supply Temp: 120.0 degrees F

Performance Standards:
- Exceeds Federal Standard 1992
- Meets Energy Star 2006
- Exceeds Federal Standard 2015

Lifetime:
- 20 Years

Cost

Measure Cost

Units	Range	Average
$/kBtuh	15 - 29	20
$	680 - 1500	1100

Figure 6.18: Screenshot of Cost Details of Replacing Existing Furnace

(Note: Screenshot shows Before-Component, After-Component, and Cost for Replacing Furnace)

Replace Clothes Washer:

Before-Component

Front-Load, MEF=0.78, WF=10

Properties:
- Energy Factor: 1.3 ft^3/kWh-cycle
- Loading Direction: front
- Modified Energy Factor: 0.78 ft^3/kWh-cycle
- Water Factor: 10.0 Gal/cycle-ft^3

Lifetime:
- 14 Years

After-Component

Front-Load, MEF=2.2, WF=4.5

Properties:
- Energy Factor: 3.7 ft^3/kWh-cycle
- Loading Direction: front
- Modified Energy Factor: 2.2 ft^3/kWh-cycle
- Water Factor: 4.5 Gal/cycle-ft^3

Performance Standards:
- Exceeds Energy Star 2009
- Exceeds Federal Standard 2009
- Exceeds Energy Star 2011
- Exceeds Federal Standard 2011

Lifetime:
- 14 Years

Cost

Measure Cost

Units	Range	Average
$	680 - 1100	880

Figure 6.19: Screenshot of Cost Details of Replacing Existing Clothes Washer

(Note: Screenshot shows Before-Component, After-Component, and Cost for Replacing Clothes Washer)

Replace Clothes Dryer:

Before-Component	After-Component	Cost
Gas **Properties:** • Drying Energy: 22.0 kBtu/load • Energy Factor: 2.75 lb/kWh • Fuel Type: gas • Machine Energy: 0.23 kWh/load **Lifetime:** • 13 Years	Gas **Properties:** • Drying Energy: 22.0 kBtu/load • Energy Factor: 2.75 lb/kWh • Fuel Type: gas • Machine Energy: 0.23 kWh/load **Lifetime:** • 13 Years	**Measure Cost** **Units** / **Range** / **Average** $ / 950 - 1000 / 1000

Figure 6.20: Screenshot of Cost Details of Replacing Existing Clothes Dryer

(Note: Screenshot shows Before-Component, After-Component, and Cost for Replacing Clothes Dryer)

It must be noted, however, that the national residential efficiency cost database has some limitations. It mainly provides the cost to replace major components such as furnaces, air conditioners, windows, etc., and this list is not exhaustive. In addition, the cost to replace components that involve series of measures is not captured in the system. For instance, Test Home #2 has moisture issues in the basement from groundwater resulting from issues such as no perimeter drain and only one sump pump. There is, therefore, a need to rectify the moisture issues and then remediate the effects it has on the basement wall. Such a contiguous component is not captured in the database. In such instances, the advice provided by the system will be for an industry professional to be consulted.

On the basis of the forgoing discussion, the final information that is provided to the Homeowner using Exsys Corvid is shown in figures 6.21. It must be noted that, there is a link for more information which can be selected by the user in order to obtain further information about the specific measure.

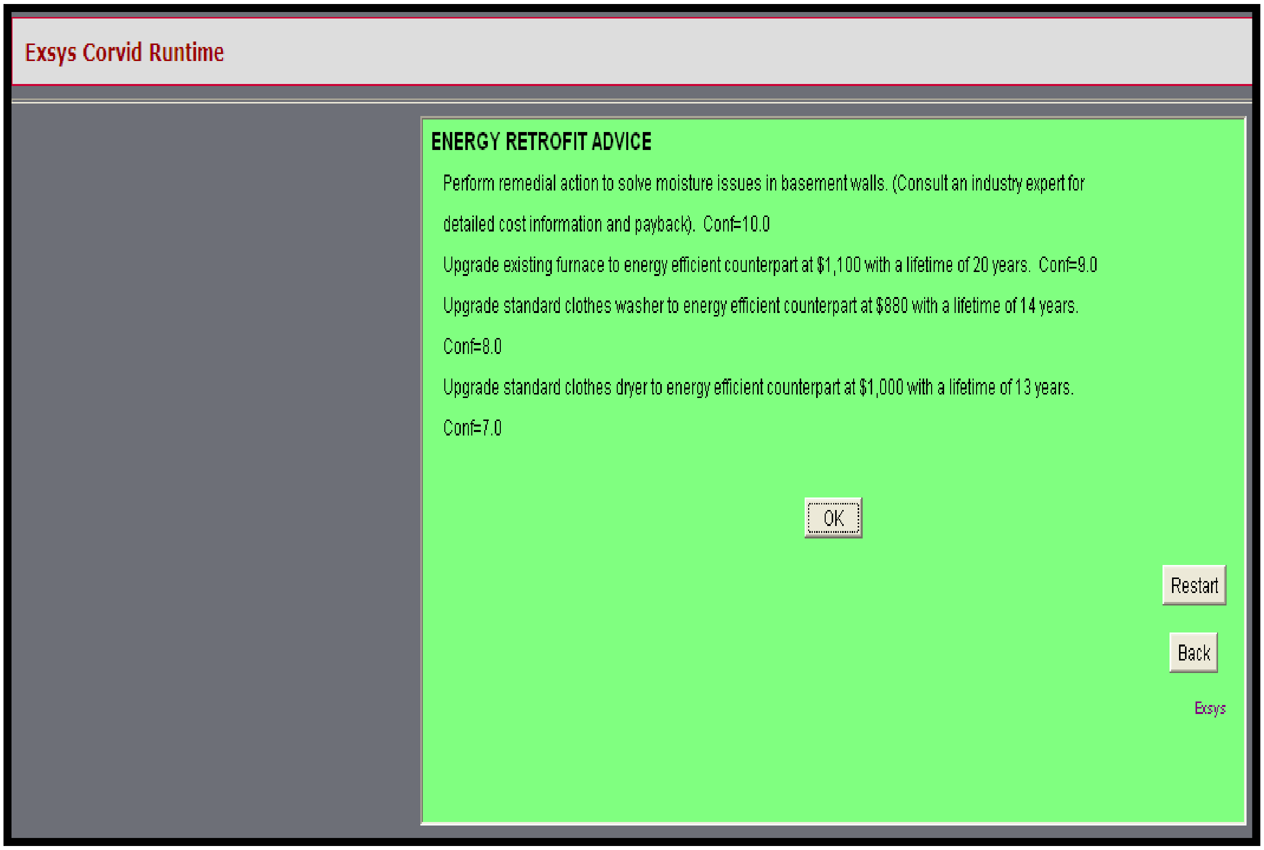


Figure 6.21: Screenshot of Results Screen for Test Home #2

(Note: Screenshot shows the following 4 energy retrofit advice: (1) Perform remedial action to solve moisture issues in basement walls [consult an industry expert for detailed cost information and payback], (2) Upgrade existing furnace to energy efficient counterpart at $1,100 with a lifetime of 20 years, (3) Upgrade standard clothes washer to energy efficient counterpart at $880 with a lifetime of 14 years, and (4) Upgrade standard clothes dryer to energy efficient counterpart at $1,000 with a lifetime of 13 years)

6.3 Functioning Capability and System Finalization

The demonstration of the capability of the system to the homeowners generated positive feedback. For both Test Homes, the Knowledgeable Homeowners appreciated the information provided since it confirmed some of their initial thoughts about the way forward to energy retrofit their homes. In addition, it served as a useful tool to validate some of their initial propositions for improving the energy efficiency of their homes, which they found difficult to explain to the respective Novice Homeowners.

The Novice Homeowners indicated that the information provided them was useful and would make them more likely to improve the energy efficiency of their home. They also indicated that the tool provided them a good basis to confirm the energy efficiency status of their home and the way forward. For Test Home #1, the Novice Homeowner indicated that as a result of this information, the measures will be implemented and there will be no second guessing of the Knowledgeable Homeowner. Both sets of homeowners, however, had major questions about the information that was provided them, mainly related to financial issues. They wanted to know the cost of each measure and the return on investment. This is in conformity with the findings of the reasons for undertaking an energy efficient retrofit, which was highlighted in Chapter four to be for financial, comfort, and health reasons.

For Test Home #2, the Novice Homeowner thought that recommendations were fitting, accurate, and absolutely helpful. The indication was that, specifically, the cost of remediating the moisture issues in the basement, and upgrading the furnace to a newer and energy efficient system was considered prohibitive given the rather long return on investment. As a result of the information provided to the homeowners of Test Home #2, they indicated their decision to move to a relatively bigger, newer, and more efficient home in a couple of years. Thus, based on the information provided, the duration they intend to live in the home (2 years), and the cost to energy retrofit their home, a decision was reached by the homeowners.

Based on feedback from all homeowners, the system was finalized. For instance, even though available cost information in the national residential efficiency measures database was provided to the users, it was identified through the feedback process that this information is not exhaustive. The researcher suggests that such additional information from other sources is included in order to enhance the information provided to users to help with the decision-making process. A couple of the questions had to be rephrased in order to capture existing conditions in the home. For instance, it was identified that both test homes had both basements and crawlspaces. The earlier system only made provision for choosing one. This was refined and incorporated into the logic built into the system.

6.4 CHAPTER SUMMARY

The intelligent decision support system framework developed in Chapter five sought to package and deliver quantitative information and expert knowledge in order to provide such information to homeowners in an easy-to-use fashion. The framework was intended to help users (homeowners) better understand the information and afford them better opportunities for making energy efficiency retrofit decisions. This Chapter focused on the applicability and use of the framework using an expert system platform. It provided the opportunity to demonstrate the suitability and practicability of the intelligent decision support system framework.

An expert system shell was obtained from Exsys Corvid knowledge automation expert system. Like an expert system, Exsys Corvid attempts to imitate the work of experts by capturing their expertise and applying it to solve problems. Exsys Corvid can be developed by fully capturing the decision-making logic and process of domain experts, designing a suitable user interface for interaction between user and the system, and integrating with other quantitative information sources including database sources and other information such as text files and web links.

The applicability of the intelligent decision support system framework on the Exsys Corvid platform was demonstrated by selecting two test homes in the study area. Using data from the test homes, the applicability of the intelligent decision support system framework on the expert system platform was demonstrated. The advice to improve the energy efficiency of both homes obtained positive feedback. A major concern of the homeowners regarding the cost of measures and the return on investment, which is not comprehensively covered in the cost database, is recommended as an area for future research.

CHAPTER 7

SUMMARY AND FUTURE RESEARCH

7.1 INTRODUCTION

This chapter provides a summary of this research and presents areas for future research. First, a summary of the research is presented. Second, a review of the research goal with emphasis on the output of each objective follows. Third, the contributions, inferences, and conclusions of this research are highlighted and finally, recommended areas for future research are underscored.

The main goal of this research is to support the implementation of home energy retrofits. This goal was envisioned to be supported through the eventual development of an easy-to-use query-based intelligent decision support system. To achieve this goal, information barriers to the uptake of energy retrofits were identified. Next, the energy retrofit decision process model was analyzed for its implementation as an intelligent decision support system. An extensive study was completed in the area of expertise development and elicitation, leading to the development of the determinants of energy retrofit expert knowledge and a knowledge elicitation strategy. An intelligent decision support system framework was developed based on the energy retrofit decision process model, published information, and elicited knowledge from industry experts. The framework highlighted the knowledge-based system, which included six knowledge-based modules. Finally, using an expert system shell obtained from Exsys Corvid, the application of the intelligent decision support system framework was demonstrated.

Chapter 1 provided the background, justification/need, goal, objectives, methodology, scope, limitations, and projected outcomes/benefits of this research. In Chapter 2, the literature regarding energy retrofit, expertise development and elicitation, and decision support systems were examined. Chapter 3 reviewed the energy retrofit decision process model and analyzed its implementation as an intelligent decision support system. In Chapter 4, the determinants of energy retrofit expert knowledge and an elicitation strategy were developed and used to elicit and compile relevant industry knowledge. Chapter 5 highlighted the development of an intelligent decision support system framework for the energy retrofit domain. Finally, the applicability of the intelligent decision support system framework was demonstrated using an expert system platform obtained from Exsys Corvid in Chapter six.

7.2 SUMMARY OF OUTPUT BY OBJECTIVES

The main goal of this research, supporting the implementation of home energy retrofits, was supported through the eventual development of an easy-to-use query-based intelligent decision support system. The purpose is to provide relevant information in a format that can be understood and used by homeowners and industry practitioners in order to help with decision-making. Based on the research objectives set in Chapter one, this section evaluates the output of the research by each objective.

7.2.1 Objective 1: To compile the information barriers to energy retrofit decision process and adoption

Generally, buildings, particularly residential ones, consume a lot of energy. The majority of the housing stock consists of existing homes, a large number of which are energy inefficient.

Retrofitting existing homes to make them energy efficient has huge economic, social, and environmental benefits. Despite the established benefits and opportunities of energy retrofitting of homes, its adoption has faced obstacles. One estimate of market penetration for home energy retrofit programs puts it at less than 2%.

Lack of information or information that is not presented in a format easily understood and used by homeowners for energy retrofit decision making were identified in the research as major barriers to the adoption of energy retrofits. Two information barriers identified were quantitative information and expert knowledge. The need for information in order to accelerate the adoption and promotion of energy retrofit among homeowners was also emphasized.

7.2.2 Objective 2: To analyze the energy retrofit decision process model and its potential implementation as an intelligent decision support system

An important basis for the development of an intelligent decision support system framework for this domain was the energy retrofit decision process model, which was analyzed in Chapter three. The common protocol followed in the energy retrofit decision process and the associated information inputs at various decision points were the basis for developing the model. Three principal steps in the model are:

1. Identify retrofit measures – these are performed under (a) thermal envelope and lighting measures, (b) heating and cooling measures, and (c) stand-alone measures.
2. Shortlist and prioritize measures – the basis includes information such as user needs, user budget, occupant health and safety, cost effectiveness, and energy assessment.

3. Provide expert advice on installation – such advice was provided under (a) techniques, (b) level of difficulty, (c) installer skill, (d) installer safety, and (e) other factors.

Information sources for the model were mainly obtained from quantitative sources:

- Cost information – National Residential Efficiency Measures (NREM) database
- Energy Simulation – Building Energy Optimization (BEopt) Software
- Financial Incentives – Database of State Incentives for Renewable Energy
- Others – Published Literature

Based on literature review conducted in Chapter two, it was identified that the energy retrofit decision process model could be used as the basis for developing an IDSS framework. Three building blocks identified were: the energy retrofit decision process model as a whole, the quantitative information, and expert knowledge. The expert knowledge part was, however, identified to be highly under-developed; hence, was explored further in Chapter four.

7.2.3 Objective 3: To investigate the process of expertise development with a focus on energy retrofit decision process

While homeowners often depend on energy retrofit professionals, such as energy auditors and trade contractors, information provided can lack comprehensiveness and accuracy. Chapter four, in part, discussed the development of expert knowledge in general and more specifically in the energy retrofit domain.

An extensive literature review established the differences in performance between novices and experts, where expertise can be defined in terms of:

1. *Experience* – experts perform better due to real world experience and extensive practice leading to long-term developmental processes
2. *Extent* – expertise exists in degrees and not in an all-or-none fashion
3. *Development* – expertise progresses from literal understanding (novices) to expert reasoning (experts)
4. *Knowledge structures* – experts have extensive and well-organized domain knowledge
5. *Reasoning process* – qualities include using prototype examples of past cases, generating scenarios, moving from declarative to procedural shift in reasoning in order to explain decisions, actions, or novel difficult situations

In terms of the development of expertise, a series of distinct, identifiable stages are novice, advanced beginner, competence, proficiency, and expert. The determinants of industry expert knowledge were identified as:

a. Building science and construction knowledge
b. Certification and continuing education
c. Field experience and expert collaboration
d. Computer and diagnostic equipment knowledge
e. Professional ethics

7.2.4 Objective 4: To develop an expertise elicitation strategy for energy retrofit knowledge

The second part of Chapter four established that a major part of the difficulty in eliciting expert knowledge is because to the expert, such knowledge is often implicit, usually committed to automaticity, and difficult to articulate. A knowledge elicitation strategy to elicit and compile energy retrofit knowledge that can be incorporated into the development of an intelligent decision support system was developed. This was based on an extensive literature review of knowledge elicitation techniques in Chapter two. The elicitation strategy involved a combination of comprehensive knowledge elicitor training, the Delphi technique, semi-structured interviews, and job shadowing. The strategy encourages experts to describe their knowledge in a way most natural to them, relate to specific problems, and reduces bias.

Based on the energy retrofit expertise identification system developed in the early part of Chapter four, the knowledge of 19 industry experts was elicited and compiled using the strategy. The elicited knowledge, accepted through consensus as relevant in decision-making in this domain, can assist homeowners with retrofit decision-making and useful to industry practitioners and academia through corroboration and enhancement of existing knowledge. The researcher posits that no previous study about knowledge elicitation in this domain meant for developing an intelligent decision support system exists.

7.2.5 Objective 5: To develop an IDSS framework for energy retrofit for homes

In Chapter five, the significant role of a knowledge-based system in an intelligent decision support system was emphasized. To operate fully, however, such as system must be integrated with published information in the data management system for it to be fully functional. The intelligent decision support system framework developed in Chapter five has three main components: knowledge-based management, a data management, and user interface subsystems.

Expert knowledge, which was a focus of this research, led to the development of 6 knowledge-based modules in the knowledge-based management subsystem for the proposed system:

1. Knowledge-based thermal envelope measures module
2. Knowledge-based heating, cooling, and air conditioning measures module
3. Knowledge-based hot water heating measures module
4. Knowledge-based lighting measures module
5. Knowledge-based stand-alone and energy saving measures module
6. Knowledge-based expert advice on installation module

The data management subsystem was made up of three databases: cost, energy assessment, and published information. The user interface subsystem provided the platform for the interaction of the user with the system.

The framework attempts to decompose the decision making process in this domain by incorporating expert knowledge with published/quantitative information in order to help users with energy retrofit decision making. The six knowledge-based systems are interconnected and linked to a database that aims to help users make energy retrofit decisions by:

1. Identifying possible energy retrofit measures of a home;
2. Shortlisting and prioritizing the measures using expert knowledge integrated with published or quantitative information; and
3. Providing expert advice on the installation of recommended energy retrofit measures.

7.2.6 Objective 6: To demonstrate the application of the IDSS framework with a pilot system

Expert system software was obtained from Exsys Corvid and was used as the basis for demonstrating the applicability of the intelligent decision support system framework. First, the researcher obtained an understanding of the functioning capability of the tool through training, practice, and studying the manual. The functioning capacity of the framework was mounted on this platform, an integration which led to the testing of two homes located within the scope of the research. Analysis of the integration of the framework using Exsys Corvid and the results of the test homes leading to the refinement of the system indicates a strong potential for extending the use of the system to a wider population. The researcher asserts that the implementation of this tool on a wide scale will lead to an improvement in the uptake of home energy retrofits.

7.3 RESEARCH CONTRIBUTIONS

Even though the benefits and opportunities of energy efficiency and energy retrofitting of homes are fairly well established, relatively few people are taking advantage of the available retrofit initiatives and cost- and energy-efficient technologies. This research will have significant benefits regarding the adoption of energy retrofits especially for homeowners, industry practitioners, and researchers. The subsequent sections highlight the specific contributions of this research.

7.3.1 Identification of Major Barriers to Home Energy Retrofits

The lack of information or the lack of information in a format that homeowners can understand and use in order to make retrofit decisions were identified as key impediments to the uptake of energy retrofits. By developing a research approach that can be used to identify, capture, and integrate such information types in order to use them as an intelligent decision support system, the packaging and delivery of such information to homeowners and other industry players has been enhanced. This research, therefore, contributes by helping to remove such barriers leading to the improvement in the uptake of energy retrofits. This will eventually lead to responsible use of energy generated from the planet's finite resources and, hence, contribute to ensuring sustainable and responsible development.

7.3.2 Identification of Main Building Blocks for Developing the IDSS

In order to develop an intelligent decision support system for energy retrofits, it is important to understand the common protocols followed in this industry as well as the relevant information for decision-making. This research contributes to the body of knowledge by identifying the three major building blocks for developing an intelligent decision support system (Figure 7.1).

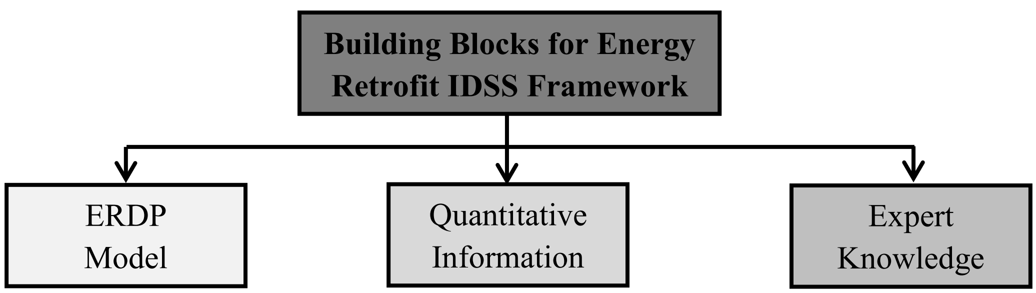


Figure 7.1: Three Main Building Blocks in Energy Retrofit IDSS Development

First, the common protocols followed in the industry were identified. An appraisal of the energy retrofit decision process model indicated its suitability as a building block for the development of the intelligent decision support system. Next, in order for the decision process to be effective, specific references to the associated information inputs at various decision points, which provides a good basis for developing the system to help users with decision making were identified. These information categories are quantitative information and expert knowledge.

Quantitative information was obtained from three main sources: (1) building energy assessment – Building Energy Optimization software, (2) cost database (national residential efficiency measures database, and (3) published texts, images, and videos. It must be noted that the comprehensive cost database as well as the energy assessment software are provided by the United States federal government. The reliability of the developed intelligent decision support system framework quantitative information is based on the on the frequency of updating the information and developing current versions of both systems based on changes in the industry.

Finally, the research identified the determinants of expert knowledge as well as the development of an expert knowledge elicitation strategy. This strategy was used to elicit energy retrofit expert knowledge which was then modeled into a usable format for an intelligent decision support system. The expert knowledge provided the last building block for the development of the system. The system combines the energy retrofit decision process model, quantitative information, and expert knowledge and provides suitable information to homeowners to help them with decision-making.

7.3.3 Development of the Determinants of Industry Experts

The determinants of expert knowledge in the energy retrofit domain and its association with the stages of expertise development offer a good metric for determining an industry expert. This can be particularly useful in the hiring of new workers, training of staff, and offer homeowners confidence in the skill levels of industry practitioners thus reducing the bias homeowners attach to some professionals. It ensures that the knowledge of competent experts are elicited and included in the development of an intelligent decision support system.

In addition, in the era where non-experts are getting the "podium" on social media, this system can be used to evaluate anybody claiming to be an expert and intending to teach others online. Such people must first satisfy the determinants of expert knowledge before the expertise they proffer can be accepted. Particularly, industry practitioners and academic institutions can used this knowledge for corroboration of existing knowledge, or for further research studies, thus expanding the body of knowledge related to the proper definition of expert knowledge in this domain and eventually improving the uptake of energy retrofits. For researchers especially involved in qualitative studies, particularly purposive sampling techniques, the selection of reliable and competent informants have been greatly emphasized since it is at the core of the validity and reliability of the data collected.

Finally, the generally mentioned metric in describing expertise in psychology literature is usually experience. The metric developed for determining experts in this industry (all seventeen attributes) enriches the body of knowledge concerning the determination of expertise in this domain. The system developed for the determinants of expert knowledge in this domain is generalizable since all participants selected for the study were either Building Performance Institute or Residential Energy Services Network certified. Both certification programs are nationally recognized in the United States.

7.3.4 Development of Knowledge Elicitation Strategy for Home Energy Retrofits

The development of the knowledge elicitation strategy provides a major contribution to solving the challenges associated with knowledge elicitation. By combining comprehensive knowledge elicitor training and relevant knowledge elicitation techniques such as the Delphi technique, semi-structured interviews, and job shadowing, the strategy encourages experts to describe their knowledge in a way most natural to them, relate to specific problems, and reduces bias. In addition, elicited expert knowledge can be incorporated into an intelligent decision support system in order to provide information to homeowners in a suitable and usable format. It can also assist homeowners with decision-making, as well as industry practitioners and academia, with corroboration and enhancement of existing knowledge. Since there is no previous study about knowledge elicitation and developing an intelligent decision support system for the energy retrofit domain, this study provides originality and value to the body of knowledge.

As a result of the elicitation strategy used and the elicited knowledge obtained a large amount of information regarding this industry for improving a home's energy efficiency were identified and are useful to the body of knowledge. This includes the following:

- Even though conducting an energy assessment of a home using techniques and tools is appropriate, there are certain features of the home that can give a good indication of its efficiency without performing a comprehensive assessment. These include building envelope features and age; HVAC equipment type, age, and characteristics; comfort complaints; visible moisture issues; visible health and safety issues; appliance and lighting characteristics; and review of utility use and billing history.
- There are limited instances where energy efficient products or appliances may not always be the most viable option in an energy retrofit process. Examples include instances where cost is prohibitive, where cost is ineffective, such as using an air conditioner for only two weeks in a year, the unavailability of the appliance such as a range microwave, or when

the emphasis is on health and safety and not energy efficiency, such as providing a basic power vent water heater that passes a combustion appliance zone test.

7.3.5 Consensus of Relevant Expert Knowledge for Decision-Making

Using the Delphi technique, a consensus-based technique where specific rounds of questions are used to collect data from selected participants, consensus was reached on relevant energy retrofit knowledge used in decision-making. Thus the knowledge obtained is mutually acceptable and hence applicable to industry practice and usable by homeowners for decision-making. In addition, since group opinion is better than individual opinion, the knowledge obtained and agreed on through consensus is a valuable contribution to the body of knowledge. This consensus-based knowledge for decision-making is enhanced due to the following reasons:

- Selected participants whose knowledge was elicited were pre-qualified using the determinants of expert knowledge developed earlier in this research. This ensured that competent participants were selected.
- The anonymity of participants and the opportunity to scale items during the iteration of the rounds enhanced the reliability and validity of the consensus reached.

7.3.6 Development of an IDSS Framework for the Home Energy Retrofit Industry

The developed IDSS framework attempts to solve the information barrier to the uptake of energy retrofits. The three major components, knowledge-based management subsystem, data management subsystem, and user interface subsystem, are integrated in order to provide homeowners with information that can assist them in making energy retrofit decisions. The system can also assist industry practitioners corroborate the knowledge and information they provide to homeowners. Even though the shelf life of the intelligent decision support system is envisaged to be long, it must be emphasized that the capacity of the cost database and energy assessment information is as good as is maintained and updated by the United States department of energy.

The system is expected to help reduce the bias homeowners have about industry professionals. For instance, it is common knowledge that replacing energy inefficient windows with energy efficient counterparts is the measure with the longest payback period, is expensive, and does not improve the efficiency of the home very much. This is in sharp contrast to air sealing, insulation or lighting measures which have good returns on investment, are relatively cheaper, and have shorter payback periods. Thus, if a homeowner uses the system and has air sealing and insulation as the top measure and this information is corroborated by an industry professional during the performance of work, bias will be reduced.

7.3.6.1 Development of Industry-Specific Knowledge-Based Modules for Decision-Making

A major focus of this research in the development of the IDSS framework was the development of the knowledge-based systems, which led to six knowledge-based modules that addresses specific components of making a home energy efficient being developed: thermal envelope; heating, cooling, and air conditioning; hot water heating; lighting; stand-alone and energy saving measures; and expert advice on installation. This provides a good understanding of implicit knowledge in each module. For instance, the first priority in most energy retrofits is to ensure that infiltration and exfiltration in the thermal envelope is reduced to acceptable levels that allow enough ventilation. However, in instances where there is an immediate need, such as a broken heating system, even though this measure has secondary consideration based on the decision-making protocol, it becomes the topmost priority since the health and safety of the homeowner is at risk. In this instance, the calculation of the heating load post retrofit is completed based on the modeled efficiency projected for the thermal envelope.

7.3.6.2 Compilation of Do-It-Yourself Measures for Successful Home Energy Retrofits

A major health and safety concern and cost-saving issue that can impede the successful uptake of energy retrofits in the industry relates to do-it-yourself measures performed by homeowners. This research contributes to this body of knowledge by indicating specific tasks that can be performed by homeowners and those that must be performed by industry practitioners. The main reasons identified for allowing measures to be self-performed by homeowners are: ease of installation, little or no tool requirement, no health and safety issues, and ease of finding information about the work to be performed. This will lead to a reduction in the cost of some retrofit measures and, hence, the overall cost, thus encouraging homeowners to perform energy retrofits which will eventually improve the uptake of energy retrofits.

7.3.7 Replication of Research Approach in Related Domains

Finally, the research approach employed in this study and used to identify, capture, and integrate the two information types, quantitative information and expert knowledge, and eventually used as an intelligent decision support system, can be replicated in other domains. The tool developed for the framework using the expert system platform obtained from Exsys Corvid provides information to users in an easily understandable and usable format.

7.4 RECOMMENDED AREAS OF FUTURE RESEARCH

The following sections highlight two key areas identified by the researcher and recommended for further research.

7.4.1 Harmonization of Vast Quantitative Information with Knowledge-Based Modules

Quantitative or published information was integrated with expert knowledge in a suitable format and platform in order to develop the intelligent decision support system. This research focused heavily on the expert knowledge part. By successfully combining these two parts in the creation of the intelligent decision support system framework, it was realized that most of the work done in this part relates to the identification of the sources and the successful integration of such sources into an intelligent decision support system framework using an expert system platform. However, limited work has been completed on the vast amounts of quantitative information relating to specific decisions in energy upgrades and the expansion of the quantitative information part in a manner comparable to the six knowledge-based modules developed for the knowledge-based management subsystem. This, therefore, brings to the fore the need to expand the quantitative information part of the intelligent decision support system framework and provide it in a suitable format that can be used by users. For instance, for the upgrade of the furnace of a home, the National Residential Efficiency Measures database has about 502 furnace measures. The vastness of such information can be overwhelming and tasking for homeowners.

The researcher recommends that further research is conducted in order to make the choices for the quantitative information easily understandable by homeowners. A good metric, or rubric, to use to identify such quantitative information will be to group them under the first five sub-modules of the knowledge-based management subsystem: (1) thermal envelope, (2) heating, cooling, and air conditioning, (3) hot water heating, (4) lighting, and (5) energy saving measures. Thus, for each sub-module, the corresponding expert knowledge and quantitative information can be synchronized on multi-levels in the system in order to generate enhanced information to help users with decision-making (Figure 7.2).

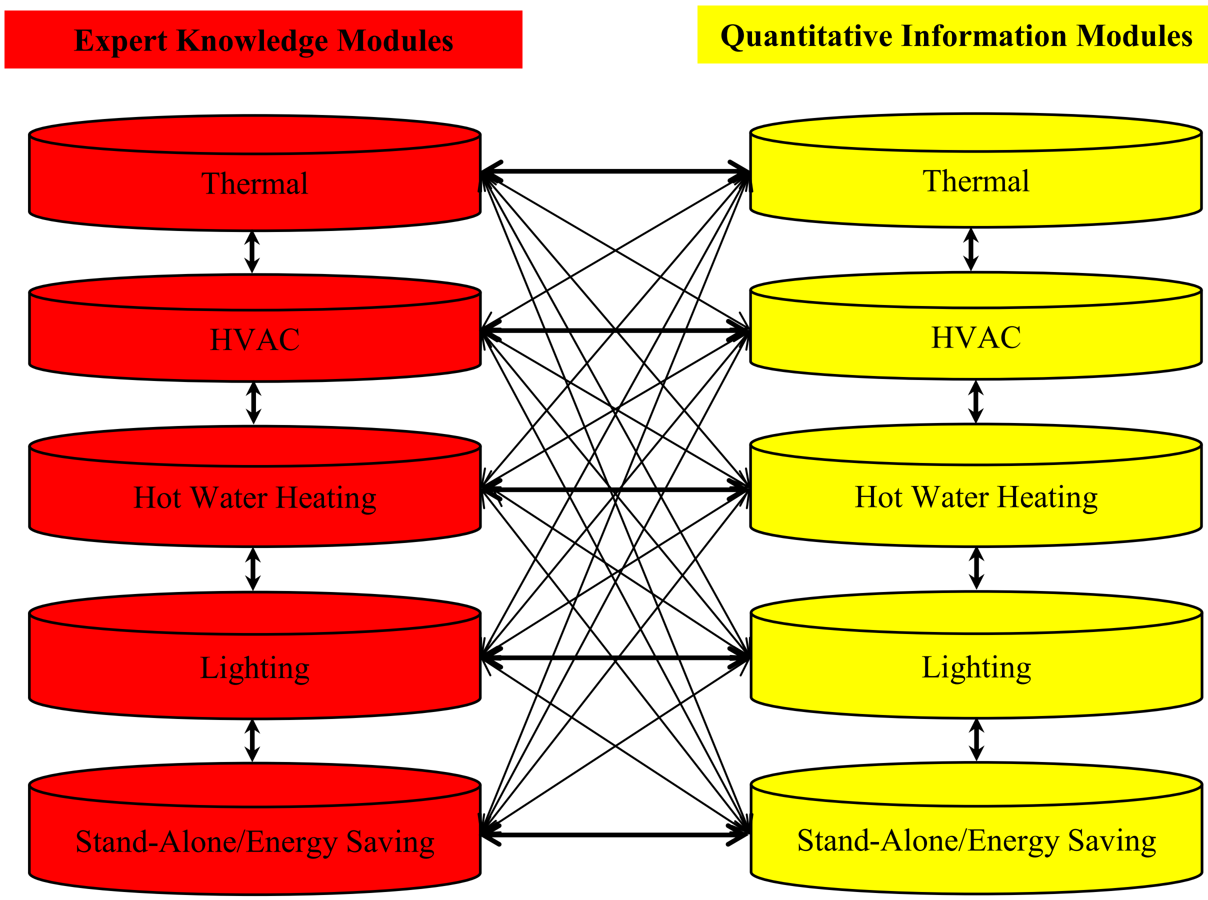


Figure 7.2: Harmonization of Quantitative Information with Knowledge-Based Modules

7.4.2 Quantification of Home Energy Retrofit Benefits

Three important reasons why homeowners undertake energy retrofits were identified as relating to financial, comfort, and health issues. Through the limited test of the system and based on inferences made during the analysis of the data, it was identified that the cost of the retrofit and the return on investment, reduced to a specific number for each retrofit action, was a priority for homeowners. An initial attempt was made in previous studies about calculating the payback on investing in each retrofit measure. There are, however, other indicators for determining such information. For instance, to determine the return on investment on a heating system retrofit, information regarding the type of system used, energy bill, cost of energy, frequency of use, how long homeowner will stay in the home, etc. are useful. The researcher recommends that future work is done in order to identify a comprehensive system that can be used for the following:

- Calculating return on investment for each measure
- Combinations of measures that will yield the most return on investment using the whole house system approach
- Developing a metric to quantify the health and comfort returns on investment.

Thus, a comprehensive quantification of the benefits of energy retrofit can be developed and provided to users using the medium developed by the researcher in order to improve the uptake of home energy retrofits.

7.5 CHAPTER SUMMARY

This chapter provided a summary of the research aim and objectives, and what was achieved regarding the development of an intelligent decision support system framework for home energy retrofits. The main goal and a summary of the outputs were provided based on each objective. Next, contributions, inferences, and conclusions of this research were highlighted. Finally, recommendations for future research were outlined. The researcher envisages that the implementation of the findings of this research will reduce the information barriers to the uptake of home energy retrofits, leading to an increase in the uptake of home energy retrofits and, hence, reducing energy consumption of buildings to acceptable levels. The researcher further envisages that the determinants of industry expert knowledge and its elicitation, and the intelligent decision support system framework will be accepted and incorporated into mainstream industry practices, training, development, and scholarly research.

APPENDICES

APPENDIX A.1

Preliminary Questionnaire for Developing EREIS and EREES in Delphi Round 1

Title: Intelligent Decision Support System Framework for Energy Retrofits in Existing Homes

1.0 OVERVIEW

In order to undertake energy efficiency retrofit, homeowners pursue information from a variety of sources such as word of mouth, trade and retrofit contractors, energy auditors, retail and lumberyard employees, federal and state government resources etc. These information sources can be put into two broad categories of "*expert knowledge/expert advice*" and "*quantitative of published information*" (Figure A.1).

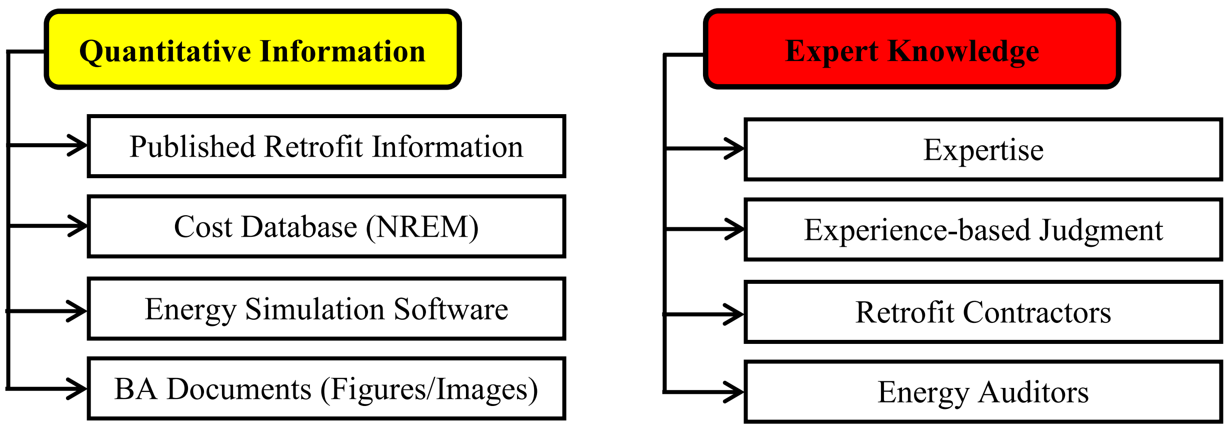


Figure A.1: Two Key Information Categories/Sources

Both of these two categories of information are utilized by stakeholders such as consumers, energy auditors, retrofit and trade contractors, designers, developers etc. This research focuses on the use of expert knowledge in energy retrofit decision making.

The purpose of this questionnaire is two-fold:

1. Elicit information that will lead the development of standard criteria for determining an energy efficiency retrofit expert
2. Elicit information to be used to compile the protocol followed for energy retrofit decision-making

A. GENERAL QUESTIONS

1. Which of the following energy retrofit businesses does your firm engage in?
   a. Whole House Contractor
   b. Energy Auditing
   c. Retrofit Contracting
   d. Quality Inspection
   e. More than one (please indicate)
   f. Others (please specify)

2. What role do you play in your firm?
   a. Owner
   b. Chief auditor
   c. Chief executive officer
   d. Other (please specify)

3. Kindly indicate the main duties you perform in the role you play in the firm. E.g. Owner and Chief Auditor and I manage the work in General Contracting.

4. What services of home energy retrofit do you perform and why?
   a. Which of the services do you self-perform and which ones are subcontracted?
   b. Which of your services have a higher profit margin?

5. What specific energy efficiency retrofit jobs are you licensed or certified to perform? Kindly mention the specific license/certificate you currently hold. E.g. licensed builders for retrofit work such as insulation, HVAC, appliances, air sealing etc.

6. What state or geographic region do you mainly operate in?

7. Do you belong to any of the professional associations in the energy efficiency retrofit domain? E.g. BPI, RESNET, Efficiency First, Air-Conditioning Contractors of America.

B. ENERGY RETROFIT EXPERIENCE SPECIFIC QUESTIONS

1. How long have you been working in energy efficiency retrofits for existing homes?
   a. 1 year
   b. 2 – 3 years
   c. 3 – 4 years
   d. 4 – 5 years
   e. Above 5 years

2. How many energy retrofits have you done since you started working in this domain?
   a. 1 – 30
   b. 31 – 60
   c. 61 – 90
   d. 91 – 150
   e. Above 150

3. How many retrofits, on average, do you complete each year?
   a. 1 – 5
   b. 6 – 10
   c. 11 – 15
   d. 16 – 20
   e. Above 20

4. Based on your experience, how many retrofits do you think must be performed by a retrofit professional in a year to make them proficient and why?

5. Does being away from the industry over a period make you less proficient? Kindly give reasons for your answer.
   a. Yes
   b. No

6. If yes, how long away from work in the retrofit industry would you consider as damaging to the skills set of a professional and hence would need some retraining?
   a. 6 – 12 months
   b. 1 – 2 years
   c. 3 – 5 years
   d. Above 5 years

7. Have you been away from the industry before? If yes, for how long were you away and did you require retraining?

C. HABITUAL DECISION MAKING SPECIFIC QUESTIONS

1. When performing your work, how often do you refer to colleagues, books, manuals, internet, etc. to reinforce information you give to homeowners?
   a. All the time
   b. Quite often
   c. Sometimes
   d. Not very often
   e. Not at all

2. Are you aware of the tax incentives, rebates, and benefits available to homeowners when they undertake an energy retrofit?
   a. Yes
   b. No

3. If yes, how do you get this information?
   a. Government websites/documents
   b. Attending government organized programs
   c. Colleagues in the industry
   d. When I come across any, I keep it
   e. Others (please specify)

4. When a homeowner asks you to justify or explain your decision or actions, how do you go about it?
    a. Do you use illustrative or similar examples of previous cases?
    b. Do you refer them to books or websites so that they can confirm your decisions?
    c. Do you usually refer them to your experience have been in the profession?
    d. Do you ask them to seek second opinion if they do not trust your advice?
    e. Other (please specify)

5. Several measures have been suggested for improving the energy efficiency of existing homes. For instance, replacing incandescent light bulbs with CFLs. Kindly list other measures to improve the energy efficiency of existing homes.

D. IDENTIFYING MEASURES SPECIFIC QUESTIONS

1. Comment on the following scenario – You have to recommend energy retrofit measures for a home and you have no means of performing testing on the home. Explain in a step by step manner, what methods you will use to make that decision. Note that the homeowner is highly informed about the home and is able to give you relevant information regarding equipment efficiencies, insulation types and levels, age of home and building system, etc.

2. What are some of the considerations you make when you have to select an energy efficient product or appliance for a home?

3. Different homes have different retrofit needs. What aspects of the home will determine the need? E.g. is it the construction type, architectural type, age of the home etc.?

4. Kindly provide a step by step method that you will use to perform an "Energy Auditing."

5. What specific benefits can be obtained when you perform energy retrofit of a home?

6. What building regulations are important at the Local, State, and Federal levels in energy retrofits?

E. SHORTLISTING/PRIORITIZING MEASURES SPECIFIC QUESTIONS

1. What are some of the most common questions that homeowners ask when they decide to retrofit their homes?

2. What are the major reasons that motivate home owners to pursue home energy retrofits?

3. What are some of the measures that provide the greatest return on investment for a home owner?

4. What are some external factors which increase the cost of the retrofit operation? What steps can homeowners take to reduce such costs?

5. Give the order of importance from the list below that home owners expect from a retrofit measure:
   a. Cost of Measure b. Return on Investment c. Comfort

6. Kindly provide a list of post occupancy health issues that must be addressed in energy retrofits.

7. Buildings behave as a system where interactions between components can affect their energy performance. Based on the list provided below, kindly prioritize the measures based on what you feel is the ideal sequence to achieve best results. Kindly give reasons for your answer.
   - Lighting
   - Air sealing
   - Appliances
   - Cooling measures
   - Heating measures
   - Thermal insulation
   - Water heating

8. An expert must not only be experienced but be competent. Can you indicate the competencies that an energy retrofit expert must possess?

F. INSTALLATION ADVICE SPECIFIC QUESTIONS

1. What are the key issues a retrofit installer should be concerned with when installing the following:
   - Crawlspace air sealing and insulation
   - Foundation wall insulation
   - Above grade wall insulation
   - Attic air sealing and insulation
   - HVAC equipment upgrade and Duct improvement

2. Kindly provide general categories of information you think are necessary for a retrofit installer.

3. Are there any measures you consider safe and can be installed by a homeowner? Kindly give reasons for your answer.

4. Kindly provide a list of measures that in your opinion must be installed by a licensed retrofit professional? Kindly give reasons for your answer.

5. Kindly provide a list of safety precautions that a retrofit installer must take.

G. COMMENTS

APPENDIX A.2

Finalized Questionnaire for Developing EREIS and EREES in Delphi Round 1

Title: Intelligent Decision Support System Framework for Energy Retrofits in Existing Homes

1.0 OVERVIEW

In order to undertake energy efficiency retrofit, homeowners pursue information from a variety of sources such as word of mouth, trade and retrofit contractors, energy auditors, retail and lumberyard employees, federal and state government resources etc. These information sources can be put into two broad categories of "*expert knowledge/expert advice*" and "*quantitative of published information*" (Figure AA.1).

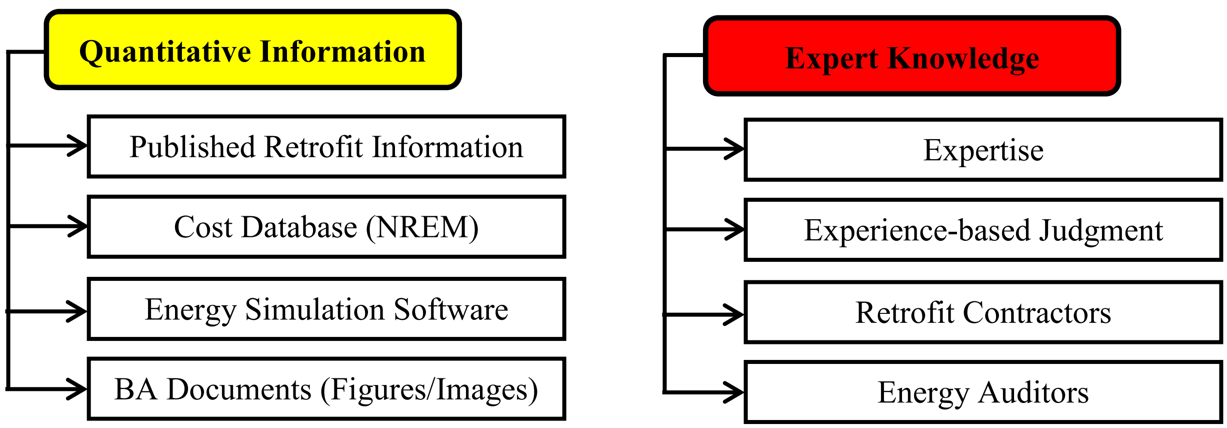


Figure A.2: Two Key Information Categories/Sources

Both of these two categories of information are utilized by stakeholders such as consumers, energy auditors, retrofit and trade contractors, designers, developers etc. This research focuses on the use of expert knowledge in energy retrofit decision making.

The purpose of this questionnaire is two-fold:

1. Elicit information that will lead the development of standard criteria for determining an energy efficiency retrofit expert
2. Elicit information to be used to compile the protocol followed for energy retrofit decision-making

A. GENERAL QUESTIONS

1. Which of the following energy retrofit businesses does your firm engage in?
    a. Whole House Contractor
    b. Energy Auditing
    c. Retrofit Contracting
    d. Quality Inspection
    e. More than one (please indicate)
    f. Others (please specify)

2. What role do you play in your firm?
    a. Owner
    b. Chief auditor
    c. Chief executive officer
    d. Other (please specify)

3. Kindly indicate the main duties you perform in the role you play in the firm. E.g. Owner and Chief Auditor and I manage the work in General Contracting.

4. What services of home energy retrofit do you perform and why?
    a. Which of the services do you self-perform and which ones are subcontracted?
    b. Which of your services have a higher profit margin?

5. What specific energy efficiency retrofit jobs are you licensed or certified to perform? Kindly mention the specific license/certificate you currently hold. E.g. licensed builders for retrofit work such as insulation, HVAC, appliances, air sealing etc.

6. What state or geographic region do you mainly operate in?

7. Do you belong to any of the professional associations in the energy efficiency retrofit domain? E.g. BPI, RESNET, Efficiency First, Air-Conditioning Contractors of America.

B. ENERGY RETROFIT EXPERIENCE SPECIFIC QUESTIONS

1. How long have you been working in energy efficiency retrofits for existing homes?
    a. 1 year
    b. 2 – 3 years
    c. 3 – 4 years
    d. 4 – 5 years
    e. Above 5 years

2. How many retrofits, on average, do you complete each year?
    a. 1 – 5
    b. 6 – 10
    c. 11 – 15
    d. 16 – 20
    e. Above 20

3. Based on your experience, how many retrofits do you think must be performed by a retrofit professional in a year to make them proficient and why?

4. Does being away from the industry over a period make you less proficient? Kindly give reasons for your answer.
   a. Yes
   b. No

5. If yes, how long away from work in the retrofit industry would you consider as damaging to the skills set of a professional and hence would need some retraining?
   c. 6 – 12 months
   d. 1 – 2 years
   e. 3 – 5 years
   f. Above 5 years

6. Have you been away from the industry before? If yes, for how long were you away and did you require retraining?

C. HABITUAL DECISION MAKING SPECIFIC QUESTIONS

1. When performing your work, how often do you refer to colleagues, books, manuals, internet, etc. to reinforce information you give to homeowners?
   a. All the time
   b. Quite often
   c. Sometimes
   d. Not very often
   e. Not at all

2. Are you aware of the tax incentives, rebates, and benefits available to homeowners when they undertake an energy retrofit? If yes, how do you get this information?
   a. Government websites/documents
   b. Attending government organized programs
   c. Colleagues in the industry
   d. When I come across any, I keep it
   e. Others (please specify)

3. When a homeowner asks you to justify or explain your decision or actions, how do you go about it?
   a. Do you use illustrative or similar examples of previous cases?
   b. Do you refer them to books or websites so that they can confirm your decisions?
   c. Do you usually refer them to your experience have been in the profession?
   d. Do you ask them to seek second opinion if they do not trust your advice?
   e. Other (please specify)

4. Several measures have been suggested for improving the energy efficiency of existing homes. For instance, replacing incandescent light bulbs with CFLs. Kindly list others.

D. IDENTIFYING MEASURES SPECIFIC QUESTIONS

1. You have to recommend retrofit measures for a home that you have no means of testing. What are the signs that will indicate that the home needs a complete energy evaluation?

2. Different homes have different retrofit needs. What aspects of the home will determine the need? E.g. is it the construction type, architectural type, age of the home etc.?

3. How would you explain what "Energy Auditing" means to a homeowner?

4. What specific benefits can be obtained when you perform energy retrofit of a home?

E. SHORTLISTING/PRIORITIZING MEASURES SPECIFIC QUESTIONS

1. What are some of the most common questions that homeowners ask when they decide to retrofit their homes?

2. What are the major reasons that motivate home owners to pursue home energy retrofits?

3. What are some of the measures that provide the greatest return on investment for a home owner?

4. What are some external factors which increase the cost of the retrofit operation? What steps can homeowners take to reduce such costs?

5. Kindly provide a list of post occupancy health issues that must be addressed in energy retrofits.

6. Buildings behave as a system where interactions between components can affect their energy performance. Based on the list provided below, kindly prioritize the measures based on what you feel is the ideal sequence to achieve best results. Kindly give reasons for your answer.
    - Lighting
    - Air sealing
    - Appliances
    - Cooling measures
    - Heating measures
    - Thermal insulation
    - Water heating

7. An expert must not only be experienced but be competent. Can you indicate the competencies that an energy retrofit expert must possess?

F. INSTALLATION ADVICE SPECIFIC QUESTIONS

1. What are the key issues a retrofit installer should be concerned with when installing the following:

    - Crawlspace air sealing and insulation

    - Foundation wall insulation

    - Above grade wall insulation

    - Attic air sealing and insulation

    - HVAC equipment upgrade and Duct improvement

2. Are there any measures you consider safe and can be installed by a homeowner? Kindly give reasons for your answer.

3. Kindly provide a list of measures that in your opinion must be installed by a licensed retrofit professional? Kindly give reasons for your answer.

G. COMMENTS

APPENDIX B.1

Detailed Analysis of Data Obtained For Developing EREIS and EREES in Delphi Round 1

ENERGY RETROFIT EXPERIENCE SPECIFIC QUESTIONS

ATTRIBUTE 1 – NUMBER OF YEARS IN ENERGY RETROFIT INDUSTRY

1. How long have you been working in energy efficiency retrofits for existing homes?
This question sought to elicit information from the panel of experts regarding the number of years they had spent in the energy retrofit industry. Since the panel member were chosen from different backgrounds and have worked in the industry for varying number of years, the intention was not to seek consensus on their responses but rather to give an indication of the spectrum of experience of the panel members.

Since the industry is a relatively new one and there was a need to develop a criteria to identify who an expert in this industry is, a close interval of number of years was used as the range for their experience. Table B.1 indicates the number of years spent in the energy retrofit industry by the panel.

Table B.1: Number of Years in the Energy Retrofit Industry

Years	Percent (%)
0 – 2	19.05
3 – 5	33.33
6 – 8	9.52
9 – 11	14.29
12 or more	23.81

From Table 1, it can be seen that, most of the panel members have worked in the industry for a period in the range of 3 – 5 years representing 33.33%. The next category of range where most of the expert panel has worked is more than 12 years representing 23.81%. The period range which has the least number of people is 6 – 8 years which has only 9.52 percent of the panel working for that amount of time in the industry.

Since no consensus was required for this question, there was no need to include this question in the second round of the Delphi process.

ATTRIBUTE 2 – NUMBER OF AUDITS/RETROFITS

2. How many audits/retrofits, on average, do you complete each year?
In order to help establish a fair criterion for the number of audits and or retrofits to be completed by experts in the industry in order to main or improve their proficiency levels, this question sought to elicit information regarding the number of audits and/or retrofits completed by the panel members. The intention was for this to serve as a guide in setting the criteria.

An analysis of the responses received indicated that, 2 panel members performed energy audits exclusively thus were unable to respond to the second part of the question requesting information for the number of retrofits performed. 11 other panel members did mainly energy auditing but did perform limited retrofits and hence did not provide information regarding the number of retrofits completed. 2 panel members did both energy audits and retrofit work and hence provided information for both. Finally, there were 5 panel members who did mainly retrofit work and some energy audit hence did not provide information regarding the number of audits they performed.

An analysis of the data received indicated 15 responses for the number of panel members who did some energy audit work and provided information and 7 responses for the number of panel members who did some retrofit work. Table B.2 shows the number of audits completed on average each year by the 15 panel members. Table B.3 shows the number of retrofits completed on average each year by the 7 panel members who did some retrofit work.

Table B.2: Average Number of Audits/Year

No. of Audits	No. of People	Percent (%)
0 - 10	0	0
11 - 20	3	20
21 - 30	1	6.67
31 - 40	1	6.67
41 - 50	2	13.33
51 - 60	1	6.67
61 or more	7	46.66
Total	**15**	**100**

Table B.3: Average Number of Retrofits/Year

No. of Retrofits	No. of People	Percent (%)
0 - 10	3	42.86
11 - 20	0	0
21 - 30	1	14.29
31 - 40	1	14.29
41 - 50	0	0
51 - 60	0	0
61 or more	2	28.57
Total	**7**	**100**

An analysis of Table B.2 indicates that, 46.66% of the panel members more than 60 audits each year translating to a minimum of 5 audits each month. The highest number of audits performed by an expert panel member was 400 per year translating to approximately 33 each month or 1 audit each day. Compared to retrofits, the audits take a relatively shorter time to complete and hence more can be performed within a given time period. An analysis of the characteristics of the panel members indicates that, there is a direct correlation between those who do mainly energy audits and those who do the highest number of audits. Based on Table B.2, it can be seen that no member of the panel did 10 or less number of audits each year and the lowest number of audits performed by the panel members were 21 – 30, 31 – 40 and 51 – 60 each representing 6.67% of the panel members.

In terms of the number of retrofits, it was found that, the most experts (42.86%) performed up to 10 retrofits each year. An analysis of the background of this group indicates that most of these experts work either in not for profit organizations or mainly concentrate on performing energy audits. For the next highest category which is more than 60 retrofits each year represented by 28.57% of the expert panel, there is a direct correlation between the experts who mainly do retrofit with little or no energy audits and the high number of retrofits approximately 5 retrofits a month.

Information elicited for this question and its analysis was useful in setting a criterion for determining who an expert is in this industry. Since this was meant to be a guide and hence there was no need for building consensus, this question was not moved to the next round of the Delphi process.

3. Based on your experience, how many retrofits do you think must be performed by a retrofit professional in a year to make them proficient and why?

This question sought the opinion of panel members about the number of audits or retrofits that has to be completed by an energy retrofit professional in order to be considered an expert. This question will be used in combination with the responses elicited and analyzed for question 2 which sought to find out the current work done by the panel members. For this question, consensus was expected to be reached in order to help develop a robust criterion for determining energy retrofit experts.

A trend similar to what was observed for question 2 above was recorded for this question too. Panel members, whose sole expertise was in performing energy retrofits, did not offer information regarding the number of retrofits that must be performed by a professional in order to maintain their proficiency. The reverse was also true for those who mainly perform retrofit work. As a result, there were only 7 responses regarding the number of audits that must be performed by a professional in order to keep up with their proficiency levels. For the number of retrofits, there were 13 responses. Tables B3A and B3B below indicates the breakdown for the number of audits and number of retrofits respectively.

An analysis of Table B.4 indicates that there is no consensus among the panel about the number of audits that must be performed by energy retrofit professionals in order to make them proficient. For the range of 41 – 50 audits and 51 or more audits per year, 28.60% each of the panel members agreed on this number. For the next group of ranges, that is 0 – 10, 21 – 30, and 31 – 40, 14.30% of the panel members agreed with each of these ranges. Since there was no clear consensus for this question, there was a need to summarize the findings and include in the next round of the Delphi survey.

Table B.4: Yearly Number of Audits for Proficiency

No. of Audits	No. of People	Percent (%)
0 - 10	1	14.30
11 - 20	0	0.00
21 - 30	1	14.30
31 - 40	1	14.30
41 - 50	2	28.60
51 or more	2	28.60
Total	**7**	**100.00**

Table B.5: Yearly Number of Retrofits for Proficiency

No. of Retrofits	No. of People	Percent (%)
0 - 10	4	30.80
11 - 20	3	23.10
21 - 30	3	23.10
31 - 40	0	0.00
41 - 50	1	7.70
51 or more	2	15.30
Total	**13**	**100.00**

A similar situation occurred for the number of retrofits as can be seen from Table B.5. There was no consensus on the ideal number of retrofits to be completed each year in order to make a energy retrofit professional proficient. 30.80% of the panel members agreed with the 0 – 10 range, whilst 23.10% of the panel members agreed with each of the following ranges 11 – 20 and 21 – 30. Clearly this is well short of the predetermined consensus percent of 70% hence this question would be included in the next round of the Delphi survey.

4. Does being away from the industry over a period make you less proficient? Kindly give reasons for your answer.

Since the energy retrofit industry in a relatively new one, this question sought the opinion of the panel members to indicate if being away from the industry for an extended period was going to affect the proficiency levels of the professionals. The panel members were also encouraged to give reasons for their answer. This was going to help to establish the importance of being constantly engaged in the industry and if being away has a negative effect on the proficiency level of professionals and hence to be included as a criterion for determining an expert.

Table B.6 indicates the responses to identify if being away from the industry over a period affects a professional's proficiency and Table B.7 indicates the reasons for this.

Table B.6: Effects of Absence from Industry on Proficiency

Response	Number of People	Percent (%)
Yes	21	100
No	0	0

Table B.7: Reasons Why Prolonged Absence Affects Proficiency

Reason	Number of People	Percent (%)
Changing industry hence knowledge update	17	81
Proficiency increases	4	19

An analysis of Table B.6 indicates that there is 100% consensus by the panel members that being away from the industry for a period of time does affect the proficiency of energy retrofit professionals. There is also consensus (81%) on the reason for this assertion made by the panel members which is that, the industry is a changing one and hence there is a need to constantly update the knowledge base of a professional in this industry in order to keep their expertise at a top level (See Table B.7).

Since consensus has been reached for this question, it will not be included in the next round.

5. If yes, how long away from work in the energy retrofit industry would you consider as damaging to the skills set of a professional and hence would need some retraining?

This question was a conditional one and premised on question 4. If there was consensus about affirming the premise of question 4, then this question part sought to identify what duration would be considered as damaging to the skills set and hence proficiency of energy retrofit professionals. Table B.8 indicates the responses of the panel members. Information regarding the two parts of question 4 and that of question 5 therefore would form a good basis in developing a criterion for determining who an expert is in this industry.

Table B.8: Duration Away from Industry Detrimental to Skills of Professional

Number of Years	Number of People	Percent (%)
0.25	1	5
0.50	4	19
1.0	16	76
2.0	0	0
Total	**21**	**100**

An analysis of Table B.8 indicates that there is consensus (76%) among the panel members that being away from the industry for 1 year will adversely affect the proficiency of energy retrofit professional. Further analysis of Table B.8 indicates that when the range for the number of years is put as "up to 1 year", there is absolute consensus (100%).

Since consensus has been reached for this question, it will not be included in the next round of the Delphi survey.

ATTRIBUTE 3 – BREAK FROM INDUSTRY

6. Have you been away from the industry before? If yes, for how long were you away and did you require retraining?

Having established that being away from the industry over a period make you less proficient mainly because it is a changing industry hence there is a need for knowledge update in question 4 and also that being away from the industry for 1 years will be damaging to the skills set and hence the proficiency of energy retrofit professionals in question 5, question 6 sought to establish a criterion that combined responses from questions 4 and 5. Thus, based on the premises for both questions indicated above are true and a professional has been away from the industry for a time period beyond a year, then their proficiency would have reduced and hence cannot be regarded as experts in this industry. The responses are indicated in Table B.9 below.

Table B.9: Responses to Indicate Absence from Energy Retrofit Industry

Response	Number of People	Percent (%)
Yes	21	100
No	0	0

Another inherent reason for this question was also to help identify whop the experts were in order to know which responses to include in the expertise elicitation section of the research. As can be seen from Table B.9, all panel members had never been away for extended period of time beyond the duration agreed on by the panel members. Even though this question did not require consensus, the absolute consensus arrived at from the responses reinforces the importance of this criterion for determining an energy retrofit expert.

HABITUAL DECISION-MAKING SPECIFIC QUESTIONS

ATTRIBUTE 4 – KNOWLEDGE UPDATE FREQUENCY

7. When performing your work, how often do you refer to colleagues, books, manuals, internet, etc. to reinforce information you give to homeowners?

In terms of expert reasoning, there is a declarative-to-procedural shift thus, highly practiced skills such as reading or cycling that is initially taught explicitly becomes tacit or automatic (Hoffman 1996; Klein & Hoffman 1993; Lesgold *et al.* 1988; Hart 1989; McGraw & Harbison-Briggs 1989; Sanderson 1989).

Based on the literature review, the initial position of the researcher was that, an expert must be knowledgeable enough so as to rely on their accumulated experience, have self confidence in decision-making, a greater skill at anticipation, have vast amount of strategies and mechanisms for applying to situations and appropriately organize their knowledge (Farrington-Darby & Wilson 2006; Shanteau 1992b; Glaser & Chi 1988; Cellier 1997; Armstrong 2003). Expert interviews established the need to constantly update your knowledge.

Based on responses from the panel members however, it was established that the industry is a relatively new one and rapidly changing thus it was important that experts constantly update their knowledge in order to maintain or improve their proficiency levels. This question therefore sought to identify how often experts updated their knowledge and from what sources.

As can be seen from Table B.10 there was consensus (76%) among the panel members about the importance of definitely making reference to other information sources in order to maintain or improve their knowledge base. This was used as a criterion in determine who an expert is thus energy retrofit professionals who rarely updated their knowledge were not considered as experts as there was going to be a knowledge gap due to the changing nature of this industry.

Table B.10: Frequency of Updating Knowledge through References

Frequency	Number of People	Percent (%)
Definite Reference	16	76
Some Reference	5	24
No Reference	0	0
Total	**21**	**100**

Since there was consensus on this question by the panel members, there was no need to include it in the next round of the Delphi survey.

ATTRIBUTE 5 – AVAILABLE FINANCIAL AID KNOWLEDGE

8. Are you aware of the tax incentives, rebates, and benefits available to homeowners when they undertake an energy retrofit? If yes, how do you get this information?

Since experts have extensive up to date content knowledge (Farrington-Darby & Wilson 2006) and this affects what they notice and how they organize, represent, and interpret information in their environment (Bransford *et al.* 2004), this question was part of a series of question that elicited the knowledge of experts on different subjects.

During the first round of the Delphi survey which initially involved the focus group, the importance of the awareness of tax rebates to the industry and the need to belong to trade organizations in order to obtain up-to-date knowledge was emphasized by that panel. An analysis of the data elicited from the panel indicated that all of them were aware of financial aid available in this industry (See Table B.11) and also indicated 5 main sources for this information. There was no upper limit placed on the number of different sources that panel members sought information from. Table B.11 indicates the number of sources of information that panel members indicated they sought information about financial aid in the industry.

Table B.11: Awareness of Available Financial Aid in HER Industry

Awareness of financial aid in industry	Number of People (%)
Yes	100
No	0

From Table B.12 it can be seen that most panel members (38%) sought financial aid information from 2 sources. Next, 33% of panel members sought information from 3 sources. There was no need for consensus on this question but rather, it was to guide in developing the criterion for identifying an expert in this industry.

Table B.12: Number of Sources of Financial Information by Panel Members

Number of Sources	Number of People	Percent (%)
1	4	19
2	8	38
3	7	33
4	1	5
5	1	5
Total	**21**	**100**

In order to establish standard sources of information for financial aid in the industry, consensus was sought on the 5 different information sources identified (Table B.13).

Table B.13: Standard Sources of Information for Financial Aid in Industry

Information Source	No. of People	Percent (%)
Trade Organization	8	38.09
Utility Program	15	71.43
Government	10	47.62
Colleagues	10	47.62
Electronic News Media	6	28.57

Again, since there was no upper limit put on the number of sources that each panel member could mention and making reference to Table B.12, the tally for all 5 information sources was more than 100%. Each information source was however calculated as a percentage of the total number of panel members. For example Utility Programs was the information source mentioned by most of the panel members. When calculated as a percentage of the total number of panel members, it was 71.43%.

Since consensus was not reached for the standard financial aid information sources in the industry, this question will be included in the next round of the Delphi survey.

ATTRIBUTE 6 – JUSTIFYING/EXPLAINING DECISIONS/ACTIONS

9. When a homeowner asks you to justify or explain your decision or actions, how do you go about it?

This question sought to elicit traits that experts possess and use when they are faced with situations necessitating the need to justify or explain decisions or actions that they take. Extensive review of literature revealed the following traits that experts possess: case based reasoning, self-confidence in decision-making, responsibility and willingness to stand by recommendations, flexibility to generate scenarios, and relying on accumulated experience (Armstrong 2003; Cellier 1997; Glaser & Chi 1988; Farrington-Darby & Wilson 2006; Hart 1989; Hoffman 1996; Klein & Hoffman 1993; Lesgold *et al.* 1988; McGraw & Harbison-Briggs 1989; Sanderson 1989; Shanteau 1992b).

Traits identified from the panel members include the following:

1. Case based reasoning (CBR)
2. Asking homeowners to seek second opinion if they do not trust their advice (SSO)
3. Relying on their accumulated personal experience (PE)
4. Extensive use of diagnostic tools (DT)
5. Using energy modeling software to explain decisions or actions (EMS)
6. Providing relevant information sources to homeowners (PRIS)
7. Making logical and emotional connection with homeowner (MLECH)
8. Making an impression that they know (MIMP)
9. Use utility company identity to engender trust (UCIET)

The first seven traits can be put under the five broad categories identified from the literature as follows:

1. Case based reasoning is the same and will be maintained (CBR)
2. By asking homeowners to seek second opinion if they do not trust their advice, the panel members display self-confidence in decision-making (SCIDM)
3. Relying on accumulated experience is the same and will be maintained (RAE)
4. Through extensive use of diagnostic tools, panel members display the flexibility to generate scenarios in order to explain difficult or new scenarios (FGS)
5. By using energy modeling software, panel members display the flexibility to generate scenarios in order to explain difficult or new scenarios (FGS)
6. Panel members are able to provide relevant information sources since they have a strong sense of responsibility and are willing to stand behind their recommendations (RWSR)
7. By making logical and emotional connection with homeowner, panel members display their flexibility to generate scenarios and the reliance on their accumulated experience (FGS and RAE)

Based on this categorization Table B.14 indicates the dominating traits employed by panel members when asked to justify or explain the decisions they make or actions they take.

Table B.14: Dominating Traits Employed by Experts in Justifying Decisions/Actions Taken

Dominating Traits	Number of People	Percent (%)
CBR, SCIDM, RAE, FGS, and/or RWSR	20	95.24
MIMP, UCIET, and RWSR	1	4.76
Total	**21**	**100.00**

Since consensus was achieved for this question (95.24%), there was no need to include it in the next round of the Delphi survey.

ATTRIBUTE 7 – RETROFIT MEASURES KNOWLEDGE

10. Several measures have been suggested for improving the energy efficiency of existing homes. For instance, replacing incandescent light bulbs with CFLs. Kindly list other measures to improve the energy efficiency of existing homes.

The purpose of this question was to elicit routine but important knowledge regarding typical measures employed by panel members in order to improve the energy efficiency of existing homes. This was then compared with existing quantitative information identified through literature review leading to the identification of the following 12 measures:

1. Low flow showerheads (LFSH)
2. Faucets (FT)
3. Ductwork and pipe wrap (DWPW)
4. Windows
5. Doors
6. Air sealing (ARSLN)
7. Insulation (INSL)
8. Heating, ventilation, and cooling (HVAC)
9. Water heater (WTH)
10. Lighting
11. Appliances
12. Homeowner education (HED)

The Home Energy Consultation (HEC) program of the DTE Energy Company is an in-home energy consultation that provides homeowners with an energy assessment of their home. Typical energy efficient measure installations include the following items: compact fluorescent light bulbs, water heater pipe insulation, water saving showerheads and faucet aerators (DTE Energy Company 2013). A home energy survey (HES) is a visual inspection and does not include the use of diagnostic testing equipment (RESNET 2013).

Since most of these measures do not have a huge effect on reducing the energy consumption of buildings, a category was created based on the DTE's HEC program and RESNET's HES definition and was called energy survey measures (ESM). Three measures included in the ESM category are: water heater pipe insulation, water saving showerheads and faucet aerators. In addition, since most retrofit contractors who perform windows also perform door measures and that both are measures that provide the least return on investment, both were put under one category door and window (DWM) measures. As a result the total number of measures was reduced from 12 to 9 and is listed below:

1. Energy saving measures (ESM)
2. Door and window measures (DWM)
3. Air sealing (ARSLN)
4. Insulation (INSL)
5. Water heater (WTH)
6. Heating, ventilation, and cooling (HVAC)
7. Lighting (LGHTN)
8. Appliances (APPLN)
9. Homeowner education (HED)

In order to enhance the criterion for determining an expert in the HER industry, the knowledge of a number of measures was critical. It was determined through literature review and panel interview that, there are at least 4 critical measures that every HER professional must know: (a) tightening of envelope measures such as air sealing and insulation; (b) heating and cooling measures such as furnaces, ventilation systems, air conditioners etc.; (c) stand-alone measures such as lighting and appliances; and (d) energy saving measures such as water heater pipe insulation, water saving showerheads and faucet aerators.

Based on the above categorization of measures, the knowledge of number of measures by panel members started form 1 measure to 4 or more measures (Table B.15) below.

Table B.15: Knowledge of Number of Measures for Improving Energy Efficiency

Number of Measures	Number of People	Percent (%)
1	1	4.8
2	0	0.0
3	3	14.3
4 or more	17	80.9
Total	**21**	**100.0**

An analysis of Table B10 reveals that there is consensus on the number of measures that panel members have in their knowledge base and employ in order to make a home energy efficient. This will help in enhancing the criterion for determining a HER expert. There was no need to include this question in the next round of the Delphi survey.

COMPETENCY SPECIFIC QUESTIONS

ATTRIBUTE 8 – BUILDING SCIENCE AND CONSTRUCTION KNOWLEDGE

11. How would you explain in a step-by-step manner, the methods you will use to recommend retrofit measures for a home that you have no means of testing?

The purpose of this question was twofold: first it sought to identify the building science and construction knowledge and experience required to succeed in this industry mainly by eliciting information about conducting visual inspection without the use of diagnostic testing equipment and secondly to elicit information that will help in the eventual development of rules for the future development of the proposed IDSS framework.

An analysis of the responses from the panel members indicated 44 various responses, which are summarized below:

1. Inspect HVAC system
2. Condition of mechanical system
3. Check window condition
4. Check for signs of air leakage
5. Check for signs of moisture leakage
6. Presence of dust and cobwebs
7. Presence of condensation
8. Leaky ductwork
9. Insulation/holes in attic
10. Holes in rim joists
11. Homeowner comfort
12. Utility bills
13. Snow on roof
14. Orange hole around chimney
15. Insulation level of kitchen bulkhead
16. Equipment efficiency
17. Type of light bulbs
18. Age of appliances

19. General condition of house
20. Holes in foundation
21. Grade away from foundation/house
22. Gas leaks
23. Roof repairs
24. Gutter repairs
25. Insulation in walls
26. Insulation on sill plate or rim joist
27. Dirty insulation, spider, cobwebs
28. Mechanical penetrations in ceiling
29. Window type and installation
30. Presence of icicles
31. Spider web and pests in basement
32. Windows have large gaps
33. Things between window panes
34. Floor temperature difference
35. No insulation
36. Construction type
37. Age of home
38. Archetype
39. Leaky attic hatch
40. Door condition
41. Window condensation
42. Peeling off/tearing of shingles
43. Plastic pipe through walls
44. Off lights – see light from outside?

In order to harmonize the 44 responses elicited, the researchers put them into 7 broad categories based on that provided by RESNET (2013) under the purpose for home energy surveys which is to assess the general energy performance of an existing home including:

1. Building envelope features (windows, doors, insulation, ducts) and ages (BEFA)
2. Heating, cooling and ventilation equipment types, characteristics and ages (HVACA)
3. Appliance and lighting characteristics (ALC)
4. Comfort complaints (CC)
5. Visible moisture issues (VMI)
6. Visible health and safety issues (VHSI)
7. Review of utility use and billing history (RUUBH)

The 7 categories mentioned above will be included in the next round of the Delphi survey.

12. What are some of the considerations you make when you have to select an energy efficient product or appliance for a home? What will make you choose one over the other?

The purpose of this question was to build consensus on the use of energy efficient products and appliances by panel members. It also sought to have an indication of typical products and appliances used in the industry. This is going to be useful in the prescription of measures for homeowners when the proposed IDSS framework is developed.

The intent of the question was not properly conveyed first to the focus group and then to the panel members hence varying responses was elicited from them. As a result, the question has been reframed as follows:

> *"Do you always use energy efficient products or appliances in home energy retrofits? If yes, kindly list some. If no, kindly indicate what situations energy efficient products or appliances may not be attractive."*

The rephrased question will therefore be included in the next round of the Delphi survey.

ATTRIBUTE 9 – BUILDING SCIENCE/CONSTRUCTION KNOWLEDGE EXAMPLE

13. Different homes have different retrofit needs. What aspects of the home will determine the need? E.g. is it the construction type, architectural type, age of the home etc.?

The objective of this question was to elicit an example of building science and construction knowledge from the panel members. Hendron & Engebrecht (2010) assert that, effective energy-retrofit solutions can vary greatly by housing characteristics such as style, construction type, materials, existing construction details, building form, number of stories, and duct systems. Mrozowski *et al.* (2013) recognize the relationship that exist among housing characteristics such as construction type (technology – balloon or platform framing, materials, number of stories); vintage (archetype – cape cod, ranch etc., number of stories, complexity of building form etc.); and age of house (walls with no insulation till mid-1970's).

The knowledge about the existing relationship among the three housing characteristics: vintage, construction type, and age of home was therefore sought from the panel members. Responses are indicated in Table B.16 below.

Table B.16: Existing Relationship among Housing Characteristics

Existing Relationship Among 3 Housing Characteristics	Number of People	Percent
Identify at least one relationship	15	78.95
Explain individual characteristics	4	21.05
Indicate that there is no relationship		0.00
Total	**19**	**100.00**

It can be seen from Table B11 that there was consensus (78.95%) that there is a definitely a relationship among the three identified housing characteristics in identifying retrofit measures. As a result, this question was not included in the next round of the Delphi survey.

ATTRIBUTE 10 – ENERGY ASSESSMENT KNOWLEDGE

14. How would you explain what "Energy Auditing" means to a homeowner?

Energy auditing or assessment has been defined as an evaluation of an existing home to determine where and how energy is being lost, what systems are operating inefficiently and what cost-effective improvements can be implemented to enhance occupant comfort, make the home more durable and lower utility costs (RESNET 2013a; USEPA 2013; DTE Energy Company 2013). On the basis of the definition found in literature, three things that a home energy assessment must achieve are the following:

- Determining where and how energy is lost (where)
- Identification of energy inefficient systems (which)
- Proposing measures to enhance occupant health, home durability, and energy efficiency (how)

This question sought the energy assessment knowledge of the panel members since it is a key factor in making a home energy efficient – you cannot fix what you do not know. Secondly, responses were going to be used as a criterion for determining who an expert is in this industry. Table B.17 indicates the energy assessment knowledge responses by the panel members.

Table B.17: Knowledge of Energy Assessment

Energy Assessment Objectives	Number of People	Percent (%)
Determine where and how energy is lost	21	100
Identify energy inefficient systems	15	71.43
Measures enhancing occupant health, home durability, & energy efficiency	15	71.43

Since panel members were explaining the energy assessment process, it included all three assessment objectives. Each of the objectives was checked for consensus by the panel members. As can be seen from Table B12, there was absolute consensus on the first objective: determining where and how energy is lost and consensus (71.43%) on the other two objectives based on the predetermined consensus percentage score of 70%. As a result, this question was included in the next round of the Delphi survey.

ATTRIBUTE 11 – RETROFIT BENEFITS KNOWLEDGE

15. What specific benefits can be obtained when you perform energy retrofit of a home?

The benefits of performing energy retrofits having satisfied the three objectives of an energy assessment are (LeBaron and Rinaldi 2010; OEE 2009; RESNET 2013b):

- Save money on your energy bills
- Increase your comfort and health
- Increase your home's resale value
- Improve home marketability
- Uncover hidden problems
- Cleaner environment
- Take advantage of government incentives
- Good return on investment
- Sure money maker
- Increased competitiveness

All of the above benefits can be put into five broad categories of: financial incentives, comfort, health, environmental, and durability. The objective of this question was to elicit the knowledge of the benefits of energy retrofitting from the panel members (Table B.18).

Table B.18: Dominant Benefits of Energy Retrofitting a Home

Type of Benefits	Number of People	Percent (%)
Financial, Comfort and/or Health	16	76
Financial, Comfort, Health and Environmental	4	19
Financial, Comfort, and Durability	1	5
Total	**21**	**100**

As can be seen from Table B.18, there was consensus by panel members that financial, comfort and/or health benefits are the dominant benefits obtained when one performs an energy efficient retrofit. Financial and comfort benefits alone however had absolute consensus (100%). Since there was consensus on this question, it was not included in the next round of the Delphi survey.

16. What are some of the most common questions that homeowners ask when they decide to retrofit their homes?

In order to develop a framework that would assist homeowners make energy retrofit decisions, it was important to identify the common questions homeowners ask. This would help in anticipating possible questions and thus develop required answers to help them with decision-making hence the rationale for this question.

Through the elicitation process for the panel members, the following are the issues that homeowners typically asked questions about:

1. Cost
2. Payback
3. Rebates
4. Comfort
5. Cold spots
6. Health
7. Aesthetics
8. Tidiness
9. Lifestyle change
10. Work related
11. Duration
12. Benefits

Since most of the issues were related, they were put together under 5 broad categories: (1) cost, payback, rebates, and benefits were put together under a new category of "Financial Benefits." (2) Next, comfort and cold spots were put under a new category of "comfort". (3) Aesthetics, tidiness, lifestyle change, and work-related were put under a new category of "Work Impact on Homeowner." (4) Health category was maintained. (5) Finally, Duration of the work was also maintained as "duration." Table B.19 is a summary of the responses elicited from the panel members about the issues about which panel member indicated homeowners asked questions.

Table B.19: Dominant Issues Forming Basis of Questions Asked by Homeowners

Dominant Issues Based on Which Questions Are Asked	Number of People	Percent (%)
Financial Benefits, Comfort, Work Impact on Homeowner, and/or Health	16	76
Financial Benefits, Work Impact on Homeowner, and Duration	5	24
Total	**21**	**100**

As can be seen from Table B.19, there is consensus among panel members that, the dominant issues that formed the basis for which questions were asked by homeowners are: financial benefits, comfort, work impact on homeowner, and/or health. Financial benefits and work impact on homeowner however had absolute consensus (100%). As a result, this question was not included in the next round of the Delphi survey.

17. What are the major reasons that motivate homeowners to pursue home energy retrofits?
Pursuant to question 16, once the common questions have been identified, it was important to obtain the reason that actually motivates them to take the decision to perform the retrofit. This was also going to be useful in developing the proposed framework to help them in energy retrofit decision-making.

There were 14 different responses elicited from the panel members and are indicated below:

1. Comfort
2. Energy savings
3. Home remodeling cost
4. Utilities cost
5. Indoor air quality
6. Insects and bugs
7. Concern for environment
8. Cost
9. Save money
10. Long stay in home
11. Improve value of home
12. Weak economy
13. Building durability
14. It is the trend

In order to harmonize the responses and also avoid reasons with similar meanings, the responses were put into the following 6 broad categories: (1) energy savings, home remodeling cost, utilities cost, cost, save money, and improve value of home were all put under a new category of *"Financial"*. (2) *Comfort* was maintained. (3) Concern for the environment was put under the new category *"Environment"*. (4), Indoor air quality and insects and bugs were put under *"Health"* category. (5) It is the trend was put under the category *"Trend."* (6) Long stay in the home by the homeowner was put under the *"Staying Home"* category. Table B.20 below indicates the responses regarding the reasons that actually motivate homeowners to undertake home energy retrofits.

Table B.20: Major Reasons Motivating Homeowners to Perform Home Energy Retrofits

Reasons	Number of People	Percent (%)
Financial, Comfort, and/or Health	17	85
Financial and Environment	1	5
Financial and Trend	1	5
Comfort and Staying Home	1	5

As seen from Table B.20, 85% of the panel members identified financial, comfort, and/or health as the major reasons that actually motivate homeowners to perform energy retrofits. As a result, this question was not included in the next round of the Delphi study.

ATTRIBUTE 12 – RETURN ON INVESTMENT KNOWLEDGE

18. What are some of the measures that provide the greatest return on investment for a homeowner and why?

In order to help in the development of cost-effective retrofit advice to homeowners to be included in the proposed information framework and the eventual; development of the IDSS, there was a need to identify the most cost effective measures that could be applied in energy retrofit in order to encourage homeowners undertake energy retrofits. Responses to this question were important since financial considerations were one of three reasons for homeowners to pursue energy retrofits and are also critical to the success of the energy retrofit process. As can be seen from Table B.20 below, there was consensus by panel members that air sealing, insulation, and/or lighting measures are the measures that provided the greatest return on investment.

Table B.21: Measures with the Greatest Return on Investment

Measures	Number of People	Percent (%)
Air sealing, Insulation and/or Lighting	15	71
Air sealing, Mechanical, and Insulation	4	19
Mechanical systems	2	10
Total	**21**	**100**

A careful analysis however of the data showed that, there was overwhelming consensus (100%) by panel members that the air sealing measure has the greatest return on investment. Since consensus was reached for this question, it was not included in the next round of the Delphi survey.

ATTRIBUTE 13 – CONSTRUCTION AND FINANCIAL KNOWLEDGE

19. What are some external factors, which increase the cost of the retrofit operation?

Construction and financial knowledge are two important qualities that an energy retrofit expert must possess in order to advice homeowners on energy retrofit measures to be installed in their homes. This question sought to identify these qualities in the experts and also to employ it in the eventual development of the proposed framework for decision-making in energy retrofits. For instance if accessibility to spaces in order to perform energy retrofits in homes is determined to increase the cost of performing a retrofit measure drastically, there would be a cost benefit analysis to indicate if the return on investment is good and if by avoiding that measure there will be no health and safety risk posed to the homeowner. When the homeowner is made aware of all of this information, they are in a better position to make good decisions concerning energy retrofitting their homes.

11 external factors were elicited from the panel members and are listed below:

1. Health and safety remediation
2. Maintaining certifications
3. Access to work areas
4. Weather condition
5. Poorly done existing work
6. Old building standards existing
7. Existing content of space
8. Existing expensive furniture
9. Existing additions to house
10. Existing archetype
11. Remote location of home and material supply

Since there were some similarities in the factors elicited above, factors 5 to 10 were grouped under the broad category of "Existing Conditions". Since the weather condition mostly affects access to work areas and the condition in which work is done, they were put into a new category of "Access and Weather". Finally factor 11 was shortened to "Remote Home Location." Table B.22 shows the responses of the panel members' regarding dominant external factors affecting the cost of energy retrofits.

Table B.22: Dominant External Factors Affecting Cost of Energy Retrofits

External Factor	Number of People	Percent (%)
Health & Safety Remediation, Access & Weather, and/or Existing Condition	18	90
Maintaining Certifications	1	5
Remote Home Location	1	5
Total	**20**	**100**

There was consensus by the panel members that health and safety remediation, access and weather, and/or existing condition were the most dominant factors affecting the cost of energy retrofits. As a result this question was not included in the next round of the Delphi survey.

ATTRIBUTE 14 – BUILDING SCIENCE KNOWLEDGE: HEALTH & SAFETY ISSUES

20. Kindly provide a list of post occupancy health and Safety issues that must be addressed in energy retrofits

Based on the interviews with the panel members and the study of literature, building science knowledge was identified as one of the most important knowledge base that has to be possessed by an expert in this industry. This question sought to elicit this knowledge particularly regarding health and safety issues in energy retrofit as this in some cases can lead to deaths. For instance combustion appliances according to USEPA (2012) can release harmful or deadly combustion pollutants into the home through a process commonly called combustion spillage or backdrafting. In addition, unvented or improperly vented appliances can add large amounts of moisture to the air, potentially resulting in both biological growth, and damage to the house.

Table B.23 below indicates the responses from the panel members about the list of post occupancy health issues that must be addressed in energy retrofits.

Table B.23: Dominant Post Occupancy Health and Safety Issues in Energy Retrofits

Health and Safety Issue	Number of People	Percent (%)
Air quality, Material off gassing, and/or Moisture Issues	17	80.95
Lead and Asbestos Test and Moisture Issues	2	9.52
Air Quality, Moisture Issues, Comfort, and Improper Installation	1	4.76
Fire Risks	1	4.76
Total	**21**	**100.00**

80.95% of the panel members indicated that air quality, material off gassing, and/or moisture issues were the dominant post occupancy health and safety issues that must be addressed in energy retrofits. Since consensus has been reached for this question, it was not included in the next round of the Delphi survey.

ATTRIBUTE 15 – BUILDING SCIENCE KNOWLEDGE: WHOLE HOUSE SYSTEM

21. Buildings behave as a system where interactions between components can affect their energy performance. What are the interrelationships among the following measures?

As a result of the importance of building science knowledge in this industry, highlighted in the discussion for question 20, this question sought to elicit responses from panel members about their knowledge about an important building science principle, which is the whole house/home system of retrofitting. According to LeBaron and Rinaldi (2010), the crucial element of a whole home retrofit is that, it looks at the many different elements within the home that result in excessive consumption or waste of energy as well as considering the ways that these elements interact. Whole home retrofit approaches also review at health and safety issues within a home as a crucial feature of a retrofit job.

This question sought to first help develop a criterion for identifying who an industry expert is and also to gauge consensus on the importance or knowledge of the need to have building components interacting and affecting the energy consumption of others hence the need for a holistic approach to energy retrofits. Table B.24 below indicates the responses elicited from the panel members. When panel members indicated their knowledge of the whole-house approach, they were asked to provide at least one example.

Table B.24: Knowledge of Whole-House Energy Retrofit by Panel Members with Examples

Knowledge of Whole-House System	Number of People	Percent (%)
Yes with at least 3 examples	17	80.95
Yes with at least 2 examples	3	14.29
Yes with at least 1 example	1	4.76
Yes with no example	0	0.00
No	0	0.00
Total	**21**	**100**

From Table B19, 80.95% of the panel members had a working knowledge of whole-house systems for energy retrofit of homes and could provide at least three examples. 100% of the panel members were at least aware of this system and could provide at least one example. As a result, this question was included in the next round of the Delphi survey.

22. An expert must not only be experienced but also be competent. Can you indicate the competencies that an energy retrofit expert must possess?

The intent of this question was to elicit responses from panel members on what in their opinion were the competencies required to be successful in this industry. Based on extensive literature, a number of competencies had been identified that distinguishes an expert from a novice. Responses from this question however identify relevant competencies in this domain. The following 11 competencies were elicited from the panel members:

1. Ability to deliver
2. Integrity and humility
3. Communication skills
4. Building science knowledge
5. Construction knowledge
6. Diagnostic equipment knowledge
7. Computer skills
8. Certification e.g. BPI/RESNET
9. Continuing education
10. Collaboration with other experts
11. Field/practical experience

Since there were some similarities in the competencies indicated above, the researchers decided to harmonize them and put them into new categories. The RESNET ethics stress the obligation of energy retrofit professionals to present accurate and unbiased information on a home's energy performance in a professional manner and disclose any potential conflicts of interest (RESNET 2013c). Energy retrofit professionals they note must display the following (RESNET 2010):

- Professional conduct – objectivity and neutrality, upright reputation, and confidentiality
- Representations of services and fees – avoid false or misleading services or qualifications, and ensure full disclosure.
- Conflict of interest – avoid conflict of interest

As a result, ability to deliver, integrity and humility, and communication skills were put under a new category of "Professional Ethics". Since building science and construction knowledge were related and had a combined effect of providing a good knowledge base for energy retrofit professionals, they were both put under a new category of "Building Science and Construction Knowledge." Since both diagnostic tools and computer skills both involved some computer knowledge, they were put together under a new category of "Computer and Diagnostic Equipment Knowledge."

Next certification by various professional bodies always includes some form of continuing education as a requirement hence both were put together under the "Certification and Continuing Education" category. Finally, the opinions expressed by the panel members relating to experience encompassed obtaining practical or field experience especially with oversight responsibility or collaboration with an expert thus these two were put under a new category of "Field experience and Expert Collaboration". As a result of the categorizations, 5 competencies identified to be successful in this industry are:

1. Building science and construction knowledge
2. Professional ethics
3. Computer and diagnostic equipment knowledge
4. Certification and continuing education
5. Field experience and expert collaboration

Table B.25 below indicates the responses obtained from panel members regarding the competencies needed to be successful in this industry.

Table B.25: Dominant Competencies required for Success in the Energy Retrofit Industry

Type of Competence	Number of People	Percent (%)
Building science and construction knowledge	14	66.67
Professional ethics	8	38.09
Computer and diagnostic equipment knowledge	8	38.09
Certification and continuing education	8	38.09
Field experience and expert collaboration	7	33.33

There was no upper limit set for the number of competencies that each panel member could identify hence each competency was computed separately as a percent of the total number of panel members. It can be seen from Table B.25 that no consensus was reached on any of the identified competencies hence this question will be included in the next round of the Delphi survey.

23. Kindly provide a list of installation strategies for the following:

- ***a. Crawlspace air sealing and insulation***
- ***b. Foundation wall insulation***
- ***c. Above grade wall insulation***
- ***d. Attic air sealing and insulation***
- ***e. HVAC equipment upgrade/duct improvement***

It is intended for the proposed information framework and eventual IDSS tool to help homeowners make energy retrofit decisions to provide installation advice based on sound literature and comprehensive expert advice. As a result the last three questions focused on providing expert installation advice to homeowners.

23a. Crawlspace and Air Sealing Insulation

Installation advice elicited from the panel members are indicated below:

1. Ensure home is not too tight
2. Air seal all holes to block outside air
3. Air seal and insulate
4. Moisture management is important

5. Treat space like a conditioned space
6. Remediate health and safety hazards first
7. Use commercial equipment for easy installation
8. Professionals of a certain height suitable for rim and joist band sealing and insulation
9. Wear proper work gear
10. Check for storage use of space

According to Lstiburek (2006), conditioned spaces are crawlspaces that are designed and constructed as mini-basements or part of the house within the conditioned space. This space he notes should have the following characteristics (Lstiburek 2006):

- Insulated on their perimeters
- Have a continuous sealed ground cover such as polyethylene
- Have perimeter drainage just like a basement when the crawlspace ground level is below the ground level of the surrounding grade

Based on the definition of conditioned crawlspaces indicated above and absence of serious moisture and mold problems and high cost to fix it, typically associated with existing vented crawl spaces, a new category called "Conditioned Spaces" was created. It includes the following measures: ensure home is not too tight, airseal all holes to block outside air, air seal and insulate, moisture management is important, and treat space like a conditioned space. The other 4 installation advices were maintained with the following slight modifications: "Health and Safety Remediation (HSR)", "Commercial Equipment Use (CEU)", "Professional with Suitable Height (PSH)", "Personal Protective Equipment (PPE)", and "Storage Use (SU)". Table B.26 below is a summary of the responses elicited from the panel members.

Table B.26: Installation Advice for Crawlspace Air Sealing and Insulation

Crawlspace Installation Advice	Number of People	Percent (%)
CS, HSR, and/or PPE	18	90
CEU and PSH	1	5
CS and SU	1	5
Total	**20**	**100**

From Table B.26, there was consensus (90%) among the panel members that, conditioned space, health and safety remediation, and/or personal protective equipment are important issues to consider when installing crawlspace air sealing and insulation. As a result, this was not included in the next section of the Delphi survey.

23b. Foundation Wall and Insulation

Installation advice elicited from the panel members are indicated below:

1. Moisture management
2. Air seal and insulate
3. Check fire code (CFC)
4. Commercial equipment use (CEU)
5. Furnished or unfurnished (FOU)
6. Return on investment (ROI)
7. Precast System Guide (PSG)

Based on the definition of condition spaces explained earlier on for question 23a, moisture management and air seal and insulate were put under a new category of "Conditioned Space" (CS). The other 3 measures remained unchanged. Table B.27 below indicates the responses of panel members about advice for installing foundation wall and insulation.

Table B.27: Installation Advice for Foundation Wall and Insulation

Foundation Wall and Insulation Installation Advice	Number of People	Percent (%)
CS and/or CFC	16	80
CS, CFC, and FOU	1	5
COU	1	5
ROI	1	5
PSG	1	5
Total	**20**	**100**

From Table B.27, there was consensus (80%) among the panel members that, *conditioned space* and/or *check for fire code* are important issues to consider when installing foundation wall and insulation. As a result, this was not included in the next section of the Delphi survey.

23c. Above Grade Wall Insulation

Installation advice elicited from the panel members are indicated below:

1. Air seal and insulate right
2. Use cellulose insulation
3. Use rigid foam for exterior walls
4. Moisture management issues
5. Return on investment (ROI)
6. Define air and thermal barriers
7. Existing condition knowledge (ECK)
8. Construction type knowledge (CTK)
9. Health and safety hazards remediation (HSHR)

Advice relating to making the space a conditioned space including air seal and insulate right, use cellulose insulation, use rigid foam insulation, define air and thermal barriers, and moisture management were all put under a new category of "Conditioned Space" (CS). The other four installation advices from the panel were maintained. Table B.28 below indicates the responses of panel members about advice for installing above grade wall insulation.

Table B.28: Installation Advice for Above Grade Wall Insulation

Type of Installation Advice	Number of People	Percent (%)
CS and/or HSHR	17	85
ROI	2	10
ECK, HSHR and CTK	1	5
Total	**20**	**100**

From Table B.28, there was consensus (85%) among the panel members that, *conditioned space* and/or *health and safety hazard remediation* are important issues to consider when installing above grade wall insulation. As a result, this was not included in the next section of the Delphi survey.

23d. Attic Air Sealing and Insulation

Installation advice elicited from the panel members are indicated below:

1. Air seal before insulation
2. Define Thermal boundary
3. Ventilate properly (VP)
4. Moisture management issues
5. Complete attic retrofit (remove and install new air sealing/insulation (CAR)
6. Avoid attic penetrations
7. Air seal and insulate attic hatch
8. Check construction type (CCT)
9. Check type of wiring
10. Health and safety remediation

Since the type of wiring such as knob and tube wiring can cause fires and hence pose a health and safety hazard, it was combined with the last installation advice under the category "Health and Safety Remediation" (HSR). Air sealing before insulation, moisture management issues, attic penetrations, and air sealing and insulating attic hatch were all put under a new category "Air Sealing and Insulation" (ASI).

The reason for this new category is that each of the measures mentioned are related to ensuring that the thermal boundary of the attic is properly air sealed and insulated lest there will be moisture management issues. The three other installation advices from the panel: ventilate properly (VP), complete attic retrofit (CAR) and check construction type (CCT) were maintained. Table B.29 below indicates the responses of panel members about advice for installing above grade wall insulation.

Table B.29: Installation Advice for Attic Air Sealing and Insulation

Type of Installation Advice	Number of People	Percent (%)
ASI, VP, and/or HSR	16	80
CAR and/or CCT	3	15
HSR and ASI	1	5
Total	**20**	**100**

From Table B21D, there was consensus (80%) among the panel members that, *air seal before insulation, ventilate properly* and/or *health and safety remediation* are important issues to consider when installing attic air sealing and insulation. As a result, this was not included in the next section of the Delphi survey.

23e. HVAC Equipment Upgrade/Duct Improvement

Installation advice elicited from the panel members are indicated below:

1. Install high efficiency equipment (IHEE)
2. Proper sizing (PS)
3. Leaky duct (LD)
4. Adequate distribution system (ADS)
5. Ensure combustion safety (ECS)
6. Good return on investment (GROI)
7. Age of equipment (AOE)
8. Proper insulation (PI)
9. Appropriate location (AL)

Since the installation of high efficiency equipment, age of the equipment, and proper sizing of the equipment were all related, they were put under a new category of "Equipment Specification" (ES). Leaky duct and proper insulation were also combined to a new category of "Air Sealing and Insulation" (ASI) since both of these measures relate to avoiding leakages.

The four other installation advices from the panel were maintained. Table B.30 below indicates the responses of panel members about advice for installing HVAC equipment upgrade/duct improvement.

Table B.30: Installation Advice for HVAC Equipment Upgrade/Duct Improvement

Type of Installation Advice	Number of People	Percent (%)
ES, ASI, ADS and/or ECS	17	85
ES and GROI	2	10
ES, ASI, ECS and AL	1	5
Total	20	100

From Table B.30, there was consensus (85%) among the panel members that, equipment specification, *air seal and insulation, adequate distribution system,* and/or *ensure combustion safety* are important issues to consider when installing HVAC equipment upgrade/duct improvement. When equipment sizing alone was considered, there was absolute consensus (100%) about that installation advice. As a result, this was not included in the next section of the Delphi survey.

ATTRIBUTE 16 – CONSTRUCTION KNOWLEDGE – SELF-PERFORM INSTALLATION ADVICE

24. What measures do you consider safe and can be installed by a homeowner? Kindly give reasons for your answer.

Installation advices elicited from the panel members and which required construction knowledge in order to indicate which energy retrofit measures can be performed by homeowners themselves are indicated below:

1. Programmable Thermostats
2. Aerators
3. Faucets
4. Monthly change of furnace filter
5. Adjust hot water heaters
6. Window/door caulking
7. Ductwork sealing
8. Sealing attic hatch
9. Most air sealing
10. Hang doors and windows
11. Air sealing
12. Dryer vent hood/hose change
13. Lights
14. Appliances
15. Foundation wall insulation
16. Spray foam insulation
17. Insulated foam buttresses on wall plugs
18. Foundation and attic insulation
19. Blown-in attic insulation
20. Most Insulation

Based on the DTE's HEC program and RESNET's HES definition explained in question 10, energy survey measures (ESM) was a generic term used for a number of measures and was added on to in this category since they all involved minimal effort by homeowners. They included the following measures: water heater pipe insulation, water saving showerheads, programmable thermostats, dryer vent hood or hose change, monthly change of furnace filter, adjust hot water heaters, and faucet aerators.

Since duct sealing and window or door caulking did not involve any major air sealing employed in the industry, they were put under a new category of “Minor Air Sealing”. Most air sealing, air sealing, and attic hatch sealing involved some expertise and hence was put under a new category of “Major Air Sealing”. Spray foam insulation and other insulation, which did not involve huge expertise, was categorized as “Minor Insulation”. Insulated foam buttresses on wall plugs, most insulation, foundation and attic insulation, and blown-in attic insulation were put under a new category of “Major Insulation”. Finally, lights, hang doors and windows, and appliances remained unchanged. Since no upper limited was placed on the number of measures that each panel member could mention, each measure was counted separately ad as a percentage of the total number of panel members. Table B.31 below indicates the responses of panel members regarding the measures can be installed by the homeowners themselves.

Table B.31: Measures That Can Be Installed By Homeowners

Type of Measure	Number of People	Percent (%)
Energy Saving Measures	7	33.33
Minor Air Sealing	13	61.90
Major Air Sealing	4	19.05
Minor Insulation	14	66.67
Major Insulation	5	23.81
Appliances	8	38.09
Lighting	20	95.24
Hang Doors and Windows	1	4.76

As seen from Table B.31, the panel members reached consensus (95.24%) only the lighting measure. An analysis of the data and literature however reveals that, a few more of the other measures were close to reaching a consensus and were measures that could be done by homeowners themselves. As is one of the strong characteristic of the Delphi method, the re-categorization of all the measures and the data obtained from the panel members will be included in the next round of the Delphi survey. That way, panel members will be aware of the thoughts of others and will be accounted for in the decision-making in the next round.

24b. Kindly give reasons for your answer.

The second part of the question sought to identify the reasons for the decision by panel members to indicate why in their opinion homeowners could perform the measures identified above. The following reasons were identified from the panel members:

1. Safety is not affected (SNA)
2. Easy installation (EINS)
3. Minimal aptitude required (MAR)
4. Not expensive (NEXP)
5. Impacts energy greatly (IEG)
6. It is tangible (IIT)
7. Save money (SMNY)
8. Generates homeowner interest (GHI)

Table B.32 below indicates a summary of the responses obtained from the panel members regarding the reasons why homeowners can install the identified energy retrofit measures.

Table B.32: Reasons for Do-It-Yourself Installation by Homeowners

Reason	Number of People	Percent (%)
SNA, EINS, and/or MAR	16	76.1
EINS and NEXP	2	9.5
EINS and SMNY	1	4.8
EINS and GHI	1	4.8
IIT	1	4.8
Total	**21**	**100.0**

As seen from Table B.32, there was consensus (76.1%) by panel members that safety is not affected, easy to install, and/or minimal aptitude required are the major reasons why homeowners themselves can install the measures identified in Table B.32. As a result, this was not included in the next round of the Delphi survey.

ATTRIBUTE 17 – CONSTRUCTION KNOWLEDGE – PROFESSIONAL-PERFORM INSTALLATION ADVICE

25. What measures in your opinion must be installed by a licensed retrofit professional? Kindly give reasons for your answer

Installation advice elicited from the panel members and which required construction knowledge in order to indicate which energy retrofit measures must only be performed by professionals in the industry are indicated below:

1. Heating, ventilation, and cooling HVAC) measures
2. Insulation
3. Air sealing
4. Diagnostic testing
5. Water heating system
6. Electricals
7. Window and doors

According to USEPA (2012), Combustion appliances are those, which burn fuels for warmth, cooking, or decorative purposes and include space heaters, ranges, furnaces, fireplaces, water heaters, and clothes dryers. Based on this definition, HVAC measures and water heating systems were categorized as “Combustion Appliances”. Since diagnostic testing using the appropriate tools was not a measure by itself but rather an assessment tool and has been covered in other parts of this research, it was removed from the list as one of the measures. Part of it was used in the second part of this question, which assessed the reasons why the identified measures had to be performed by a professional. All other measures remained unchanged. Since no upper limited was placed on the number of measures each panel member could mention, each was counted separately and as a percentage of the total number of panel members. Table B.33 indicates the responses of the panel regarding measures that must be installed by energy retrofit professionals.

Table B.33: Measures That Must Be Installed By Energy Retrofit Professionals

Type of Measure	Number of People	Percent (%)
Combustion Appliances	21	100.0
Air Sealing	13	61.9
Insulation	14	66.7
Electricals	3	14.3
Window and doors	4	19.0

As seen from Table B.33, the panel members reached absolute consensus (100%) on only the combustion appliance measure. An analysis of the data and literature however reveals that, a few more of the other measures were close to reaching a consensus and were measures that should be done by professionals in the industry. As explained in question 24, a strong characteristic of the Delphi method allows panel members to modify their opinions based on the knowledge of other panel members. Thus, the re-categorization of all the measures and the data obtained from the panel members will be included in the next round of the Delphi survey.

25b. Kindly give reasons for your answer.
The second part of the question sought to identify the reasons for the decision by panel members to indicate why in their opinion professionals must perform the measures identified above. The following reasons were identified from the panel members:

1. Required by law (RBL)
2. Health and safety issues (HSI)
3. Saves Money (SMNY)
4. Properly prescribed work (PPW)
5. Homeowner lack of expertise (HLE)

Table B.34 below indicates a summary of the responses obtained from the panel members regarding the reasons why professionals must install the identified energy retrofit measures.

Table B.34: Reasons for Installation by Energy Retrofit Professionals

Reason	Number of People	Percent (%)
RBL, HSI, and/or HLE	19	90.5
SMNY, HIS and PPW	2	9.5
Total	**21**	**100.0**

As seen from Table B..34, there was consensus (90.5%) by panel members that: required by law, health and safety, and/or homeowner lack of expertise are the major reasons why energy retrofit professionals must install the measures identified in Table B.34. As a result, this was not included in the next round of the Delphi survey.

SUMMARY
Table B.35 below indicates the summary of consensus reached for each question in first round of Delphi.

Table B.35: Summary of Consensus Reached for Each Question in First Round of Delphi

Question Number	Expert Criteria Only	Knowledge Elicitation Only	Expert Criteria & Knowledge Elicitation	Consensus Reached
1	Yes	N/A	N/A	Not Needed
2	Yes	N/A	N/A	Not Needed
3a	Yes	N/A	N/A	No
3b	Yes	N/A	N/A	No
4	Yes	N/A	N/A	Yes
5	Yes	N/A	N/A	Yes
6	Yes	N/A	N/A	Not Needed
7	Yes	N/A	N/A	Yes

Table B.35 (Cont'd)

8a	Yes	N/A	N/A	Yes
8b	Yes	N/A	N/A	Not Needed
8c	Yes	N/A	N/A	No
9	Yes	N/A	N/A	Yes
10	N/A	N/A	Yes	Yes
11	N/A	N/A	Yes	No
12	N/A	Yes	N/A	No
13	N/A	N/A	Yes	Yes
14	N/A	N/A	Yes	Yes
15	N/A	N/A	Yes	Yes
16	N/A	Yes	N/A	Yes
17	N/A	Yes	N/A	Yes
18	N/A	N/A	Yes	Yes
19	N/A	N/A	Yes	Yes
20	N/A	N/A	Yes	Yes
21	N/A	N/A	Yes	Yes
22	N/A	Yes	N/A	No
23a	N/A	Yes	N/A	Yes
23b	N/A	Yes	N/A	Yes
23c	N/A	Yes	N/A	Yes
23d	N/A	Yes	N/A	Yes
23e	N/A	Yes	N/A	Yes
24a	N/A	N/A	Yes	No
24b	N/A	N/A	Yes	Yes
25a	N/A	N/A	Yes	Yes
25b	N/A	N/A	Yes	Yes

There were a total of 25 questions in all. These questions combined two objectives of the research: determining criteria for determining who an expert is in the energy retrofit industry and eliciting the expertise of energy retrofit expertise in order to combine with existing quantitative information to be incorporated into the proposed IDSS to help homeowners with decision-making. Some of the questions had two or more parts, thus, there was a total of 34 questions in all. Of the total of 34 questions posed, 12 related exclusively with expert determination, 9 related exclusively to knowledge elicitation, and 13 related to both expert determination and knowledge elicitation.

At the end of the first round of Delphi study, it was established that, whilst there was no need for consensus to be reached on 4 (11.76%) of the questions, consensus was reached on 23 (67.66%) of the questions. There was no consensus reached on 7 (20.58%) of the questions and hence would be included in the second round of the Delphi survey. This means that, no need for consensus and consensus reached accounted for 79.42% of the questions.

The 7 questions that would be included in the second round of the Delphi study as indicated below:

1. ***Based on your experience, how many audits do you think must be performed by a retrofit professional in a year to make them proficient?***
   a. Less than 20
   b. 21 – 30/year
   c. 31 – 40/year
   d. 41 – 50/year
   e. More than 50/year

2. ***Based on your experience, how many retrofits do you think must be performed by a retrofit professional in a year to make them proficient?***
   a. Less than 10/year
   b. 11 - 15/year
   c. 16 – 20/year
   d. 21 - 24/year
   e. More than 24/year

3. ***Would you agree the following are standard sources of information that retrofit professionals seek information regarding tax incentives, rebates, and benefits available to homeowners when they undertake an energy retrofit?***
   a. Trade organizations
   b. Utility programs
   c. Colleagues in the industry
   d. Government sources (Federal, state, local)
   e. Electronic news media

4. ***Would you agree that the following 7 categories of sources can be used to assess the general energy performance of an existing home including when you have no means of testing?***
   a. Comfort complaints
   b. Visible moisture issues
   c. Visible health and safety issues
   d. Appliance and lighting characteristics
   e. Review of utility use and billing history
   f. Building envelope features (windows, doors, insulation, ducts) and ages
   g. Heating, cooling and ventilation equipment types, characteristics and ages

5. ***Do you always use energy efficient products or appliances in home energy retrofits? If yes, kindly list some. If no, kindly indicate what situations energy efficient products or appliances may not be attractive.***

6. ***Would you agree that the following are competencies that an energy retrofit expert must have?***
   a. Building science and construction knowledge
   b. Professional ethics
   c. Computer and diagnostic equipment knowledge
   d. Certification and continuing education
   e. Field experience and expert collaboration

7. ***Which of the following measures would you considered safe and can be installed by a homeowner?***
   a. Lighting
   b. Minor Air Sealing (caulking)
   c. Major Air Sealing (Spray foam)
   d. Minor Insulation
   e. Major Insulation
   f. Appliances
   g. Hang Doors and Windows

h. Energy Saving Measures (showerheads, programmable thermostats, furnace filter change, adjust hot water heater, faucet aerators, dryer vent or hose change, pipe insulation etc.)

Before conducting the second round of the Delphi survey, the criteria for determining an expert in this industry developed by the research team was used to determine which of the panel members qualified as experts. Table B.36 is a summary of the results of panel members designation based on responses received which were run through the expert system criteria developed by the research team. There were 16 panel members who qualified as "*Experts*" and another 4 as "*Upper Proficient*". 2 panel members qualified as "*Lower Proficient*". For the purposes of this research, all panel members who were either experts or upper proficient were regarded as qualified panel members and, hence, were included in the second round of the Delphi survey.

Table B.36: Summary of Panel Member Designation Based on Expert Criteria

Panel Member #	Expertise Designation	Score (Max – 360)	Inclusion in Next Round
1	Upper Proficient	305	Yes
2	Expert	327	Yes
3	Expert	324	Yes
4	Upper Proficient	296	Yes
5	Expert	334	Yes
6	Expert	331	Yes
7	Expert	339	Yes
8	Expert	354	Yes
9	Expert	337	Yes
10	Expert	333	Yes
11	Lower Proficient	260	No
12	Expert	326	Yes
13	Expert	329	Yes
14	Expert	323	Yes
15	Lower Proficient	263	No
16	Upper Proficient	295	Yes
17	Expert	323	Yes
18	Expert	319	Yes
19	Expert	335	Yes
20	Expert	321	Yes
21	Upper Proficient	308	Yes
22	Expert	331	Yes

APPENDIX B.2

Detailed Analysis of Data Obtained For Developing EREIS and EREES in Delphi Round 2

ENERGY RETROFIT EXPERIENCE SPECIFIC QUESTIONS

ATTRIBUTE 2 – NUMBER OF AUDITS/RETROFITS

1. Based on you experience, how many audits do you think must be performed by a retrofit professional in a year to make them proficient?

Each panelist in the second round was asked to respond to this question based on the anonymous feedback provided. The reported data is indicated below in Table BB.1.

Table BB.1: Initial Reported Data for Annual Number of Audits

Annual Number of Audits	Percentage of Experts (%)
10 – 20	27.78
21 – 30	50.00
31 – 40	11.11
41 – 50	0
51 or more	11.11
Total	**100**

A detailed analysis of the transcript of the interview revealed an interesting pattern. It emerged that, even though there was no consensus on the exact number of audits to be completed annually by the experts, the pattern was that, so long as an energy retrofit professional was doing about a couple of energy audits a month, it was good enough for them to maintain their proficiency level. As a result, a new categorization was provided with only three options for the annual number of audits: 10 – 30, 31 – 50, and 51 or more. Based on this new categorization which emerged from the pattern of expert responses analyzed, inferences drawn, and a combination of KE training and quantitative information, consensus was reached (76.48%) for this question and is shown in Table BB.2 below:

Table BB.2: Modified Categories for Annual Number of Audits

Annual Number of Audits	Percentage of Experts (%)
10 – 30	76.48
31 – 50	11.61
51 or more	11.61
Total	**100.00**

ATTRIBUTE 2 – NUMBER OF AUDITS/RETROFITS

2. Based on you experience, how many retrofits do you think must be performed by a retrofit professional in a year to make them proficient?

Reported data is indicated below in Table BB.3.

Table BB.3: Initial Reported Data for Annual Number of Retrofits

Annual Number of Retrofits	Percentage of Experts (%)
Less than 5	0
6 – 10	33.33
11 – 15	33.33
16 – 20	11.11
21 or more	22.23
Total	**100.00**

Based on the protocol generated, it was determined that, even though there was no consensus on the exact number of retrofits to be completed annually by the experts, generally they expected at least 1 retrofit to be completed each month in order to main ones proficiency in this industry. As a result, a new categorization was provided with only three options for the annual number of retrofits: less than 5, 6 – 20, and 21 or more.

Based on this new categorization, consensus was reached (72.22%) for this question and is shown in Table BB.2 below:

Table BB.4: Modified Categories for Annual Number of Retrofits

Annual Number of Retrofits	Percentage of Experts (%)
Less than 5	0.00
6 – 20	72.22
21 or more	27.78
Total	**100.00**

HABITUAL DECISION-MAKING SPECIFIC QUESTIONS

ATTRIBUTE 5 – AVAILABLE FINANCIAL AID KNOWLEDGE

3. Would you agree the following are the most common sources that retrofit professionals seek information from regarding tax incentives, rebates, benefits etc.?

f. Trade organizations
g. Utility programs
h. Colleagues in the industry
i. Internet and news media
j. Government sources (Federal, state, local)
k. Other…………………………………...

In this round of the survey, consensus was reached on the most common sources that retrofit professionals seek financial benefits information from and is shown in. In order to avoid ambiguity, responses were elicited for each of the sources and are shown in Table BB.5. In addition to these sources however, a new source of Not-for Profit Organizations like Habitat for Humanity or Michigan Energy options was included.

Table BB.5: Common Financial Aid Information Sources

Common Financial Aid Sources	Yes (%)	No (%)	Maybe (%)
Trade Organizations	100.00	0.00	0.00
Utility Programs	100.00	0.00	0.00
Industry Colleagues	100.00	0.00	0.00

Table BB.5 (Cont'd)

Government Sources	94.45	5.55	0.00
Internet and News Media	88.89	0.00	11.11
(Other) Not-For Profits			

COMPETENCY SPECIFIC QUESTIONS

ATTRIBUTE 8 – BUILDING SCIENCE AND CONSTRUCTION KNOWLEDGE

4. Would you agree that the following 7 categories of sources can be used to assess the general energy performance of an existing home when you have no means of testing?

a. Building envelope features (windows, doors, insulation, ducts) and ages
b. Heating, cooling and ventilation equipment types, characteristics and ages
c. Comfort complaints
d. Visible moisture issues
e. Appliance and lighting characteristics
f. Review of utility use and billing history
g. Visible health and safety issues
h. Other……………………………

Based on the anonymous feedback provided to the participants during this round, consensus was determined for each of the 7 new categories provided after the analysis of the data in the first round. As shown in Table BB.6 below, consensus was reached for each of the sources:

Table BB.6: Information Sources to Assess Energy Performance of Home without Testing

Information Sources	Yes (%)	No (%)	Further Tests (%)
Building envelope features	88.89	0.00	11.11
HVAC equipment type, characteristics, and ages	88.89	0.00	11.11
Comfort complaints	88.89	0.00	11.11
Visible moisture issues	88.89	0.00	11.11
Visible health and safety issues	88.89	0.00	11.11
Appliances and lighting characteristics	88.89	0.00	11.11
Reviewing utility use and billing history	88.89	5.55	5.55

Even though additional sources were elicited from the participants, it was determined that they were all related to the building envelope features (doors, windows, insulation, ducts etc.) category:

- Cantilevers
- Wooden spaces above garages
- Rafter built cape cod and cathedral ceilings
- Insulation depth
- Ventilation strategy
- Size and style of house

5. Do you always use energy efficient products or appliances in home energy retrofits? If yes, kindly list some. If no, kindly indicate the scenarios where energy efficient products or appliances may not be attractive. E.g. running air conditioner for only 2 weeks in a year or CFL lights not preferred because it cannot be dimmed.

Anonymous feedback which included the rephrasing of the question provided in the first round of the Delphi was provided to the participants in the second round. It emerged that, there was consensus by the participants that, they did not always proffer the advice of using energy efficient appliances or products to homeowners during energy retrofits (See table BB.7).

Table BB.7: Constant Use of Energy Efficient Products or appliances

Always Using Energy Efficient Appliances/Products	No. of People (%)
Yes	27.77
No	72.23
Total	**100.00**

Dominant reasons why they do not always recommend the use of energy efficient appliances or products include the following:

- In instances where cost is prohibitive or
- When it is not cost effective for example bathroom fans that are rarely used
- Where products are not available for example, range microwave
- Where it is for health and safety and not energy efficiency reasons. For example, using less efficient power vent water heater good enough to pass a combustion appliance zone test
- In instances where it is a lifestyle issue

6. Would you agree that the following are competencies that an energy retrofit expert must have?

a. Building science and construction knowledge
b. Computer and diagnostic equipment knowledge
c. Professional ethics
d. Certification and continuing education
e. Field experience and expert collaboration
f. Other

Based on anonymous feedback provided to the panel members in the second round, data for responses are shown in Table BB.8.

Table BB.8: Energy Efficient Retrofit Expert Competencies

Competency	Yes (%)	Maybe (%)	No (%)
Building science and construction knowledge	100.00	0.00	0.00
Computer and diagnostic equipment knowledge	100.00	0.00	0.00
Certification/continuing education	88.89	11.11	0.00
Field experience and expert collaboration	100.00	0.00	0.00
Professional ethics	100.00	0.00	0.00

As indicated in Table C4.8, consensus was reached for all the competencies. Even though there could be a distinction made between industry professionals performing energy assessment only or energy retrofit only, to be an expert, a practitioner must possess all of these competencies.

ATTRIBUTE 16 – CONSTRUCTION KNOWLEDGE – SELF-PERFORM INSTALLATION ADVICE

7. Which of the following measures would you considered safe and can be installed by a homeowner?

a. Energy Saving Measures (showerheads, programmable thermostats, furnace filter change, adjust hot water heater, faucet aerators, dryer vent or hose change, pipe insulation Etc.
b. Lighting
c. Minor Air Sealing (caulking)
d. Major Air Sealing (Attic)
e. Minor Insulation (Spray foam)
f. Major Insulation (Attic)
g. Appliances Replacement
h. Hang Doors and Windows
i. Other

Based on anonymous information provided to the participants which included creating categories for retrofit measures and the creation of 2 sub categories for air sealing (minor and major air sealing) and insulation (minor and major insulation), responses were elicited and documented. Consensus was reached on the following measures that can be performed by homeowners themselves (See Table BB.9):

1. Energy saving measures (72.23%) – respondents however indicated that for two of the ESMs, some amount of homeowner education is required or must be installed by a professional (programmable thermostat and showerhead installation).
2. Lighting (100%) – there was overwhelming consensus
3. Minor air sealing (83.33%) – these includes caulking around doors and windows or around hatches to attics and basements or crawlspaces.
4. Appliances replacement (100%) – there was overwhelming consensus

Table BB.9: Measures that Can Be Installed by Homeowners Themselves

Measure	Yes (%)	Maybe (%)	No (%)
Energy saving measures	72.23	0.00	0.00
Lighting	100.00	0.00	0.00
Minor air sealing	83.33	0.00	11.11
Major air sealing	5.88	0.00	94.44
Minor insulation	38.89	11.11	50.00
Major insulation	0.00	0.00	100.00
Appliances replacement	100.00	0.00	0.00
Hang doors and windows	11.11	0.00	88.89

As shown in Table C4.9, the following three measures that reached consensus and will be excluded from the homeowner self-perform measure lists are:

1. Major air sealing (94.44%)
2. Major insulation (100%)
3. Hang doors and windows (88.89%)

There was however no consensus on the minor insulation measure. When the maybe and no responses are aggregated, there is still no consensus (61.11%). Base on the background knowledge and knowledge engineer training, this measure will be included in the list of measures to be completed by a professional due to the following reasons:

- There are possible health and safety hazards from off-gassing of some insulation products
- To be properly done, the homeowner needs education and hence might not have the expertise to do it
- The homeowner may not have the equipment to install this measure
- Homeowner might not have the skill to implement this measure
- A good insulation depends on having a well-sealed house. since some air seal gaps might be missed by homeowners, it is better to allow industry experts to perform insulation measures

SUMMARY

At the end of the second round of the Delphi process, when all 7 questions were analyzed, consensus was reached on all the questions. The data generated will be included in the analysis stage of the development steps for the energy retrofit expertise identification system (EREIS) and energy retrofit expertise elicitation system (EREES).

APPENDIX C.1

Detailed Description of Questions for Developing Rules for KB-Therm Module

The elements of a building that separate the controlled interior environment from the uncontrolled exterior environment are referred to as the building or thermal envelope. This includes elements such as: walls, windows, doors, roofs, foundations, and ceilings. When carefully designed and well maintained, the thermal envelope minimizes energy used by the heating, ventilation, and air conditioning (HVAC), and lighting systems. For optimum efficiency when a building is being heated, cold exterior air should not leak into conditioned spaces (infiltration) and conditioned air should not leak from the conditioned space inside to the exterior (exfiltration). The reverse is also true when the building is being cooled. The exception is when natural ventilation is needed for ventilation, cooling, or heating. For lighting, the thermal envelope can be designed to maximize the use of natural daylighting in order to reduce the energy load (ACEE 2012; Gellings & Parmenter 2004; Krigger & Dorsi 2009). These reinforce the correlation between the thermal envelope and other building systems highlighted in whole house systems of buildings. It is, therefore, important to address thermal envelope measures first in most energy retrofits.

Based on the knowledge elicited and compiled from energy retrofit experts using the energy retrofit expertise elicitation strategy combined with the compiled quantitative information particularly, the work completed by the CEER team on market characterization (Hendron & Engebrecht 2010; Kim *et al.* 2014), influential architectural variables in determining high energy consuming buildings which makes them candidates for energy efficient retrofits are shown below:

1. Size of house
2. Number of stories
3. Age of house
4. Main heating/cooling system
5. Presence of a fireplace unit
6. Presence of basement
7. Attached garage or carport
8. Comfort complaints
9. Visible moisture issues
10. Visible health and safety issues
11. Appliances and lighting characteristics
12. Exposed concrete blocks or stucco foundation

Based on literature review combined with the expert knowledge elicited through the knowledge elicitation process, discussed in Chapter four, the following discusses all the questions used in identifying the condition of the thermal envelope. Based on the discussion, the rules were developed.

1. ***Which of the following best describes your home?***
    a. 1-story house b. 2-story house c. 3 or more story house

Housing types that have a high energy consumption rates based on monthly energy bills in the Midwest region of the United States are relatively larger, typically over 2500 square feet, have three or more stories, and were built prior to the energy crisis of the 1970s. Particularly, 1.5 story homes, such as, Cape Cod homes constructed between 1930 and 1960 have insulation challenges across the Midwest region of the United States (Kim *et al.* 2014).

2. ***When was your home built?***
   a. 1929 or before
   b. 1930 – 1949
   c. 1950 – 1969
   d. 1970 – 2000
   e. After 2000

Energy codes and standards for buildings assure that there are reductions in the use of energy and emissions over its life by setting minimum efficiency requirements for new and renovated building. Thus, the energy efficiency of buildings is increased, resulting in significant cost savings in private and public sectors of the United States economy (USDOE 2013). Energy codes were established in the late 1990s, thus, majority of housing in the Great Lakes region do not have modern energy efficient features since they were built prior to the 1970's and has undergone limited upgrades. While houses built before 1930 have an energy-inefficient balloon frame system of construction, those built beyond this period have a more energy efficient platform frame construction system.

3. ***What is the approximate size of your home (kindly exclude unconditioned spaces)?***
   a. Up to 900 sq. ft.
   b. 901 – 2500 sq. ft.
   c. More than 2500 sq. ft.

Housing types that have a high energy consumption rates based on monthly energy bills in the Midwest region of the United States fall into these categories:

3. 3 or more stories, 2500 square feet or larger and built since 1970
4. 3 or more stories, 900 – 2500 square feet, and built between 1930 and 1949

4. ***Which of the following upgrades have be performed on your home?***
   a. Attic air sealing and insulation
   b. Basement air sealing and insulation
   c. Crawlspace air sealing and insulation
   d. Conditioned space air sealing and insulation
   e. None of the above

5. ***Which of the following describes the lower level of your home?***
   a. Unconditioned basement
   b. Conditioned basement
   c. Unconditioned crawlspace
   d. Conditioned crawlspace

All house types that are dominant in the Midwest have basements irrespective of the year they were built, and approximately 90.10% of high energy consuming housing types have a basement (Kim *et al.* 2014). In terms of the condition of the lower level, especially regarding performed upgrades below grade level, Lstiburek (2004) has noted that existing vented crawl spaces are experiencing serious moisture and mold problems, and involve significant resources to repair. As a result, he proposes conditioned crawl spaces, which perform better regarding cost, safety, health, comfort, durability and energy consumption, over vented crawl spaces. The problem with vented crawlspaces is that when outside air with a dew point higher than the interior crawl space surface temperature is permitted to enter it, there are obvious moisture problems. Conditioned crawl spaces are designed and constructed as mini-basements or part of the conditioned space of the house. There must be perimeter insulation, a continuous sealed ground cover–such as taped polyethylene, and perimeter drainage similar to a basement when the ground level of the crawlspace is below that of the surrounding grade (Lstiburek 2004).

6. ***Is your home occupied all year round?***
   a. Yes, all year round
   b. No, winter only
   c. No, summer only
   d. No, spring only
   e. No, fall only

The duration of home occupation and the specific periods of occupation play an important role in determining the energy upgrades that can be performed on a home. For instance, if the home is main occupied during summer periods in the Midwest region of the United States, the cooling system will have priority over the heating system.

7. ***Which of the following describes the condition of your basement/crawlspace?***
   a. There are visible moisture issues
   b. There are cobwebs and dust in my insulation
   c. There are holes in my rim/band joists
   d. There is no insulation on the sill plate or rim joists
   e. None of the above

Based mainly on the knowledge elicited from the experts, specific indicators were agreed via the Delphi process that the options provided above, gives a good indication of the efficiency of a home when there is no means of performing a comprehensive energy retrofit assessment. The presence of any of the first four options will mean that further investigation has to be conducted. This logic is linked with other questions such as the age of the home, upgrades performed, period of occupation of the home, etc.

8. ***Which of the following best describes the external appearance of your home?***
   a. There is usually snow on my roof in the winter
   b. There are usually a lot of icicles outside
   c. Water slopes towards my house

Apart from the interior indicators of the energy efficiency status of the home, there are certain external that help determine the energy efficiency status of a home. Pizinno (2012) has posited that four external signs to determine low insulation levels include: icicles hanging from the eaves, snow melted off the roof, snow melted around boundary of home, and ice forming in roof gutters. Ojczyk *et al.* (2013) assert that ice dams can be expensive to remove or repair and particularly frustrating to homeowners. When the attic is well insulated, it prevents exfiltration through the roof, thus, there will be no heat to melt the snow. Snow on the roof generally points to a well-insulated and ventilated attic.

9. ***Which of the following best describes the windows in your home?***
   d. Majority are single pane
   e. Majority are double pane
   f. Majority has triple pane or better

Energy-efficient windows, doors, and skylights are useful in reducing heating, cooling, and lighting costs of a home. The type of frame and glazing of a window can give a good indication of its energy efficiency properties. When properly combined to suit the climate, energy-efficient frames and glazing can be adapted to suit specific needs of a home (USDOE 2012). Generally, double pane storm windows (or better) have better efficiency properties than single-pane windows. It must be noted, however, that fenestration upgrades such as windows or doors have very long payback periods and are generally the last measure recommended for the energy retrofit of a home.

10. ***Which of the following best describes air leakage/flow/drafts around doors and windows in your home?***
    a. There is little or no draft
    b. There is some draft
    c. There is a lot of draft

Controlling how much air leaks into or out of the home is very important in having an energy efficient and comfortable home and is at the core of ensuring acceptable thermal envelope properties of homes. Tightening of the thermal envelope of a home through caulking and sealants has several advantages including the following (Building Energy Codes 2011):

- Low loss of heat leading to lower heating bills
- Little or no draft making the home more comfortable
- Less chances of mold and rot penetration into the home
- Better performing ventilation system
- Possibility to resize heating and equipment capacities

The following questions, part of the initial questionnaire developed, were removed from the list based on the review of literature and particularly interaction with industry experts:

How many usable rooms are in your home?
Square footage was determined to be a more valuable metric. For instance, during a recent visit to a 40,000 square feet home by one of the experts, it emerged that even though there were many rooms, there were two very huge rooms – a ball room and a museum. In this instance, the number of rooms is not a good indicator, compared to square footage which will give a good indication of energy consumption.

Approximately how many people live in your home each year?
The sizing of air conditioning for residential homes rarely considers the number of people living in the house as it has no impact on winter operation but minimal impact on summer cooling or air conditioning. Commercially, however, this makes a huge difference. The rule of thumb for residential is by assuming two people per bedroom and this barely affects the air conditioning load.

APPENDIX C.2

Detailed Description of Questions for Developing Rules for KB-HVAC Module

1. ***Is your house heated with a boiler?***
   a. No *b. Yes, steam Boiler* *c. Yes, Hot Water Boiler*

It is important to make this distinction of identifying whether the home has a boiler for hot water or steam heat because that is not forced air, leading to a number of options. Boilers are very expensive and in terms of payback, they generally cost 2 – 3 times more than forced air furnaces. An illustration of how expensive a boiler is was by an expert who indicated that he had recently taken out an old furnace and the boiler was $7,000. A furnace would have cost them about $2,000.

In terms of efficiency, furnaces and boilers_are about the same – boilers either heat with hot water or steam while a furnace heats with forced air. Boiler life expectancy is 30years and it is generally recommended that when old boilers (30 years) are taken out, they are not replaced with a more efficient system since the payback is 25 – 30 years and is considered a bad investment. A forced-air system would be a better replacement.

2. ***What is the fuel source?***
   a. Natural gas b. Electric c. Propane d. Fuel oil

Even though natural gas is the cheapest and commonly available in the Midwest region of the United States, homes located in the country may not have natural gas available (MSUE 2008) and may rely on propane gas (Metoyer 2013). For central forced air heating, gas and oil furnaces, and electric heat pumps are comparable options.

3. What is the main type of heating system used in your home?

a. furnaces and boilers
b. Electric resistance heating
c. Heat pump
d. Wood and pellet-fuel stoves
e. Solar

When you know that a home has natural gas central forced air, in order to tell whether or not it could be upgraded for savings, you need to know the age of the appliance or the efficiency of the appliance. There is some correlation between the age and efficiency of the system and this gives a good indication for upgrade options.

Furnaces and Boilers (MSUE 2013; USDOE 2012)
In the United States, most of the homes are either heated with furnaces or boilers. Furnaces basically heat air and this is distributed through ducts into the house. Boilers however heat water, and this is provided either as hot water or steam to be used for heating. The mode of distribution for steam is through pipes to steam radiators whilst hot water can be distributed using baseboard radiators or radiant floor systems, or air can be heated through a coil. Compared to hot water boilers, steam boilers operate at higher temperatures and essentially less efficient (USDOE 2012).

Replacing a very old furnace with a new energy efficient replacement makes economic sense due to the following benefits: saving money on heating and air conditioning, conserving fuel, and maintaining a consistent warn winter and cool summer conditions in a home.

Electric Resistance Heating (Energy Saver 2012e)
Even though electric resistance heating converts nearly 100% of the energy in the electricity to heat, most electricity is produced from coal, gas, or oil generators that convert only about 30% of the fuel's energy into electricity. As a result of the generation and transmission losses, electric heat generally more expensive than heat produced using combustion appliances, such as natural gas, propane, and oil furnaces.

In instances where there has been an addition to the home and there are practical challenges to extending existing heating system to the new addition, electric resistance heating is desirable. Some type of thermostat is used to control all types of electric resistance heating.

Wood and Pellet Heating (Energy Saver 2012f)
Proper sizing is important in the selection of a wood- or pellet-burning appliance. A good rule-of-thumb is that a stove rated at 60,000 British Thermal Units (Btu) can heat a 2,000-square-foot home, while a stove rated at 42,000 Btu can heat a 1,300-square-foot space. Such appliances however may emit large quantities of air pollutants, many of which have adverse health effects. Newer appliances certified by the USEPA are more energy efficient.

A yearly (preferably before each heating season) chimney sweep certified by the Chimney Safety Institute of America to inspect the wood-burning system is highly recommended. This ensures the chimney is clean, ensure the appliance, hearth, connecting pipe, air inlets, chimney, and all other components are functioning efficiently and safely.

Active Solar Heating (Energy saver 2012g)
These systems use solar energy to heat a fluid (either liquid or air) and the solar heat is directly transferred to the interior space or to a storage system for later use. Supplementary or a back-up system provides the additional heat if active solar heating is inadequate. When storage is included, liquid systems are typically used and are well suited for radiant heating systems, boilers with hot water radiators, and absorption heat pumps and coolers. Both systems (liquid and air) can supplement forced air systems.

4. What is the age of your main heating system?

a. More than 30 years b. 11 – 29 years c. 10 years or less

Systems that are 10 years or less can have AFUE of as low as 75% and as high as 95% since homeowners had the option 10 years ago and sooner of a wide range of efficiencies, even though, most of them would not know the efficiency. The highest is available is about 97% efficiency. Whether a furnace is 10 years or a year old, the same efficiencies were available in those year ranges.

A condensing furnace or boiler is an ideal investment in cold climates and lasts for about 15– 30 years. Apart from AFUEs, the efficiency of a system can be compared by the features of the equipment:

Old, low-efficiency heating systems:

- Natural draft that creates a flow of combustion gases
- Continuous pilot light
- Heavy heat exchanger
- 56% to 70% AFUE.

Mid-efficiency heating systems:

- Exhaust fan controls the flow of combustion air and combustion gases more precisely
- Electronic ignition (no pilot light)
- Compact size and lighter weight to reduce cycling losses
- Small-diameter flue pipe
- 80% to 83% AFUE.

High-efficiency heating systems:

- Condensing flue gases in a second heat exchanger for extra efficiency
- Sealed combustion
- 90% to 98.5% AFUE.

Compared to older furnace and boiler systems which had efficiencies in the range of 56% to 70%, modern conventional heating systems converts nearly all the fuel to useful heat for a home and can achieve efficiencies as high as 98.5%. Energy retrofitting and installation of new high-efficiency heating system can often cut fuel bills and furnace pollution output in half. For instance, when a furnace or boiler is upgraded from 56% to 90% efficiency in an average cold-climate house, 1.5 tons of carbon dioxide emissions each year will be saved if the home is heated with gas or 2.5 tons if it is oil.

The simplest solution for upgrading an energy inefficient furnace or boiler is to replace it with a modern high-efficiency model. Leading candidates for such upgrades are old coal burners that were switched over to oil or gas are and gas furnaces with pilot lights rather than electronic ignitions. Where systems are relatively new, even though they may be more efficient, they are typically oversized and can usually be improved to lower their operating capacity.

Furnaces and boilers with an ENERGY STAR® label are highly efficient and must be sought after especially for homes in a cold climate region. It makes economic sense to upgrade to a newer and efficient system since most of the older systems are oversized and this is pronounced when the thermal envelope is tightened further, thus making the case for a newer and efficient system.

5. ***What is the size and efficiency of your main heating system?***
   a. 150kBtuhr or more
   b. 100 – 149 kBtuhr
   c. 50 – 99 kBtuhr
   d. 49 kBtuhr or less

The calculation of the heating requirements of a home is the best way to ensure proper sizing. Knowledgeable industry professionals must be consulted to perform the calculation. Most furnaces are generally oversized and this leads to an inefficient operation which costs money on fuel whilst the additional costs on the bigger-sized furnace could have been avoided.

6. ***What is the size and efficiency of your main heating system?***
   a. Up to 80%
   b. 81% – 89%
   c. 90% or more

This basically indicates how much of the total energy used is actually delivered to the home as heat, measured using the Annual Fuel Utilization Efficiency (AFUE). The higher the AFUE (expressed in percentage), the better the furnace performs. A furnace that is 90% efficient delivers is the most efficient.

7. ***Which of the following describes the use of a programmable thermostat in your home?***
   a. I do not have a programmable thermostat
   b. I maintain a constant setting for my programmable thermostat
   c. I vary the settings of my programmable thermostat

If you maintain constant settings (b), then vary it (and link to website for more information). Varying it definitely saves energy. In fact, you can manually vary a regular thermostat that's not programmable – just like in the winter when I leave here, I turn my thermostat down and that's not programmable but at home, my air conditioner is off right now because I've got a programmable thermostat and it will turn on before I get home so it won't be hot in there.

8. ***Which of the following describes the cooling system used in your home?***
   a. Central air conditioning system
   b. Heat pump system
   c. Room air conditioning system
   d. Ventilation system

Central Air Conditioning

These circulate cool air through a system of supply and return ducts. Cooled air from the air conditioner is carried through supply ducts and registers (i.e., openings in the walls, floors, or ceilings covered by grills) to the home. As the cooled air becomes warmer when it circulates through the home, it flows back to the central air conditioner through return ducts and registers.

If a home has a furnace but no air conditioner (AC), it makes economic sense to install a split-system type of central AC. Central ACs are more efficient than room ACs, are very quiet, and convenient to operate. The choice of installing a central AC depends on the need for ductwork.

Replacing a 10 year old air conditioner with a newer, more efficient model may save 20% to 40% of cooling energy costs.

Central ACs are rated according to their seasonal energy efficiency ratio (SEER) which basically specifies the relative amount of energy needed to provide a specific cooling output. Several older systems have SEER ratings of 6 or less but the minimum SEER allowed today is 13. If manufactured after January 23, 2006, ACs must achieve a SEER of 13 or higher. A central AC typically lasts for about 15 to 20 years though replacement parts are available to meet new standards.

Room Air Conditioner

Rather than cooling the entire home, room or window air conditioners cool rooms thus providing cooling only where needed. Compared to central units, room units are cheaper to operate but they generally have lower efficiencies. The efficiency of a room air conditioner is measured by the energy efficiency ratio which is the ratio of the cooling capacity (in British thermal units [Btu] per hour) to the power input (in watts). A higher ratio rating means the air conditioner is more efficient. Minimum ratio for such units ranges from 8.0–9.8 or greater, depending on the type and capacity. For instance, by replacing a 1970s-vintage unit with a ratio of 5 with a new one with a ratio of 10 will reduce air conditioning energy costs in half. Units with ratios of 10.0 or above are ideal.

Ventilation System

Very few people use ventilation fans unless it is poorly distributed, in which case they might have an attic ventilation fan. Many people do not know whether they a ventilation fan or not unless they actually paid to have it installed. These fans have limited impact on the energy consumption of a home. One of the experts indicated that, a study has been conducted by Consumers' Energy regarding claims by manufacturers that ventilation fans cuts down on the number of hours that an air conditioner will run because the attic is cooler, thus, minimal heat is gained through the ceiling into the home. The findings indicate that, the amount of energy that the attic fan uses offsets the amount of energy you save with your air conditioner.

9. ***What is the age of your cooling system?***
   a. More than 30 years
   b. 16 – 30 years
   c. 11 – 15 years
   d. 6 – 10 years
   e. 1 – 5 years
   f. Less than 1 year (New)

Unlike furnaces, air conditioners are more efficient, typically going in about 2 – 3 years blocks where the manufacturers increase their efficiency mainly due to government regulations. Systems 7 years or less are considered new, 8 – 15 years could be changed depending on other conditions, but more than 15 years require a new system. This logic, however, is dependent of the frequency of use of the system which is included as a separate question. When there is a need to replace the system, energy efficient appliances such as Energy Star labeled ones are good candidates.

10. ***Which of the following describes the frequency of use of your cooling system?***
    a. I use it all the time
    b. I usually use it
    c. I sometimes use it
    d. I rarely or never use it

The advice regarding the cooling system will depend on the frequency of use of the system. This question is therefore like a control question. For instance, IF they use it usually (b) AND it is between 11 – 15 years old, THEN consider replacing it with a more energy efficient one. I agree because if they don't use it or they rarely use it, as long as it works, they should just keep it.

11. What is the seasonal efficiency ratio (SEER) rating of your central air conditioning?

a. SEER 13 or more b. SEER 10 -12 c. SEER 9 or less

Central ACs are rated according to their seasonal energy efficiency ratio (SEER), which basically specifies the relative amount of energy needed to provide a specific cooling output. Several older systems have SEER ratings of 6 or less, but the minimum SEER allowed today is 13. If manufactured after January 23, 2006, ACs must achieve a SEER of 13 or higher. A central AC typically lasts for about 15 to 20 years though replacement parts are available to meet new standards (Energy Saver 2012c).

The following questions were not included in the questionnaire used for developing the logic due to the reasons indicated below.

If you have additional heating, kindly indicate which of the following systems is used
Which of the following describes the frequency of use of your additional heating system?
It is very uncommon for people to have additional heating – the main heating system should be enough for the home. The only time you see where people have an additional system is if they have made an addition to their home, probably due to the addition of a family room or a bedroom and it is just less expensive to put an electric heater in that room rather than connect it to the main system for the rest of the house but that's unusual.

How many window/wall mounted air conditioners do you use in your home?
Well a room air conditioner and a mini-split air conditioner which mounts part on the wall and the other part outside and inside the building it looks like a room air conditioning system. As a result, there was no need to differentiate between both systems.

Which of the following describes the type and number of fans used in your home?
Is there a residential economizer installed in your home?
Which of the following describes the frequency of use of your portable fans?
Which of the following describes the frequency of use of your ceiling fans?
Which of the following describes the frequency of use of your residential economizer?

Out of a 100 people, you might find one that has an economizer and so you can almost eliminate that question. An effective heating and cooling system adequately caters for ventilating the home since such systems are designed to bring air in from outside for ventilation, thus, a separate system for ventilation is not needed.

APPENDIX C.3

Detailed Description of Questions for Developing Rules for KB-HWH Module

1. ***Choose from the options which best describes the water heater system used in your home?***
   a. Conventional water storage
   b. Tankless or demand type
   c. Heat pump
   d. Tankless coil
   e. Indirect water heaters
   f. Solar

2. ***What is the age of your water heating system?***
   a. 16 or more years
   b. 15 years or less

While an average household uses 64 gallons of water each day, it is instructive to note that water heating is the second largest expense in a household's utility bills accounting for 14–46% and costs between $400 and $600 annually. It is therefore important to select an energy efficient water heater for a home. An average water heater lasts 10–15 years beyond which it needs changing. In the United States, there are about 27 million households that have water heaters that are more than 10 years old (Energy Saver 2013, 2012h).

Conventional storage water heaters (Energy Saver 2013, 2012h)
These offer a ready reservoir (storage tank) of hot water and are the most popular system of heating water for the home. Fuel sources include natural gas, propane, fuel oil, and electricity. As a result of the constant heating of water in the tank, energy is wasted even when tap is not running and this phenomenon is referred to as "standby heat loss". Heavily insulated tanks significantly reduce standby heat losses and lower annual operating costs especially models with a thermal resistance (R-Value) of R-12 to R-25.

Periodic maintenance can significantly prolong the life of the water heater and also minimize its loss of efficiency. Routing maintenance tips include the following:

- Flushing a quart of water from the storage tank every three months
- Checking the temperature and pressure valve every six months
- Inspecting the anode rod every three to four years.

Tankless or demand-type water heaters (Energy Saver 2013, 2012h)
Water is directly heated without the use of a storage tank thus providing hot water only when needed. Unlike storage water heaters, there are no standby energy losses with this system. It uses either a gas burner or an electric element to heat the water to deliver a constant hot water supply even though the flow rate is limited with gas fired ones producing higher flow rates. Even though tankless water heaters have high initial costs when compared to conventional water heaters, they typically last longer and have lower operating and energy costs that can offset the high initial

price. Unlike conventional storage water heaters which lasts 10–15years, most tankless water heaters last over 20 years which can be extended further due to their easily replaceable parts.

Heat pump water heaters (Energy Saver 2013, 2012h)

These use electricity to move heat from one place to another instead of generating heat directly for providing hot water. It can be used either as stand-alone water heating system, or as combination water heating and space conditioning system but they work more efficiently in warm climates. Though they have initial costs compared to conventional storage water heaters, their lower operating costs can offset this cost. Compared to conventional water storage water heaters, they have higher initial costs which can be offset by their lower operating costs.

Solar water heaters (Energy Saver 2013, 2012h)

These use the sun's heat to provide hot water and are usable in any climate. The system includes storage tanks and solar collectors. Conventional storage water heaters are used as part of the solar system package and are particularly useful on cloudy days. Even though simple solar water heating systems require regular maintenance every 3–5 years by a solar professional, electrical replacement components require a replacement part of two after 10 years.

Tankless coil and indirect water heaters(Energy Saver 2013, 2012h)

Use a home's space heating system to heat water as part of an integrated or combination water and space heating system. Water is heated as it flows through a heating coil (or heat exchanger) installed in a main furnace or boiler when a hot water faucet is turned on. These systems are most efficient during cold months and inefficient for many homes in warmer climates.

APPENDIX C.4

Detailed Description of Questions for Developing Rules for KB-Light Module

1. Which of the following best describes the type of lights used in your home?

a. Majority are incandescent light bulbs
b. There are some incandescent light bulbs
c. Majority are compact fluorescent or Low emitting diode (LED) lights

Traditional incandescent lights are known to be energy inefficient when compared to their energy efficient counterparts such as energy-saving incandescent lights, compact fluorescent lamps (CFLs), and light emitting diodes (LEDs), all of which typically use about 25%-80% less energy thus economically beneficial and last 3 – 25 times longer. Even though the initial cost of energy efficient bulbs is higher than traditional incandescent lights, energy efficient bulbs have lower operating costs and last longer, thus saving money over the life of the bulb (Energy Saver 2012d).

Compared to commercial buildings, lighting in residential homes does not consume that much energy. Payback on lighting upgrades is short and is relatively inexpensive compared to other energy upgrades in a home, such as heating or cooling system installation.

Dimmable CFLs are currently available on the markets but are very expensive and are rarely carried by places like Home Depot or Lowes. A good solution would be to provide non-dimmable lights for most of them and then leave out those they really want to dim as incandescent because a person will not want to dim all of their lights – just a portion of them.

APPENDIX C.5

Detailed Description of Questions for Developing Rules for KB-ESM Module

When performing energy efficiency upgrades it is important to use the whole-house approach, which basically operates on the understanding that there is interaction of all systems in a home and this has an effect on the energy performance of the home. Baechler *et al.* (2011) posit that energy upgrading using the whole-house approach ensures the health and safety of the homeowner and also leads to cost-effective energy savings. On the contrary, as the name suggests, stand-alone measures are those that have limited or no interaction with the energy performance of other systems. Examples of stand-alone measures include major non-HVAC appliances or appliances such as refrigerators, clothes washers and dryers, and dishwashers. In addition, there are some measures that do not have a huge effect on reducing the energy consumption of buildings. Such measures, referred to as energy saving measures, include water heater pipe insulation, water saving showerheads, furnace filter change, and faucet aerators.

A key determinant of the efficiency of appliances is the ENERGY STAR labeling. Every appliance has the purchase price, and the operation and maintenance costs. Compared to standard rated appliances, ENERGY STAR qualified appliances use 10 to 50 percent less energy, thus saving energy, money, and helping reduce emissions of greenhouse gases and air pollutants. Available appliances from ENERGY STAR include refrigerators, clothes washers, clothes dryers, dishwashers etc. (Energy Star 2013a).

1. *What is the efficiency of your clothes washer*?
   a. My clothes washer is Energy Star rated
   b. My clothes washer has a standard rating
   c. I do not have a clothes washer

2. *What is the efficiency of your clothes dryer*?
   a. My clothes dryer is Energy Star rated
   b. My clothes dryer has a standard rating
   c. I do not have a clothes dryer

3. What is the efficiency of your refrigerator?
   a. My refrigerator is Energy Star rated
   b. My refrigerator has a standard rating
   c. I do not have a refrigerator

4. Is your refrigerator more than 10 years old?
   a. Yes   b. No

Fridges and freezers made before 1993 are inefficient since the unit costs more than $100 per year in electricity—twice as much as a new ENERGY STAR qualified model. And fridges and freezers from the 1970s cost four times more to operate (Energy star 2013c). It is estimated that there are 170 million refrigerators and refrigerator-freezers currently being used in the United States. About a third of this number is over 10 years old and costs consumers $4.4 billion a year in energy costs. Consumers can save from $200–$1,100 on energy costs over the lifetime of a refrigerator if it is replaced with a new ENERGY STAR certified refrigerator (Energy Star 2013f). Based on this the threshold for old refrigerators was set at more than 10 years old.

5. What is the efficiency of your stand-alone freezers?

a. My stand-alone freezer is Energy Star rated
b. My stand-alone freezer has a standard rating
c. I do not have a stand-alone freezer

It is estimated that 35 million freezers are currently being used in the United States out of which a little over half are more than 10 years old and this costs consumers $940 million per year on their energy bills (Energy Star 2013g). Stand-alone freezers are very common – my estimate will be that probably 25% of homeowners have a separate freezer either in the garage or in the basement.

- ***Which of the following best describes your dishwasher?***
  a. My stand-alone freezer is Energy Star rated
  b. My stand-alone freezer has a standard rating
  c. I do not have a stand-alone freezer

- ***Which of the following best describes the number of showerheads in your home are low flow energy-saving?***
  a. All b. Some c. None

- ***Which of the following describes the faucets in your home?***
  a. All have water saving aerators c. None has water saving aerators
  b. Some have water saving aerators

APPENDIX D.1

Table D.1: Detailed EREIS Scores for Participant 1

	UPPER PROFICIENT								
	RESPONDENT #1		**Expertise ID**						
Number	**ATTRIBUTE-BASED QUESTIONS**	**RIS**	**Novice**	**Advanced Beginner**	**Competent**	**Proficient**	**Expert**	**Selected Option**
1	***How long have you been working in energy efficiency retrofits for existing homes?***	**0.4**	**10**	**20**	**30**	**40**	**50**	
	IF up to a year, **THEN Novice**		4					
	IF more than 1 year but up to 2 years, **THEN Advanced Beginner**			8				
	IF more than 2 years but up to 3 years, **THEN Competent**				12			
	IF more than 3 years but up to 4 years, **THEN Proficient**					16		**16**
	IF more than 4 years, **THEN Expert**						20	
2	***How many retrofits on average, do you complete each year?***	**0.4**	**10**	**20**	**30**	**40**	**50**	
	IF performs between 1 and 6 audits each year, **THEN Novice**		4					
	IF performs between 7 and 12 audits each year, **THEN Advanced Beginner**			8				
	IF performs between 13 and 18 audits each year, **THEN Competent**				12			
	IF performs between 19 and 24 audits each year, **THEN Proficient**					16		**16**
	IF more than 24 audits each year, **THEN Expert**						20	

Table D.1 (Cont'd)

3	***Have you been away from the industry before? If yes, for how long were you away and did you require retraining?***	**0.3**	**10**	**20**	**30**	**40**	**50**	
	IF more than 3 years, **THEN Novice**		3					
	IF more than 2 years up to 3 years, **THEN Advanced Beginner**			6				
	IF more than 1 year up to 2 years, **THEN Competent**				9			
	IF up to 1 year, **THEN Proficient**					12		
	IF never been away (0 years), **THEN Expert**						15	**15**
4	***How often do you update your knowledge in your work by referring to colleagues, books, manuals, internet, etc. to reinforce information you give to homeowners?***	**0.3**	**10**	**20**	**30**	**40**	**50**	
	IF knowledge is NOT updated, **THEN Novice**		3					
	IF knowledge is updated rarely, **THEN Advanced Beginner**			6				
	IF knowledge is updated sometimes, **THEN Competent**				9			
	IF knowledge is updated regularly, **THEN Proficient**					12		**12**
	IF knowledge is updated always, **THEN Expert**						15	
5	***Are you aware of the tax incentives, rebates, and benefits available to homeowners when they undertake an energy retrofit? If yes, how do you get this information?***	**0.3**	**10**	**20**	**30**	**40**	**50**	
	IF no, **THEN Novice**		3					
	IF yes/chance upon information, **THEN Advanced Beginner**			6				
	IF yes/obtains from 1 source, **THEN Competent**				9			
	If yes/obtains from 2 sources excluding trade organizations, **THEN Proficient**					12		**12**
	IF yes/obtains from 3 or more sources including trade organization							
	and/or government, **THEN Expert**						15	
6	***When a homeowner asks you to justify or explain your decision or actions, how do you go about it?***	**0.4**	**10**	**20**	**30**	**40**	**50**	
	IF make impression and/or company identity builds trust, **THEN Novice**		4					
	IF anyone apart from case based reasoning, **THEN Advanced Beginner**			8				
	IF case based reasoning **THEN Competent**				12			

Table D.1 (Cont'd)

	If any 2 including CBR, **THEN Proficient**					16		**16**
	IF any 3 including CBR - CBR, SSO, RAE, FGS, and/or RWSR, THEN **Expert**						20	
7	***Several measures have been suggested for improving the energy efficiency of existing homes. For e.g. replacing incandescent light bulbs with CFLs. Kindly list others.***	**0.1**	**10**	**20**	**30**	**40**	**50**	
	IF mentions only energy saving measures, **THEN Novice**		1					
	IF mentions measures, **THEN Advanced Beginner**			2				
	IF mentions 3 measures, **THEN Competent**				3			
	IF explains 3 measures/examples, **THEN Proficient**					4		
	IF explains more than 3 measures/examples, **THEN Expert**						5	**5**
8	***How would you explain in a step by step manner, the methods you will use to make recommend retrofit measures for a home that you have no means of testing?***	**0.6**	**10**	**20**	**30**	**40**	**50**	
	IF mentions/explains 1 sign, **THEN Novice**		6					
	IF mentions/explains 2 signs, **THEN Advanced Beginner**			12				
	IF mentions/explains 3 signs, **THEN Competent**				18			
	IF mentions/explains 4 signs, **THEN Proficient**					24		
	IF mentions/explains 5 or more signs, **THEN Expert**						30	**30**
9	***Different homes have different retrofit needs. What aspects of the home will determine the need? E.g. is it the construction type, archetype type, age of the home etc.?***	**0.6**	**10**	**20**	**30**	**40**	**50**	
	IF does not see link among aspects, **THEN Novice**		6					
	IF links 2 aspects, **THEN Advanced Beginner**			12				
	IF links 2 aspects and gives example, **THEN Competent**				18			**18**
	IF links 3 aspects/identify 1 retrofit need, **THEN Proficient**					24		
	IF links 3 aspects/identify 1 retrofit need/e.g., **THEN Expert**						30	
10	***How would you explain to a homeowner in a step by step manner what "Energy Auditing" means?***	**0.5**	**10**	**20**	**30**	**40**	**50**	
	IF unable to explain, **THEN Novice**		5					

Table D.1 (cont'd)

	IF only explains tools used, **THEN Advanced Beginner**			10				
	IF explains/mention 1 of 3 objectives, **THEN Competent**				15			
	IF explains/mention 2 of 3 objectives, **THEN Proficient**					20		**20**
	IF explains/mentions 3 of 3 objectives, **THEN Expert**						25	
11	***What specific benefits can be obtained when you perform energy retrofit of a home?***	**0.2**	**10**	**20**	**30**	**40**	**50**	
	IF cannot mention 1 benefit, **THEN Novice**		2					
	IF mentions 1 benefit, **THEN Advanced Beginner**			4				
	IF mentions 2 benefits, **THEN Competent**				6			**6**
	IF mentions 3 benefits, **THEN Proficient**					8		
	IF mentions 3 benefits, **THEN Expert**						10	
12	***What are some of the measures that provide the greatest return on investment for a home owner and why?***	**0.3**	**10**	**20**	**30**	**40**	**50**	
	IF cannot mention, **THEN Novice**		3					
	IF correctly mentions 1 measure, **THEN Advanced Beginner**			6				
	IF correctly mentions 2 measures, **THEN Competent**				9			
	IF correctly mentions 2 measures, **THEN Proficient**					12		**12**
	IF correctly mentions 2 or more measures/contextualizes, **THEN Expert**						15	
13	***What are some external factors which increase the cost of the retrofit operation?***	**0.4**	**10**	**20**	**30**	**40**	**50**	
	IF none, **THEN Novice**		4					
	IF correctly mentions 1 but cannot explain, **THEN Advanced Beginner**			4				
	IF 1 well-explained factor, **THEN Competent**				12			
	IF 1 well-explained factor/context, **THEN Proficient**					16		**16**
	IF 2 or more well-explained factors/examples, **THEN Expert**						20	
14	***Kindly provide a list of post occupancy health issues that must be addressed in energy retrofits.***	**0.6**	**10**	**20**	**30**	**40**	**50**	
	IF none, **THEN Novice**		6					

Table D.1 (Cont'd)

	IF correctly mentions 1 but cannot explain, **THEN Advanced Beginner**			12				
	IF 1 well-explained post-occupancy H&S issue, **THEN Competent**				18			
	IF 2 well-explained post-occupancy H&S issues, **THEN Proficient**					24		
	IF 2 or more well-explained post-occupancy H&S issues/e.gs., **THEN Expert**						30	**30**
15	***Buildings behave as a system where interactions between components can affect their energy performance. What are the interrelationships among the following measures?***	**0.6**	**10**	**20**	**30**	**40**	**50**	
	If no relationship, **THEN Novice**		6					
	IF relationship/cannot explain, **THEN Advanced Beginner**			12				
	IF explains relationship between 2, **THEN Competent**				18			
	IF explains relationship between 2 with example, **THEN Proficient**					24		
	IF explains relationship among 3 or more/contextualizes, **THEN Expert**						30	**30**
16	***What measures do you consider safe and can be installed by a homeowner? Kindly give reasons for your answer.***	**0.6**	**10**	**20**	**30**	**40**	**50**	
	IF none, **THEN Novice**		6					
	IF mentions 1 measure, **THEN Advanced Beginner**			12				
	IF mentions 1 measure/provides reasons, **THEN Competent**				18			
	IF mentions 2 measures/provides reasons, **THEN Proficient**					24		
	IF mentions 3 measures/provides reasons, **THEN Expert**						30	**30**
17	***What measures do you think must be installed by a licensed retrofit professional? Kindly give reasons.***	**0.6**	**10**	**20**	**30**	**40**	**50**	
	IF none, **THEN Novice**		6					
	IF mentions 1 measure, **THEN Advanced Beginner**			12				
	IF mentions 1 measure/provides reasons, **THEN Competent**				18			
	IF mentions 2 measures/provides reasons, **THEN Proficient**					24		**24**
	IF mentions 3 measures/provides reasons, **THEN Expert**						30	
			72	**140**	**216**	**288**	**360**	**305**

APPENDIX D.2

Table D.1: Detailed EREIS Scores for Participant 2

	EXPERT							
	RESPONDENT #2		**Expertise ID**					
Number	**ATTRIBUTE-BASED QUESTIONS**	**RIS**	**Novice**	**Advanced Beginner**	**Competent**	**Proficient**	**Expert**	**Selected Option**
1	***How long have you been working in energy efficiency retrofits for existing homes?***	**0.4**	**10**	**20**	**30**	**40**	**50**	
	IF up to a year, **THEN Novice**		4					
	IF more than 1 year but up to 2 years, **THEN Advanced Beginner**			8				
	IF more than 2 years but up to 3 years, **THEN Competent**				12			
	IF more than 3 years but up to 4 years, **THEN Proficient**					16		
	IF more than 4 years, **THEN Expert**						20	**20**
2	***How many retrofits on average, do you complete each year?***	**0.4**	**10**	**20**	**30**	**40**	**50**	
	IF performs between 1 and 6 audits each year, **THEN Novice**		4					
	IF performs between 7 and 12 audits each year, **THEN Advanced Beginner**			8				
	IF performs between 13 and 18 audits each year, **THEN Competent**				12			
	IF performs between 19 and 24 audits each year, **THEN Proficient**					16		
	IF more than 24 audits each year, **THEN Expert**						20	**20**

Table D.2 (Cont'd)

3	***Have you been away from the industry before? If yes, for how long were you away and did you require retraining?***	**0.3**	**10**	**20**	**30**	**40**	**50**	
	IF more than 3 years, **THEN Novice**		3					
	IF more than 2 years up to 3 years, **THEN Advanced Beginner**			6				
	IF more than 1 year up to 2 years, **THEN Competent**				9			
	IF up to 1 year, **THEN Proficient**					12		
	IF never been away (0 years), **THEN Expert**						15	**15**
4	***How often do you update your knowledge in your work by referring to colleagues, books, manuals, internet, etc. to reinforce information you give to homeowners?***	**0.3**	**10**	**20**	**30**	**40**	**50**	
	IF knowledge is NOT updated, **THEN Novice**		3					
	IF knowledge is updated rarely, **THEN Advanced Beginner**			6				
	IF knowledge is updated sometimes, **THEN Competent**				9			
	IF knowledge is updated regularly, **THEN Proficient**					12		**12**
	IF knowledge is updated always, **THEN Expert**						15	
5	***Are you aware of the tax incentives, rebates, and benefits available to homeowners when they undertake an energy retrofit? If yes, how do you get this information?***	**0.3**	**10**	**20**	**30**	**40**	**50**	
	IF no, **THEN Novice**		3					
	IF yes/chance upon information, **THEN Advanced Beginner**			6				
	IF yes/obtains from 1 source, **THEN Competent**				9			
	If yes/obtains from 2 sources excluding trade organizations, **THEN Proficient**					12		
	IF yes/obtains from 3 or more sources including trade organization							
	and/or government, **THEN Expert**						15	**15**
6	***When a homeowner asks you to justify or explain your decision or actions, how do you go about it?***	**0.4**	**10**	**20**	**30**	**40**	**50**	
	IF make impression and/or company identity builds trust, **THEN Novice**		4					
	IF anyone apart from case based reasoning, **THEN Advanced Beginner**			8				
	IF case based reasoning **THEN Competent**				12			

Table D.2 (Cont'd)

	If any 2 including CBR, **THEN Proficient**					16		
	IF any 3 including CBR - CBR, SSO, RAE, FGS, and/or RWSR, THEN **Expert**						20	**20**
7	***Several measures have been suggested for improving the energy efficiency of existing homes. For e.g. replacing incandescent light bulbs with CFLs. Kindly list others.***	**0.1**	**10**	**20**	**30**	**40**	**50**	
	IF mentions only energy saving measures, **THEN Novice**		1					
	IF mentions measures, **THEN Advanced Beginner**			2				
	IF mentions 3 measures, **THEN Competent**				3			
	IF explains 3 measures/examples, **THEN Proficient**					4		
	IF explains more than 3 measures/examples, **THEN Expert**						5	**5**
8	***How would you explain in a step by step manner, the methods you will use to make recommend retrofit measures for a home that you have no means of testing?***	**0.6**	**10**	**20**	**30**	**40**	**50**	
	IF mentions/explains 1 sign, **THEN Novice**		6					
	IF mentions/explains 2 signs, **THEN Advanced Beginner**			12				
	IF mentions/explains 3 signs, **THEN Competent**				18			**18**
	IF mentions/explains 4 signs, **THEN Proficient**					24		
	IF mentions/explains 5 or more signs, **THEN Expert**						30	
9	***Different homes have different retrofit needs. What aspects of the home will determine the need? E.g. is it the construction type, archetype type, age of the home etc.?***	**0.6**	**10**	**20**	**30**	**40**	**50**	
	IF does not see link among aspects, **THEN Novice**		6					
	IF links 2 aspects, **THEN Advanced Beginner**			12				
	IF links 2 aspects and gives example, **THEN Competent**				18			
	IF links 3 aspects/identify 1 retrofit need, **THEN Proficient**					24		
	IF links 3 aspects/identify 1 retrofit need/e.g., **THEN Expert**						30	**30**
10	***How would you explain to a homeowner in a step by step manner what "Energy Auditing" means?***	**0.5**	**10**	**20**	**30**	**40**	**50**	
	IF unable to explain, **THEN Novice**		5					

Table D.2 (cont'd)

	IF only explains tools used, **THEN Advanced Beginner**			10				
	IF explains/mention 1 of 3 objectives, **THEN Competent**				15			
	IF explains/mention 2 of 3 objectives, **THEN Proficient**					20		**20**
	IF explains/mentions 3 of 3 objectives, **THEN Expert**						25	
11	***What specific benefits can be obtained when you perform energy retrofit of a home?***	**0.2**	**10**	**20**	**30**	**40**	**50**	
	IF cannot mention 1 benefit, **THEN Novice**		2					
	IF mentions 1 benefit, **THEN Advanced Beginner**			4				
	IF mentions 2 benefits, **THEN Competent**				6			
	IF mentions 3 benefits, **THEN Proficient**					8		
	IF mentions 3 benefits, **THEN Expert**						10	**10**
12	***What are some of the measures that provide the greatest return on investment for a home owner and why?***	**0.3**	**10**	**20**	**30**	**40**	**50**	
	IF cannot mention, **THEN Novice**		3					
	IF correctly mentions 1 measure, **THEN Advanced Beginner**			6				**6**
	IF correctly mentions 2 measures, **THEN Competent**				9			
	IF correctly mentions 2 measures, **THEN Proficient**					12		
	IF correctly mentions 2 or more measures/contextualizes, **THEN Expert**						15	
13	***What are some external factors which increase the cost of the retrofit operation?***	**0.4**	**10**	**20**	**30**	**40**	**50**	
	IF none, **THEN Novice**		4					
	IF correctly mentions 1 but cannot explain, **THEN Advanced Beginner**			4				
	IF 1 well-explained factor, **THEN Competent**				12			
	IF 1 well-explained factor/context, **THEN Proficient**					16		**16**
	IF 2 or more well-explained factors/examples, **THEN Expert**						20	
14	***Kindly provide a list of post occupancy health issues that must be addressed in energy retrofits.***	**0.6**	**10**	**20**	**30**	**40**	**50**	
	IF none, **THEN Novice**		6					

Table D.2 (Cont'd)

	IF correctly mentions 1 but cannot explain, **THEN Advanced Beginner**			12				
	IF 1 well-explained post-occupancy H&S issue, **THEN Competent**				18			
	IF 2 well-explained post-occupancy H&S issues, **THEN Proficient**					24		
	IF 2 or more well-explained post-occupancy H&S issues/e.gs., **THEN Expert**						30	**30**
15	***Buildings behave as a system where interactions between components can affect their energy performance. What are the interrelationships among the following measures?***	**0.6**	**10**	**20**	**30**	**40**	**50**	
	If no relationship, **THEN Novice**		6					
	IF relationship/cannot explain, **THEN Advanced Beginner**			12				
	IF explains relationship between 2, **THEN Competent**				18			
	IF explains relationship between 2 with example, **THEN Proficient**					24		
	IF explains relationship among 3 or more/contextualizes, **THEN Expert**						30	**30**
16	***What measures do you consider safe and can be installed by a homeowner? Kindly give reasons for your answer.***	**0.6**	**10**	**20**	**30**	**40**	**50**	
	IF none, **THEN Novice**		6					
	IF mentions 1 measure, **THEN Advanced Beginner**			12				
	IF mentions 1 measure/provides reasons, **THEN Competent**				18			
	IF mentions 2 measures/provides reasons, **THEN Proficient**					24		
	IF mentions 3 measures/provides reasons, **THEN Expert**						30	**30**
17	***What measures do you think must be installed by a licensed retrofit professional? Kindly give reasons.***	**0.6**	**10**	**20**	**30**	**40**	**50**	
	IF none, **THEN Novice**		6					
	IF mentions 1 measure, **THEN Advanced Beginner**			12				
	IF mentions 1 measure/provides reasons, **THEN Competent**				18			
	IF mentions 2 measures/provides reasons, **THEN Proficient**					24		
	IF mentions 3 measures/provides reasons, **THEN Expert**						30	**30**
			72	**140**	**216**	**288**	**360**	**327**

APPENDIX D.3

Table D.1: Detailed EREIS Scores for Participant 3

EXPERT

RESPONDENT #3

Number	ATTRIBUTE-BASED QUESTIONS	RIS	Expertise ID: Novice	Advanced Beginner	Competent	Proficient	Expert	Selected Option
1	***How long have you been working in energy efficiency retrofits for existing homes?***	**0.4**	**10**	**20**	**30**	**40**	**50**	
	IF up to a year, **THEN Novice**		4					
	IF more than 1 year but up to 2 years, **THEN Advanced Beginner**			8				
	IF more than 2 years but up to 3 years, **THEN Competent**				12			
	IF more than 3 years but up to 4 years, **THEN Proficient**					16		
	IF more than 4 years, **THEN Expert**						20	**20**
2	***How many retrofits on average, do you complete each year?***	**0.4**	**10**	**20**	**30**	**40**	**50**	
	IF performs between 1 and 6 audits each year, **THEN Novice**		4					
	IF performs between 7 and 12 audits each year, **THEN Advanced Beginner**			8				
	IF performs between 13 and 18 audits each year, **THEN Competent**				12			
	IF performs between 19 and 24 audits each year, **THEN Proficient**					16		
	IF more than 24 audits each year, **THEN Expert**						20	**20**

Table D.3 (Cont'd)

3	***Have you been away from the industry before? If yes, for how long were you away and did you require retraining?***	**0.3**	**10**	**20**	**30**	**40**	**50**	
	IF more than 3 years, **THEN Novice**		3					
	IF more than 2 years up to 3 years, **THEN Advanced Beginner**			6				
	IF more than 1 year up to 2 years, **THEN Competent**				9			
	IF up to 1 year, **THEN Proficient**					12		
	IF never been away (0 years), **THEN Expert**						15	**15**
4	***How often do you update your knowledge in your work by referring to colleagues, books, manuals, internet, etc. to reinforce information you give to homeowners?***	**0.3**	**10**	**20**	**30**	**40**	**50**	
	IF knowledge is NOT updated, **THEN Novice**		3					
	IF knowledge is updated rarely, **THEN Advanced Beginner**			6				
	IF knowledge is updated sometimes, **THEN Competent**				9			
	IF knowledge is updated regularly, **THEN Proficient**					12		
	IF knowledge is updated always, **THEN Expert**						15	**15**
5	***Are you aware of the tax incentives, rebates, and benefits available to homeowners when they undertake an energy retrofit? If yes, how do you get this information?***	**0.3**	**10**	**20**	**30**	**40**	**50**	
	IF no, **THEN Novice**		3					
	IF yes/chance upon information, **THEN Advanced Beginner**			6				
	IF yes/obtains from 1 source, **THEN Competent**				9			
	If yes/obtains from 2 sources excluding trade organizations, **THEN Proficient**					12		**12**
	IF yes/obtains from 3 or more sources including trade organization							
	and/or government, **THEN Expert**						15	
6	***When a homeowner asks you to justify or explain your decision or actions, how do you go about it?***	**0.4**	**10**	**20**	**30**	**40**	**50**	
	IF make impression and/or company identity builds trust, **THEN Novice**		4					
	IF anyone apart from case based reasoning, **THEN Advanced Beginner**			8				
	IF case based reasoning **THEN Competent**				12			

Table D.3 (Cont'd)

	If any 2 including CBR, **THEN Proficient**					16		
	IF any 3 including CBR - CBR, SSO, RAE, FGS, and/or RWSR, THEN **Expert**						20	**20**
7	***Several measures have been suggested for improving the energy efficiency of existing homes. For e.g. replacing incandescent light bulbs with CFLs. Kindly list others.***	**0.1**	**10**	**20**	**30**	**40**	**50**	
	IF mentions only energy saving measures, **THEN Novice**		1					
	IF mentions measures, **THEN Advanced Beginner**			2				
	IF mentions 3 measures, **THEN Competent**				3			
	IF explains 3 measures/examples, **THEN Proficient**					4		
	IF explains more than 3 measures/examples, **THEN Expert**						5	**5**
8	***How would you explain in a step by step manner, the methods you will use to make recommend retrofit measures for a home that you have no means of testing?***	**0.6**	**10**	**20**	**30**	**40**	**50**	
	IF mentions/explains 1 sign, **THEN Novice**		6					
	IF mentions/explains 2 signs, **THEN Advanced Beginner**			12				
	IF mentions/explains 3 signs, **THEN Competent**				18			
	IF mentions/explains 4 signs, **THEN Proficient**					24		
	IF mentions/explains 5 or more signs, **THEN Expert**						30	**30**
9	***Different homes have different retrofit needs. What aspects of the home will determine the need? E.g. is it the construction type, archetype type, age of the home etc.?***	**0.6**	**10**	**20**	**30**	**40**	**50**	
	IF does not see link among aspects, **THEN Novice**		6					
	IF links 2 aspects, **THEN Advanced Beginner**			12				
	IF links 2 aspects and gives example, **THEN Competent**				18			**18**
	IF links 3 aspects/identify 1 retrofit need, **THEN Proficient**					24		
	IF links 3 aspects/identify 1 retrofit need/e.g., **THEN Expert**						30	
10	***How would you explain to a homeowner in a step by step manner what "Energy Auditing" means?***	**0.5**	**10**	**20**	**30**	**40**	**50**	
	IF unable to explain, **THEN Novice**		5					

Table D.3 (cont'd)

	IF only explains tools used, **THEN Advanced Beginner**			10				
	IF explains/mention 1 of 3 objectives, **THEN Competent**				15			
	IF explains/mention 2 of 3 objectives, **THEN Proficient**					20		
	IF explains/mentions 3 of 3 objectives, **THEN Expert**						25	**25**
11	***What specific benefits can be obtained when you perform energy retrofit of a home?***	**0.2**	**10**	**20**	**30**	**40**	**50**	
	IF cannot mention 1 benefit, **THEN Novice**		2					
	IF mentions 1 benefit, **THEN Advanced Beginner**			4				
	IF mentions 2 benefits, **THEN Competent**				6			
	IF mentions 3 benefits, **THEN Proficient**					8		
	IF mentions 3 benefits, **THEN Expert**						10	**10**
12	***What are some of the measures that provide the greatest return on investment for a home owner and why?***	**0.3**	**10**	**20**	**30**	**40**	**50**	
	IF cannot mention, **THEN Novice**		3					
	IF correctly mentions 1 measure, **THEN Advanced Beginner**			6				
	IF correctly mentions 2 measures, **THEN Competent**				9			
	IF correctly mentions 2 measures, **THEN Proficient**					12		**12**
	IF correctly mentions 2 or more measures/contextualizes, **THEN Expert**						15	
13	***What are some external factors which increase the cost of the retrofit operation?***	**0.4**	**10**	**20**	**30**	**40**	**50**	
	IF none, **THEN Novice**		4					
	IF correctly mentions 1 but cannot explain, **THEN Advanced Beginner**			4				
	IF 1 well-explained factor, **THEN Competent**				12			
	IF 1 well-explained factor/context, **THEN Proficient**					16		
	IF 2 or more well-explained factors/examples, **THEN Expert**						20	**20**
14	***Kindly provide a list of post occupancy health issues that must be addressed in energy retrofits.***	**0.6**	**10**	**20**	**30**	**40**	**50**	
	IF none, **THEN Novice**		6					

Table D.3 (Cont'd)

	IF correctly mentions 1 but cannot explain, **THEN Advanced Beginner**			12				
	IF 1 well-explained post-occupancy H&S issue, **THEN Competent**				18			
	IF 2 well-explained post-occupancy H&S issues, **THEN Proficient**					24		
	IF 2 or more well-explained post-occupancy H&S issues/e.gs., **THEN Expert**						30	**30**
15	***Buildings behave as a system where interactions between components can affect their energy performance. What are the interrelationships among the following measures?***	**0.6**	**10**	**20**	**30**	**40**	**50**	
	If no relationship, **THEN Novice**		6					
	IF relationship/cannot explain, **THEN Advanced Beginner**			12				
	IF explains relationship between 2, **THEN Competent**				18			
	IF explains relationship between 2 with example, **THEN Proficient**					24		**24**
	IF explains relationship among 3 or more/contextualizes, **THEN Expert**						30	
16	***What measures do you consider safe and can be installed by a homeowner? Kindly give reasons for your answer.***	**0.6**	**10**	**20**	**30**	**40**	**50**	
	IF none, **THEN Novice**		6					
	IF mentions 1 measure, **THEN Advanced Beginner**			12				
	IF mentions 1 measure/provides reasons, **THEN Competent**				18			**18**
	IF mentions 2 measures/provides reasons, **THEN Proficient**					24		
	IF mentions 3 measures/provides reasons, **THEN Expert**						30	
17	***What measures do you think must be installed by a licensed retrofit professional? Kindly give reasons.***	**0.6**	**10**	**20**	**30**	**40**	**50**	
	IF none, **THEN Novice**		6					
	IF mentions 1 measure, **THEN Advanced Beginner**			12				
	IF mentions 1 measure/provides reasons, **THEN Competent**				18			
	IF mentions 2 measures/provides reasons, **THEN Proficient**					24		
	IF mentions 3 measures/provides reasons, **THEN Expert**						30	**30**
			72	**140**	**216**	**288**	**360**	**324**

APPENDIX D.4

Table D.4: Detailed EREIS Scores for Participant 4

UPPER PROFICIENT

RESPONDENT #4

Number	ATTRIBUTE-BASED QUESTIONS	RIS	Expertise ID: Novice	Advanced Beginner	Competent	Proficient	Expert	Selected Option
1	***How long have you been working in energy efficiency retrofits for existing homes?***	**0.4**	**10**	**20**	**30**	**40**	**50**	
	IF up to a year, **THEN Novice**		4					
	IF more than 1 year but up to 2 years, **THEN Advanced Beginner**			8				
	IF more than 2 years but up to 3 years, **THEN Competent**				12			
	IF more than 3 years but up to 4 years, **THEN Proficient**					16		
	IF more than 4 years, **THEN Expert**						20	**20**
2	***How many retrofits on average, do you complete each year?***	**0.4**	**10**	**20**	**30**	**40**	**50**	
	IF performs between 1 and 6 audits each year, **THEN Novice**		4					
	IF performs between 7 and 12 audits each year, **THEN Advanced Beginner**			8				
	IF performs between 13 and 18 audits each year, **THEN Competent**				12			
	IF performs between 19 and 24 audits each year, **THEN Proficient**					16		
	IF more than 24 audits each year, **THEN Expert**						20	**20**

Table D.4 (Cont'd)

3	***Have you been away from the industry before? If yes, for how long were you away and did you require retraining?***	**0.3**	**10**	**20**	**30**	**40**	**50**	
	IF more than 3 years, **THEN Novice**		3					
	IF more than 2 years up to 3 years, **THEN Advanced Beginner**			6				
	IF more than 1 year up to 2 years, **THEN Competent**				9			
	IF up to 1 year, **THEN Proficient**					12		
	IF never been away (0 years), **THEN Expert**						15	**15**
4	***How often do you update your knowledge in your work by referring to colleagues, books, manuals, internet, etc. to reinforce information you give to homeowners?***	**0.3**	**10**	**20**	**30**	**40**	**50**	
	IF knowledge is NOT updated, **THEN Novice**		3					
	IF knowledge is updated rarely, **THEN Advanced Beginner**			6				
	IF knowledge is updated sometimes, **THEN Competent**				9			
	IF knowledge is updated regularly, **THEN Proficient**					12		
	IF knowledge is updated always, **THEN Expert**						15	**15**
5	***Are you aware of the tax incentives, rebates, and benefits available to homeowners when they undertake an energy retrofit? If yes, how do you get this information?***	**0.3**	**10**	**20**	**30**	**40**	**50**	
	IF no, **THEN Novice**		3					
	IF yes/chance upon information, **THEN Advanced Beginner**			6				
	IF yes/obtains from 1 source, **THEN Competent**				9			**9**
	If yes/obtains from 2 sources excluding trade organizations, **THEN Proficient**					12		
	IF yes/obtains from 3 or more sources including trade organization							
	and/or government, **THEN Expert**						15	
6	***When a homeowner asks you to justify or explain your decision or actions, how do you go about it?***	**0.4**	**10**	**20**	**30**	**40**	**50**	
	IF make impression and/or company identity builds trust, **THEN Novice**		4					
	IF anyone apart from case based reasoning, **THEN Advanced Beginner**			8				**8**
	IF case based reasoning **THEN Competent**				12			

Table D.4 (Cont'd)

	If any 2 including CBR, **THEN Proficient**					16		
	IF any 3 including CBR - CBR, SSO, RAE, FGS, and/or RWSR, THEN **Expert**						20	
7	***Several measures have been suggested for improving the energy efficiency of existing homes. For e.g. replacing incandescent light bulbs with CFLs. Kindly list others.***	**0.1**	**10**	**20**	**30**	**40**	**50**	
	IF mentions only energy saving measures, **THEN Novice**		1					
	IF mentions measures, **THEN Advanced Beginner**			2				
	IF mentions 3 measures, **THEN Competent**				3			
	IF explains 3 measures/examples, **THEN Proficient**					4		
	IF explains more than 3 measures/examples, **THEN Expert**						5	**5**
8	***How would you explain in a step by step manner, the methods you will use to make recommend retrofit measures for a home that you have no means of testing?***	**0.6**	**10**	**20**	**30**	**40**	**50**	
	IF mentions/explains 1 sign, **THEN Novice**		6					
	IF mentions/explains 2 signs, **THEN Advanced Beginner**			12				**12**
	IF mentions/explains 3 signs, **THEN Competent**				18			
	IF mentions/explains 4 signs, **THEN Proficient**					24		
	IF mentions/explains 5 or more signs, **THEN Expert**						30	
9	***Different homes have different retrofit needs. What aspects of the home will determine the need? E.g. is it the construction type, archetype type, age of the home etc.?***	**0.6**	**10**	**20**	**30**	**40**	**50**	
	IF does not see link among aspects, **THEN Novice**		6					
	IF links 2 aspects, **THEN Advanced Beginner**			12				
	IF links 2 aspects and gives example, **THEN Competent**				18			**18**
	IF links 3 aspects/identify 1 retrofit need, **THEN Proficient**					24		
	IF links 3 aspects/identify 1 retrofit need/e.g., **THEN Expert**						30	
10	***How would you explain to a homeowner in a step by step manner what "Energy Auditing" means?***	**0.5**	**10**	**20**	**30**	**40**	**50**	
	IF unable to explain, **THEN Novice**		5					

Table D.4 (cont'd)

	IF only explains tools used, **THEN Advanced Beginner**			10				
	IF explains/mention 1 of 3 objectives, **THEN Competent**				15			**15**
	IF explains/mention 2 of 3 objectives, **THEN Proficient**					20		
	IF explains/mentions 3 of 3 objectives, **THEN Expert**						25	
11	***What specific benefits can be obtained when you perform energy retrofit of a home?***	**0.2**	**10**	**20**	**30**	**40**	**50**	
	IF cannot mention 1 benefit, **THEN Novice**		2					
	IF mentions 1 benefit, **THEN Advanced Beginner**			4				
	IF mentions 2 benefits, **THEN Competent**				6			
	IF mentions 3 benefits, **THEN Proficient**					8		
	IF mentions 3 benefits, **THEN Expert**						10	**10**
12	***What are some of the measures that provide the greatest return on investment for a home owner and why?***	**0.3**	**10**	**20**	**30**	**40**	**50**	
	IF cannot mention, **THEN Novice**		3					
	IF correctly mentions 1 measure, **THEN Advanced Beginner**			6				
	IF correctly mentions 2 measures, **THEN Competent**				9			
	IF correctly mentions 2 measures, **THEN Proficient**					12		
	IF correctly mentions 2 or more measures/contextualizes, **THEN Expert**						15	**15**
13	***What are some external factors which increase the cost of the retrofit operation?***	**0.4**	**10**	**20**	**30**	**40**	**50**	
	IF none, **THEN Novice**		4					
	IF correctly mentions 1 but cannot explain, **THEN Advanced Beginner**			4				
	IF 1 well-explained factor, **THEN Competent**				12			
	IF 1 well-explained factor/context, **THEN Proficient**					16		
	IF 2 or more well-explained factors/examples, **THEN Expert**						20	**20**
14	***Kindly provide a list of post occupancy health issues that must be addressed in energy retrofits.***	**0.6**	**10**	**20**	**30**	**40**	**50**	
	IF none, **THEN Novice**		6					

Table D.4 (Cont'd)

	IF correctly mentions 1 but cannot explain, **THEN Advanced Beginner**			12				
	IF 1 well-explained post-occupancy H&S issue, **THEN Competent**				18			
	IF 2 well-explained post-occupancy H&S issues, **THEN Proficient**					24		
	IF 2 or more well-explained post-occupancy H&S issues/e.gs., **THEN Expert**						30	**30**
15	***Buildings behave as a system where interactions between components can affect their energy performance. What are the interrelationships among the following measures?***	**0.6**	**10**	**20**	**30**	**40**	**50**	
	If no relationship, **THEN Novice**		6					
	IF relationship/cannot explain, **THEN Advanced Beginner**			12				
	IF explains relationship between 2, **THEN Competent**				18			
	IF explains relationship between 2 with example, **THEN Proficient**					24		
	IF explains relationship among 3 or more/contextualizes, **THEN Expert**						30	**30**
16	***What measures do you consider safe and can be installed by a homeowner? Kindly give reasons for your answer.***	**0.6**	**10**	**20**	**30**	**40**	**50**	
	IF none, **THEN Novice**		6					
	IF mentions 1 measure, **THEN Advanced Beginner**			12				
	IF mentions 1 measure/provides reasons, **THEN Competent**				18			
	IF mentions 2 measures/provides reasons, **THEN Proficient**					24		
	IF mentions 3 measures/provides reasons, **THEN Expert**						30	**30**
17	***What measures do you think must be installed by a licensed retrofit professional? Kindly give reasons.***	**0.6**	**10**	**20**	**30**	**40**	**50**	
	IF none, **THEN Novice**		6					
	IF mentions 1 measure, **THEN Advanced Beginner**			12				
	IF mentions 1 measure/provides reasons, **THEN Competent**				18			
	IF mentions 2 measures/provides reasons, **THEN Proficient**					24		**24**
	IF mentions 3 measures/provides reasons, **THEN Expert**						30	
			72	**140**	**216**	**288**	**360**	**296**

APPENDIX D.5

Table D.5: Detailed EREIS Scores for Participant 5

EXPERT

RESPONDENT #5

			Expertise ID					
Number	**ATTRIBUTE-BASED QUESTIONS**	**RIS**	**Novice**	**Advanced Beginner**	**Competent**	**Proficient**	**Expert**	**Selected Option**
1	***How long have you been working in energy efficiency retrofits for existing homes?***	**0.4**	**10**	**20**	**30**	**40**	**50**	
	IF up to a year, **THEN Novice**		4					
	IF more than 1 year but up to 2 years, **THEN Advanced Beginner**			8				
	IF more than 2 years but up to 3 years, **THEN Competent**				12			
	IF more than 3 years but up to 4 years, **THEN Proficient**					16		
	IF more than 4 years, **THEN Expert**						20	**20**
2	***How many retrofits on average, do you complete each year?***	**0.4**	**10**	**20**	**30**	**40**	**50**	
	IF performs between 1 and 6 audits each year, **THEN Novice**		4					
	IF performs between 7 and 12 audits each year, **THEN Advanced Beginner**			8				
	IF performs between 13 and 18 audits each year, **THEN Competent**				12			
	IF performs between 19 and 24 audits each year, **THEN Proficient**					16		
	IF more than 24 audits each year, **THEN Expert**						20	**20**

Table D.5 (Cont'd)

3	***Have you been away from the industry before? If yes, for how long were you away and did you require retraining?***	**0.3**	**10**	**20**	**30**	**40**	**50**	
	IF more than 3 years, **THEN Novice**		3					
	IF more than 2 years up to 3 years, **THEN Advanced Beginner**			6				
	IF more than 1 year up to 2 years, **THEN Competent**				9			
	IF up to 1 year, **THEN Proficient**					12		
	IF never been away (0 years), **THEN Expert**						15	**15**
4	***How often do you update your knowledge in your work by referring to colleagues, books, manuals, internet, etc. to reinforce information you give to homeowners?***	**0.3**	**10**	**20**	**30**	**40**	**50**	
	IF knowledge is NOT updated, **THEN Novice**		3					
	IF knowledge is updated rarely, **THEN Advanced Beginner**			6				
	IF knowledge is updated sometimes, **THEN Competent**				9			**9**
	IF knowledge is updated regularly, **THEN Proficient**					12		
	IF knowledge is updated always, **THEN Expert**						15	
5	***Are you aware of the tax incentives, rebates, and benefits available to homeowners when they undertake an energy retrofit? If yes, how do you get this information?***	**0.3**	**10**	**20**	**30**	**40**	**50**	
	IF no, **THEN Novice**		3					
	IF yes/chance upon information, **THEN Advanced Beginner**			6				
	IF yes/obtains from 1 source, **THEN Competent**				9			
	If yes/obtains from 2 sources excluding trade organizations, **THEN Proficient**					12		
	IF yes/obtains from 3 or more sources including trade organization							
	and/or government, **THEN Expert**						15	**15**
6	***When a homeowner asks you to justify or explain your decision or actions, how do you go about it?***	**0.4**	**10**	**20**	**30**	**40**	**50**	
	IF make impression and/or company identity builds trust, **THEN Novice**		4					
	IF anyone apart from case based reasoning, **THEN Advanced Beginner**			8				
	IF case based reasoning **THEN Competent**				12			

Table D.5 (Cont'd)

	If any 2 including CBR, **THEN Proficient**					16		**16**
	IF any 3 including CBR - CBR, SSO, RAE, FGS, and/or RWSR, THEN **Expert**						20	
7	***Several measures have been suggested for improving the energy efficiency of existing homes. For e.g. replacing incandescent light bulbs with CFLs. Kindly list others.***	**0.1**	**10**	**20**	**30**	**40**	**50**	
	IF mentions only energy saving measures, **THEN Novice**		1					
	IF mentions measures, **THEN Advanced Beginner**			2				
	IF mentions 3 measures, **THEN Competent**				3			
	IF explains 3 measures/examples, **THEN Proficient**					4		
	IF explains more than 3 measures/examples, **THEN Expert**						5	**5**
8	***How would you explain in a step by step manner, the methods you will use to make recommend retrofit measures for a home that you have no means of testing?***	**0.6**	**10**	**20**	**30**	**40**	**50**	
	IF mentions/explains 1 sign, **THEN Novice**		6					
	IF mentions/explains 2 signs, **THEN Advanced Beginner**			12				
	IF mentions/explains 3 signs, **THEN Competent**				18			
	IF mentions/explains 4 signs, **THEN Proficient**					24		
	IF mentions/explains 5 or more signs, **THEN Expert**						30	**30**
9	***Different homes have different retrofit needs. What aspects of the home will determine the need? E.g. is it the construction type, archetype type, age of the home etc.?***	**0.6**	**10**	**20**	**30**	**40**	**50**	
	IF does not see link among aspects, **THEN Novice**		6					
	IF links 2 aspects, **THEN Advanced Beginner**			12				
	IF links 2 aspects and gives example, **THEN Competent**				18			
	IF links 3 aspects/identify 1 retrofit need, **THEN Proficient**					24		
	IF links 3 aspects/identify 1 retrofit need/e.g., **THEN Expert**						30	**30**
10	***How would you explain to a homeowner in a step by step manner what "Energy Auditing" means?***	**0.5**	**10**	**20**	**30**	**40**	**50**	
	IF unable to explain, **THEN Novice**		5					

Table D.5 (cont'd)

	IF only explains tools used, **THEN Advanced Beginner**			10				
	IF explains/mention 1 of 3 objectives, **THEN Competent**				15			
	IF explains/mention 2 of 3 objectives, **THEN Proficient**					20		**20**
	IF explains/mentions 3 of 3 objectives, **THEN Expert**						25	
11	***What specific benefits can be obtained when you perform energy retrofit of a home?***	**0.2**	**10**	**20**	**30**	**40**	**50**	
	IF cannot mention 1 benefit, **THEN Novice**		2					
	IF mentions 1 benefit, **THEN Advanced Beginner**			4				
	IF mentions 2 benefits, **THEN Competent**				6			
	IF mentions 3 benefits, **THEN Proficient**					8		**8**
	IF mentions 3 benefits, **THEN Expert**						10	
12	***What are some of the measures that provide the greatest return on investment for a home owner and why?***	**0.3**	**10**	**20**	**30**	**40**	**50**	
	IF cannot mention, **THEN Novice**		3					
	IF correctly mentions 1 measure, **THEN Advanced Beginner**			6				
	IF correctly mentions 2 measures, **THEN Competent**				9			
	IF correctly mentions 2 measures, **THEN Proficient**					12		**12**
	IF correctly mentions 2 or more measures/contextualizes, **THEN Expert**						15	
13	***What are some external factors which increase the cost of the retrofit operation?***	**0.4**	**10**	**20**	**30**	**40**	**50**	
	IF none, **THEN Novice**		4					
	IF correctly mentions 1 but cannot explain, **THEN Advanced Beginner**			4				
	IF 1 well-explained factor, **THEN Competent**				12			
	IF 1 well-explained factor/context, **THEN Proficient**					16		
	IF 2 or more well-explained factors/examples, **THEN Expert**						20	**20**
14	***Kindly provide a list of post occupancy health issues that must be addressed in energy retrofits.***	**0.6**	**10**	**20**	**30**	**40**	**50**	
	IF none, **THEN Novice**		6					

Table D.5 (Cont'd)

	IF correctly mentions 1 but cannot explain, **THEN Advanced Beginner**			12				
	IF 1 well-explained post-occupancy H&S issue, **THEN Competent**				18			
	IF 2 well-explained post-occupancy H&S issues, **THEN Proficient**					24		
	IF 2 or more well-explained post-occupancy H&S issues/e.gs., **THEN Expert**						30	**30**
15	***Buildings behave as a system where interactions between components can affect their energy performance. What are the interrelationships among the following measures?***	**0.6**	**10**	**20**	**30**	**40**	**50**	
	If no relationship, **THEN Novice**		6					
	IF relationship/cannot explain, **THEN Advanced Beginner**			12				
	IF explains relationship between 2, **THEN Competent**				18			
	IF explains relationship between 2 with example, **THEN Proficient**					24		
	IF explains relationship among 3 or more/contextualizes, **THEN Expert**						30	**30**
16	***What measures do you consider safe and can be installed by a homeowner? Kindly give reasons for your answer.***	**0.6**	**10**	**20**	**30**	**40**	**50**	
	IF none, **THEN Novice**		6					
	IF mentions 1 measure, **THEN Advanced Beginner**			12				
	IF mentions 1 measure/provides reasons, **THEN Competent**				18			
	IF mentions 2 measures/provides reasons, **THEN Proficient**					24		
	IF mentions 3 measures/provides reasons, **THEN Expert**						30	**30**
17	***What measures do you think must be installed by a licensed retrofit professional? Kindly give reasons.***	**0.6**	**10**	**20**	**30**	**40**	**50**	
	IF none, **THEN Novice**		6					
	IF mentions 1 measure, **THEN Advanced Beginner**			12				
	IF mentions 1 measure/provides reasons, **THEN Competent**				18			
	IF mentions 2 measures/provides reasons, **THEN Proficient**					24		**24**
	IF mentions 3 measures/provides reasons, **THEN Expert**						30	
			72	**140**	**216**	**288**	**360**	**334**

APPENDIX D.6

Table D.6: Detailed EREIS Scores for Participant 6

	EXPERT							
	RESPONDENT #6		Expertise ID					
Number	**ATTRIBUTE-BASED QUESTIONS**	**RIS**	**Novice**	**Advanced Beginner**	**Competent**	**Proficient**	**Expert**	**Selected Option**
1	***How long have you been working in energy efficiency retrofits for existing homes?***	**0.4**	**10**	**20**	**30**	**40**	**50**	
	IF up to a year, **THEN Novice**		4					
	IF more than 1 year but up to 2 years, **THEN Advanced Beginner**			8				
	IF more than 2 years but up to 3 years, **THEN Competent**				12			
	IF more than 3 years but up to 4 years, **THEN Proficient**					16		
	IF more than 4 years, **THEN Expert**						20	**20**
2	***How many retrofits on average, do you complete each year?***	**0.4**	**10**	**20**	**30**	**40**	**50**	
	IF performs between 1 and 6 audits each year, **THEN Novice**		4					
	IF performs between 7 and 12 audits each year, **THEN Advanced Beginner**			8				
	IF performs between 13 and 18 audits each year, **THEN Competent**				12			
	IF performs between 19 and 24 audits each year, **THEN Proficient**					16		
	IF more than 24 audits each year, **THEN Expert**						20	**20**

Table D.6 (Cont'd)

3	***Have you been away from the industry before? If yes, for how long were you away and did you require retraining?***	**0.3**	**10**	**20**	**30**	**40**	**50**	
	IF more than 3 years, **THEN Novice**		3					
	IF more than 2 years up to 3 years, **THEN Advanced Beginner**			6				
	IF more than 1 year up to 2 years, **THEN Competent**				9			
	IF up to 1 year, **THEN Proficient**					12		
	IF never been away (0 years), **THEN Expert**						15	**15**
4	***How often do you update your knowledge in your work by referring to colleagues, books, manuals, internet, etc. to reinforce information you give to homeowners?***	**0.3**	**10**	**20**	**30**	**40**	**50**	
	IF knowledge is NOT updated, **THEN Novice**		3					
	IF knowledge is updated rarely, **THEN Advanced Beginner**			6				
	IF knowledge is updated sometimes, **THEN Competent**				9			
	IF knowledge is updated regularly, **THEN Proficient**					12		
	IF knowledge is updated always, **THEN Expert**						15	**15**
5	***Are you aware of the tax incentives, rebates, and benefits available to homeowners when they undertake an energy retrofit? If yes, how do you get this information?***	**0.3**	**10**	**20**	**30**	**40**	**50**	
	IF no, **THEN Novice**		3					
	IF yes/chance upon information, **THEN Advanced Beginner**			6				
	IF yes/obtains from 1 source, **THEN Competent**				9			
	If yes/obtains from 2 sources excluding trade organizations, **THEN Proficient**					12		
	IF yes/obtains from 3 or more sources including trade organization							
	and/or government, **THEN Expert**						15	**15**
6	***When a homeowner asks you to justify or explain your decision or actions, how do you go about it?***	**0.4**	**10**	**20**	**30**	**40**	**50**	
	IF make impression and/or company identity builds trust, **THEN Novice**		4					
	IF anyone apart from case based reasoning, **THEN Advanced Beginner**			8				
	IF case based reasoning **THEN Competent**				12			

Table D.6 (Cont'd)

	If any 2 including CBR, **THEN Proficient**					16		**16**
	IF any 3 including CBR - CBR, SSO, RAE, FGS, and/or RWSR, THEN **Expert**						20	
7	***Several measures have been suggested for improving the energy efficiency of existing homes. For e.g. replacing incandescent light bulbs with CFLs. Kindly list others.***	**0.1**	**10**	**20**	**30**	**40**	**50**	
	IF mentions only energy saving measures, **THEN Novice**		1					
	IF mentions measures, **THEN Advanced Beginner**			2				
	IF mentions 3 measures, **THEN Competent**				3			
	IF explains 3 measures/examples, **THEN Proficient**					4		**4**
	IF explains more than 3 measures/examples, **THEN Expert**						5	
8	***How would you explain in a step by step manner, the methods you will use to make recommend retrofit measures for a home that you have no means of testing?***	**0.6**	**10**	**20**	**30**	**40**	**50**	
	IF mentions/explains 1 sign, **THEN Novice**		6					
	IF mentions/explains 2 signs, **THEN Advanced Beginner**			12				
	IF mentions/explains 3 signs, **THEN Competent**				18			
	IF mentions/explains 4 signs, **THEN Proficient**					24		**24**
	IF mentions/explains 5 or more signs, **THEN Expert**						30	
9	***Different homes have different retrofit needs. What aspects of the home will determine the need? E.g. is it the construction type, archetype type, age of the home etc.?***	**0.6**	**10**	**20**	**30**	**40**	**50**	
	IF does not see link among aspects, **THEN Novice**		6					
	IF links 2 aspects, **THEN Advanced Beginner**			12				
	IF links 2 aspects and gives example, **THEN Competent**				18			
	IF links 3 aspects/identify 1 retrofit need, **THEN Proficient**					24		
	IF links 3 aspects/identify 1 retrofit need/e.g., **THEN Expert**						30	**30**
10	***How would you explain to a homeowner in a step by step manner what "Energy Auditing" means?***	**0.5**	**10**	**20**	**30**	**40**	**50**	
	IF unable to explain, **THEN Novice**		5					

Table D.6 (cont'd)

	IF only explains tools used, **THEN Advanced Beginner**			10				
	IF explains/mention 1 of 3 objectives, **THEN Competent**				15			
	IF explains/mention 2 of 3 objectives, **THEN Proficient**					20		**20**
	IF explains/mentions 3 of 3 objectives, **THEN Expert**						25	
11	***What specific benefits can be obtained when you perform energy retrofit of a home?***	**0.2**	**10**	**20**	**30**	**40**	**50**	
	IF cannot mention 1 benefit, **THEN Novice**		2					
	IF mentions 1 benefit, **THEN Advanced Beginner**			4				**4**
	IF mentions 2 benefits, **THEN Competent**				6			
	IF mentions 3 benefits, **THEN Proficient**					8		
	IF mentions 3 benefits, **THEN Expert**						10	
12	***What are some of the measures that provide the greatest return on investment for a home owner and why?***	**0.3**	**10**	**20**	**30**	**40**	**50**	
	IF cannot mention, **THEN Novice**		3					
	IF correctly mentions 1 measure, **THEN Advanced Beginner**			6				
	IF correctly mentions 2 measures, **THEN Competent**				9			
	IF correctly mentions 2 measures, **THEN Proficient**					12		**12**
	IF correctly mentions 2 or more measures/contextualizes, **THEN Expert**						15	
13	***What are some external factors which increase the cost of the retrofit operation?***	**0.4**	**10**	**20**	**30**	**40**	**50**	
	IF none, **THEN Novice**		4					
	IF correctly mentions 1 but cannot explain, **THEN Advanced Beginner**			4				
	IF 1 well-explained factor, **THEN Competent**				12			
	IF 1 well-explained factor/context, **THEN Proficient**					16		**16**
	IF 2 or more well-explained factors/examples, **THEN Expert**						20	
14	***Kindly provide a list of post occupancy health issues that must be addressed in energy retrofits.***	**0.6**	**10**	**20**	**30**	**40**	**50**	
	IF none, **THEN Novice**		6					

Table D.6 (Cont'd)

	IF correctly mentions 1 but cannot explain, **THEN Advanced Beginner**			12				
	IF 1 well-explained post-occupancy H&S issue, **THEN Competent**				18			
	IF 2 well-explained post-occupancy H&S issues, **THEN Proficient**					24		
	IF 2 or more well-explained post-occupancy H&S issues/e.gs., **THEN Expert**						30	**30**
15	***Buildings behave as a system where interactions between components can affect their energy performance. What are the interrelationships among the following measures?***	**0.6**	**10**	**20**	**30**	**40**	**50**	
	If no relationship, **THEN Novice**		6					
	IF relationship/cannot explain, **THEN Advanced Beginner**			12				
	IF explains relationship between 2, **THEN Competent**				18			
	IF explains relationship between 2 with example, **THEN Proficient**					24		
	IF explains relationship among 3 or more/contextualizes, **THEN Expert**						30	**30**
16	***What measures do you consider safe and can be installed by a homeowner? Kindly give reasons for your answer.***	**0.6**	**10**	**20**	**30**	**40**	**50**	
	IF none, **THEN Novice**		6					
	IF mentions 1 measure, **THEN Advanced Beginner**			12				
	IF mentions 1 measure/provides reasons, **THEN Competent**				18			
	IF mentions 2 measures/provides reasons, **THEN Proficient**					24		
	IF mentions 3 measures/provides reasons, **THEN Expert**						30	**30**
17	***What measures do you think must be installed by a licensed retrofit professional? Kindly give reasons.***	**0.6**	**10**	**20**	**30**	**40**	**50**	
	IF none, **THEN Novice**		6					
	IF mentions 1 measure, **THEN Advanced Beginner**			12				
	IF mentions 1 measure/provides reasons, **THEN Competent**				18			
	IF mentions 2 measures/provides reasons, **THEN Proficient**					24		
	IF mentions 3 measures/provides reasons, **THEN Expert**						30	**30**
			72	**140**	**216**	**288**	**360**	**331**

APPENDIX D.7

Table D.7: Detailed EREIS Scores for Participant 7

EXPERT

RESPONDENT #7

Number	ATTRIBUTE-BASED QUESTIONS	RIS	Expertise ID: Novice	Advanced Beginner	Competent	Proficient	Expert	Selected Option
1	***How long have you been working in energy efficiency retrofits for existing homes?***	**0.4**	**10**	**20**	**30**	**40**	**50**	
	IF up to a year, **THEN Novice**		4					
	IF more than 1 year but up to 2 years, **THEN Advanced Beginner**			8				
	IF more than 2 years but up to 3 years, **THEN Competent**				12			**12**
	IF more than 3 years but up to 4 years, **THEN Proficient**					16		
	IF more than 4 years, **THEN Expert**						20	
2	***How many retrofits on average, do you complete each year?***	**0.4**	**10**	**20**	**30**	**40**	**50**	
	IF performs between 1 and 6 audits each year, **THEN Novice**		4					
	IF performs between 7 and 12 audits each year, **THEN Advanced Beginner**			8				
	IF performs between 13 and 18 audits each year, **THEN Competent**				12			
	IF performs between 19 and 24 audits each year, **THEN Proficient**					16		
	IF more than 24 audits each year, **THEN Expert**						20	**20**

Table D.7 (Cont'd)

3	***Have you been away from the industry before? If yes, for how long were you away and did you require retraining?***	**0.3**	**10**	**20**	**30**	**40**	**50**	
	IF more than 3 years, **THEN Novice**		3					
	IF more than 2 years up to 3 years, **THEN Advanced Beginner**			6				
	IF more than 1 year up to 2 years, **THEN Competent**				9			
	IF up to 1 year, **THEN Proficient**					12		
	IF never been away (0 years), **THEN Expert**						15	**15**
4	***How often do you update your knowledge in your work by referring to colleagues, books, manuals, internet, etc. to reinforce information you give to homeowners?***	**0.3**	**10**	**20**	**30**	**40**	**50**	
	IF knowledge is NOT updated, **THEN Novice**		3					
	IF knowledge is updated rarely, **THEN Advanced Beginner**			6				
	IF knowledge is updated sometimes, **THEN Competent**				9			**9**
	IF knowledge is updated regularly, **THEN Proficient**					12		
	IF knowledge is updated always, **THEN Expert**						15	
5	***Are you aware of the tax incentives, rebates, and benefits available to homeowners when they undertake an energy retrofit? If yes, how do you get this information?***	**0.3**	**10**	**20**	**30**	**40**	**50**	
	IF no, **THEN Novice**		3					
	IF yes/chance upon information, **THEN Advanced Beginner**			6				
	IF yes/obtains from 1 source, **THEN Competent**				9			
	If yes/obtains from 2 sources excluding trade organizations, **THEN Proficient**					12		
	IF yes/obtains from 3 or more sources including trade organization							
	and/or government, **THEN Expert**						15	**15**
6	***When a homeowner asks you to justify or explain your decision or actions, how do you go about it?***	**0.4**	**10**	**20**	**30**	**40**	**50**	
	IF make impression and/or company identity builds trust, **THEN Novice**		4					
	IF anyone apart from case based reasoning, **THEN Advanced Beginner**			8				
	IF case based reasoning **THEN Competent**				12			

Table D.7 (Cont'd)

	If any 2 including CBR, **THEN Proficient**					16		
	IF any 3 including CBR - CBR, SSO, RAE, FGS, and/or RWSR, THEN **Expert**						20	**20**
7	***Several measures have been suggested for improving the energy efficiency of existing homes. For e.g. replacing incandescent light bulbs with CFLs. Kindly list others.***	**0.1**	**10**	**20**	**30**	**40**	**50**	
	IF mentions only energy saving measures, **THEN Novice**		1					
	IF mentions measures, **THEN Advanced Beginner**			2				
	IF mentions 3 measures, **THEN Competent**				3			
	IF explains 3 measures/examples, **THEN Proficient**					4		
	IF explains more than 3 measures/examples, **THEN Expert**						5	**5**
8	***How would you explain in a step by step manner, the methods you will use to make recommend retrofit measures for a home that you have no means of testing?***	**0.6**	**10**	**20**	**30**	**40**	**50**	
	IF mentions/explains 1 sign, **THEN Novice**		6					
	IF mentions/explains 2 signs, **THEN Advanced Beginner**			12				
	IF mentions/explains 3 signs, **THEN Competent**				18			
	IF mentions/explains 4 signs, **THEN Proficient**					24		
	IF mentions/explains 5 or more signs, **THEN Expert**						30	**30**
9	***Different homes have different retrofit needs. What aspects of the home will determine the need? E.g. is it the construction type, archetype type, age of the home etc.?***	**0.6**	**10**	**20**	**30**	**40**	**50**	
	IF does not see link among aspects, **THEN Novice**		6					
	IF links 2 aspects, **THEN Advanced Beginner**			12				
	IF links 2 aspects and gives example, **THEN Competent**				18			
	IF links 3 aspects/identify 1 retrofit need, **THEN Proficient**					24		
	IF links 3 aspects/identify 1 retrofit need/e.g., **THEN Expert**						30	**30**
10	***How would you explain to a homeowner in a step by step manner what "Energy Auditing" means?***	**0.5**	**10**	**20**	**30**	**40**	**50**	
	IF unable to explain, **THEN Novice**		5					

Table D.7 (cont'd)

	IF only explains tools used, **THEN Advanced Beginner**			10				
	IF explains/mention 1 of 3 objectives, **THEN Competent**				15			
	IF explains/mention 2 of 3 objectives, **THEN Proficient**					20		
	IF explains/mentions 3 of 3 objectives, **THEN Expert**						25	**25**
11	***What specific benefits can be obtained when you perform energy retrofit of a home?***	**0.2**	**10**	**20**	**30**	**40**	**50**	
	IF cannot mention 1 benefit, **THEN Novice**		2					
	IF mentions 1 benefit, **THEN Advanced Beginner**			4				
	IF mentions 2 benefits, **THEN Competent**				6			
	IF mentions 3 benefits, **THEN Proficient**					8		
	IF mentions 3 benefits, **THEN Expert**						10	**10**
12	***What are some of the measures that provide the greatest return on investment for a home owner and why?***	**0.3**	**10**	**20**	**30**	**40**	**50**	
	IF cannot mention, **THEN Novice**		3					
	IF correctly mentions 1 measure, **THEN Advanced Beginner**			6				
	IF correctly mentions 2 measures, **THEN Competent**				9			
	IF correctly mentions 2 measures, **THEN Proficient**					12		**12**
	IF correctly mentions 2 or more measures/contextualizes, **THEN Expert**						15	
13	***What are some external factors which increase the cost of the retrofit operation?***	**0.4**	**10**	**20**	**30**	**40**	**50**	
	IF none, **THEN Novice**		4					
	IF correctly mentions 1 but cannot explain, **THEN Advanced Beginner**			4				
	IF 1 well-explained factor, **THEN Competent**				12			
	IF 1 well-explained factor/context, **THEN Proficient**					16		
	IF 2 or more well-explained factors/examples, **THEN Expert**						20	**20**
14	***Kindly provide a list of post occupancy health issues that must be addressed in energy retrofits.***	**0.6**	**10**	**20**	**30**	**40**	**50**	
	IF none, **THEN Novice**		6					

Table D.7 (Cont'd)

	IF correctly mentions 1 but cannot explain, **THEN Advanced Beginner**			12				
	IF 1 well-explained post-occupancy H&S issue, **THEN Competent**				18			
	IF 2 well-explained post-occupancy H&S issues, **THEN Proficient**					24		
	IF 2 or more well-explained post-occupancy H&S issues/e.gs., **THEN Expert**						30	**30**
15	***Buildings behave as a system where interactions between components can affect their energy performance. What are the interrelationships among the following measures?***	**0.6**	**10**	**20**	**30**	**40**	**50**	
	If no relationship, **THEN Novice**		6					
	IF relationship/cannot explain, **THEN Advanced Beginner**			12				
	IF explains relationship between 2, **THEN Competent**				18			
	IF explains relationship between 2 with example, **THEN Proficient**					24		**24**
	IF explains relationship among 3 or more/contextualizes, **THEN Expert**						30	
16	***What measures do you consider safe and can be installed by a homeowner? Kindly give reasons for your answer.***	**0.6**	**10**	**20**	**30**	**40**	**50**	
	IF none, **THEN Novice**		6					
	IF mentions 1 measure, **THEN Advanced Beginner**			12				
	IF mentions 1 measure/provides reasons, **THEN Competent**				18			**18**
	IF mentions 2 measures/provides reasons, **THEN Proficient**					24		
	IF mentions 3 measures/provides reasons, **THEN Expert**						30	
17	***What measures do you think must be installed by a licensed retrofit professional? Kindly give reasons.***	**0.6**	**10**	**20**	**30**	**40**	**50**	
	IF none, **THEN Novice**		6					
	IF mentions 1 measure, **THEN Advanced Beginner**			12				
	IF mentions 1 measure/provides reasons, **THEN Competent**				18			
	IF mentions 2 measures/provides reasons, **THEN Proficient**					24		
	IF mentions 3 measures/provides reasons, **THEN Expert**						30	**30**
			72	**140**	**216**	**288**	**360**	**324**

APPENDIX D.8

Table D.8: Detailed EREIS Scores for Participant 8

	EXPERT							
	RESPONDENT #8		**Expertise ID**					
Number	**ATTRIBUTE-BASED QUESTIONS**	**RIS**	**Novice**	**Advanced Beginner**	**Competent**	**Proficient**	**Expert**	**Selected Option**
1	***How long have you been working in energy efficiency retrofits for existing homes?***	**0.4**	**10**	**20**	**30**	**40**	**50**	
	IF up to a year, **THEN Novice**		4					
	IF more than 1 year but up to 2 years, **THEN Advanced Beginner**			8				
	IF more than 2 years but up to 3 years, **THEN Competent**				12			
	IF more than 3 years but up to 4 years, **THEN Proficient**					16		
	IF more than 4 years, **THEN Expert**						20	**20**
2	***How many retrofits on average, do you complete each year?***	**0.4**	**10**	**20**	**30**	**40**	**50**	
	IF performs between 1 and 6 audits each year, **THEN Novice**		4					
	IF performs between 7 and 12 audits each year, **THEN Advanced Beginner**			8				
	IF performs between 13 and 18 audits each year, **THEN Competent**				12			
	IF performs between 19 and 24 audits each year, **THEN Proficient**					16		
	IF more than 24 audits each year, **THEN Expert**						20	**20**

Table D.8 (Cont'd)

3	***Have you been away from the industry before? If yes, for how long were you away and did you require retraining?***	**0.3**	**10**	**20**	**30**	**40**	**50**	
	IF more than 3 years, **THEN Novice**		3					
	IF more than 2 years up to 3 years, **THEN Advanced Beginner**			6				
	IF more than 1 year up to 2 years, **THEN Competent**				9			
	IF up to 1 year, **THEN Proficient**					12		
	IF never been away (0 years), **THEN Expert**						15	**15**
4	***How often do you update your knowledge in your work by referring to colleagues, books, manuals, internet, etc. to reinforce information you give to homeowners?***	**0.3**	**10**	**20**	**30**	**40**	**50**	
	IF knowledge is NOT updated, **THEN Novice**		3					
	IF knowledge is updated rarely, **THEN Advanced Beginner**			6				
	IF knowledge is updated sometimes, **THEN Competent**				9			
	IF knowledge is updated regularly, **THEN Proficient**					12		
	IF knowledge is updated always, **THEN Expert**						15	**15**
5	***Are you aware of the tax incentives, rebates, and benefits available to homeowners when they undertake an energy retrofit? If yes, how do you get this information?***	**0.3**	**10**	**20**	**30**	**40**	**50**	
	IF no, **THEN Novice**		3					
	IF yes/chance upon information, **THEN Advanced Beginner**			6				
	IF yes/obtains from 1 source, **THEN Competent**				9			
	If yes/obtains from 2 sources excluding trade organizations, **THEN Proficient**					12		
	IF yes/obtains from 3 or more sources including trade organization							
	and/or government, **THEN Expert**						15	**15**
6	***When a homeowner asks you to justify or explain your decision or actions, how do you go about it?***	**0.4**	**10**	**20**	**30**	**40**	**50**	
	IF make impression and/or company identity builds trust, **THEN Novice**		4					
	IF anyone apart from case based reasoning, **THEN Advanced Beginner**			8				
	IF case based reasoning **THEN Competent**				12			

Table D.8 (Cont'd)

	If any 2 including CBR, **THEN Proficient**					16		
	IF any 3 including CBR - CBR, SSO, RAE, FGS, and/or RWSR, THEN **Expert**						20	**20**
7	***Several measures have been suggested for improving the energy efficiency of existing homes. For e.g. replacing incandescent light bulbs with CFLs. Kindly list others.***	**0.1**	**10**	**20**	**30**	**40**	**50**	
	IF mentions only energy saving measures, **THEN Novice**		1					
	IF mentions measures, **THEN Advanced Beginner**			2				
	IF mentions 3 measures, **THEN Competent**				3			
	IF explains 3 measures/examples, **THEN Proficient**					4		
	IF explains more than 3 measures/examples, **THEN Expert**						5	**5**
8	***How would you explain in a step by step manner, the methods you will use to make recommend retrofit measures for a home that you have no means of testing?***	**0.6**	**10**	**20**	**30**	**40**	**50**	
	IF mentions/explains 1 sign, **THEN Novice**		6					
	IF mentions/explains 2 signs, **THEN Advanced Beginner**			12				
	IF mentions/explains 3 signs, **THEN Competent**				18			
	IF mentions/explains 4 signs, **THEN Proficient**					24		
	IF mentions/explains 5 or more signs, **THEN Expert**						30	**30**
9	***Different homes have different retrofit needs. What aspects of the home will determine the need? E.g. is it the construction type, archetype type, age of the home etc.?***	**0.6**	**10**	**20**	**30**	**40**	**50**	
	IF does not see link among aspects, **THEN Novice**		6					
	IF links 2 aspects, **THEN Advanced Beginner**			12				
	IF links 2 aspects and gives example, **THEN Competent**				18			
	IF links 3 aspects/identify 1 retrofit need, **THEN Proficient**					24		**24**
	IF links 3 aspects/identify 1 retrofit need/e.g., **THEN Expert**						30	
10	***How would you explain to a homeowner in a step by step manner what "Energy Auditing" means?***	**0.5**	**10**	**20**	**30**	**40**	**50**	
	IF unable to explain, **THEN Novice**		5					

Table D.8 (cont'd)

	IF only explains tools used, **THEN Advanced Beginner**			10				
	IF explains/mention 1 of 3 objectives, **THEN Competent**				15			
	IF explains/mention 2 of 3 objectives, **THEN Proficient**					20		
	IF explains/mentions 3 of 3 objectives, **THEN Expert**						25	**25**
11	***What specific benefits can be obtained when you perform energy retrofit of a home?***	**0.2**	**10**	**20**	**30**	**40**	**50**	
	IF cannot mention 1 benefit, **THEN Novice**		2					
	IF mentions 1 benefit, **THEN Advanced Beginner**			4				
	IF mentions 2 benefits, **THEN Competent**				6			
	IF mentions 3 benefits, **THEN Proficient**					8		
	IF mentions 3 benefits, **THEN Expert**						10	**10**
12	***What are some of the measures that provide the greatest return on investment for a home owner and why?***	**0.3**	**10**	**20**	**30**	**40**	**50**	
	IF cannot mention, **THEN Novice**		3					
	IF correctly mentions 1 measure, **THEN Advanced Beginner**			6				
	IF correctly mentions 2 measures, **THEN Competent**				9			
	IF correctly mentions 2 measures, **THEN Proficient**					12		
	IF correctly mentions 2 or more measures/contextualizes, **THEN Expert**						15	**15**
13	***What are some external factors which increase the cost of the retrofit operation?***	**0.4**	**10**	**20**	**30**	**40**	**50**	
	IF none, **THEN Novice**		4					
	IF correctly mentions 1 but cannot explain, **THEN Advanced Beginner**			4				
	IF 1 well-explained factor, **THEN Competent**				12			
	IF 1 well-explained factor/context, **THEN Proficient**					16		
	IF 2 or more well-explained factors/examples, **THEN Expert**						20	**20**
14	***Kindly provide a list of post occupancy health issues that must be addressed in energy retrofits.***	**0.6**	**10**	**20**	**30**	**40**	**50**	
	IF none, **THEN Novice**		6					

Table D.8 (Cont'd)

	IF correctly mentions 1 but cannot explain, **THEN Advanced Beginner**			12				
	IF 1 well-explained post-occupancy H&S issue, **THEN Competent**				18			
	IF 2 well-explained post-occupancy H&S issues, **THEN Proficient**					24		
	IF 2 or more well-explained post-occupancy H&S issues/e.gs., **THEN Expert**						30	**30**
15	***Buildings behave as a system where interactions between components can affect their energy performance. What are the interrelationships among the following measures?***	**0.6**	**10**	**20**	**30**	**40**	**50**	
	If no relationship, **THEN Novice**		6					
	IF relationship/cannot explain, **THEN Advanced Beginner**			12				
	IF explains relationship between 2, **THEN Competent**				18			
	IF explains relationship between 2 with example, **THEN Proficient**					24		
	IF explains relationship among 3 or more/contextualizes, **THEN Expert**						30	**30**
16	***What measures do you consider safe and can be installed by a homeowner? Kindly give reasons for your answer.***	**0.6**	**10**	**20**	**30**	**40**	**50**	
	IF none, **THEN Novice**		6					
	IF mentions 1 measure, **THEN Advanced Beginner**			12				
	IF mentions 1 measure/provides reasons, **THEN Competent**				18			
	IF mentions 2 measures/provides reasons, **THEN Proficient**					24		
	IF mentions 3 measures/provides reasons, **THEN Expert**						30	**30**
17	***What measures do you think must be installed by a licensed retrofit professional? Kindly give reasons.***	**0.6**	**10**	**20**	**30**	**40**	**50**	
	IF none, **THEN Novice**		6					
	IF mentions 1 measure, **THEN Advanced Beginner**			12				
	IF mentions 1 measure/provides reasons, **THEN Competent**				18			
	IF mentions 2 measures/provides reasons, **THEN Proficient**					24		
	IF mentions 3 measures/provides reasons, **THEN Expert**						30	**30**
			72	**140**	**216**	**288**	**360**	**354**

APPENDIX D.9

Table D.9: Detailed EREIS Scores for Participant 9

	EXPERT							
	RESPONDENT #9		Expertise ID					
Number	ATTRIBUTE-BASED QUESTIONS	RIS	Novice	Advanced Beginner	Competent	Proficient	Expert	Selected Option
1	***How long have you been working in energy efficiency retrofits for existing homes?***	**0.4**	**10**	**20**	**30**	**40**	**50**	
	IF up to a year, **THEN Novice**		4					
	IF more than 1 year but up to 2 years, **THEN Advanced Beginner**			8				
	IF more than 2 years but up to 3 years, **THEN Competent**				12			**12**
	IF more than 3 years but up to 4 years, **THEN Proficient**					16		
	IF more than 4 years, **THEN Expert**						20	
2	***How many retrofits on average, do you complete each year?***	**0.4**	**10**	**20**	**30**	**40**	**50**	
	IF performs between 1 and 6 audits each year, **THEN Novice**		4					
	IF performs between 7 and 12 audits each year, **THEN Advanced Beginner**			8				
	IF performs between 13 and 18 audits each year, **THEN Competent**				12			
	IF performs between 19 and 24 audits each year, **THEN Proficient**					16		
	IF more than 24 audits each year, **THEN Expert**						20	**20**

Table D.9 (Cont'd)

3	***Have you been away from the industry before? If yes, for how long were you away and did you require retraining?***	**0.3**	**10**	**20**	**30**	**40**	**50**	
	IF more than 3 years, **THEN Novice**		3					
	IF more than 2 years up to 3 years, **THEN Advanced Beginner**			6				
	IF more than 1 year up to 2 years, **THEN Competent**				9			
	IF up to 1 year, **THEN Proficient**					12		
	IF never been away (0 years), **THEN Expert**						15	**15**
4	***How often do you update your knowledge in your work by referring to colleagues, books, manuals, internet, etc. to reinforce information you give to homeowners?***	**0.3**	**10**	**20**	**30**	**40**	**50**	
	IF knowledge is NOT updated, **THEN Novice**		3					
	IF knowledge is updated rarely, **THEN Advanced Beginner**			6				
	IF knowledge is updated sometimes, **THEN Competent**				9			
	IF knowledge is updated regularly, **THEN Proficient**					12		
	IF knowledge is updated always, **THEN Expert**						15	**15**
5	***Are you aware of the tax incentives, rebates, and benefits available to homeowners when they undertake an energy retrofit? If yes, how do you get this information?***	**0.3**	**10**	**20**	**30**	**40**	**50**	
	IF no, **THEN Novice**		3					
	IF yes/chance upon information, **THEN Advanced Beginner**			6				
	IF yes/obtains from 1 source, **THEN Competent**				9			
	If yes/obtains from 2 sources excluding trade organizations, **THEN Proficient**					12		
	IF yes/obtains from 3 or more sources including trade organization							
	and/or government, **THEN Expert**						15	**15**
6	***When a homeowner asks you to justify or explain your decision or actions, how do you go about it?***	**0.4**	**10**	**20**	**30**	**40**	**50**	
	IF make impression and/or company identity builds trust, **THEN Novice**		4					
	IF anyone apart from case based reasoning, **THEN Advanced Beginner**			8				
	IF case based reasoning **THEN Competent**				12			

Table D.9 (Cont'd)

	If any 2 including CBR, **THEN Proficient**					16		**16**
	IF any 3 including CBR - CBR, SSO, RAE, FGS, and/or RWSR, THEN **Expert**						20	
7	***Several measures have been suggested for improving the energy efficiency of existing homes. For e.g. replacing incandescent light bulbs with CFLs. Kindly list others.***	**0.1**	**10**	**20**	**30**	**40**	**50**	
	IF mentions only energy saving measures, **THEN Novice**		1					
	IF mentions measures, **THEN Advanced Beginner**			2				
	IF mentions 3 measures, **THEN Competent**				3			
	IF explains 3 measures/examples, **THEN Proficient**					4		
	IF explains more than 3 measures/examples, **THEN Expert**						5	**5**
8	***How would you explain in a step by step manner, the methods you will use to make recommend retrofit measures for a home that you have no means of testing?***	**0.6**	**10**	**20**	**30**	**40**	**50**	
	IF mentions/explains 1 sign, **THEN Novice**		6					
	IF mentions/explains 2 signs, **THEN Advanced Beginner**			12				
	IF mentions/explains 3 signs, **THEN Competent**				18			
	IF mentions/explains 4 signs, **THEN Proficient**					24		
	IF mentions/explains 5 or more signs, **THEN Expert**						30	**30**
9	***Different homes have different retrofit needs. What aspects of the home will determine the need? E.g. is it the construction type, archetype type, age of the home etc.?***	**0.6**	**10**	**20**	**30**	**40**	**50**	
	IF does not see link among aspects, **THEN Novice**		6					
	IF links 2 aspects, **THEN Advanced Beginner**			12				
	IF links 2 aspects and gives example, **THEN Competent**				18			
	IF links 3 aspects/identify 1 retrofit need, **THEN Proficient**					24		
	IF links 3 aspects/identify 1 retrofit need/e.g., **THEN Expert**						30	**30**
10	***How would you explain to a homeowner in a step by step manner what "Energy Auditing" means?***	**0.5**	**10**	**20**	**30**	**40**	**50**	
	IF unable to explain, **THEN Novice**		5					

Table D.9 (cont'd)

	IF only explains tools used, **THEN Advanced Beginner**			10				
	IF explains/mention 1 of 3 objectives, **THEN Competent**				15			
	IF explains/mention 2 of 3 objectives, **THEN Proficient**					20		**20**
	IF explains/mentions 3 of 3 objectives, **THEN Expert**						25	
11	***What specific benefits can be obtained when you perform energy retrofit of a home?***	**0.2**	**10**	**20**	**30**	**40**	**50**	
	IF cannot mention 1 benefit, **THEN Novice**		2					
	IF mentions 1 benefit, **THEN Advanced Beginner**			4				
	IF mentions 2 benefits, **THEN Competent**				6			
	IF mentions 3 benefits, **THEN Proficient**					8		
	IF mentions 3 benefits, **THEN Expert**						10	**10**
12	***What are some of the measures that provide the greatest return on investment for a home owner and why?***	**0.3**	**10**	**20**	**30**	**40**	**50**	
	IF cannot mention, **THEN Novice**		3					
	IF correctly mentions 1 measure, **THEN Advanced Beginner**			6				
	IF correctly mentions 2 measures, **THEN Competent**				9			
	IF correctly mentions 2 measures, **THEN Proficient**					12		
	IF correctly mentions 2 or more measures/contextualizes, **THEN Expert**						15	**15**
13	***What are some external factors which increase the cost of the retrofit operation?***	**0.4**	**10**	**20**	**30**	**40**	**50**	
	IF none, **THEN Novice**		4					
	IF correctly mentions 1 but cannot explain, **THEN Advanced Beginner**			4				
	IF 1 well-explained factor, **THEN Competent**				12			
	IF 1 well-explained factor/context, **THEN Proficient**					16		
	IF 2 or more well-explained factors/examples, **THEN Expert**						20	**20**
14	***Kindly provide a list of post occupancy health issues that must be addressed in energy retrofits.***	**0.6**	**10**	**20**	**30**	**40**	**50**	
	IF none, **THEN Novice**		6					

Table D.9 (Cont'd)

	IF correctly mentions 1 but cannot explain, **THEN Advanced Beginner**			12				
	IF 1 well-explained post-occupancy H&S issue, **THEN Competent**				18			
	IF 2 well-explained post-occupancy H&S issues, **THEN Proficient**					24		
	IF 2 or more well-explained post-occupancy H&S issues/e.gs., **THEN Expert**						30	**30**
15	***Buildings behave as a system where interactions between components can affect their energy performance. What are the interrelationships among the following measures?***	**0.6**	**10**	**20**	**30**	**40**	**50**	
	If no relationship, **THEN Novice**		6					
	IF relationship/cannot explain, **THEN Advanced Beginner**			12				
	IF explains relationship between 2, **THEN Competent**				18			
	IF explains relationship between 2 with example, **THEN Proficient**					24		
	IF explains relationship among 3 or more/contextualizes, **THEN Expert**						30	**30**
16	***What measures do you consider safe and can be installed by a homeowner? Kindly give reasons for your answer.***	**0.6**	**10**	**20**	**30**	**40**	**50**	
	IF none, **THEN Novice**		6					
	IF mentions 1 measure, **THEN Advanced Beginner**			12				
	IF mentions 1 measure/provides reasons, **THEN Competent**				18			
	IF mentions 2 measures/provides reasons, **THEN Proficient**					24		
	IF mentions 3 measures/provides reasons, **THEN Expert**						30	**30**
17	***What measures do you think must be installed by a licensed retrofit professional? Kindly give reasons.***	**0.6**	**10**	**20**	**30**	**40**	**50**	
	IF none, **THEN Novice**		6					
	IF mentions 1 measure, **THEN Advanced Beginner**			12				
	IF mentions 1 measure/provides reasons, **THEN Competent**				18			
	IF mentions 2 measures/provides reasons, **THEN Proficient**					24		**24**
	IF mentions 3 measures/provides reasons, **THEN Expert**						30	
			72	**140**	**216**	**288**	**360**	**337**

APPENDIX D.10

Table D.10: Detailed EREIS Scores for Participant 10

	EXPERT							
	RESPONDENT #10		Expertise ID					
Number	ATTRIBUTE-BASED QUESTIONS	RIS	Novice	Advanced Beginner	Competent	Proficient	Expert	Selected Option
1	***How long have you been working in energy efficiency retrofits for existing homes?***	**0.4**	**10**	**20**	**30**	**40**	**50**	
	IF up to a year, **THEN Novice**		4					
	IF more than 1 year but up to 2 years, **THEN Advanced Beginner**			8				
	IF more than 2 years but up to 3 years, **THEN Competent**				12			
	IF more than 3 years but up to 4 years, **THEN Proficient**					16		
	IF more than 4 years, **THEN Expert**						20	**20**
2	***How many retrofits on average, do you complete each year?***	**0.4**	**10**	**20**	**30**	**40**	**50**	
	IF performs between 1 and 6 audits each year, **THEN Novice**		4					
	IF performs between 7 and 12 audits each year, **THEN Advanced Beginner**			8				
	IF performs between 13 and 18 audits each year, **THEN Competent**				12			
	IF performs between 19 and 24 audits each year, **THEN Proficient**					16		
	IF more than 24 audits each year, **THEN Expert**						20	**20**

Table D.10 (Cont'd)

3	***Have you been away from the industry before? If yes, for how long were you away and did you require retraining?***	**0.3**	**10**	**20**	**30**	**40**	**50**	
	IF more than 3 years, **THEN Novice**		3					
	IF more than 2 years up to 3 years, **THEN Advanced Beginner**			6				
	IF more than 1 year up to 2 years, **THEN Competent**				9			
	IF up to 1 year, **THEN Proficient**					12		
	IF never been away (0 years), **THEN Expert**						15	**15**
4	***How often do you update your knowledge in your work by referring to colleagues, books, manuals, internet, etc. to reinforce information you give to homeowners?***	**0.3**	**10**	**20**	**30**	**40**	**50**	
	IF knowledge is NOT updated, **THEN Novice**		3					
	IF knowledge is updated rarely, **THEN Advanced Beginner**			6				
	IF knowledge is updated sometimes, **THEN Competent**				9			**9**
	IF knowledge is updated regularly, **THEN Proficient**					12		
	IF knowledge is updated always, **THEN Expert**						15	
5	***Are you aware of the tax incentives, rebates, and benefits available to homeowners when they undertake an energy retrofit? If yes, how do you get this information?***	**0.3**	**10**	**20**	**30**	**40**	**50**	
	IF no, **THEN Novice**		3					
	IF yes/chance upon information, **THEN Advanced Beginner**			6				
	IF yes/obtains from 1 source, **THEN Competent**				9			
	If yes/obtains from 2 sources excluding trade organizations, **THEN Proficient**					12		
	IF yes/obtains from 3 or more sources including trade organization							
	and/or government, **THEN Expert**						15	**15**
6	***When a homeowner asks you to justify or explain your decision or actions, how do you go about it?***	**0.4**	**10**	**20**	**30**	**40**	**50**	
	IF make impression and/or company identity builds trust, **THEN Novice**		4					
	IF anyone apart from case based reasoning, **THEN Advanced Beginner**			8				
	IF case based reasoning **THEN Competent**				12			

Table D.10 (Cont'd)

	If any 2 including CBR, **THEN Proficient**					16		
	IF any 3 including CBR - CBR, SSO, RAE, FGS, and/or RWSR, THEN **Expert**						20	**20**
7	***Several measures have been suggested for improving the energy efficiency of existing homes. For e.g. replacing incandescent light bulbs with CFLs. Kindly list others.***	**0.1**	**10**	**20**	**30**	**40**	**50**	
	IF mentions only energy saving measures, **THEN Novice**		1					
	IF mentions measures, **THEN Advanced Beginner**			2				
	IF mentions 3 measures, **THEN Competent**				3			
	IF explains 3 measures/examples, **THEN Proficient**					4		
	IF explains more than 3 measures/examples, **THEN Expert**						5	**5**
8	***How would you explain in a step by step manner, the methods you will use to make recommend retrofit measures for a home that you have no means of testing?***	**0.6**	**10**	**20**	**30**	**40**	**50**	
	IF mentions/explains 1 sign, **THEN Novice**		6					
	IF mentions/explains 2 signs, **THEN Advanced Beginner**			12				
	IF mentions/explains 3 signs, **THEN Competent**				18			
	IF mentions/explains 4 signs, **THEN Proficient**					24		
	IF mentions/explains 5 or more signs, **THEN Expert**						30	**30**
9	***Different homes have different retrofit needs. What aspects of the home will determine the need? E.g. is it the construction type, archetype type, age of the home etc.?***	**0.6**	**10**	**20**	**30**	**40**	**50**	
	IF does not see link among aspects, **THEN Novice**		6					
	IF links 2 aspects, **THEN Advanced Beginner**			12				
	IF links 2 aspects and gives example, **THEN Competent**				18			**18**
	IF links 3 aspects/identify 1 retrofit need, **THEN Proficient**					24		
	IF links 3 aspects/identify 1 retrofit need/e.g., **THEN Expert**						30	
10	***How would you explain to a homeowner in a step by step manner what "Energy Auditing" means?***	**0.5**	**10**	**20**	**30**	**40**	**50**	
	IF unable to explain, **THEN Novice**		5					

Table D.10 (cont'd)

	IF only explains tools used, **THEN Advanced Beginner**			10				
	IF explains/mention 1 of 3 objectives, **THEN Competent**				15			
	IF explains/mention 2 of 3 objectives, **THEN Proficient**					20		**20**
	IF explains/mentions 3 of 3 objectives, **THEN Expert**						25	
11	***What specific benefits can be obtained when you perform energy retrofit of a home?***	**0.2**	**10**	**20**	**30**	**40**	**50**	
	IF cannot mention 1 benefit, **THEN Novice**		2					
	IF mentions 1 benefit, **THEN Advanced Beginner**			4				
	IF mentions 2 benefits, **THEN Competent**				6			**6**
	IF mentions 3 benefits, **THEN Proficient**					8		
	IF mentions 3 benefits, **THEN Expert**						10	
12	***What are some of the measures that provide the greatest return on investment for a home owner and why?***	**0.3**	**10**	**20**	**30**	**40**	**50**	
	IF cannot mention, **THEN Novice**		3					
	IF correctly mentions 1 measure, **THEN Advanced Beginner**			6				
	IF correctly mentions 2 measures, **THEN Competent**				9			
	IF correctly mentions 2 measures, **THEN Proficient**					12		
	IF correctly mentions 2 or more measures/contextualizes, **THEN Expert**						15	**15**
13	***What are some external factors which increase the cost of the retrofit operation?***	**0.4**	**10**	**20**	**30**	**40**	**50**	
	IF none, **THEN Novice**		4					
	IF correctly mentions 1 but cannot explain, **THEN Advanced Beginner**			4				
	IF 1 well-explained factor, **THEN Competent**				12			
	IF 1 well-explained factor/context, **THEN Proficient**					16		
	IF 2 or more well-explained factors/examples, **THEN Expert**						20	**20**
14	***Kindly provide a list of post occupancy health issues that must be addressed in energy retrofits.***	**0.6**	**10**	**20**	**30**	**40**	**50**	
	IF none, **THEN Novice**		6					

Table D.10 (Cont'd)

	IF correctly mentions 1 but cannot explain, **THEN Advanced Beginner**			12				
	IF 1 well-explained post-occupancy H&S issue, **THEN Competent**				18			
	IF 2 well-explained post-occupancy H&S issues, **THEN Proficient**					24		
	IF 2 or more well-explained post-occupancy H&S issues/e.gs., **THEN Expert**						30	**30**
15	***Buildings behave as a system where interactions between components can affect their energy performance. What are the interrelationships among the following measures?***	**0.6**	**10**	**20**	**30**	**40**	**50**	
	If no relationship, **THEN Novice**		6					
	IF relationship/cannot explain, **THEN Advanced Beginner**			12				
	IF explains relationship between 2, **THEN Competent**				18			
	IF explains relationship between 2 with example, **THEN Proficient**					24		
	IF explains relationship among 3 or more/contextualizes, **THEN Expert**						30	**30**
16	***What measures do you consider safe and can be installed by a homeowner? Kindly give reasons for your answer.***	**0.6**	**10**	**20**	**30**	**40**	**50**	
	IF none, **THEN Novice**		6					
	IF mentions 1 measure, **THEN Advanced Beginner**			12				
	IF mentions 1 measure/provides reasons, **THEN Competent**				18			
	IF mentions 2 measures/provides reasons, **THEN Proficient**					24		
	IF mentions 3 measures/provides reasons, **THEN Expert**						30	**30**
17	***What measures do you think must be installed by a licensed retrofit professional? Kindly give reasons.***	**0.6**	**10**	**20**	**30**	**40**	**50**	
	IF none, **THEN Novice**		6					
	IF mentions 1 measure, **THEN Advanced Beginner**			12				
	IF mentions 1 measure/provides reasons, **THEN Competent**				18			
	IF mentions 2 measures/provides reasons, **THEN Proficient**					24		
	IF mentions 3 measures/provides reasons, **THEN Expert**						30	**30**
			72	**140**	**216**	**288**	**360**	**333**

APPENDIX D.11

Table D.11: Detailed EREIS Scores for Participant 11

	LOWER PROFICIENT							
	RESPONDENT #11		Expertise ID					
Number	ATTRIBUTE-BASED QUESTIONS	RIS	Novice	Advanced Beginner	Competent	Proficient	Expert	Selected Option
1	***How long have you been working in energy efficiency retrofits for existing homes?***	**0.4**	**10**	**20**	**30**	**40**	**50**	
	IF up to a year, **THEN Novice**		4					
	IF more than 1 year but up to 2 years, **THEN Advanced Beginner**			8				**8**
	IF more than 2 years but up to 3 years, **THEN Competent**				12			
	IF more than 3 years but up to 4 years, **THEN Proficient**					16		
	IF more than 4 years, **THEN Expert**						20	
2	***How many retrofits on average, do you complete each year?***	**0.4**	**10**	**20**	**30**	**40**	**50**	
	IF performs between 1 and 6 audits each year, **THEN Novice**		4					
	IF performs between 7 and 12 audits each year, **THEN Advanced Beginner**			8				
	IF performs between 13 and 18 audits each year, **THEN Competent**				12			
	IF performs between 19 and 24 audits each year, **THEN Proficient**					16		
	IF more than 24 audits each year, **THEN Expert**						20	**20**

Table D.11 (Cont'd)

3	***Have you been away from the industry before? If yes, for how long were you away and did you require retraining?***	**0.3**	**10**	**20**	**30**	**40**	**50**	
	IF more than 3 years, **THEN Novice**		3					
	IF more than 2 years up to 3 years, **THEN Advanced Beginner**			6				
	IF more than 1 year up to 2 years, **THEN Competent**				9			**9**
	IF up to 1 year, **THEN Proficient**					12		
	IF never been away (0 years), **THEN Expert**						15	
4	***How often do you update your knowledge in your work by referring to colleagues, books, manuals, internet, etc. to reinforce information you give to homeowners?***	**0.3**	**10**	**20**	**30**	**40**	**50**	
	IF knowledge is NOT updated, **THEN Novice**		3					
	IF knowledge is updated rarely, **THEN Advanced Beginner**			6				
	IF knowledge is updated sometimes, **THEN Competent**				9			
	IF knowledge is updated regularly, **THEN Proficient**					12		
	IF knowledge is updated always, **THEN Expert**						15	**15**
5	***Are you aware of the tax incentives, rebates, and benefits available to homeowners when they undertake an energy retrofit? If yes, how do you get this information?***	**0.3**	**10**	**20**	**30**	**40**	**50**	
	IF no, **THEN Novice**		3					
	IF yes/chance upon information, **THEN Advanced Beginner**			6				
	IF yes/obtains from 1 source, **THEN Competent**				9			**9**
	If yes/obtains from 2 sources excluding trade organizations, **THEN Proficient**					12		
	IF yes/obtains from 3 or more sources including trade organization							
	and/or government, **THEN Expert**						15	
6	***When a homeowner asks you to justify or explain your decision or actions, how do you go about it?***	**0.4**	**10**	**20**	**30**	**40**	**50**	
	IF make impression and/or company identity builds trust, **THEN Novice**		4					
	IF anyone apart from case based reasoning, **THEN Advanced Beginner**			8				
	IF case based reasoning **THEN Competent**				12			

Table D.11 (Cont'd)

	If any 2 including CBR, **THEN Proficient**					16		**16**
	IF any 3 including CBR - CBR, SSO, RAE, FGS, and/or RWSR, THEN **Expert**						20	
7	***Several measures have been suggested for improving the energy efficiency of existing homes. For e.g. replacing incandescent light bulbs with CFLs. Kindly list others.***	**0.1**	**10**	**20**	**30**	**40**	**50**	
	IF mentions only energy saving measures, **THEN Novice**		1					
	IF mentions measures, **THEN Advanced Beginner**			2				
	IF mentions 3 measures, **THEN Competent**				3			
	IF explains 3 measures/examples, **THEN Proficient**					4		
	IF explains more than 3 measures/examples, **THEN Expert**						5	**5**
8	***How would you explain in a step by step manner, the methods you will use to make recommend retrofit measures for a home that you have no means of testing?***	**0.6**	**10**	**20**	**30**	**40**	**50**	
	IF mentions/explains 1 sign, **THEN Novice**		6					
	IF mentions/explains 2 signs, **THEN Advanced Beginner**			12				
	IF mentions/explains 3 signs, **THEN Competent**				18			
	IF mentions/explains 4 signs, **THEN Proficient**					24		
	IF mentions/explains 5 or more signs, **THEN Expert**						30	**30**
9	***Different homes have different retrofit needs. What aspects of the home will determine the need? E.g. is it the construction type, archetype type, age of the home etc.?***	**0.6**	**10**	**20**	**30**	**40**	**50**	
	IF does not see link among aspects, **THEN Novice**		6					
	IF links 2 aspects, **THEN Advanced Beginner**			12				
	IF links 2 aspects and gives example, **THEN Competent**				18			**18**
	IF links 3 aspects/identify 1 retrofit need, **THEN Proficient**					24		
	IF links 3 aspects/identify 1 retrofit need/e.g., **THEN Expert**						30	
10	***How would you explain to a homeowner in a step by step manner what "Energy Auditing" means?***	**0.5**	**10**	**20**	**30**	**40**	**50**	
	IF unable to explain, **THEN Novice**		5					

Table D.11 (cont'd)

	IF only explains tools used, **THEN Advanced Beginner**			10				
	IF explains/mention 1 of 3 objectives, **THEN Competent**				15			
	IF explains/mention 2 of 3 objectives, **THEN Proficient**					20		**20**
	IF explains/mentions 3 of 3 objectives, **THEN Expert**						25	
11	***What specific benefits can be obtained when you perform energy retrofit of a home?***	**0.2**	**10**	**20**	**30**	**40**	**50**	
	IF cannot mention 1 benefit, **THEN Novice**		2					
	IF mentions 1 benefit, **THEN Advanced Beginner**			4				
	IF mentions 2 benefits, **THEN Competent**				6			**6**
	IF mentions 3 benefits, **THEN Proficient**					8		
	IF mentions 3 benefits, **THEN Expert**						10	
12	***What are some of the measures that provide the greatest return on investment for a home owner and why?***	**0.3**	**10**	**20**	**30**	**40**	**50**	
	IF cannot mention, **THEN Novice**		3					
	IF correctly mentions 1 measure, **THEN Advanced Beginner**			6				**6**
	IF correctly mentions 2 measures, **THEN Competent**				9			
	IF correctly mentions 2 measures, **THEN Proficient**					12		
	IF correctly mentions 2 or more measures/contextualizes, **THEN Expert**						15	
13	***What are some external factors which increase the cost of the retrofit operation?***	**0.4**	**10**	**20**	**30**	**40**	**50**	
	IF none, **THEN Novice**		4					
	IF correctly mentions 1 but cannot explain, **THEN Advanced Beginner**			4				
	IF 1 well-explained factor, **THEN Competent**				12			
	IF 1 well-explained factor/context, **THEN Proficient**					16		
	IF 2 or more well-explained factors/examples, **THEN Expert**						20	**20**
14	***Kindly provide a list of post occupancy health issues that must be addressed in energy retrofits.***	**0.6**	**10**	**20**	**30**	**40**	**50**	
	IF none, **THEN Novice**		6					

Table D.11 (Cont'd)

	IF correctly mentions 1 but cannot explain, **THEN Advanced Beginner**			12				
	IF 1 well-explained post-occupancy H&S issue, **THEN Competent**				18			**18**
	IF 2 well-explained post-occupancy H&S issues, **THEN Proficient**					24		
	IF 2 or more well-explained post-occupancy H&S issues/e.gs., **THEN Expert**						30	
15	***Buildings behave as a system where interactions between components can affect their energy performance. What are the interrelationships among the following measures?***	**0.6**	**10**	**20**	**30**	**40**	**50**	
	If no relationship, **THEN Novice**		6					
	IF relationship/cannot explain, **THEN Advanced Beginner**			12				
	IF explains relationship between 2, **THEN Competent**				18			
	IF explains relationship between 2 with example, **THEN Proficient**					24		**24**
	IF explains relationship among 3 or more/contextualizes, **THEN Expert**						30	
16	***What measures do you consider safe and can be installed by a homeowner? Kindly give reasons for your answer.***	**0.6**	**10**	**20**	**30**	**40**	**50**	
	IF none, **THEN Novice**		6					
	IF mentions 1 measure, **THEN Advanced Beginner**			12				
	IF mentions 1 measure/provides reasons, **THEN Competent**				18			
	IF mentions 2 measures/provides reasons, **THEN Proficient**					24		**24**
	IF mentions 3 measures/provides reasons, **THEN Expert**						30	
17	***What measures do you think must be installed by a licensed retrofit professional? Kindly give reasons.***	**0.6**	**10**	**20**	**30**	**40**	**50**	
	IF none, **THEN Novice**		6					
	IF mentions 1 measure, **THEN Advanced Beginner**			12				**12**
	IF mentions 1 measure/provides reasons, **THEN Competent**				18			
	IF mentions 2 measures/provides reasons, **THEN Proficient**					24		
	IF mentions 3 measures/provides reasons, **THEN Expert**						30	
			72	**140**	**216**	**288**	**360**	**260**

APPENDIX D.12

Table D.12: Detailed EREIS Scores for Participant 12

	EXPERT							
	RESPONDENT #12		Expertise ID					
Number	ATTRIBUTE-BASED QUESTIONS	RIS	Novice	Advanced Beginner	Competent	Proficient	Expert	Selected Option
1	***How long have you been working in energy efficiency retrofits for existing homes?***	**0.4**	**10**	**20**	**30**	**40**	**50**	
	IF up to a year, **THEN Novice**		4					
	IF more than 1 year but up to 2 years, **THEN Advanced Beginner**			8				
	IF more than 2 years but up to 3 years, **THEN Competent**				12			
	IF more than 3 years but up to 4 years, **THEN Proficient**					16		
	IF more than 4 years, **THEN Expert**						20	**20**
2	***How many retrofits on average, do you complete each year?***	**0.4**	**10**	**20**	**30**	**40**	**50**	
	IF performs between 1 and 6 audits each year, **THEN Novice**		4					
	IF performs between 7 and 12 audits each year, **THEN Advanced Beginner**			8				
	IF performs between 13 and 18 audits each year, **THEN Competent**				12			
	IF performs between 19 and 24 audits each year, **THEN Proficient**					16		
	IF more than 24 audits each year, **THEN Expert**						20	**20**

Table D.12 (Cont'd)

3	***Have you been away from the industry before? If yes, for how long were you away and did you require retraining?***	**0.3**	**10**	**20**	**30**	**40**	**50**	
	IF more than 3 years, **THEN Novice**		3					
	IF more than 2 years up to 3 years, **THEN Advanced Beginner**			6				
	IF more than 1 year up to 2 years, **THEN Competent**				9			
	IF up to 1 year, **THEN Proficient**					12		
	IF never been away (0 years), **THEN Expert**						15	**15**
4	***How often do you update your knowledge in your work by referring to colleagues, books, manuals, internet, etc. to reinforce information you give to homeowners?***	**0.3**	**10**	**20**	**30**	**40**	**50**	
	IF knowledge is NOT updated, **THEN Novice**		3					
	IF knowledge is updated rarely, **THEN Advanced Beginner**			6				
	IF knowledge is updated sometimes, **THEN Competent**				9			**9**
	IF knowledge is updated regularly, **THEN Proficient**					12		
	IF knowledge is updated always, **THEN Expert**						15	
5	***Are you aware of the tax incentives, rebates, and benefits available to homeowners when they undertake an energy retrofit? If yes, how do you get this information?***	**0.3**	**10**	**20**	**30**	**40**	**50**	
	IF no, **THEN Novice**		3					
	IF yes/chance upon information, **THEN Advanced Beginner**			6				
	IF yes/obtains from 1 source, **THEN Competent**				9			
	If yes/obtains from 2 sources excluding trade organizations, **THEN Proficient**					12		
	IF yes/obtains from 3 or more sources including trade organization							
	and/or government, **THEN Expert**						15	**15**
6	***When a homeowner asks you to justify or explain your decision or actions, how do you go about it?***	**0.4**	**10**	**20**	**30**	**40**	**50**	
	IF make impression and/or company identity builds trust, **THEN Novice**		4					
	IF anyone apart from case based reasoning, **THEN Advanced Beginner**			8				
	IF case based reasoning **THEN Competent**				12			

Table D.12 (Cont'd)

	If any 2 including CBR, **THEN Proficient**					16		
	IF any 3 including CBR - CBR, SSO, RAE, FGS, and/or RWSR, THEN **Expert**						20	**20**
7	***Several measures have been suggested for improving the energy efficiency of existing homes. For e.g. replacing incandescent light bulbs with CFLs. Kindly list others.***	**0.1**	**10**	**20**	**30**	**40**	**50**	
	IF mentions only energy saving measures, **THEN Novice**		1					
	IF mentions measures, **THEN Advanced Beginner**			2				
	IF mentions 3 measures, **THEN Competent**				3			
	IF explains 3 measures/examples, **THEN Proficient**					4		**4**
	IF explains more than 3 measures/examples, **THEN Expert**						5	
8	***How would you explain in a step by step manner, the methods you will use to make recommend retrofit measures for a home that you have no means of testing?***	**0.6**	**10**	**20**	**30**	**40**	**50**	
	IF mentions/explains 1 sign, **THEN Novice**		6					
	IF mentions/explains 2 signs, **THEN Advanced Beginner**			12				
	IF mentions/explains 3 signs, **THEN Competent**				18			
	IF mentions/explains 4 signs, **THEN Proficient**					24		
	IF mentions/explains 5 or more signs, **THEN Expert**						30	**30**
9	***Different homes have different retrofit needs. What aspects of the home will determine the need? E.g. is it the construction type, archetype type, age of the home etc.?***	**0.6**	**10**	**20**	**30**	**40**	**50**	
	IF does not see link among aspects, **THEN Novice**		6					
	IF links 2 aspects, **THEN Advanced Beginner**			12				
	IF links 2 aspects and gives example, **THEN Competent**				18			**18**
	IF links 3 aspects/identify 1 retrofit need, **THEN Proficient**					24		
	IF links 3 aspects/identify 1 retrofit need/e.g., **THEN Expert**						30	
10	***How would you explain to a homeowner in a step by step manner what "Energy Auditing" means?***	**0.5**	**10**	**20**	**30**	**40**	**50**	
	IF unable to explain, **THEN Novice**		5					

Table D.12 (cont'd)

	IF only explains tools used, **THEN Advanced Beginner**			10				
	IF explains/mention 1 of 3 objectives, **THEN Competent**				15			
	IF explains/mention 2 of 3 objectives, **THEN Proficient**					20		
	IF explains/mentions 3 of 3 objectives, **THEN Expert**						25	**25**
11	***What specific benefits can be obtained when you perform energy retrofit of a home?***	**0.2**	**10**	**20**	**30**	**40**	**50**	
	IF cannot mention 1 benefit, **THEN Novice**		2					
	IF mentions 1 benefit, **THEN Advanced Beginner**			4				**4**
	IF mentions 2 benefits, **THEN Competent**				6			
	IF mentions 3 benefits, **THEN Proficient**					8		
	IF mentions 3 benefits, **THEN Expert**						10	
12	***What are some of the measures that provide the greatest return on investment for a home owner and why?***	**0.3**	**10**	**20**	**30**	**40**	**50**	
	IF cannot mention, **THEN Novice**		3					
	IF correctly mentions 1 measure, **THEN Advanced Beginner**			6				
	IF correctly mentions 2 measures, **THEN Competent**				9			
	IF correctly mentions 2 measures, **THEN Proficient**					12		**12**
	IF correctly mentions 2 or more measures/contextualizes, **THEN Expert**						15	
13	***What are some external factors which increase the cost of the retrofit operation?***	**0.4**	**10**	**20**	**30**	**40**	**50**	
	IF none, **THEN Novice**		4					
	IF correctly mentions 1 but cannot explain, **THEN Advanced Beginner**			4				
	IF 1 well-explained factor, **THEN Competent**				12			
	IF 1 well-explained factor/context, **THEN Proficient**					16		
	IF 2 or more well-explained factors/examples, **THEN Expert**						20	**20**
14	***Kindly provide a list of post occupancy health issues that must be addressed in energy retrofits.***	**0.6**	**10**	**20**	**30**	**40**	**50**	
	IF none, **THEN Novice**		6					

Table D.12 (Cont'd)

	IF correctly mentions 1 but cannot explain, **THEN Advanced Beginner**			12				
	IF 1 well-explained post-occupancy H&S issue, **THEN Competent**				18			
	IF 2 well-explained post-occupancy H&S issues, **THEN Proficient**					24		
	IF 2 or more well-explained post-occupancy H&S issues/e.gs., **THEN Expert**						30	**30**
15	***Buildings behave as a system where interactions between components can affect their energy performance. What are the interrelationships among the following measures?***	**0.6**	**10**	**20**	**30**	**40**	**50**	
	If no relationship, **THEN Novice**		6					
	IF relationship/cannot explain, **THEN Advanced Beginner**			12				
	IF explains relationship between 2, **THEN Competent**				18			
	IF explains relationship between 2 with example, **THEN Proficient**					24		
	IF explains relationship among 3 or more/contextualizes, **THEN Expert**						30	**30**
16	***What measures do you consider safe and can be installed by a homeowner? Kindly give reasons for your answer.***	**0.6**	**10**	**20**	**30**	**40**	**50**	
	IF none, **THEN Novice**		6					
	IF mentions 1 measure, **THEN Advanced Beginner**			12				
	IF mentions 1 measure/provides reasons, **THEN Competent**				18			
	IF mentions 2 measures/provides reasons, **THEN Proficient**					24		
	IF mentions 3 measures/provides reasons, **THEN Expert**						30	**30**
17	***What measures do you think must be installed by a licensed retrofit professional? Kindly give reasons.***	**0.6**	**10**	**20**	**30**	**40**	**50**	
	IF none, **THEN Novice**		6					
	IF mentions 1 measure, **THEN Advanced Beginner**			12				
	IF mentions 1 measure/provides reasons, **THEN Competent**				18			
	IF mentions 2 measures/provides reasons, **THEN Proficient**					24		**24**
	IF mentions 3 measures/provides reasons, **THEN Expert**						30	
			72	**140**	**216**	**288**	**360**	**326**

APPENDIX D.13

Table D.13: Detailed EREIS Scores for Participant 13

	EXPERT							
	RESPONDENT #13		**Expertise ID**					
Number	**ATTRIBUTE-BASED QUESTIONS**	**RIS**	**Novice**	**Advanced Beginner**	**Competent**	**Proficient**	**Expert**	**Selected Option**
1	***How long have you been working in energy efficiency retrofits for existing homes?***	**0.4**	**10**	**20**	**30**	**40**	**50**	
	IF up to a year, **THEN Novice**		4					
	IF more than 1 year but up to 2 years, **THEN Advanced Beginner**			8				
	IF more than 2 years but up to 3 years, **THEN Competent**				12			
	IF more than 3 years but up to 4 years, **THEN Proficient**					16		**16**
	IF more than 4 years, **THEN Expert**						20	
2	***How many retrofits on average, do you complete each year?***	**0.4**	**10**	**20**	**30**	**40**	**50**	
	IF performs between 1 and 6 audits each year, **THEN Novice**		4					
	IF performs between 7 and 12 audits each year, **THEN Advanced Beginner**			8				
	IF performs between 13 and 18 audits each year, **THEN Competent**				12			
	IF performs between 19 and 24 audits each year, **THEN Proficient**					16		
	IF more than 24 audits each year, **THEN Expert**						20	**20**

Table D.13 (Cont'd)

3	***Have you been away from the industry before? If yes, for how long were you away and did you require retraining?***	**0.3**	**10**	**20**	**30**	**40**	**50**	
	IF more than 3 years, **THEN Novice**		3					
	IF more than 2 years up to 3 years, **THEN Advanced Beginner**			6				
	IF more than 1 year up to 2 years, **THEN Competent**				9			
	IF up to 1 year, **THEN Proficient**					12		
	IF never been away (0 years), **THEN Expert**						15	**15**
4	***How often do you update your knowledge in your work by referring to colleagues, books, manuals, internet, etc. to reinforce information you give to homeowners?***	**0.3**	**10**	**20**	**30**	**40**	**50**	
	IF knowledge is NOT updated, **THEN Novice**		3					
	IF knowledge is updated rarely, **THEN Advanced Beginner**			6				
	IF knowledge is updated sometimes, **THEN Competent**				9			
	IF knowledge is updated regularly, **THEN Proficient**					12		
	IF knowledge is updated always, **THEN Expert**						15	**15**
5	***Are you aware of the tax incentives, rebates, and benefits available to homeowners when they undertake an energy retrofit? If yes, how do you get this information?***	**0.3**	**10**	**20**	**30**	**40**	**50**	
	IF no, **THEN Novice**		3					
	IF yes/chance upon information, **THEN Advanced Beginner**			6				
	IF yes/obtains from 1 source, **THEN Competent**				9			**9**
	If yes/obtains from 2 sources excluding trade organizations, **THEN Proficient**					12		
	IF yes/obtains from 3 or more sources including trade organization							
	and/or government, **THEN Expert**						15	
6	***When a homeowner asks you to justify or explain your decision or actions, how do you go about it?***	**0.4**	**10**	**20**	**30**	**40**	**50**	
	IF make impression and/or company identity builds trust, **THEN Novice**		4					
	IF anyone apart from case based reasoning, **THEN Advanced Beginner**			8				
	IF case based reasoning **THEN Competent**				12			

Table D.13 (Cont'd)

	If any 2 including CBR, **THEN Proficient**					16		
	IF any 3 including CBR - CBR, SSO, RAE, FGS, and/or RWSR, THEN **Expert**						20	**20**
7	***Several measures have been suggested for improving the energy efficiency of existing homes. For e.g. replacing incandescent light bulbs with CFLs. Kindly list others.***	**0.1**	**10**	**20**	**30**	**40**	**50**	
	IF mentions only energy saving measures, **THEN Novice**		1					
	IF mentions measures, **THEN Advanced Beginner**			2				
	IF mentions 3 measures, **THEN Competent**				3			
	IF explains 3 measures/examples, **THEN Proficient**					4		
	IF explains more than 3 measures/examples, **THEN Expert**						5	**5**
8	***How would you explain in a step by step manner, the methods you will use to make recommend retrofit measures for a home that you have no means of testing?***	**0.6**	**10**	**20**	**30**	**40**	**50**	
	IF mentions/explains 1 sign, **THEN Novice**		6					
	IF mentions/explains 2 signs, **THEN Advanced Beginner**			12				
	IF mentions/explains 3 signs, **THEN Competent**				18			
	IF mentions/explains 4 signs, **THEN Proficient**					24		
	IF mentions/explains 5 or more signs, **THEN Expert**						30	**30**
9	***Different homes have different retrofit needs. What aspects of the home will determine the need? E.g. is it the construction type, archetype type, age of the home etc.?***	**0.6**	**10**	**20**	**30**	**40**	**50**	
	IF does not see link among aspects, **THEN Novice**		6					
	IF links 2 aspects, **THEN Advanced Beginner**			12				
	IF links 2 aspects and gives example, **THEN Competent**				18			
	IF links 3 aspects/identify 1 retrofit need, **THEN Proficient**					24		**24**
	IF links 3 aspects/identify 1 retrofit need/e.g., **THEN Expert**						30	
10	***How would you explain to a homeowner in a step by step manner what "Energy Auditing" means?***	**0.5**	**10**	**20**	**30**	**40**	**50**	
	IF unable to explain, **THEN Novice**		5					

Table D.13 (cont'd)

	IF only explains tools used, **THEN Advanced Beginner**			10				
	IF explains/mention 1 of 3 objectives, **THEN Competent**				15			
	IF explains/mention 2 of 3 objectives, **THEN Proficient**					20		**20**
	IF explains/mentions 3 of 3 objectives, **THEN Expert**						25	
11	***What specific benefits can be obtained when you perform energy retrofit of a home?***	**0.2**	**10**	**20**	**30**	**40**	**50**	
	IF cannot mention 1 benefit, **THEN Novice**		2					
	IF mentions 1 benefit, **THEN Advanced Beginner**			4				
	IF mentions 2 benefits, **THEN Competent**				6			**6**
	IF mentions 3 benefits, **THEN Proficient**					8		
	IF mentions 3 benefits, **THEN Expert**						10	
12	***What are some of the measures that provide the greatest return on investment for a home owner and why?***	**0.3**	**10**	**20**	**30**	**40**	**50**	
	IF cannot mention, **THEN Novice**		3					
	IF correctly mentions 1 measure, **THEN Advanced Beginner**			6				
	IF correctly mentions 2 measures, **THEN Competent**				9			**9**
	IF correctly mentions 2 measures, **THEN Proficient**					12		
	IF correctly mentions 2 or more measures/contextualizes, **THEN Expert**						15	
13	***What are some external factors which increase the cost of the retrofit operation?***	**0.4**	**10**	**20**	**30**	**40**	**50**	
	IF none, **THEN Novice**		4					
	IF correctly mentions 1 but cannot explain, **THEN Advanced Beginner**			4				
	IF 1 well-explained factor, **THEN Competent**				12			
	IF 1 well-explained factor/context, **THEN Proficient**					16		
	IF 2 or more well-explained factors/examples, **THEN Expert**						20	**20**
14	***Kindly provide a list of post occupancy health issues that must be addressed in energy retrofits.***	**0.6**	**10**	**20**	**30**	**40**	**50**	
	IF none, **THEN Novice**		6					

Table D.13 (Cont'd)

	IF correctly mentions 1 but cannot explain, **THEN Advanced Beginner**			12				
	IF 1 well-explained post-occupancy H&S issue, **THEN Competent**				18			
	IF 2 well-explained post-occupancy H&S issues, **THEN Proficient**					24		
	IF 2 or more well-explained post-occupancy H&S issues/e.gs., **THEN Expert**						30	**30**
15	***Buildings behave as a system where interactions between components can affect their energy performance. What are the interrelationships among the following measures?***	**0.6**	**10**	**20**	**30**	**40**	**50**	
	If no relationship, **THEN Novice**		6					
	IF relationship/cannot explain, **THEN Advanced Beginner**			12				
	IF explains relationship between 2, **THEN Competent**				18			
	IF explains relationship between 2 with example, **THEN Proficient**					24		
	IF explains relationship among 3 or more/contextualizes, **THEN Expert**						30	**30**
16	***What measures do you consider safe and can be installed by a homeowner? Kindly give reasons for your answer.***	**0.6**	**10**	**20**	**30**	**40**	**50**	
	IF none, **THEN Novice**		6					
	IF mentions 1 measure, **THEN Advanced Beginner**			12				
	IF mentions 1 measure/provides reasons, **THEN Competent**				18			
	IF mentions 2 measures/provides reasons, **THEN Proficient**					24		
	IF mentions 3 measures/provides reasons, **THEN Expert**						30	**30**
17	***What measures do you think must be installed by a licensed retrofit professional? Kindly give reasons.***	**0.6**	**10**	**20**	**30**	**40**	**50**	
	IF none, **THEN Novice**		6					
	IF mentions 1 measure, **THEN Advanced Beginner**			12				
	IF mentions 1 measure/provides reasons, **THEN Competent**				18			
	IF mentions 2 measures/provides reasons, **THEN Proficient**					24		
	IF mentions 3 measures/provides reasons, **THEN Expert**						30	**30**
			72	**140**	**216**	**288**	**360**	**329**

APPENDIX D.14

Table D.14: Detailed EREIS Scores for Participant 14

EXPERT

RESPONDENT #14

Number	ATTRIBUTE-BASED QUESTIONS	RIS	Expertise ID: Novice	Advanced Beginner	Competent	Proficient	Expert	Selected Option
1	***How long have you been working in energy efficiency retrofits for existing homes?***	**0.4**	**10**	**20**	**30**	**40**	**50**	
	IF up to a year, **THEN Novice**		4					**4**
	IF more than 1 year but up to 2 years, **THEN Advanced Beginner**			8				
	IF more than 2 years but up to 3 years, **THEN Competent**				12			
	IF more than 3 years but up to 4 years, **THEN Proficient**					16		
	IF more than 4 years, **THEN Expert**						20	
2	***How many retrofits on average, do you complete each year?***	**0.4**	**10**	**20**	**30**	**40**	**50**	
	IF performs between 1 and 6 audits each year, **THEN Novice**		4					
	IF performs between 7 and 12 audits each year, **THEN Advanced Beginner**			8				
	IF performs between 13 and 18 audits each year, **THEN Competent**				12			
	IF performs between 19 and 24 audits each year, **THEN Proficient**					16		
	IF more than 24 audits each year, **THEN Expert**						20	**20**

Table D.14 (Cont'd)

3	***Have you been away from the industry before? If yes, for how long were you away and did you require retraining?***	**0.3**	**10**	**20**	**30**	**40**	**50**	
	IF more than 3 years, **THEN Novice**		3					
	IF more than 2 years up to 3 years, **THEN Advanced Beginner**			6				
	IF more than 1 year up to 2 years, **THEN Competent**				9			
	IF up to 1 year, **THEN Proficient**					12		
	IF never been away (0 years), **THEN Expert**						15	**15**
4	***How often do you update your knowledge in your work by referring to colleagues, books, manuals, internet, etc. to reinforce information you give to homeowners?***	**0.3**	**10**	**20**	**30**	**40**	**50**	
	IF knowledge is NOT updated, **THEN Novice**		3					
	IF knowledge is updated rarely, **THEN Advanced Beginner**			6				
	IF knowledge is updated sometimes, **THEN Competent**				9			
	IF knowledge is updated regularly, **THEN Proficient**					12		
	IF knowledge is updated always, **THEN Expert**						15	**15**
5	***Are you aware of the tax incentives, rebates, and benefits available to homeowners when they undertake an energy retrofit? If yes, how do you get this information?***	**0.3**	**10**	**20**	**30**	**40**	**50**	
	IF no, **THEN Novice**		3					
	IF yes/chance upon information, **THEN Advanced Beginner**			6				**6**
	IF yes/obtains from 1 source, **THEN Competent**				9			
	If yes/obtains from 2 sources excluding trade organizations, **THEN Proficient**					12		
	IF yes/obtains from 3 or more sources including trade organization							
	and/or government, **THEN Expert**						15	
6	***When a homeowner asks you to justify or explain your decision or actions, how do you go about it?***	**0.4**	**10**	**20**	**30**	**40**	**50**	
	IF make impression and/or company identity builds trust, **THEN Novice**		4					
	IF anyone apart from case based reasoning, **THEN Advanced Beginner**			8				
	IF case based reasoning **THEN Competent**				12			

Table D.14 (Cont'd)

	If any 2 including CBR, **THEN Proficient**					16		**16**
	IF any 3 including CBR - CBR, SSO, RAE, FGS, and/or RWSR, THEN **Expert**						20	
7	***Several measures have been suggested for improving the energy efficiency of existing homes. For e.g. replacing incandescent light bulbs with CFLs. Kindly list others.***	**0.1**	**10**	**20**	**30**	**40**	**50**	
	IF mentions only energy saving measures, **THEN Novice**		1					
	IF mentions measures, **THEN Advanced Beginner**			2				
	IF mentions 3 measures, **THEN Competent**				3			
	IF explains 3 measures/examples, **THEN Proficient**					4		
	IF explains more than 3 measures/examples, **THEN Expert**						5	**5**
8	***How would you explain in a step by step manner, the methods you will use to make recommend retrofit measures for a home that you have no means of testing?***	**0.6**	**10**	**20**	**30**	**40**	**50**	
	IF mentions/explains 1 sign, **THEN Novice**		6					
	IF mentions/explains 2 signs, **THEN Advanced Beginner**			12				
	IF mentions/explains 3 signs, **THEN Competent**				18			
	IF mentions/explains 4 signs, **THEN Proficient**					24		
	IF mentions/explains 5 or more signs, **THEN Expert**						30	**30**
9	***Different homes have different retrofit needs. What aspects of the home will determine the need? E.g. is it the construction type, archetype type, age of the home etc.?***	**0.6**	**10**	**20**	**30**	**40**	**50**	
	IF does not see link among aspects, **THEN Novice**		6					
	IF links 2 aspects, **THEN Advanced Beginner**			12				
	IF links 2 aspects and gives example, **THEN Competent**				18			
	IF links 3 aspects/identify 1 retrofit need, **THEN Proficient**					24		
	IF links 3 aspects/identify 1 retrofit need/e.g., **THEN Expert**						30	**30**
10	***How would you explain to a homeowner in a step by step manner what "Energy Auditing" means?***	**0.5**	**10**	**20**	**30**	**40**	**50**	
	IF unable to explain, **THEN Novice**		5					

Table D.14 (cont'd)

	IF only explains tools used, **THEN Advanced Beginner**			10				
	IF explains/mention 1 of 3 objectives, **THEN Competent**				15			
	IF explains/mention 2 of 3 objectives, **THEN Proficient**					20		**20**
	IF explains/mentions 3 of 3 objectives, **THEN Expert**						25	
11	***What specific benefits can be obtained when you perform energy retrofit of a home?***	**0.2**	**10**	**20**	**30**	**40**	**50**	
	IF cannot mention 1 benefit, **THEN Novice**		2					
	IF mentions 1 benefit, **THEN Advanced Beginner**			4				
	IF mentions 2 benefits, **THEN Competent**				6			
	IF mentions 3 benefits, **THEN Proficient**					8		
	IF mentions 3 benefits, **THEN Expert**						10	**10**
12	***What are some of the measures that provide the greatest return on investment for a home owner and why?***	**0.3**	**10**	**20**	**30**	**40**	**50**	
	IF cannot mention, **THEN Novice**		3					
	IF correctly mentions 1 measure, **THEN Advanced Beginner**			6				
	IF correctly mentions 2 measures, **THEN Competent**				9			
	IF correctly mentions 2 measures, **THEN Proficient**					12		**12**
	IF correctly mentions 2 or more measures/contextualizes, **THEN Expert**						15	
13	***What are some external factors which increase the cost of the retrofit operation?***	**0.4**	**10**	**20**	**30**	**40**	**50**	
	IF none, **THEN Novice**		4					
	IF correctly mentions 1 but cannot explain, **THEN Advanced Beginner**			4				
	IF 1 well-explained factor, **THEN Competent**				12			
	IF 1 well-explained factor/context, **THEN Proficient**					16		
	IF 2 or more well-explained factors/examples, **THEN Expert**						20	**20**
14	***Kindly provide a list of post occupancy health issues that must be addressed in energy retrofits.***	**0.6**	**10**	**20**	**30**	**40**	**50**	
	IF none, **THEN Novice**		6					

Table D.14 (Cont'd)

	IF correctly mentions 1 but cannot explain, **THEN Advanced Beginner**			12				
	IF 1 well-explained post-occupancy H&S issue, **THEN Competent**				18			
	IF 2 well-explained post-occupancy H&S issues, **THEN Proficient**					24		
	IF 2 or more well-explained post-occupancy H&S issues/e.gs., **THEN Expert**						30	**30**
15	***Buildings behave as a system where interactions between components can affect their energy performance. What are the interrelationships among the following measures?***	**0.6**	**10**	**20**	**30**	**40**	**50**	
	If no relationship, **THEN Novice**		6					
	IF relationship/cannot explain, **THEN Advanced Beginner**			12				
	IF explains relationship between 2, **THEN Competent**				18			
	IF explains relationship between 2 with example, **THEN Proficient**					24		
	IF explains relationship among 3 or more/contextualizes, **THEN Expert**						30	**30**
16	***What measures do you consider safe and can be installed by a homeowner? Kindly give reasons for your answer.***	**0.6**	**10**	**20**	**30**	**40**	**50**	
	IF none, **THEN Novice**		6					
	IF mentions 1 measure, **THEN Advanced Beginner**			12				
	IF mentions 1 measure/provides reasons, **THEN Competent**				18			
	IF mentions 2 measures/provides reasons, **THEN Proficient**					24		
	IF mentions 3 measures/provides reasons, **THEN Expert**						30	**30**
17	***What measures do you think must be installed by a licensed retrofit professional? Kindly give reasons.***	**0.6**	**10**	**20**	**30**	**40**	**50**	
	IF none, **THEN Novice**		6					
	IF mentions 1 measure, **THEN Advanced Beginner**			12				
	IF mentions 1 measure/provides reasons, **THEN Competent**				18			
	IF mentions 2 measures/provides reasons, **THEN Proficient**					24		
	IF mentions 3 measures/provides reasons, **THEN Expert**						30	**30**
			72	**140**	**216**	**288**	**360**	**323**

APPENDIX D.15

Table D.15: Detailed EREIS Scores for Participant 15

LOWER PROFICIENT

RESPONDENT #15

Number	ATTRIBUTE-BASED QUESTIONS	RIS	Expertise ID: Novice	Advanced Beginner	Competent	Proficient	Expert	Selected Option
1	***How long have you been working in energy efficiency retrofits for existing homes?***	**0.4**	**10**	**20**	**30**	**40**	**50**	
	IF up to a year, **THEN Novice**		4					
	IF more than 1 year but up to 2 years, **THEN Advanced Beginner**			8				
	IF more than 2 years but up to 3 years, **THEN Competent**				12			
	IF more than 3 years but up to 4 years, **THEN Proficient**					16		**16**
	IF more than 4 years, **THEN Expert**						20	
2	***How many retrofits on average, do you complete each year?***	**0.4**	**10**	**20**	**30**	**40**	**50**	
	IF performs between 1 and 6 audits each year, **THEN Novice**		4					
	IF performs between 7 and 12 audits each year, **THEN Advanced Beginner**			8				
	IF performs between 13 and 18 audits each year, **THEN Competent**				12			
	IF performs between 19 and 24 audits each year, **THEN Proficient**					16		**16**
	IF more than 24 audits each year, **THEN Expert**						20	

Table D.15 (Cont'd)

3	***Have you been away from the industry before? If yes, for how long were you away and did you require retraining?***	**0.3**	**10**	**20**	**30**	**40**	**50**	
	IF more than 3 years, **THEN Novice**		3					
	IF more than 2 years up to 3 years, **THEN Advanced Beginner**			6				
	IF more than 1 year up to 2 years, **THEN Competent**				9			
	IF up to 1 year, **THEN Proficient**					12		
	IF never been away (0 years), **THEN Expert**						15	**15**
4	***How often do you update your knowledge in your work by referring to colleagues, books, manuals, internet, etc. to reinforce information you give to homeowners?***	**0.3**	**10**	**20**	**30**	**40**	**50**	
	IF knowledge is NOT updated, **THEN Novice**		3					
	IF knowledge is updated rarely, **THEN Advanced Beginner**			6				
	IF knowledge is updated sometimes, **THEN Competent**				9			
	IF knowledge is updated regularly, **THEN Proficient**					12		
	IF knowledge is updated always, **THEN Expert**						15	**15**
5	***Are you aware of the tax incentives, rebates, and benefits available to homeowners when they undertake an energy retrofit? If yes, how do you get this information?***	**0.3**	**10**	**20**	**30**	**40**	**50**	
	IF no, **THEN Novice**		3					
	IF yes/chance upon information, **THEN Advanced Beginner**			6				
	IF yes/obtains from 1 source, **THEN Competent**				9			**9**
	If yes/obtains from 2 sources excluding trade organizations, **THEN Proficient**					12		
	IF yes/obtains from 3 or more sources including trade organization							
	and/or government, **THEN Expert**						15	
6	***When a homeowner asks you to justify or explain your decision or actions, how do you go about it?***	**0.4**	**10**	**20**	**30**	**40**	**50**	
	IF make impression and/or company identity builds trust, **THEN Novice**		4					
	IF anyone apart from case based reasoning, **THEN Advanced Beginner**			8				**8**
	IF case based reasoning **THEN Competent**				12			

Table D.15 (Cont'd)

	If any 2 including CBR, **THEN Proficient**					16		
	IF any 3 including CBR - CBR, SSO, RAE, FGS, and/or RWSR, THEN **Expert**						20	
7	***Several measures have been suggested for improving the energy efficiency of existing homes. For e.g. replacing incandescent light bulbs with CFLs. Kindly list others.***	**0.1**	**10**	**20**	**30**	**40**	**50**	
	IF mentions only energy saving measures, **THEN Novice**		1					**1**
	IF mentions measures, **THEN Advanced Beginner**			2				
	IF mentions 3 measures, **THEN Competent**				3			
	IF explains 3 measures/examples, **THEN Proficient**					4		
	IF explains more than 3 measures/examples, **THEN Expert**						5	
8	***How would you explain in a step by step manner, the methods you will use to make recommend retrofit measures for a home that you have no means of testing?***	**0.6**	**10**	**20**	**30**	**40**	**50**	
	IF mentions/explains 1 sign, **THEN Novice**		6					
	IF mentions/explains 2 signs, **THEN Advanced Beginner**			12				
	IF mentions/explains 3 signs, **THEN Competent**				18			**18**
	IF mentions/explains 4 signs, **THEN Proficient**					24		
	IF mentions/explains 5 or more signs, **THEN Expert**						30	
9	***Different homes have different retrofit needs. What aspects of the home will determine the need? E.g. is it the construction type, archetype type, age of the home etc.?***	**0.6**	**10**	**20**	**30**	**40**	**50**	
	IF does not see link among aspects, **THEN Novice**		6					
	IF links 2 aspects, **THEN Advanced Beginner**			12				
	IF links 2 aspects and gives example, **THEN Competent**				18			**18**
	IF links 3 aspects/identify 1 retrofit need, **THEN Proficient**					24		
	IF links 3 aspects/identify 1 retrofit need/e.g., **THEN Expert**						30	
10	***How would you explain to a homeowner in a step by step manner what "Energy Auditing" means?***	**0.5**	**10**	**20**	**30**	**40**	**50**	
	IF unable to explain, **THEN Novice**		5					

Table D.15 (cont'd)

	IF only explains tools used, **THEN Advanced Beginner**			10				
	IF explains/mention 1 of 3 objectives, **THEN Competent**				15			**15**
	IF explains/mention 2 of 3 objectives, **THEN Proficient**					20		
	IF explains/mentions 3 of 3 objectives, **THEN Expert**						25	
11	***What specific benefits can be obtained when you perform energy retrofit of a home?***	**0.2**	**10**	**20**	**30**	**40**	**50**	
	IF cannot mention 1 benefit, **THEN Novice**		2					
	IF mentions 1 benefit, **THEN Advanced Beginner**			4				
	IF mentions 2 benefits, **THEN Competent**				6			**6**
	IF mentions 3 benefits, **THEN Proficient**					8		
	IF mentions 3 benefits, **THEN Expert**						10	
12	***What are some of the measures that provide the greatest return on investment for a home owner and why?***	**0.3**	**10**	**20**	**30**	**40**	**50**	
	IF cannot mention, **THEN Novice**		3					
	IF correctly mentions 1 measure, **THEN Advanced Beginner**			6				
	IF correctly mentions 2 measures, **THEN Competent**				9			
	IF correctly mentions 2 measures, **THEN Proficient**					12		**12**
	IF correctly mentions 2 or more measures/contextualizes, **THEN Expert**						15	
13	***What are some external factors which increase the cost of the retrofit operation?***	**0.4**	**10**	**20**	**30**	**40**	**50**	
	IF none, **THEN Novice**		4					
	IF correctly mentions 1 but cannot explain, **THEN Advanced Beginner**			4				
	IF 1 well-explained factor, **THEN Competent**				12			**12**
	IF 1 well-explained factor/context, **THEN Proficient**					16		
	IF 2 or more well-explained factors/examples, **THEN Expert**						20	
14	***Kindly provide a list of post occupancy health issues that must be addressed in energy retrofits.***	**0.6**	**10**	**20**	**30**	**40**	**50**	
	IF none, **THEN Novice**		6					

Table D.15 (Cont'd)

	IF correctly mentions 1 but cannot explain, **THEN Advanced Beginner**			12				
	IF 1 well-explained post-occupancy H&S issue, **THEN Competent**				18			**18**
	IF 2 well-explained post-occupancy H&S issues, **THEN Proficient**					24		
	IF 2 or more well-explained post-occupancy H&S issues/e.gs., **THEN Expert**						30	
15	***Buildings behave as a system where interactions between components can affect their energy performance. What are the interrelationships among the following measures?***	**0.6**	**10**	**20**	**30**	**40**	**50**	
	If no relationship, **THEN Novice**		6					
	IF relationship/cannot explain, **THEN Advanced Beginner**			12				
	IF explains relationship between 2, **THEN Competent**				18			
	IF explains relationship between 2 with example, **THEN Proficient**					24		
	IF explains relationship among 3 or more/contextualizes, **THEN Expert**						30	**30**
16	***What measures do you consider safe and can be installed by a homeowner? Kindly give reasons for your answer.***	**0.6**	**10**	**20**	**30**	**40**	**50**	
	IF none, **THEN Novice**		6					
	IF mentions 1 measure, **THEN Advanced Beginner**			12				
	IF mentions 1 measure/provides reasons, **THEN Competent**				18			
	IF mentions 2 measures/provides reasons, **THEN Proficient**					24		**24**
	IF mentions 3 measures/provides reasons, **THEN Expert**						30	
17	***What measures do you think must be installed by a licensed retrofit professional? Kindly give reasons.***	**0.6**	**10**	**20**	**30**	**40**	**50**	
	IF none, **THEN Novice**		6					
	IF mentions 1 measure, **THEN Advanced Beginner**			12				
	IF mentions 1 measure/provides reasons, **THEN Competent**				18			
	IF mentions 2 measures/provides reasons, **THEN Proficient**					24		
	IF mentions 3 measures/provides reasons, **THEN Expert**						30	**30**
			72	**140**	**216**	**288**	**360**	**263**

APPENDIX D.16

Table D.16: Detailed EREIS Scores for Participant 16

UPPER PROFICIENT

	RESPONDENT #16		**Expertise ID**					
Number	**ATTRIBUTE-BASED QUESTIONS**	**RIS**	**Novice**	**Advanced Beginner**	**Competent**	**Proficient**	**Expert**	**Selected Option**
1	***How long have you been working in energy efficiency retrofits for existing homes?***	**0.4**	**10**	**20**	**30**	**40**	**50**	
	IF up to a year, **THEN Novice**		4					
	IF more than 1 year but up to 2 years, **THEN Advanced Beginner**			8				
	IF more than 2 years but up to 3 years, **THEN Competent**				12			
	IF more than 3 years but up to 4 years, **THEN Proficient**					16		
	IF more than 4 years, **THEN Expert**						20	**20**
2	***How many retrofits on average, do you complete each year?***	**0.4**	**10**	**20**	**30**	**40**	**50**	
	IF performs between 1 and 6 audits each year, **THEN Novice**		4					
	IF performs between 7 and 12 audits each year, **THEN Advanced Beginner**			8				
	IF performs between 13 and 18 audits each year, **THEN Competent**				12			
	IF performs between 19 and 24 audits each year, **THEN Proficient**					16		
	IF more than 24 audits each year, **THEN Expert**						20	**20**

Table D.16 (Cont'd)

3	***Have you been away from the industry before? If yes, for how long were you away and did you require retraining?***	**0.3**	**10**	**20**	**30**	**40**	**50**	
	IF more than 3 years, **THEN Novice**		3					
	IF more than 2 years up to 3 years, **THEN Advanced Beginner**			6				
	IF more than 1 year up to 2 years, **THEN Competent**				9			**9**
	IF up to 1 year, **THEN Proficient**					12		
	IF never been away (0 years), **THEN Expert**						15	
4	***How often do you update your knowledge in your work by referring to colleagues, books, manuals, internet, etc. to reinforce information you give to homeowners?***	**0.3**	**10**	**20**	**30**	**40**	**50**	
	IF knowledge is NOT updated, **THEN Novice**		3					
	IF knowledge is updated rarely, **THEN Advanced Beginner**			6				
	IF knowledge is updated sometimes, **THEN Competent**				9			
	IF knowledge is updated regularly, **THEN Proficient**					12		**12**
	IF knowledge is updated always, **THEN Expert**						15	
5	***Are you aware of the tax incentives, rebates, and benefits available to homeowners when they undertake an energy retrofit? If yes, how do you get this information?***	**0.3**	**10**	**20**	**30**	**40**	**50**	
	IF no, **THEN Novice**		3					
	IF yes/chance upon information, **THEN Advanced Beginner**			6				**6**
	IF yes/obtains from 1 source, **THEN Competent**				9			
	If yes/obtains from 2 sources excluding trade organizations, **THEN Proficient**					12		
	IF yes/obtains from 3 or more sources including trade organization							
	and/or government, **THEN Expert**						15	
6	***When a homeowner asks you to justify or explain your decision or actions, how do you go about it?***	**0.4**	**10**	**20**	**30**	**40**	**50**	
	IF make impression and/or company identity builds trust, **THEN Novice**		4					
	IF anyone apart from case based reasoning, **THEN Advanced Beginner**			8				
	IF case based reasoning **THEN Competent**				12			

Table D.16 (Cont'd)

	If any 2 including CBR, **THEN Proficient**					16		**16**
	IF any 3 including CBR - CBR, SSO, RAE, FGS, and/or RWSR, THEN **Expert**						20	
7	***Several measures have been suggested for improving the energy efficiency of existing homes. For e.g. replacing incandescent light bulbs with CFLs. Kindly list others.***	**0.1**	**10**	**20**	**30**	**40**	**50**	
	IF mentions only energy saving measures, **THEN Novice**		1					
	IF mentions measures, **THEN Advanced Beginner**			2				
	IF mentions 3 measures, **THEN Competent**				3			
	IF explains 3 measures/examples, **THEN Proficient**					4		
	IF explains more than 3 measures/examples, **THEN Expert**						5	**5**
8	***How would you explain in a step by step manner, the methods you will use to make recommend retrofit measures for a home that you have no means of testing?***	**0.6**	**10**	**20**	**30**	**40**	**50**	
	IF mentions/explains 1 sign, **THEN Novice**		6					
	IF mentions/explains 2 signs, **THEN Advanced Beginner**			12				
	IF mentions/explains 3 signs, **THEN Competent**				18			
	IF mentions/explains 4 signs, **THEN Proficient**					24		**24**
	IF mentions/explains 5 or more signs, **THEN Expert**						30	
9	***Different homes have different retrofit needs. What aspects of the home will determine the need? E.g. is it the construction type, archetype type, age of the home etc.?***	**0.6**	**10**	**20**	**30**	**40**	**50**	
	IF does not see link among aspects, **THEN Novice**		6					
	IF links 2 aspects, **THEN Advanced Beginner**			12				**12**
	IF links 2 aspects and gives example, **THEN Competent**				18			
	IF links 3 aspects/identify 1 retrofit need, **THEN Proficient**					24		
	IF links 3 aspects/identify 1 retrofit need/e.g., **THEN Expert**						30	
10	***How would you explain to a homeowner in a step by step manner what "Energy Auditing" means?***	**0.5**	**10**	**20**	**30**	**40**	**50**	
	IF unable to explain, **THEN Novice**		5					

Table D.16 (cont'd)

	IF only explains tools used, **THEN Advanced Beginner**			10				
	IF explains/mention 1 of 3 objectives, **THEN Competent**				15			
	IF explains/mention 2 of 3 objectives, **THEN Proficient**					20		**20**
	IF explains/mentions 3 of 3 objectives, **THEN Expert**						25	
11	***What specific benefits can be obtained when you perform energy retrofit of a home?***	**0.2**	**10**	**20**	**30**	**40**	**50**	
	IF cannot mention 1 benefit, **THEN Novice**		2					
	IF mentions 1 benefit, **THEN Advanced Beginner**			4				
	IF mentions 2 benefits, **THEN Competent**				6			
	IF mentions 3 benefits, **THEN Proficient**					8		**8**
	IF mentions 3 benefits, **THEN Expert**						10	
12	***What are some of the measures that provide the greatest return on investment for a home owner and why?***	**0.3**	**10**	**20**	**30**	**40**	**50**	
	IF cannot mention, **THEN Novice**		3					
	IF correctly mentions 1 measure, **THEN Advanced Beginner**			6				
	IF correctly mentions 2 measures, **THEN Competent**				9			**9**
	IF correctly mentions 2 measures, **THEN Proficient**					12		
	IF correctly mentions 2 or more measures/contextualizes, **THEN Expert**						15	
13	***What are some external factors which increase the cost of the retrofit operation?***	**0.4**	**10**	**20**	**30**	**40**	**50**	
	IF none, **THEN Novice**		4					
	IF correctly mentions 1 but cannot explain, **THEN Advanced Beginner**			4				
	IF 1 well-explained factor, **THEN Competent**				12			
	IF 1 well-explained factor/context, **THEN Proficient**					16		
	IF 2 or more well-explained factors/examples, **THEN Expert**						20	**20**
14	***Kindly provide a list of post occupancy health issues that must be addressed in energy retrofits.***	**0.6**	**10**	**20**	**30**	**40**	**50**	
	IF none, **THEN Novice**		6					

Table D.16 (Cont'd)

	IF correctly mentions 1 but cannot explain, **THEN Advanced Beginner**			12				
	IF 1 well-explained post-occupancy H&S issue, **THEN Competent**				18			
	IF 2 well-explained post-occupancy H&S issues, **THEN Proficient**					24		**24**
	IF 2 or more well-explained post-occupancy H&S issues/e.gs., **THEN Expert**						30	
15	***Buildings behave as a system where interactions between components can affect their energy performance. What are the interrelationships among the following measures?***	**0.6**	**10**	**20**	**30**	**40**	**50**	
	If no relationship, **THEN Novice**		6					
	IF relationship/cannot explain, **THEN Advanced Beginner**			12				
	IF explains relationship between 2, **THEN Competent**				18			
	IF explains relationship between 2 with example, **THEN Proficient**					24		
	IF explains relationship among 3 or more/contextualizes, **THEN Expert**						30	**30**
16	***What measures do you consider safe and can be installed by a homeowner? Kindly give reasons for your answer.***	**0.6**	**10**	**20**	**30**	**40**	**50**	
	IF none, **THEN Novice**		6					
	IF mentions 1 measure, **THEN Advanced Beginner**			12				
	IF mentions 1 measure/provides reasons, **THEN Competent**				18			
	IF mentions 2 measures/provides reasons, **THEN Proficient**					24		
	IF mentions 3 measures/provides reasons, **THEN Expert**						30	**30**
17	***What measures do you think must be installed by a licensed retrofit professional? Kindly give reasons.***	**0.6**	**10**	**20**	**30**	**40**	**50**	
	IF none, **THEN Novice**		6					
	IF mentions 1 measure, **THEN Advanced Beginner**			12				
	IF mentions 1 measure/provides reasons, **THEN Competent**				18			
	IF mentions 2 measures/provides reasons, **THEN Proficient**					24		
	IF mentions 3 measures/provides reasons, **THEN Expert**						30	**30**
			72	**140**	**216**	**288**	**360**	**295**

APPENDIX D.17

Table D.17: Detailed EREIS Scores for Participant 17

	EXPERT								
	RESPONDENT #17		**Expertise ID**						
Number	**ATTRIBUTE-BASED QUESTIONS**	**RIS**	**Novice**	**Advanced Beginner**	**Competent**	**Proficient**	**Expert**	**Selected Option**
1	***How long have you been working in energy efficiency retrofits for existing homes?***	**0.4**	**10**	**20**	**30**	**40**	**50**	
	IF up to a year, **THEN Novice**		4					
	IF more than 1 year but up to 2 years, **THEN Advanced Beginner**			8				
	IF more than 2 years but up to 3 years, **THEN Competent**				12			**12**
	IF more than 3 years but up to 4 years, **THEN Proficient**					16		
	IF more than 4 years, **THEN Expert**						20	
2	***How many retrofits on average, do you complete each year?***	**0.4**	**10**	**20**	**30**	**40**	**50**	
	IF performs between 1 and 6 audits each year, **THEN Novice**		4					
	IF performs between 7 and 12 audits each year, **THEN Advanced Beginner**			8				
	IF performs between 13 and 18 audits each year, **THEN Competent**				12			
	IF performs between 19 and 24 audits each year, **THEN Proficient**					16		
	IF more than 24 audits each year, **THEN Expert**						20	**20**

Table D.17 (Cont'd)

3	***Have you been away from the industry before? If yes, for how long were you away and did you require retraining?***	**0.3**	**10**	**20**	**30**	**40**	**50**	
	IF more than 3 years, **THEN Novice**		3					
	IF more than 2 years up to 3 years, **THEN Advanced Beginner**			6				
	IF more than 1 year up to 2 years, **THEN Competent**				9			
	IF up to 1 year, **THEN Proficient**					12		
	IF never been away (0 years), **THEN Expert**						15	**15**
4	***How often do you update your knowledge in your work by referring to colleagues, books, manuals, internet, etc. to reinforce information you give to homeowners?***	**0.3**	**10**	**20**	**30**	**40**	**50**	
	IF knowledge is NOT updated, **THEN Novice**		3					
	IF knowledge is updated rarely, **THEN Advanced Beginner**			6				
	IF knowledge is updated sometimes, **THEN Competent**				9			
	IF knowledge is updated regularly, **THEN Proficient**					12		
	IF knowledge is updated always, **THEN Expert**						15	**15**
5	***Are you aware of the tax incentives, rebates, and benefits available to homeowners when they undertake an energy retrofit? If yes, how do you get this information?***	**0.3**	**10**	**20**	**30**	**40**	**50**	
	IF no, **THEN Novice**		3					
	IF yes/chance upon information, **THEN Advanced Beginner**			6				
	IF yes/obtains from 1 source, **THEN Competent**				9			
	If yes/obtains from 2 sources excluding trade organizations, **THEN Proficient**					12		
	IF yes/obtains from 3 or more sources including trade organization							
	and/or government, **THEN Expert**						15	**15**
6	***When a homeowner asks you to justify or explain your decision or actions, how do you go about it?***	**0.4**	**10**	**20**	**30**	**40**	**50**	
	IF make impression and/or company identity builds trust, **THEN Novice**		4					
	IF anyone apart from case based reasoning, **THEN Advanced Beginner**			8				
	IF case based reasoning **THEN Competent**				12			

Table D.17 (Cont'd)

	If any 2 including CBR, **THEN Proficient**					16		
	IF any 3 including CBR - CBR, SSO, RAE, FGS, and/or RWSR, THEN **Expert**						20	**20**
7	***Several measures have been suggested for improving the energy efficiency of existing homes. For e.g. replacing incandescent light bulbs with CFLs. Kindly list others.***	**0.1**	**10**	**20**	**30**	**40**	**50**	
	IF mentions only energy saving measures, **THEN Novice**		1					
	IF mentions measures, **THEN Advanced Beginner**			2				
	IF mentions 3 measures, **THEN Competent**				3			
	IF explains 3 measures/examples, **THEN Proficient**					4		
	IF explains more than 3 measures/examples, **THEN Expert**						5	**5**
8	***How would you explain in a step by step manner, the methods you will use to make recommend retrofit measures for a home that you have no means of testing?***	**0.6**	**10**	**20**	**30**	**40**	**50**	
	IF mentions/explains 1 sign, **THEN Novice**		6					
	IF mentions/explains 2 signs, **THEN Advanced Beginner**			12				
	IF mentions/explains 3 signs, **THEN Competent**				18			
	IF mentions/explains 4 signs, **THEN Proficient**					24		
	IF mentions/explains 5 or more signs, **THEN Expert**						30	**30**
9	***Different homes have different retrofit needs. What aspects of the home will determine the need? E.g. is it the construction type, archetype type, age of the home etc.?***	**0.6**	**10**	**20**	**30**	**40**	**50**	
	IF does not see link among aspects, **THEN Novice**		6					
	IF links 2 aspects, **THEN Advanced Beginner**			12				
	IF links 2 aspects and gives example, **THEN Competent**				18			**18**
	IF links 3 aspects/identify 1 retrofit need, **THEN Proficient**					24		
	IF links 3 aspects/identify 1 retrofit need/e.g., **THEN Expert**						30	
10	***How would you explain to a homeowner in a step by step manner what "Energy Auditing" means?***	**0.5**	**10**	**20**	**30**	**40**	**50**	
	IF unable to explain, **THEN Novice**		5					

Table D.17 (cont'd)

	IF only explains tools used, **THEN Advanced Beginner**			10				
	IF explains/mention 1 of 3 objectives, **THEN Competent**				15			
	IF explains/mention 2 of 3 objectives, **THEN Proficient**					20		**20**
	IF explains/mentions 3 of 3 objectives, **THEN Expert**						25	
11	***What specific benefits can be obtained when you perform energy retrofit of a home?***	**0.2**	**10**	**20**	**30**	**40**	**50**	
	IF cannot mention 1 benefit, **THEN Novice**		2					
	IF mentions 1 benefit, **THEN Advanced Beginner**			4				
	IF mentions 2 benefits, **THEN Competent**				6			
	IF mentions 3 benefits, **THEN Proficient**					8		
	IF mentions 3 benefits, **THEN Expert**						10	**10**
12	***What are some of the measures that provide the greatest return on investment for a home owner and why?***	**0.3**	**10**	**20**	**30**	**40**	**50**	
	IF cannot mention, **THEN Novice**		3					
	IF correctly mentions 1 measure, **THEN Advanced Beginner**			6				
	IF correctly mentions 2 measures, **THEN Competent**				9			
	IF correctly mentions 2 measures, **THEN Proficient**					12		
	IF correctly mentions 2 or more measures/contextualizes, **THEN Expert**						15	**15**
13	***What are some external factors which increase the cost of the retrofit operation?***	**0.4**	**10**	**20**	**30**	**40**	**50**	
	IF none, **THEN Novice**		4					
	IF correctly mentions 1 but cannot explain, **THEN Advanced Beginner**			4				
	IF 1 well-explained factor, **THEN Competent**				12			
	IF 1 well-explained factor/context, **THEN Proficient**					16		
	IF 2 or more well-explained factors/examples, **THEN Expert**						20	**20**
14	***Kindly provide a list of post occupancy health issues that must be addressed in energy retrofits.***	**0.6**	**10**	**20**	**30**	**40**	**50**	
	IF none, **THEN Novice**		6					

Table D.17 (Cont'd)

	IF correctly mentions 1 but cannot explain, **THEN Advanced Beginner**			12				
	IF 1 well-explained post-occupancy H&S issue, **THEN Competent**				18			
	IF 2 well-explained post-occupancy H&S issues, **THEN Proficient**					24		**24**
	IF 2 or more well-explained post-occupancy H&S issues/e.gs., **THEN Expert**						30	
15	***Buildings behave as a system where interactions between components can affect their energy performance. What are the interrelationships among the following measures?***	**0.6**	**10**	**20**	**30**	**40**	**50**	
	If no relationship, **THEN Novice**		6					
	IF relationship/cannot explain, **THEN Advanced Beginner**			12				
	IF explains relationship between 2, **THEN Competent**				18			
	IF explains relationship between 2 with example, **THEN Proficient**					24		
	IF explains relationship among 3 or more/contextualizes, **THEN Expert**						30	**30**
16	***What measures do you consider safe and can be installed by a homeowner? Kindly give reasons for your answer.***	**0.6**	**10**	**20**	**30**	**40**	**50**	
	IF none, **THEN Novice**		6					
	IF mentions 1 measure, **THEN Advanced Beginner**			12				
	IF mentions 1 measure/provides reasons, **THEN Competent**				18			
	IF mentions 2 measures/provides reasons, **THEN Proficient**					24		
	IF mentions 3 measures/provides reasons, **THEN Expert**						30	**30**
17	***What measures do you think must be installed by a licensed retrofit professional? Kindly give reasons.***	**0.6**	**10**	**20**	**30**	**40**	**50**	
	IF none, **THEN Novice**		6					
	IF mentions 1 measure, **THEN Advanced Beginner**			12				
	IF mentions 1 measure/provides reasons, **THEN Competent**				18			
	IF mentions 2 measures/provides reasons, **THEN Proficient**					24		**24**
	IF mentions 3 measures/provides reasons, **THEN Expert**						30	
			72	**140**	**216**	**288**	**360**	**323**

APPENDIX D.18

Table D.18: Detailed EREIS Scores for Participant 18

EXPERT

RESPONDENT #18

Number	ATTRIBUTE-BASED QUESTIONS	RIS	Expertise ID: Novice	Advanced Beginner	Competent	Proficient	Expert	Selected Option
1	***How long have you been working in energy efficiency retrofits for existing homes?***	**0.4**	**10**	**20**	**30**	**40**	**50**	
	IF up to a year, **THEN Novice**		4					
	IF more than 1 year but up to 2 years, **THEN Advanced Beginner**			8				
	IF more than 2 years but up to 3 years, **THEN Competent**				12			**12**
	IF more than 3 years but up to 4 years, **THEN Proficient**					16		
	IF more than 4 years, **THEN Expert**						20	
2	***How many retrofits on average, do you complete each year?***	**0.4**	**10**	**20**	**30**	**40**	**50**	
	IF performs between 1 and 6 audits each year, **THEN Novice**		4					
	IF performs between 7 and 12 audits each year, **THEN Advanced Beginner**			8				
	IF performs between 13 and 18 audits each year, **THEN Competent**				12			
	IF performs between 19 and 24 audits each year, **THEN Proficient**					16		
	IF more than 24 audits each year, **THEN Expert**						20	**20**

Table D.18 (Cont'd)

3	***Have you been away from the industry before? If yes, for how long were you away and did you require retraining?***	**0.3**	**10**	**20**	**30**	**40**	**50**	
	IF more than 3 years, **THEN Novice**		3					
	IF more than 2 years up to 3 years, **THEN Advanced Beginner**			6				
	IF more than 1 year up to 2 years, **THEN Competent**				9			
	IF up to 1 year, **THEN Proficient**					12		
	IF never been away (0 years), **THEN Expert**						15	**15**
4	***How often do you update your knowledge in your work by referring to colleagues, books, manuals, internet, etc. to reinforce information you give to homeowners?***	**0.3**	**10**	**20**	**30**	**40**	**50**	
	IF knowledge is NOT updated, **THEN Novice**		3					
	IF knowledge is updated rarely, **THEN Advanced Beginner**			6				
	IF knowledge is updated sometimes, **THEN Competent**				9			
	IF knowledge is updated regularly, **THEN Proficient**					12		**12**
	IF knowledge is updated always, **THEN Expert**						15	
5	***Are you aware of the tax incentives, rebates, and benefits available to homeowners when they undertake an energy retrofit? If yes, how do you get this information?***	**0.3**	**10**	**20**	**30**	**40**	**50**	
	IF no, **THEN Novice**		3					
	IF yes/chance upon information, **THEN Advanced Beginner**			6				
	IF yes/obtains from 1 source, **THEN Competent**				9			**9**
	If yes/obtains from 2 sources excluding trade organizations, **THEN Proficient**					12		
	IF yes/obtains from 3 or more sources including trade organization							
	and/or government, **THEN Expert**						15	
6	***When a homeowner asks you to justify or explain your decision or actions, how do you go about it?***	**0.4**	**10**	**20**	**30**	**40**	**50**	
	IF make impression and/or company identity builds trust, **THEN Novice**		4					
	IF anyone apart from case based reasoning, **THEN Advanced Beginner**			8				
	IF case based reasoning **THEN Competent**				12			

Table D.18 (Cont'd)

	If any 2 including CBR, **THEN Proficient**					16		
	IF any 3 including CBR - CBR, SSO, RAE, FGS, and/or RWSR, THEN **Expert**						20	**20**
7	***Several measures have been suggested for improving the energy efficiency of existing homes. For e.g. replacing incandescent light bulbs with CFLs. Kindly list others.***	**0.1**	**10**	**20**	**30**	**40**	**50**	
	IF mentions only energy saving measures, **THEN Novice**		1					
	IF mentions measures, **THEN Advanced Beginner**			2				
	IF mentions 3 measures, **THEN Competent**				3			
	IF explains 3 measures/examples, **THEN Proficient**					4		
	IF explains more than 3 measures/examples, **THEN Expert**						5	**5**
8	***How would you explain in a step by step manner, the methods you will use to make recommend retrofit measures for a home that you have no means of testing?***	**0.6**	**10**	**20**	**30**	**40**	**50**	
	IF mentions/explains 1 sign, **THEN Novice**		6					
	IF mentions/explains 2 signs, **THEN Advanced Beginner**			12				
	IF mentions/explains 3 signs, **THEN Competent**				18			
	IF mentions/explains 4 signs, **THEN Proficient**					24		
	IF mentions/explains 5 or more signs, **THEN Expert**						30	**30**
9	***Different homes have different retrofit needs. What aspects of the home will determine the need? E.g. is it the construction type, archetype type, age of the home etc.?***	**0.6**	**10**	**20**	**30**	**40**	**50**	
	IF does not see link among aspects, **THEN Novice**		6					
	IF links 2 aspects, **THEN Advanced Beginner**			12				
	IF links 2 aspects and gives example, **THEN Competent**				18			**18**
	IF links 3 aspects/identify 1 retrofit need, **THEN Proficient**					24		
	IF links 3 aspects/identify 1 retrofit need/e.g., **THEN Expert**						30	
10	***How would you explain to a homeowner in a step by step manner what "Energy Auditing" means?***	**0.5**	**10**	**20**	**30**	**40**	**50**	
	IF unable to explain, **THEN Novice**		5					

Table D.18 (cont'd)

	IF only explains tools used, **THEN Advanced Beginner**			10				
	IF explains/mention 1 of 3 objectives, **THEN Competent**				15			
	IF explains/mention 2 of 3 objectives, **THEN Proficient**					20		**20**
	IF explains/mentions 3 of 3 objectives, **THEN Expert**						25	
11	***What specific benefits can be obtained when you perform energy retrofit of a home?***	**0.2**	**10**	**20**	**30**	**40**	**50**	
	IF cannot mention 1 benefit, **THEN Novice**		2					
	IF mentions 1 benefit, **THEN Advanced Beginner**			4				
	IF mentions 2 benefits, **THEN Competent**				6			
	IF mentions 3 benefits, **THEN Proficient**					8		
	IF mentions 3 benefits, **THEN Expert**						10	**10**
12	***What are some of the measures that provide the greatest return on investment for a home owner and why?***	**0.3**	**10**	**20**	**30**	**40**	**50**	
	IF cannot mention, **THEN Novice**		3					
	IF correctly mentions 1 measure, **THEN Advanced Beginner**			6				
	IF correctly mentions 2 measures, **THEN Competent**				9			
	IF correctly mentions 2 measures, **THEN Proficient**					12		**12**
	IF correctly mentions 2 or more measures/contextualizes, **THEN Expert**						15	
13	***What are some external factors which increase the cost of the retrofit operation?***	**0.4**	**10**	**20**	**30**	**40**	**50**	
	IF none, **THEN Novice**		4					
	IF correctly mentions 1 but cannot explain, **THEN Advanced Beginner**			4				
	IF 1 well-explained factor, **THEN Competent**				12			
	IF 1 well-explained factor/context, **THEN Proficient**					16		**16**
	IF 2 or more well-explained factors/examples, **THEN Expert**						20	
14	***Kindly provide a list of post occupancy health issues that must be addressed in energy retrofits.***	**0.6**	**10**	**20**	**30**	**40**	**50**	
	IF none, **THEN Novice**		6					

Table D.18 (Cont'd)

	IF correctly mentions 1 but cannot explain, **THEN Advanced Beginner**			12				
	IF 1 well-explained post-occupancy H&S issue, **THEN Competent**				18			
	IF 2 well-explained post-occupancy H&S issues, **THEN Proficient**					24		
	IF 2 or more well-explained post-occupancy H&S issues/e.gs., **THEN Expert**						30	**30**
15	***Buildings behave as a system where interactions between components can affect their energy performance. What are the interrelationships among the following measures?***	**0.6**	**10**	**20**	**30**	**40**	**50**	
	If no relationship, **THEN Novice**		6					
	IF relationship/cannot explain, **THEN Advanced Beginner**			12				
	IF explains relationship between 2, **THEN Competent**				18			
	IF explains relationship between 2 with example, **THEN Proficient**					24		
	IF explains relationship among 3 or more/contextualizes, **THEN Expert**						30	**30**
16	***What measures do you consider safe and can be installed by a homeowner? Kindly give reasons for your answer.***	**0.6**	**10**	**20**	**30**	**40**	**50**	
	IF none, **THEN Novice**		6					
	IF mentions 1 measure, **THEN Advanced Beginner**			12				
	IF mentions 1 measure/provides reasons, **THEN Competent**				18			
	IF mentions 2 measures/provides reasons, **THEN Proficient**					24		
	IF mentions 3 measures/provides reasons, **THEN Expert**						30	**30**
17	***What measures do you think must be installed by a licensed retrofit professional? Kindly give reasons.***	**0.6**	**10**	**20**	**30**	**40**	**50**	
	IF none, **THEN Novice**		6					
	IF mentions 1 measure, **THEN Advanced Beginner**			12				
	IF mentions 1 measure/provides reasons, **THEN Competent**				18			
	IF mentions 2 measures/provides reasons, **THEN Proficient**					24		
	IF mentions 3 measures/provides reasons, **THEN Expert**						30	**30**
			72	**140**	**216**	**288**	**360**	**319**

APPENDIX D.19

Table D.19: Detailed EREIS Scores for Participant 19

	EXPERT								
	RESPONDENT #19		Expertise ID						
Number	ATTRIBUTE-BASED QUESTIONS	RIS	Novice	Advanced Beginner	Competent	Proficient	Expert	Selected Option
1	***How long have you been working in energy efficiency retrofits for existing homes?***	**0.4**	**10**	**20**	**30**	**40**	**50**	
	IF up to a year, **THEN Novice**		4					
	IF more than 1 year but up to 2 years, **THEN Advanced Beginner**			8				
	IF more than 2 years but up to 3 years, **THEN Competent**				12			
	IF more than 3 years but up to 4 years, **THEN Proficient**					16		
	IF more than 4 years, **THEN Expert**						20	**20**
2	***How many retrofits on average, do you complete each year?***	**0.4**	**10**	**20**	**30**	**40**	**50**	
	IF performs between 1 and 6 audits each year, **THEN Novice**		4					
	IF performs between 7 and 12 audits each year, **THEN Advanced Beginner**			8				
	IF performs between 13 and 18 audits each year, **THEN Competent**				12			**12**
	IF performs between 19 and 24 audits each year, **THEN Proficient**					16		
	IF more than 24 audits each year, **THEN Expert**						20	

Table D.19 (Cont'd)

3	***Have you been away from the industry before? If yes, for how long were you away and did you require retraining?***	**0.3**	**10**	**20**	**30**	**40**	**50**	
	IF more than 3 years, **THEN Novice**		3					
	IF more than 2 years up to 3 years, **THEN Advanced Beginner**			6				
	IF more than 1 year up to 2 years, **THEN Competent**				9			
	IF up to 1 year, **THEN Proficient**					12		
	IF never been away (0 years), **THEN Expert**						15	**15**
4	***How often do you update your knowledge in your work by referring to colleagues, books, manuals, internet, etc. to reinforce information you give to homeowners?***	**0.3**	**10**	**20**	**30**	**40**	**50**	
	IF knowledge is NOT updated, **THEN Novice**		3					
	IF knowledge is updated rarely, **THEN Advanced Beginner**			6				
	IF knowledge is updated sometimes, **THEN Competent**				9			
	IF knowledge is updated regularly, **THEN Proficient**					12		
	IF knowledge is updated always, **THEN Expert**						15	**15**
5	***Are you aware of the tax incentives, rebates, and benefits available to homeowners when they undertake an energy retrofit? If yes, how do you get this information?***	**0.3**	**10**	**20**	**30**	**40**	**50**	
	IF no, **THEN Novice**		3					
	IF yes/chance upon information, **THEN Advanced Beginner**			6				
	IF yes/obtains from 1 source, **THEN Competent**				9			
	If yes/obtains from 2 sources excluding trade organizations, **THEN Proficient**					12		
	IF yes/obtains from 3 or more sources including trade organization							
	and/or government, **THEN Expert**						15	**15**
6	***When a homeowner asks you to justify or explain your decision or actions, how do you go about it?***	**0.4**	**10**	**20**	**30**	**40**	**50**	
	IF make impression and/or company identity builds trust, **THEN Novice**		4					
	IF anyone apart from case based reasoning, **THEN Advanced Beginner**			8				
	IF case based reasoning **THEN Competent**				12			

Table D.19 (Cont'd)

	If any 2 including CBR, **THEN Proficient**					16		**16**
	IF any 3 including CBR - CBR, SSO, RAE, FGS, and/or RWSR, THEN **Expert**						20	
7	***Several measures have been suggested for improving the energy efficiency of existing homes. For e.g. replacing incandescent light bulbs with CFLs. Kindly list others.***	**0.1**	**10**	**20**	**30**	**40**	**50**	
	IF mentions only energy saving measures, **THEN Novice**		1					
	IF mentions measures, **THEN Advanced Beginner**			2				
	IF mentions 3 measures, **THEN Competent**				3			
	IF explains 3 measures/examples, **THEN Proficient**					4		
	IF explains more than 3 measures/examples, **THEN Expert**						5	**5**
8	***How would you explain in a step by step manner, the methods you will use to make recommend retrofit measures for a home that you have no means of testing?***	**0.6**	**10**	**20**	**30**	**40**	**50**	
	IF mentions/explains 1 sign, **THEN Novice**		6					
	IF mentions/explains 2 signs, **THEN Advanced Beginner**			12				
	IF mentions/explains 3 signs, **THEN Competent**				18			
	IF mentions/explains 4 signs, **THEN Proficient**					24		
	IF mentions/explains 5 or more signs, **THEN Expert**						30	**30**
9	***Different homes have different retrofit needs. What aspects of the home will determine the need? E.g. is it the construction type, archetype type, age of the home etc.?***	**0.6**	**10**	**20**	**30**	**40**	**50**	
	IF does not see link among aspects, **THEN Novice**		6					
	IF links 2 aspects, **THEN Advanced Beginner**			12				
	IF links 2 aspects and gives example, **THEN Competent**				18			
	IF links 3 aspects/identify 1 retrofit need, **THEN Proficient**					24		**24**
	IF links 3 aspects/identify 1 retrofit need/e.g., **THEN Expert**						30	
10	***How would you explain to a homeowner in a step by step manner what "Energy Auditing" means?***	**0.5**	**10**	**20**	**30**	**40**	**50**	
	IF unable to explain, **THEN Novice**		5					

Table D.19 (cont'd)

	IF only explains tools used, **THEN Advanced Beginner**			10				
	IF explains/mention 1 of 3 objectives, **THEN Competent**				15			
	IF explains/mention 2 of 3 objectives, **THEN Proficient**					20		**20**
	IF explains/mentions 3 of 3 objectives, **THEN Expert**						25	
11	***What specific benefits can be obtained when you perform energy retrofit of a home?***	**0.2**	**10**	**20**	**30**	**40**	**50**	
	IF cannot mention 1 benefit, **THEN Novice**		2					
	IF mentions 1 benefit, **THEN Advanced Beginner**			4				
	IF mentions 2 benefits, **THEN Competent**				6			
	IF mentions 3 benefits, **THEN Proficient**					8		**8**
	IF mentions 3 benefits, **THEN Expert**						10	
12	***What are some of the measures that provide the greatest return on investment for a home owner and why?***	**0.3**	**10**	**20**	**30**	**40**	**50**	
	IF cannot mention, **THEN Novice**		3					
	IF correctly mentions 1 measure, **THEN Advanced Beginner**			6				
	IF correctly mentions 2 measures, **THEN Competent**				9			
	IF correctly mentions 2 measures, **THEN Proficient**					12		
	IF correctly mentions 2 or more measures/contextualizes, **THEN Expert**						15	**15**
13	***What are some external factors which increase the cost of the retrofit operation?***	**0.4**	**10**	**20**	**30**	**40**	**50**	
	IF none, **THEN Novice**		4					
	IF correctly mentions 1 but cannot explain, **THEN Advanced Beginner**			4				
	IF 1 well-explained factor, **THEN Competent**				12			
	IF 1 well-explained factor/context, **THEN Proficient**					16		
	IF 2 or more well-explained factors/examples, **THEN Expert**						20	**20**
14	***Kindly provide a list of post occupancy health issues that must be addressed in energy retrofits.***	**0.6**	**10**	**20**	**30**	**40**	**50**	
	IF none, **THEN Novice**		6					

Table D.19 (Cont'd)

	IF correctly mentions 1 but cannot explain, **THEN Advanced Beginner**			12				
	IF 1 well-explained post-occupancy H&S issue, **THEN Competent**				18			
	IF 2 well-explained post-occupancy H&S issues, **THEN Proficient**					24		
	IF 2 or more well-explained post-occupancy H&S issues/e.gs., **THEN Expert**						30	**30**
15	***Buildings behave as a system where interactions between components can affect their energy performance. What are the interrelationships among the following measures?***	**0.6**	**10**	**20**	**30**	**40**	**50**	
	If no relationship, **THEN Novice**		6					
	IF relationship/cannot explain, **THEN Advanced Beginner**			12				
	IF explains relationship between 2, **THEN Competent**				18			
	IF explains relationship between 2 with example, **THEN Proficient**					24		
	IF explains relationship among 3 or more/contextualizes, **THEN Expert**						30	**30**
16	***What measures do you consider safe and can be installed by a homeowner? Kindly give reasons for your answer.***	**0.6**	**10**	**20**	**30**	**40**	**50**	
	IF none, **THEN Novice**		6					
	IF mentions 1 measure, **THEN Advanced Beginner**			12				
	IF mentions 1 measure/provides reasons, **THEN Competent**				18			
	IF mentions 2 measures/provides reasons, **THEN Proficient**					24		
	IF mentions 3 measures/provides reasons, **THEN Expert**						30	**30**
17	***What measures do you think must be installed by a licensed retrofit professional? Kindly give reasons.***	**0.6**	**10**	**20**	**30**	**40**	**50**	
	IF none, **THEN Novice**		6					
	IF mentions 1 measure, **THEN Advanced Beginner**			12				
	IF mentions 1 measure/provides reasons, **THEN Competent**				18			
	IF mentions 2 measures/provides reasons, **THEN Proficient**					24		
	IF mentions 3 measures/provides reasons, **THEN Expert**						30	**30**
			72	**140**	**216**	**288**	**360**	**335**

APPENDIX D.20

Table D.20: Detailed EREIS Scores for Participant 20

	EXPERT								
	RESPONDENT #20		**Expertise ID**						
Number	**ATTRIBUTE-BASED QUESTIONS**	**RIS**	**Novice**	**Advanced Beginner**	**Competent**	**Proficient**	**Expert**	**Selected Option**
1	***How long have you been working in energy efficiency retrofits for existing homes?***	**0.4**	**10**	**20**	**30**	**40**	**50**	
	IF up to a year, **THEN Novice**		4					
	IF more than 1 year but up to 2 years, **THEN Advanced Beginner**			8				
	IF more than 2 years but up to 3 years, **THEN Competent**				12			
	IF more than 3 years but up to 4 years, **THEN Proficient**					16		
	IF more than 4 years, **THEN Expert**						20	**20**
2	***How many retrofits on average, do you complete each year?***	**0.4**	**10**	**20**	**30**	**40**	**50**	
	IF performs between 1 and 6 audits each year, **THEN Novice**		4					
	IF performs between 7 and 12 audits each year, **THEN Advanced Beginner**			8				
	IF performs between 13 and 18 audits each year, **THEN Competent**				12			**12**
	IF performs between 19 and 24 audits each year, **THEN Proficient**					16		
	IF more than 24 audits each year, **THEN Expert**						20	

Table D.20 (Cont'd)

3	***Have you been away from the industry before? If yes, for how long were you away and did you require retraining?***	**0.3**	**10**	**20**	**30**	**40**	**50**	
	IF more than 3 years, **THEN Novice**		3					
	IF more than 2 years up to 3 years, **THEN Advanced Beginner**			6				
	IF more than 1 year up to 2 years, **THEN Competent**				9			
	IF up to 1 year, **THEN Proficient**					12		
	IF never been away (0 years), **THEN Expert**						15	**15**
4	***How often do you update your knowledge in your work by referring to colleagues, books, manuals, internet, etc. to reinforce information you give to homeowners?***	**0.3**	**10**	**20**	**30**	**40**	**50**	
	IF knowledge is NOT updated, **THEN Novice**		3					
	IF knowledge is updated rarely, **THEN Advanced Beginner**			6				
	IF knowledge is updated sometimes, **THEN Competent**				9			
	IF knowledge is updated regularly, **THEN Proficient**					12		
	IF knowledge is updated always, **THEN Expert**						15	**15**
5	***Are you aware of the tax incentives, rebates, and benefits available to homeowners when they undertake an energy retrofit? If yes, how do you get this information?***	**0.3**	**10**	**20**	**30**	**40**	**50**	
	IF no, **THEN Novice**		3					
	IF yes/chance upon information, **THEN Advanced Beginner**			6				
	IF yes/obtains from 1 source, **THEN Competent**				9			
	If yes/obtains from 2 sources excluding trade organizations, **THEN Proficient**					12		
	IF yes/obtains from 3 or more sources including trade organization							
	and/or government, **THEN Expert**						15	**15**
6	***When a homeowner asks you to justify or explain your decision or actions, how do you go about it?***	**0.4**	**10**	**20**	**30**	**40**	**50**	
	IF make impression and/or company identity builds trust, **THEN Novice**		4					
	IF anyone apart from case based reasoning, **THEN Advanced Beginner**			8				
	IF case based reasoning **THEN Competent**				12			

Table D.20 (Cont'd)

	If any 2 including CBR, **THEN Proficient**					16		**16**
	IF any 3 including CBR - CBR, SSO, RAE, FGS, and/or RWSR, THEN **Expert**						20	
7	***Several measures have been suggested for improving the energy efficiency of existing homes. For e.g. replacing incandescent light bulbs with CFLs. Kindly list others.***	**0.1**	**10**	**20**	**30**	**40**	**50**	
	IF mentions only energy saving measures, **THEN Novice**		1					
	IF mentions measures, **THEN Advanced Beginner**			2				
	IF mentions 3 measures, **THEN Competent**				3			
	IF explains 3 measures/examples, **THEN Proficient**					4		
	IF explains more than 3 measures/examples, **THEN Expert**						5	**5**
8	***How would you explain in a step by step manner, the methods you will use to make recommend retrofit measures for a home that you have no means of testing?***	**0.6**	**10**	**20**	**30**	**40**	**50**	
	IF mentions/explains 1 sign, **THEN Novice**		6					
	IF mentions/explains 2 signs, **THEN Advanced Beginner**			12				
	IF mentions/explains 3 signs, **THEN Competent**				18			
	IF mentions/explains 4 signs, **THEN Proficient**					24		
	IF mentions/explains 5 or more signs, **THEN Expert**						30	**30**
9	***Different homes have different retrofit needs. What aspects of the home will determine the need? E.g. is it the construction type, archetype type, age of the home etc.?***	**0.6**	**10**	**20**	**30**	**40**	**50**	
	IF does not see link among aspects, **THEN Novice**		6					
	IF links 2 aspects, **THEN Advanced Beginner**			12				
	IF links 2 aspects and gives example, **THEN Competent**				18			
	IF links 3 aspects/identify 1 retrofit need, **THEN Proficient**					24		
	IF links 3 aspects/identify 1 retrofit need/e.g., **THEN Expert**						30	**30**
10	***How would you explain to a homeowner in a step by step manner what "Energy Auditing" means?***	**0.5**	**10**	**20**	**30**	**40**	**50**	
	IF unable to explain, **THEN Novice**		5					

Table D.20 (cont'd)

	IF only explains tools used, **THEN Advanced Beginner**			10				
	IF explains/mention 1 of 3 objectives, **THEN Competent**				15			
	IF explains/mention 2 of 3 objectives, **THEN Proficient**					20		**20**
	IF explains/mentions 3 of 3 objectives, **THEN Expert**						25	
11	***What specific benefits can be obtained when you perform energy retrofit of a home?***	**0.2**	**10**	**20**	**30**	**40**	**50**	
	IF cannot mention 1 benefit, **THEN Novice**		2					
	IF mentions 1 benefit, **THEN Advanced Beginner**			4				
	IF mentions 2 benefits, **THEN Competent**				6			**6**
	IF mentions 3 benefits, **THEN Proficient**					8		
	IF mentions 3 benefits, **THEN Expert**						10	
12	***What are some of the measures that provide the greatest return on investment for a home owner and why?***	**0.3**	**10**	**20**	**30**	**40**	**50**	
	IF cannot mention, **THEN Novice**		3					
	IF correctly mentions 1 measure, **THEN Advanced Beginner**			6				
	IF correctly mentions 2 measures, **THEN Competent**				9			
	IF correctly mentions 2 measures, **THEN Proficient**					12		
	IF correctly mentions 2 or more measures/contextualizes, **THEN Expert**						15	**15**
13	***What are some external factors which increase the cost of the retrofit operation?***	**0.4**	**10**	**20**	**30**	**40**	**50**	
	IF none, **THEN Novice**		4					
	IF correctly mentions 1 but cannot explain, **THEN Advanced Beginner**			4				
	IF 1 well-explained factor, **THEN Competent**				12			
	IF 1 well-explained factor/context, **THEN Proficient**					16		
	IF 2 or more well-explained factors/examples, **THEN Expert**						20	**20**
14	***Kindly provide a list of post occupancy health issues that must be addressed in energy retrofits.***	**0.6**	**10**	**20**	**30**	**40**	**50**	
	IF none, **THEN Novice**		6					

Table D.20 (Cont'd)

	IF correctly mentions 1 but cannot explain, **THEN Advanced Beginner**			12				
	IF 1 well-explained post-occupancy H&S issue, **THEN Competent**				18			
	IF 2 well-explained post-occupancy H&S issues, **THEN Proficient**					24		**24**
	IF 2 or more well-explained post-occupancy H&S issues/e.gs., **THEN Expert**						30	
15	***Buildings behave as a system where interactions between components can affect their energy performance. What are the interrelationships among the following measures?***	**0.6**	**10**	**20**	**30**	**40**	**50**	
	If no relationship, **THEN Novice**		6					
	IF relationship/cannot explain, **THEN Advanced Beginner**			12				
	IF explains relationship between 2, **THEN Competent**				18			
	IF explains relationship between 2 with example, **THEN Proficient**					24		
	IF explains relationship among 3 or more/contextualizes, **THEN Expert**						30	**30**
16	***What measures do you consider safe and can be installed by a homeowner? Kindly give reasons for your answer.***	**0.6**	**10**	**20**	**30**	**40**	**50**	
	IF none, **THEN Novice**		6					
	IF mentions 1 measure, **THEN Advanced Beginner**			12				
	IF mentions 1 measure/provides reasons, **THEN Competent**				18			
	IF mentions 2 measures/provides reasons, **THEN Proficient**					24		**24**
	IF mentions 3 measures/provides reasons, **THEN Expert**						30	
17	***What measures do you think must be installed by a licensed retrofit professional? Kindly give reasons.***	**0.6**	**10**	**20**	**30**	**40**	**50**	
	IF none, **THEN Novice**		6					
	IF mentions 1 measure, **THEN Advanced Beginner**			12				
	IF mentions 1 measure/provides reasons, **THEN Competent**				18			
	IF mentions 2 measures/provides reasons, **THEN Proficient**					24		**24**
	IF mentions 3 measures/provides reasons, **THEN Expert**						30	
			72	**140**	**216**	**288**	**360**	**321**

APPENDIX D.21

Table D.21: Detailed EREIS Scores for Participant 21

UPPER PROFICIENT

RESPONDENT #21

Number	ATTRIBUTE-BASED QUESTIONS	RIS	Expertise ID: Novice	Advanced Beginner	Competent	Proficient	Expert	Selected Option
1	***How long have you been working in energy efficiency retrofits for existing homes?***	**0.4**	**10**	**20**	**30**	**40**	**50**	
	IF up to a year, **THEN Novice**		4					
	IF more than 1 year but up to 2 years, **THEN Advanced Beginner**			8				
	IF more than 2 years but up to 3 years, **THEN Competent**				12			
	IF more than 3 years but up to 4 years, **THEN Proficient**					16		
	IF more than 4 years, **THEN Expert**						20	**20**
2	***How many retrofits on average, do you complete each year?***	**0.4**	**10**	**20**	**30**	**40**	**50**	
	IF performs between 1 and 6 audits each year, **THEN Novice**		4					
	IF performs between 7 and 12 audits each year, **THEN Advanced Beginner**			8				
	IF performs between 13 and 18 audits each year, **THEN Competent**				12			**12**
	IF performs between 19 and 24 audits each year, **THEN Proficient**					16		
	IF more than 24 audits each year, **THEN Expert**						20	

Table D.21 (Cont'd)

3	***Have you been away from the industry before? If yes, for how long were you away and did you require retraining?***	**0.3**	**10**	**20**	**30**	**40**	**50**	
	IF more than 3 years, **THEN Novice**		3					
	IF more than 2 years up to 3 years, **THEN Advanced Beginner**			6				
	IF more than 1 year up to 2 years, **THEN Competent**				9			
	IF up to 1 year, **THEN Proficient**					12		
	IF never been away (0 years), **THEN Expert**						15	**15**
4	***How often do you update your knowledge in your work by referring to colleagues, books, manuals, internet, etc. to reinforce information you give to homeowners?***	**0.3**	**10**	**20**	**30**	**40**	**50**	
	IF knowledge is NOT updated, **THEN Novice**		3					
	IF knowledge is updated rarely, **THEN Advanced Beginner**			6				
	IF knowledge is updated sometimes, **THEN Competent**				9			
	IF knowledge is updated regularly, **THEN Proficient**					12		
	IF knowledge is updated always, **THEN Expert**						15	**15**
5	***Are you aware of the tax incentives, rebates, and benefits available to homeowners when they undertake an energy retrofit? If yes, how do you get this information?***	**0.3**	**10**	**20**	**30**	**40**	**50**	
	IF no, **THEN Novice**		3					
	IF yes/chance upon information, **THEN Advanced Beginner**			6				
	IF yes/obtains from 1 source, **THEN Competent**				9			**9**
	If yes/obtains from 2 sources excluding trade organizations, **THEN Proficient**					12		
	IF yes/obtains from 3 or more sources including trade organization							
	and/or government, **THEN Expert**						15	
6	***When a homeowner asks you to justify or explain your decision or actions, how do you go about it?***	**0.4**	**10**	**20**	**30**	**40**	**50**	
	IF make impression and/or company identity builds trust, **THEN Novice**		4					
	IF anyone apart from case based reasoning, **THEN Advanced Beginner**			8				
	IF case based reasoning **THEN Competent**				12			

Table D.21 (Cont'd)

	If any 2 including CBR, **THEN Proficient**					16		**16**
	IF any 3 including CBR - CBR, SSO, RAE, FGS, and/or RWSR, THEN **Expert**						20	
7	***Several measures have been suggested for improving the energy efficiency of existing homes. For e.g. replacing incandescent light bulbs with CFLs. Kindly list others.***	**0.1**	**10**	**20**	**30**	**40**	**50**	
	IF mentions only energy saving measures, **THEN Novice**		1					
	IF mentions measures, **THEN Advanced Beginner**			2				
	IF mentions 3 measures, **THEN Competent**				3			
	IF explains 3 measures/examples, **THEN Proficient**					4		
	IF explains more than 3 measures/examples, **THEN Expert**						5	**5**
8	***How would you explain in a step by step manner, the methods you will use to make recommend retrofit measures for a home that you have no means of testing?***	**0.6**	**10**	**20**	**30**	**40**	**50**	
	IF mentions/explains 1 sign, **THEN Novice**		6					
	IF mentions/explains 2 signs, **THEN Advanced Beginner**			12				
	IF mentions/explains 3 signs, **THEN Competent**				18			
	IF mentions/explains 4 signs, **THEN Proficient**					24		
	IF mentions/explains 5 or more signs, **THEN Expert**						30	**30**
9	***Different homes have different retrofit needs. What aspects of the home will determine the need? E.g. is it the construction type, archetype type, age of the home etc.?***	**0.6**	**10**	**20**	**30**	**40**	**50**	
	IF does not see link among aspects, **THEN Novice**		6					
	IF links 2 aspects, **THEN Advanced Beginner**			12				
	IF links 2 aspects and gives example, **THEN Competent**				18			
	IF links 3 aspects/identify 1 retrofit need, **THEN Proficient**					24		
	IF links 3 aspects/identify 1 retrofit need/e.g., **THEN Expert**						30	**30**
10	***How would you explain to a homeowner in a step by step manner what "Energy Auditing" means?***	**0.5**	**10**	**20**	**30**	**40**	**50**	
	IF unable to explain, **THEN Novice**		5					

Table D.21 (cont'd)

	IF only explains tools used, **THEN Advanced Beginner**			10				
	IF explains/mention 1 of 3 objectives, **THEN Competent**				15			
	IF explains/mention 2 of 3 objectives, **THEN Proficient**					20		
	IF explains/mentions 3 of 3 objectives, **THEN Expert**						25	**25**
11	***What specific benefits can be obtained when you perform energy retrofit of a home?***	**0.2**	**10**	**20**	**30**	**40**	**50**	
	IF cannot mention 1 benefit, **THEN Novice**		2					
	IF mentions 1 benefit, **THEN Advanced Beginner**			4				
	IF mentions 2 benefits, **THEN Competent**				6			
	IF mentions 3 benefits, **THEN Proficient**					8		
	IF mentions 3 benefits, **THEN Expert**						10	**10**
12	***What are some of the measures that provide the greatest return on investment for a home owner and why?***	**0.3**	**10**	**20**	**30**	**40**	**50**	
	IF cannot mention, **THEN Novice**		3					
	IF correctly mentions 1 measure, **THEN Advanced Beginner**			6				
	IF correctly mentions 2 measures, **THEN Competent**				9			**9**
	IF correctly mentions 2 measures, **THEN Proficient**					12		
	IF correctly mentions 2 or more measures/contextualizes, **THEN Expert**						15	
13	***What are some external factors which increase the cost of the retrofit operation?***	**0.4**	**10**	**20**	**30**	**40**	**50**	
	IF none, **THEN Novice**		4					
	IF correctly mentions 1 but cannot explain, **THEN Advanced Beginner**			4				
	IF 1 well-explained factor, **THEN Competent**				12			
	IF 1 well-explained factor/context, **THEN Proficient**					16		**16**
	IF 2 or more well-explained factors/examples, **THEN Expert**						20	
14	***Kindly provide a list of post occupancy health issues that must be addressed in energy retrofits.***	**0.6**	**10**	**20**	**30**	**40**	**50**	
	IF none, **THEN Novice**		6					

Table D.21 (Cont'd)

	IF correctly mentions 1 but cannot explain, **THEN Advanced Beginner**			12				
	IF 1 well-explained post-occupancy H&S issue, **THEN Competent**				18			**18**
	IF 2 well-explained post-occupancy H&S issues, **THEN Proficient**					24		
	IF 2 or more well-explained post-occupancy H&S issues/e.gs., **THEN Expert**						30	
15	***Buildings behave as a system where interactions between components can affect their energy performance. What are the interrelationships among the following measures?***	**0.6**	**10**	**20**	**30**	**40**	**50**	
	If no relationship, **THEN Novice**		6					
	IF relationship/cannot explain, **THEN Advanced Beginner**			12				
	IF explains relationship between 2, **THEN Competent**				18			
	IF explains relationship between 2 with example, **THEN Proficient**					24		
	IF explains relationship among 3 or more/contextualizes, **THEN Expert**						30	**30**
16	***What measures do you consider safe and can be installed by a homeowner? Kindly give reasons for your answer.***	**0.6**	**10**	**20**	**30**	**40**	**50**	
	IF none, **THEN Novice**		6					
	IF mentions 1 measure, **THEN Advanced Beginner**			12				
	IF mentions 1 measure/provides reasons, **THEN Competent**				18			
	IF mentions 2 measures/provides reasons, **THEN Proficient**					24		**24**
	IF mentions 3 measures/provides reasons, **THEN Expert**						30	
17	***What measures do you think must be installed by a licensed retrofit professional? Kindly give reasons.***	**0.6**	**10**	**20**	**30**	**40**	**50**	
	IF none, **THEN Novice**		6					
	IF mentions 1 measure, **THEN Advanced Beginner**			12				
	IF mentions 1 measure/provides reasons, **THEN Competent**				18			
	IF mentions 2 measures/provides reasons, **THEN Proficient**					24		**24**
	IF mentions 3 measures/provides reasons, **THEN Expert**						30	
			72	**140**	**216**	**288**	**360**	**308**

APPENDIX D.22

Table D.22: Detailed EREIS Scores for Participant 22

	EXPERT							
	RESPONDENT #22		Expertise ID					
Number	**ATTRIBUTE-BASED QUESTIONS**	**RIS**	**Novice**	**Advanced Beginner**	**Competent**	**Proficient**	**Expert**	**Selected Option**
1	***How long have you been working in energy efficiency retrofits for existing homes?***	**0.4**	**10**	**20**	**30**	**40**	**50**	
	IF up to a year, **THEN Novice**		4					
	IF more than 1 year but up to 2 years, **THEN Advanced Beginner**			8				
	IF more than 2 years but up to 3 years, **THEN Competent**				12			
	IF more than 3 years but up to 4 years, **THEN Proficient**					16		
	IF more than 4 years, **THEN Expert**						20	**20**
2	***How many retrofits on average, do you complete each year?***	**0.4**	**10**	**20**	**30**	**40**	**50**	
	IF performs between 1 and 6 audits each year, **THEN Novice**		4					
	IF performs between 7 and 12 audits each year, **THEN Advanced Beginner**			8				
	IF performs between 13 and 18 audits each year, **THEN Competent**				12			
	IF performs between 19 and 24 audits each year, **THEN Proficient**					16		**16**
	IF more than 24 audits each year, **THEN Expert**						20	

Table D.22 (Cont'd)

3	***Have you been away from the industry before? If yes, for how long were you away and did you require retraining?***	**0.3**	**10**	**20**	**30**	**40**	**50**	
	IF more than 3 years, **THEN Novice**		3					
	IF more than 2 years up to 3 years, **THEN Advanced Beginner**			6				
	IF more than 1 year up to 2 years, **THEN Competent**				9			
	IF up to 1 year, **THEN Proficient**					12		**12**
	IF never been away (0 years), **THEN Expert**						15	
4	***How often do you update your knowledge in your work by referring to colleagues, books, manuals, internet, etc. to reinforce information you give to homeowners?***	**0.3**	**10**	**20**	**30**	**40**	**50**	
	IF knowledge is NOT updated, **THEN Novice**		3					
	IF knowledge is updated rarely, **THEN Advanced Beginner**			6				
	IF knowledge is updated sometimes, **THEN Competent**				9			
	IF knowledge is updated regularly, **THEN Proficient**					12		
	IF knowledge is updated always, **THEN Expert**						15	**15**
5	***Are you aware of the tax incentives, rebates, and benefits available to homeowners when they undertake an energy retrofit? If yes, how do you get this information?***	**0.3**	**10**	**20**	**30**	**40**	**50**	
	IF no, **THEN Novice**		3					
	IF yes/chance upon information, **THEN Advanced Beginner**			6				
	IF yes/obtains from 1 source, **THEN Competent**				9			**9**
	If yes/obtains from 2 sources excluding trade organizations, **THEN Proficient**					12		
	IF yes/obtains from 3 or more sources including trade organization							
	and/or government, **THEN Expert**						15	
6	***When a homeowner asks you to justify or explain your decision or actions, how do you go about it?***	**0.4**	**10**	**20**	**30**	**40**	**50**	
	IF make impression and/or company identity builds trust, **THEN Novice**		4					
	IF anyone apart from case based reasoning, **THEN Advanced Beginner**			8				
	IF case based reasoning **THEN Competent**				12			

Table D.22 (Cont'd)

	If any 2 including CBR, **THEN Proficient**					16		**16**
	IF any 3 including CBR - CBR, SSO, RAE, FGS, and/or RWSR, THEN **Expert**						20	
7	***Several measures have been suggested for improving the energy efficiency of existing homes. For e.g. replacing incandescent light bulbs with CFLs. Kindly list others.***	**0.1**	**10**	**20**	**30**	**40**	**50**	
	IF mentions only energy saving measures, **THEN Novice**		1					
	IF mentions measures, **THEN Advanced Beginner**			2				
	IF mentions 3 measures, **THEN Competent**				3			
	IF explains 3 measures/examples, **THEN Proficient**					4		
	IF explains more than 3 measures/examples, **THEN Expert**						5	**5**
8	***How would you explain in a step by step manner, the methods you will use to make recommend retrofit measures for a home that you have no means of testing?***	**0.6**	**10**	**20**	**30**	**40**	**50**	
	IF mentions/explains 1 sign, **THEN Novice**		6					
	IF mentions/explains 2 signs, **THEN Advanced Beginner**			12				
	IF mentions/explains 3 signs, **THEN Competent**				18			
	IF mentions/explains 4 signs, **THEN Proficient**					24		
	IF mentions/explains 5 or more signs, **THEN Expert**						30	**30**
9	***Different homes have different retrofit needs. What aspects of the home will determine the need? E.g. is it the construction type, archetype type, age of the home etc.?***	**0.6**	**10**	**20**	**30**	**40**	**50**	
	IF does not see link among aspects, **THEN Novice**		6					
	IF links 2 aspects, **THEN Advanced Beginner**			12				
	IF links 2 aspects and gives example, **THEN Competent**				18			
	IF links 3 aspects/identify 1 retrofit need, **THEN Proficient**					24		
	IF links 3 aspects/identify 1 retrofit need/e.g., **THEN Expert**						30	**30**
10	***How would you explain to a homeowner in a step by step manner what "Energy Auditing" means?***	**0.5**	**10**	**20**	**30**	**40**	**50**	
	IF unable to explain, **THEN Novice**		5					

Table D.22 (cont'd)

	IF only explains tools used, **THEN Advanced Beginner**			10				
	IF explains/mention 1 of 3 objectives, **THEN Competent**				15			
	IF explains/mention 2 of 3 objectives, **THEN Proficient**					20		
	IF explains/mentions 3 of 3 objectives, **THEN Expert**						25	**25**
11	***What specific benefits can be obtained when you perform energy retrofit of a home?***	**0.2**	**10**	**20**	**30**	**40**	**50**	
	IF cannot mention 1 benefit, **THEN Novice**		2					
	IF mentions 1 benefit, **THEN Advanced Beginner**			4				
	IF mentions 2 benefits, **THEN Competent**				6			
	IF mentions 3 benefits, **THEN Proficient**					8		
	IF mentions 3 benefits, **THEN Expert**						10	**10**
12	***What are some of the measures that provide the greatest return on investment for a home owner and why?***	**0.3**	**10**	**20**	**30**	**40**	**50**	
	IF cannot mention, **THEN Novice**		3					
	IF correctly mentions 1 measure, **THEN Advanced Beginner**			6				
	IF correctly mentions 2 measures, **THEN Competent**				9			
	IF correctly mentions 2 measures, **THEN Proficient**					12		
	IF correctly mentions 2 or more measures/contextualizes, **THEN Expert**						15	**15**
13	***What are some external factors which increase the cost of the retrofit operation?***	**0.4**	**10**	**20**	**30**	**40**	**50**	
	IF none, **THEN Novice**		4					
	IF correctly mentions 1 but cannot explain, **THEN Advanced Beginner**			4				
	IF 1 well-explained factor, **THEN Competent**				12			
	IF 1 well-explained factor/context, **THEN Proficient**					16		
	IF 2 or more well-explained factors/examples, **THEN Expert**						20	**20**
14	***Kindly provide a list of post occupancy health issues that must be addressed in energy retrofits.***	**0.6**	**10**	**20**	**30**	**40**	**50**	
	IF none, **THEN Novice**		6					

Table D.22 (Cont'd)

	IF correctly mentions 1 but cannot explain, **THEN Advanced Beginner**			12				
	IF 1 well-explained post-occupancy H&S issue, **THEN Competent**				18			
	IF 2 well-explained post-occupancy H&S issues, **THEN Proficient**					24		**24**
	IF 2 or more well-explained post-occupancy H&S issues/e.gs., **THEN Expert**						30	
15	***Buildings behave as a system where interactions between components can affect their energy performance. What are the interrelationships among the following measures?***	**0.6**	**10**	**20**	**30**	**40**	**50**	
	If no relationship, **THEN Novice**		6					
	IF relationship/cannot explain, **THEN Advanced Beginner**			12				
	IF explains relationship between 2, **THEN Competent**				18			
	IF explains relationship between 2 with example, **THEN Proficient**					24		**24**
	IF explains relationship among 3 or more/contextualizes, **THEN Expert**						30	
16	***What measures do you consider safe and can be installed by a homeowner? Kindly give reasons for your answer.***	**0.6**	**10**	**20**	**30**	**40**	**50**	
	IF none, **THEN Novice**		6					
	IF mentions 1 measure, **THEN Advanced Beginner**			12				
	IF mentions 1 measure/provides reasons, **THEN Competent**				18			
	IF mentions 2 measures/provides reasons, **THEN Proficient**					24		
	IF mentions 3 measures/provides reasons, **THEN Expert**						30	**30**
17	***What measures do you think must be installed by a licensed retrofit professional? Kindly give reasons.***	**0.6**	**10**	**20**	**30**	**40**	**50**	
	IF none, **THEN Novice**		6					
	IF mentions 1 measure, **THEN Advanced Beginner**			12				
	IF mentions 1 measure/provides reasons, **THEN Competent**				18			
	IF mentions 2 measures/provides reasons, **THEN Proficient**					24		
	IF mentions 3 measures/provides reasons, **THEN Expert**						30	**30**
			72	**140**	**216**	**288**	**360**	**331**

APPENDIX D.23

Table D.23: Detailed EREIS Scores for Participant 23

UPPER PROFICIENT

RESPONDENT #23

Number	ATTRIBUTE-BASED QUESTIONS	RIS	Expertise ID: Novice	Advanced Beginner	Competent	Proficient	Expert	Selected Option
1	***How long have you been working in energy efficiency retrofits for existing homes?***	**0.4**	**10**	**20**	**30**	**40**	**50**	
	IF up to a year, **THEN Novice**		4					
	IF more than 1 year but up to 2 years, **THEN Advanced Beginner**			8				
	IF more than 2 years but up to 3 years, **THEN Competent**				12			
	IF more than 3 years but up to 4 years, **THEN Proficient**					16		
	IF more than 4 years, **THEN Expert**						20	**20**
2	***How many retrofits on average, do you complete each year?***	**0.4**	**10**	**20**	**30**	**40**	**50**	
	IF performs between 1 and 6 audits each year, **THEN Novice**		4					
	IF performs between 7 and 12 audits each year, **THEN Advanced Beginner**			8				
	IF performs between 13 and 18 audits each year, **THEN Competent**				12			
	IF performs between 19 and 24 audits each year, **THEN Proficient**					16		
	IF more than 24 audits each year, **THEN Expert**						20	**20**

Table D.23 (Cont'd)

3	***Have you been away from the industry before? If yes, for how long were you away and did you require retraining?***	**0.3**	**10**	**20**	**30**	**40**	**50**	
	IF more than 3 years, **THEN Novice**		3					
	IF more than 2 years up to 3 years, **THEN Advanced Beginner**			6				
	IF more than 1 year up to 2 years, **THEN Competent**				9			
	IF up to 1 year, **THEN Proficient**					12		
	IF never been away (0 years), **THEN Expert**						15	**15**
4	***How often do you update your knowledge in your work by referring to colleagues, books, manuals, internet, etc. to reinforce information you give to homeowners?***	**0.3**	**10**	**20**	**30**	**40**	**50**	
	IF knowledge is NOT updated, **THEN Novice**		3					
	IF knowledge is updated rarely, **THEN Advanced Beginner**			6				
	IF knowledge is updated sometimes, **THEN Competent**				9			
	IF knowledge is updated regularly, **THEN Proficient**					12		**12**
	IF knowledge is updated always, **THEN Expert**						15	
5	***Are you aware of the tax incentives, rebates, and benefits available to homeowners when they undertake an energy retrofit? If yes, how do you get this information?***	**0.3**	**10**	**20**	**30**	**40**	**50**	
	IF no, **THEN Novice**		3					
	IF yes/chance upon information, **THEN Advanced Beginner**			6				
	IF yes/obtains from 1 source, **THEN Competent**				9			
	If yes/obtains from 2 sources excluding trade organizations, **THEN Proficient**					12		**12**
	IF yes/obtains from 3 or more sources including trade organization							
	and/or government, **THEN Expert**						15	
6	***When a homeowner asks you to justify or explain your decision or actions, how do you go about it?***	**0.4**	**10**	**20**	**30**	**40**	**50**	
	IF make impression and/or company identity builds trust, **THEN Novice**		4					
	IF anyone apart from case based reasoning, **THEN Advanced Beginner**			8				
	IF case based reasoning **THEN Competent**				12			**12**

Table D.23 (Cont'd)

	If any 2 including CBR, **THEN Proficient**					16		
	IF any 3 including CBR - CBR, SSO, RAE, FGS, and/or RWSR, THEN **Expert**						20	
7	***Several measures have been suggested for improving the energy efficiency of existing homes. For e.g. replacing incandescent light bulbs with CFLs. Kindly list others.***	**0.1**	**10**	**20**	**30**	**40**	**50**	
	IF mentions only energy saving measures, **THEN Novice**		1					
	IF mentions measures, **THEN Advanced Beginner**			2				
	IF mentions 3 measures, **THEN Competent**				3			
	IF explains 3 measures/examples, **THEN Proficient**					4		
	IF explains more than 3 measures/examples, **THEN Expert**						5	**5**
8	***How would you explain in a step by step manner, the methods you will use to make recommend retrofit measures for a home that you have no means of testing?***	**0.6**	**10**	**20**	**30**	**40**	**50**	
	IF mentions/explains 1 sign, **THEN Novice**		6					
	IF mentions/explains 2 signs, **THEN Advanced Beginner**			12				
	IF mentions/explains 3 signs, **THEN Competent**				18			
	IF mentions/explains 4 signs, **THEN Proficient**					24		
	IF mentions/explains 5 or more signs, **THEN Expert**						30	**30**
9	***Different homes have different retrofit needs. What aspects of the home will determine the need? E.g. is it the construction type, archetype type, age of the home etc.?***	**0.6**	**10**	**20**	**30**	**40**	**50**	
	IF does not see link among aspects, **THEN Novice**		6					
	IF links 2 aspects, **THEN Advanced Beginner**			12				
	IF links 2 aspects and gives example, **THEN Competent**				18			
	IF links 3 aspects/identify 1 retrofit need, **THEN Proficient**					24		**24**
	IF links 3 aspects/identify 1 retrofit need/e.g., **THEN Expert**						30	
10	***How would you explain to a homeowner in a step by step manner what "Energy Auditing" means?***	**0.5**	**10**	**20**	**30**	**40**	**50**	
	IF unable to explain, **THEN Novice**		5					

Table D.23 (cont'd)

	IF only explains tools used, **THEN Advanced Beginner**			10				
	IF explains/mention 1 of 3 objectives, **THEN Competent**				15			**15**
	IF explains/mention 2 of 3 objectives, **THEN Proficient**					20		
	IF explains/mentions 3 of 3 objectives, **THEN Expert**						25	
11	***What specific benefits can be obtained when you perform energy retrofit of a home?***	**0.2**	**10**	**20**	**30**	**40**	**50**	
	IF cannot mention 1 benefit, **THEN Novice**		2					
	IF mentions 1 benefit, **THEN Advanced Beginner**			4				
	IF mentions 2 benefits, **THEN Competent**				6			
	IF mentions 3 benefits, **THEN Proficient**					8		
	IF mentions 3 benefits, **THEN Expert**						10	**10**
12	***What are some of the measures that provide the greatest return on investment for a home owner and why?***	**0.3**	**10**	**20**	**30**	**40**	**50**	
	IF cannot mention, **THEN Novice**		3					
	IF correctly mentions 1 measure, **THEN Advanced Beginner**			6				**6**
	IF correctly mentions 2 measures, **THEN Competent**				9			
	IF correctly mentions 2 measures, **THEN Proficient**					12		
	IF correctly mentions 2 or more measures/contextualizes, **THEN Expert**						15	
13	***What are some external factors which increase the cost of the retrofit operation?***	**0.4**	**10**	**20**	**30**	**40**	**50**	
	IF none, **THEN Novice**		4					
	IF correctly mentions 1 but cannot explain, **THEN Advanced Beginner**			4				
	IF 1 well-explained factor, **THEN Competent**				12			
	IF 1 well-explained factor/context, **THEN Proficient**					16		
	IF 2 or more well-explained factors/examples, **THEN Expert**						20	**20**
14	***Kindly provide a list of post occupancy health issues that must be addressed in energy retrofits.***	**0.6**	**10**	**20**	**30**	**40**	**50**	
	IF none, **THEN Novice**		6					

Table D.23 (Cont'd)

	IF correctly mentions 1 but cannot explain, **THEN Advanced Beginner**			12				
	IF 1 well-explained post-occupancy H&S issue, **THEN Competent**				18			
	IF 2 well-explained post-occupancy H&S issues, **THEN Proficient**					24		**24**
	IF 2 or more well-explained post-occupancy H&S issues/e.gs., **THEN Expert**						30	
15	***Buildings behave as a system where interactions between components can affect their energy performance. What are the interrelationships among the following measures?***	**0.6**	**10**	**20**	**30**	**40**	**50**	
	If no relationship, **THEN Novice**		6					
	IF relationship/cannot explain, **THEN Advanced Beginner**			12				
	IF explains relationship between 2, **THEN Competent**				18			
	IF explains relationship between 2 with example, **THEN Proficient**					24		**24**
	IF explains relationship among 3 or more/contextualizes, **THEN Expert**						30	
16	***What measures do you consider safe and can be installed by a homeowner? Kindly give reasons for your answer.***	**0.6**	**10**	**20**	**30**	**40**	**50**	
	IF none, **THEN Novice**		6					
	IF mentions 1 measure, **THEN Advanced Beginner**			12				
	IF mentions 1 measure/provides reasons, **THEN Competent**				18			
	IF mentions 2 measures/provides reasons, **THEN Proficient**					24		
	IF mentions 3 measures/provides reasons, **THEN Expert**						30	**30**
17	***What measures do you think must be installed by a licensed retrofit professional? Kindly give reasons.***	**0.6**	**10**	**20**	**30**	**40**	**50**	
	IF none, **THEN Novice**		6					
	IF mentions 1 measure, **THEN Advanced Beginner**			12				
	IF mentions 1 measure/provides reasons, **THEN Competent**				18			
	IF mentions 2 measures/provides reasons, **THEN Proficient**					24		
	IF mentions 3 measures/provides reasons, **THEN Expert**						30	**30**
			72	**140**	**216**	**288**	**360**	**309**

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