This is to certify that the
thesis entitled

HEALTH PERFORMANCE CRITERIA FRAMEWORK FOR HOMES BASED ON "WHOLE HOUSE" AND "LEED" APPROACHES

presented by

GOPU GOPINATHAN PILLAI

has been accepted towards fulfillment
of the requirements for the

M.S. degree in Construction Management Program

Major Professor's Signature

Dec. 6, 2006

Date

HEALTH PERFORMANCE CRITERIA FRAMEWORK FOR HOMES BASED ON "WHOLE HOUSE" AND "LEED" APPROACHES

By

Gopu Gopinathan Pillai

A THESIS

Submitted to
Michigan State University
in the partial fulfillment of the requirements
for the degree of

MASTER OF SCIENCE

Construction Management Program

2006

ABSTRACT

HEALTH PERFORMANCE CRITERIA FRAMEWORK FOR HOMES BASED ON "WHOLE HOUSE" AND "LEED" APPROACHES

By

Gopu Gopinathan Pillai

Indoor air may be more polluted than outside air. Since Americans often spent most of their time indoors, Indoor Environment Quality (IEQ) has received much attention lately. IEQ problems often result in negative impacts to occupant health. Various physical, chemical and biological processes determine the fate of IEQ. IEQ problems can be attributed to negative interactions between building systems.

"Whole House" approach promotes the idea that the home be viewed as a system composed of different components which work together, so that negative interactions between various building systems can be avoided. External environment is inextricably connected to the indoor environment. The "LEED" green building criteria utilizes the whole system approach, with the intent to minimize environment damage attributable to buildings; while enhancing occupant health, safety and comfort.

Various health effects associated with IEQ in homes were analyzed and a Health Performance Criteria Framework was developed through research, by utilizing the "Whole House" approach and the "LEED" criteria. This framework will help in developing the criteria for an ideal "Whole House" that epitomizes the situation where all involved building systems work synergistically, thereby enhancing the health performance of the home and avoiding any negative interactions.

ACKNOWLEDGEMENTS

I am extremely grateful to Dr. Matt Syal for his continued support and guidance throughout the span of this thesis. I acknowledge that he literally hand molded much of my academic and personal growth during this period of time.

I would like to thank Dr. Joanne Westphal for sharing her expertise in human health. I also wish to acknowledge the support and guidance of Dr. Tariq Abdelhamid.

I would like to acknowledge my family, especially my mother, Geetha Pillai and father, Gopinathan Pillai for their love and support.

I would like to thank Mallik Chaganti, Lori Swarup and Jimish Gandhi for their encouragement and advice when I started working on this thesis. Finally I am grateful to Shilpi Mago and Parth Kembavi for their assistance and support.

TABLE OF CONTENTS

CHAPTER 5
FEEDBACK AND CASE STUDY APPLICATIONS

CHAPTER 6
SUMMARY AND CONCLUSIONS

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1

INTRODUCTION

1.1 Overview

Research funded by National Science Foundation [NSF] and other sponsoring agencies at Michigan State University [MSU] and Purdue University focused on improving the efficiency of housing production process and housing production facility. Emphasis was placed on various aspects of the production process, facility layout and material supply chain, with the overall goal of being able to produce homes, faster at lower costs and with high quality (Senghore 2001, Hammad 2001, Chitla 2002, Barriga 2003, Syal et al 2002, Hammad 2003, Jeong 2003, Barshan 2003, Banerjee 2003, Sabharwal 2004). However, lately the focus is shifting towards the very design of house itself and the interactions of building systems. This logical transition is a part of the national trend known as the "Whole House" approach (PATH 2001, PATH 2003, Swarup 2005).

The "Whole House" approach is rooted on the idea of "systems thinking" in design, construction and maintenance of homes. The involvement of large number of trades in home building causes each building system to be dealt in isolation and discreetly optimized, resulting in negative interactions among them. Systems fail to function efficiently leading to development of deficiencies in the performance of home. In order to solve this problem researchers are focusing on the interactions between various building systems and integration possibilities between them, with the objective of improving the overall performance of homes (O'Brien et al. 2005, Swarup 2005).

The "Whole House" approach views the home as a system composed of different components that must work together. The challenge is to use the synergies among building systems to better the performance of the home. According to the "Whole House roadmap," the "Whole House" approach is based on "Total systems integration, which leads to (1) an understanding of the impact of various systems on other aspects of the house and, (2) use the understanding of the impact of systems interactions, for better future designs with the goal of both avoiding unintended negative interactions and improving performance without increasing cost" (PATH 2003).

Performance attributes and expectations from a home may vary according to individual requirements and broadly refers to the characteristics that the design of a home must achieve to be considered as a "Whole House" (Swarup 2005). Occupant health is an important performance expectation that has received much attention lately. Various studies point to the effects of the design of a home on the health of its occupants (Levin 1989, Fisk et al 2002). Indoor air quality (IAQ) is considered to be a critical part of the residential occupant health performance (DoH, Washington 1999). Though several reasons can be attributed to the decline in indoor air quality, the major cause can be traced back to isolated optimization of building systems to achieve energy efficiency (Bass et al 2003).

During the 1970's, the cost of energy increased by almost ten times due to the energy crisis, triggering research and development initiatives focusing on energy conservation and better envelope design. Most of these initiatives concentrated on saving energy by decreasing ventilation, thereby reducing the amount of outside air that needs to be heated or conditioned. Reduced ventilation together with increasing use of synthetic building materials has led to a rise in concentrations of indoor pollutants and associated health implications (DoH Washington 1999). These factors, combined with less than optimal performance in temperature comfort, humidity control, lighting, acoustics and ergonomics has the potential to seriously undermine the indoor environmental quality (IEQ) of homes. Research has associated indoor environmental quality with occupant health and comfort (Fisk 2005, Wood 2003). The adoption of the "Whole House" approach can assist in the understanding and subsequently, improving the health and environmental performance of homes.

Indoor environmental quality is intrinsically related to the quality of external environment and the impact of buildings on the overall environment needs to be understood in a proper perspective. The concept of 'Green Buildings" promotes the idea of sustainable buildings with limited environmental and human health impacts. The United States Green Building Council (USGBC) has developed the Leadership in Energy and Environmental Design (LEED) green building rating system to rate this category of buildings. The "LEED" criterion has separate provisions for new construction (LEED-NC), homes (LEED-H) and neighborhood development (LEED-ND). Green buildings purportedly have environmental, economic, health and safety benefits associated with both the external and internal environs of a building (USGBC 2005).

Figure 1.1 shows all the topics that are relevant to this research effort – health performance of homes, physical-chemical-biological processes related to Indoor Environment Quality, the Green Building concept and the "Whole House" Approach.

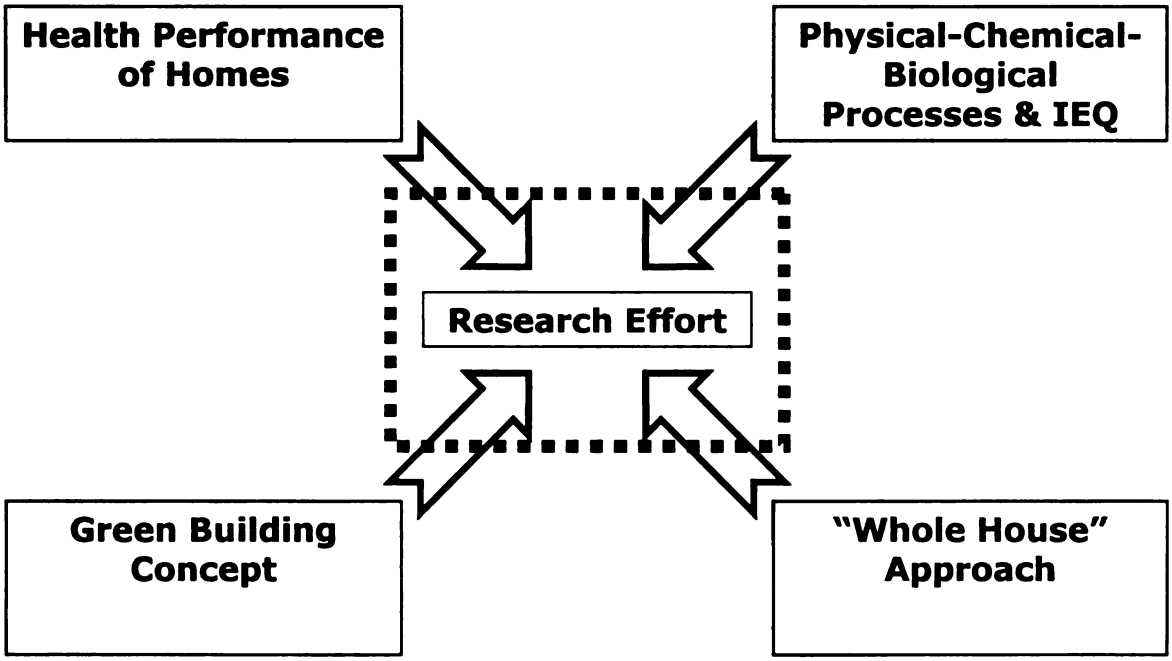

Figure 1.1: Research effort and related topics

1.2 Need statement

Current research is pointing towards the fact that indoor air may be more polluted than outside air (DoH, Washington 1999). This is exacerbated by the fact that Americans often spent most of their time indoors, in the artificial controlled environments of buildings (Klepeis et al. 2001). National Institute for Occupational Safety and Health (NIOSH) investigators have found Indoor Environment Quality (IEQ) problems caused by ventilation system deficiencies, overcrowding, off gassing from materials in the office and mechanical equipment, tobacco smoke, microbiological contamination, and outside air pollutants. NIOSH researchers have also found comfort problems due to improper temperature and relative humidity conditions, poor lighting, and unacceptable noise levels, as well as adverse ergonomic conditions, and job related psychosocial stressors (NIOSH 2005). All these factors can lead to significant health issues. Many of these factors can be attributed to negative interactions between building systems and can be solved through the systems integration approach. Figure 1.2 shows the relationship between design of homes and the health and comfort of occupants.

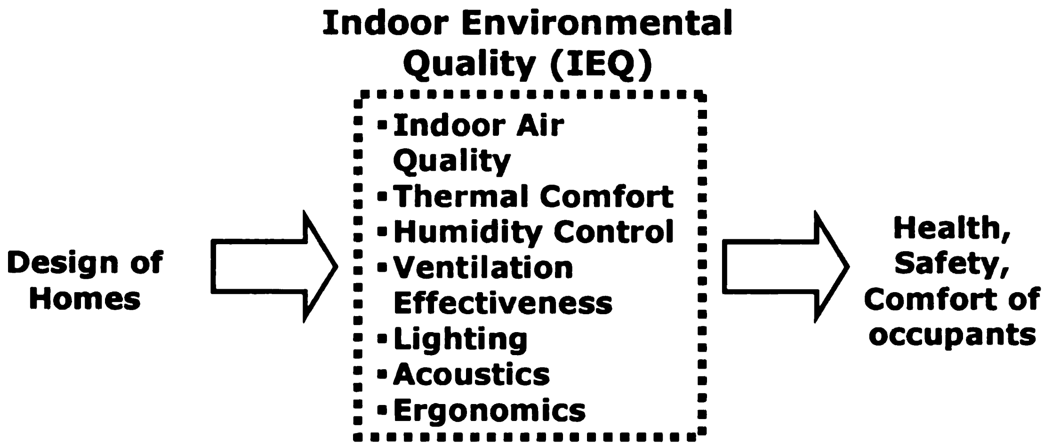

Figure 1.2: Relationship between design of homes and health/comfort of occupants

There is a definite need for research to analyze health effects associated with indoor environmental quality in the framework of physical, chemical and biological processes involved; and find solutions by utilizing the "Whole House" approach and the "LEED" criteria. Various aspects related to indoor environment, driving processes, the green building concept and "Whole House" approach, which have implications for occupant health are covered in the following sections.

1.2.1 Indoor environment and human health

From 1992 through 1994, the U.S. Environmental Protection Agency (EPA) conducted the probability-based National Human Activity Pattern Survey (NHAPS). The results showed that Americans spent, on average, 87% of their time indoors. This was broken down into 69% of the time at home and 18% of the time indoors, but not at home including work, bar, school, shopping, church, restaurant, and various other microenvironments. Also sociological studies suggest that the time Americans spend indoors has remained fairly uniform over the past few decades (Klepeis et al. 2001). The importance of these studies lies in the fact that a majority of our lives are spent in the artificial controlled environments of buildings, particularly homes. So it is imperative that the indoor environment be designed to avoid negative effects on occupant health and to enhance their wellbeing.

In July 1976, a mysterious acute respiratory illness - *Legionnaires disease* - struck 182 delegates to an American Legion convention in Philadelphia. The cause was later found to be a strain of bacteria called *Legionella pneumophila*, found in close proximity of stagnant water zones inside buildings. Highly publicized issues like the *Legionnaires disease* and *Sick Building Syndrome (SBS),* brought health effects associated with buildings, to the attention of research community (LHC 1990). Some other common negative health effects associated with buildings includes: allergy, asthma, chest infections, eye problems, headache, hypersensitivity pneumonitis, humidifier fever, lethargy, nasal problems, nausea, dizziness, respiratory infections, skin problems and throat problems. Some of the chemical contaminants found inside buildings are known carcinogens (e.g., radon).

Indoor environment quality problems can also result in stress and mental fatigue. The acute problems associated with stress include headaches, digestive disorders, fatigue and lethargy, sleeping problems, skin disorders and reduced immunological response. Fluctuations in some components of indoor environment like temperature and humidity can lead to feelings of discomfort (LHC 1990). Most of these impacts on occupant health can be directly attributed to decline in indoor environment quality [IEQ] (Fisk 2005, Fisk 2002, EPA 1994, LHC 1990). IEQ takes into account aspects of Indoor Air Quality (IAQ), indoor temperature, humidity, ventilation, lighting, acoustics and ergonomic design.

Reductions in adverse health effects associated with Indoor Environmental Quality can lead to possible productivity gains and savings in comparatively higher health care costs. The annual cost associated with respiratory infections in the U.S. is approximately $64 billion. It is suggested that building and ventilation characteristics can influence the rates of respiratory disease by a factor of approximately 1.2 to 2. The annual cost associated with allergies and asthma is about $13 billion in United States. This includes both direct medical expenditures and indirect costs, e.g., loss of work. Control measures can be targeted at the homes or offices of susceptible individuals, which can result in a 10% to 30% reduction in symptoms and associated costs. With this estimate, the materialized annual savings would be $1 billion to $4 billion. Responses to Sick Building Syndrome (SBS) have included costly changes in the building or in some cases have lead to costly litigation. It is estimated that the productivity decrease caused by SBS equals 2%. As SBS is primarily associated with office buildings and the annual gross national product of office workers was approximately $2.5trillion in the 1990's, the estimated annual cost of SBS is $50 billion (Fisk & Rosenfeld 1997).

Buildings are complex environments, which can trap and concentrate pollutants as well as generate them. Nearly all materials used in buildings shed particles or give off gases, particularly when new. Outside pollutants also find their way into buildings through air intakes and inadequate filtering systems. Airborne pollutants can be either chemical or biological in nature. When air monitoring for any of these substances is carried out, levels are likely to be below those considered to be 'acceptable' or 'safe'. However, little is known about the health effects of long-term exposure to low levels for many of these chemicals and some people are sensitive to extremely low concentrations of toxic agents. Temperature, humidity and air movement are also main factors influencing comfort and these factors often interact. For example, if the air is very humid, the temperature appears to be warmer than it would be in drier air (LHC 1990). Temperature and humidity conditions also play a critical role in the growth of mold and off gassing from building materials (EPA 2005).

Lighting is significantly associated with indoor environment quality. Glare, flicker, lack of contrast, inadequate illumination or unsuitable spot lighting can all lead to health problems and discomfort. Conventional white fluorescent lighting should be replaced with non-fluorescent lighting and as much daylight as possible since it is likely to cause eyestrain and headaches. Noise is another factor that people find particularly stressful in indoor environments. Noise that is too loud for comfort is intrusive whether it is a single, unexpected sound or a continuous one (LHC 1990). Since health performance of homes is associated with the above mentioned aspects of Indoor Environment Quality, it is imperative that they should be studied in detail.

1.2.2 Physical, chemical and biological processes in the indoor environment

Various physical, chemical and biological processes determine the fate of IAQ, indoor temperature, humidity, ventilation, lighting and acoustical aspects of IEQ in buildings. Physical processes like air flow, air mixing and energy transfer across envelope induce changes in temperature, humidity ventilation effectiveness and airborne level of indoor pollutants. Chemical interactions involving sorption, volatilization and dissolution processes, hydrolysis, photolysis, redox reactions etc. have substantial effect on concentration of chemical pollutants in indoor air (ESP 2005, Arens & Baughman 1996a). Condensation process and microbial growth often decides the fate of biological pollutants. Many of these processes are often interrelated and the effects they cause are a result of combined action. For example, thermal and vapor pressure gradients across envelope can lead to condensation, which often results in microbial growth that produces biological pollutants (Arens & Baughman 1996b). The various interactions between building systems and the physical, chemical and biological processes associated with them should be studied first, in order to better understand the issue of health performance of homes.

1.2.3 Green buildings

Indoor environment quality cannot exist in isolation since it is intrinsically related to the quality of the external environment (LEED 2003). So it is necessary to consider the impact of buildings on the external environment, while planning for a healthy indoor environment. Buildings can play an important role in deciding the fate of the environment by reducing the negative impacts. US construction market represents 20% of the national economy. Buildings represent 39% of U.S. primary energy use and 12.2% of all potable water use. Buildings are major contributors to global warming since about one quarter (¼) of the increase in carbon dioxide in the atmosphere is attributed to the building sector worldwide. It is estimated that buildings use 40% of raw materials globally. Also building construction often results in destruction of natural areas and biodiversity. According to EPA, building related construction and demolition generated 136 million tons of debris in a single year in United States (GBFS 2005).

Residential building industry alone accounts for 20% of all energy consumption in United States (Koeleian et al. 2005). On average, a home built between 1990 and 2001 consumed about 12,800 kWh per year for space and water heating, cooling, and lights and appliances. Total energy expenditures during a year cost these homeowners about $1,600. The mean per capita indoor daily water use in today's homes is slightly over 64 gallons (NAHB 2004). It is evident that the impact of buildings, particularly housing industry, on the environment is substantial. If the growth pattern continues like this, it can result in serious environmental consequences and depletion of finite resources.

The Green building concept addresses these issues and strives to significantly reduce the negative impact of buildings on the environment (LEED 2005). ASTM defines a green building as – "a building that provides the specified building performance requirements while minimizing disturbance to and improving the functioning of local, regional, and global ecosystems both during and after its construction and specified service life" (ASTM 2005). The "LEED" green building criteria utilizes the whole system approach, with the intent to minimize environmental damage attributable to the built environment, while enhancing occupant health, safety and comfort (LEED 2005 a). Study of "LEED" criteria was utilized in the development of health performance criteria framework for homes.

1.2.4 "Whole House" and building systems integration

Due to several reasons including fragmentation of the industry, availability, or lack thereof, of new techniques and a large number of trades involved in the building process, it is difficult to affect change in a complex industry such as home building. Assimilation of new technology is slow and the industry has remained unchanged for a large period of time. Therefore, the inherent inefficiencies, which are inbuilt into the production process, remain. Each building system is dealt with separately such that there are inevitable negative interactions among them. In order to combat this trend, systems integration techniques must be adopted (PATH 2001).

The "Whole House" approach promotes the idea that the home be viewed as a system composed of different components which work together (Swarup 2005). It is the author's opinion that many of the negative health effects associated with indoor environments can be attributed to negative interactions between various building systems. There is a need to explore the potential of the "Whole House" approach in improving the indoor environment quality, with associated occupant health and comfort benefits.

1.2.5 Need for health performance criteria framework for homes

Previous research in the "Whole House" domain concentrated on developing a broad criteria framework and rating system for designing and evaluating the performance of homes based on the building systems integration approach. These researchers have stressed the need for expanding this research domain by including health and IEQ aspects related to housing (Swarup 2005, O'Brien et al. 2005). Due to limited scientific effort within the area of indoor environment quality as it relates to design and construction of buildings and also, due to the fact that research on indoor environment and health involves many scientific disciplines and not often reflected in the literature, there is a deficiency of knowledge in this area as it applies to buildings and housing.

There are a few multidisciplinary studies that are mainly done with an emphasis on one or a few disciplines, and the peer-review process in scientific journals mostly uses expertise from mainly one discipline. Published studies are thus often excellent in one or few disciplines but can have major flaws in other, equally important disciplines (Sundell & Nordling 2003, Bornehag et al 2004). Multidisciplinary studies within the framework of building systems integration and environment responsive design should address these deficiencies. There is a definite need for developing a health performance criteria framework for homes by incorporating the "Whole House" approach, the LEED criteria and the understanding of the physical, chemical and biological processes in the indoor and exterior environment.

1.3 Goal and objectives

Goal: To develop a framework for the design and construction of healthy homes.

The framework is intended as a tool for the development of criteria that will ensure the health performance during the design and construction of homes.

1.3.1 Objectives

1. To define the attributes of a healthy home with focus on IEQ.
2. To explore "Whole House" and "LEED" approaches for health impacts.
3. To develop a health performance criteria framework for homes.

1.4 Methodology

The proposed research was comprised of the following steps. Each research objective indicated above is associated with one or more of the steps as described below.

1.4.1 Objective 1:

Define the attributes of a healthy home with focus on Indoor Environmental Quality (IEQ).

Step 1: Literature review of all four aspects related to the research.

1. "Whole House" and building systems integration.
2. "LEED" green building criteria.
3. Health impacts associated with Indoor Environmental Quality (IEQ).
4. Physical, chemical and biological interactions in buildings, related to occupant health.

Step 2: Identify attributes that define Indoor Environmental Quality (IEQ).

Literature review of health impacts associated with IEQ and associated physical, chemical and biological interactions aided in identifying the attributes that determine the quality of the indoor environment.

1.4.2 Objective 2:

To explore "Whole House" and "LEED" approaches for health impacts.

Step 3: Define all applicable building systems.

All relevant building systems/sub systems were defined through literature review.

Step 4: Review health impacts of "LEED" criteria.

Literature study was conducted to identify the health impacts of LEED criteria related to:

a. LEED for new construction.

b. LEED for homes, with emphasis on indoor environment quality.

Step 5: Develop a framework for associating health impacts related to Indoor Environment Quality (IEQ) with physical, chemical, biological interactions in the indoor environment, and relevant attributes of IEQ.

This framework was developed with an intention to effectively link health effects associated with Indoor Environment Quality with physical, chemical and biological interactions and attributes of IEQ. This step is only relevant for attributes that can be controlled from a design point of view.

Step 6: Establish a model for generating systems integration strategies to improve the health performance of homes.

This model will allow the user to generate or choose strategies involving the integration of various building systems, to improve the health performance of a home. The user can make informed physical decisions regarding the integration when two or more building systems need to be integrated with each other in order to improve performance related to a particular attribute of IEQ.

1.4.3 Objective 3:

Develop a health performance criteria framework for homes.

The format for the framework was based on the one developed for "Whole House" performance (Swarup 2005). The existing format was expanded to incorporate the health performance scoring system.

Step 7: Explore expansion potential of the existing "Whole House" performance criteria framework to include health performance.

This step involved the integration of health performance into the existing "Whole House" performance criteria framework.

Step 8: Frame a scoring system for evaluating health performance.

This scoring system will help to evaluate the capability of each systems integration strategy to maintain an ideal indoor environment. The system integration strategies were scored against the attributes that determine the quality of indoor environment.

Step 9: Case study application of the scoring system for health performance and development of an example criteria.

The scoring system was applied to three case study homes to verify its effectiveness in assessing the health performance. An example criterion was formulated to demonstrate the usage of the framework.

Step 10: Feedback and finalize the health performance criteria framework.

Feedback on the health performance criteria framework was obtained through interviews with researchers and industry professionals involved in healthy and sustainable housing initiatives. Necessary changes were incorporated and the framework was finalized.

1.5 Research scope and uniqueness

The proposed research addressed the issues related to health and environmental performance of homes from the "Whole house" and LEED perspectives. Both performance topics are too extensive, and in order to make this thesis feasible at a Masters Thesis level, the environment performance issue is addressed with focus on the IEQ aspects. The research concentrated on the study of controllable attributes of an indoor environment (e.g., indoor air quality, temperature). The factors that influence indoor environment, but which cannot be controlled from a designer's point of view (e.g., outdoor air quality, occupant behavior), were addressed generally. Design solutions for them were proposed based on the author's knowledge of the topic. The author acknowledges the fact that social and economic factors can influence the indoor environment in a variety of ways, but these were not included in the proposed research.

Literature review has revealed that only a limited number of studies have tried to address the health issues associated with indoor environment from a physical/chemical/biological process perspective as it relates to building design and construction. For example, in order to understand the humidity related health effects; it is beneficial to consider the life cycle of causative organisms in the context of the buildings (e.g., properties of surface materials, mechanical systems and operation schedules and surrounding climate). Further this research is unique in the sense that not many studies have concentrated on solving indoor environment quality issues through the frame work of "building systems integration" during the design and construction of buildings.

1.6 Research outcomes

The outcomes of this research are as follows:

1. Definition of attributes of a healthy indoor environment.
2. Organization of literature related to health effects associated with indoor environment quality (IEQ) and related physical, chemical and biological interactions.
3. Framework for criteria development for health performance of homes based on "LEED" and "Whole House" approaches, with an example rating system.

1.7 Summary

This research focused on the health and comfort effects associated with indoor home environment. Given that the indoor environment cannot exist in isolation from the exterior environment, the research also addressed the issue of environmental performance of buildings. The issue of indoor environment quality was analyzed within a framework of physical, chemical and biological issues involved. This seems the most appropriate approach because the attributes that define the indoor environment are interrelated. Detailed study of these driving processes aided in a better understanding of potential indoor environment issues. The solutions for indoor environment quality issues were discussed from the perspective of "Whole House" approach. This is a creditable approach to adopt, because the root causes of many of the indoor environment issues may be traced back to negative interactions or lack of integration between involved building systems. The results from the research was consolidated and utilized to develop a framework for criteria development for healthy indoor environments.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This research is a continuing academic exploration, in the area of housing set out by the National Science Foundation in the form of research grants awarded over the past 5-6 years. Previous research focused on improving the housing production process, housing production facility design and the criteria framework development for the "Whole House" approach. Here, the attempt is to address the health aspects of housing from building systems integration, and green design and construction perspectives. The following chapters review the body of literature relevant to this area including indoor environmental quality, associated health effects, the "Whole House" approach and green design and construction.

2.2 Results of prior NSF research

Until the National Science Foundation (NSF) intervened, limited research work had been completed in the area of manufactured housing. NSF has funded two projects so far (NSF-CMS 0080209 and NSF-CMS 0229856) at Michigan State University and Purdue University/University of Cincinnati to focus on manufactured housing production, facility layout, and material supply chain process, along with an effort to define "whole house" production (Syal et al 2004). The first research project focused on modeling the manufactured housing production and material flow process and developing simulation models to identify the bottlenecks in this process with further explorations into preliminary aspects of production facility layout. The following theses and reports were produced as a part of this research project and other related research efforts, at Michigan State University and Purdue University/University of Cincinnati.

- Production and Material Flow Process Model for Manufactured Housing Industry (Senghore 2001)
- Simulation Modeling for Manufactured Housing Processes (Abu Hammad 2001)
- Performance Assessment Of Planning Processes During Manufactured Housing Production Operations Using Lean Production Principles (Chitla 2002)
- Facilities Design Process of a Manufactured Housing Production Plant (Mehrotra 2002)
- Manufactured Housing Industry: Material Flow and Management (Barriga 2003)
- Manufactured Housing Trends and Building Codes (Syal et al 2002)

The second research project consisted of two parts. The first part focused on aspects of production facility layout and supply chain management. The following theses and reports were produced for this research effort.

- Decision Support System (DSS) for Manufactured Housing Production Process and Facility Design (Abu Hammad 2003)
- Supply Chain Analysis and Simulation Modeling for the Manufactured Housing Industry (Jeong 2003)
- Methodology for Evaluating and Ranking Manufactured Houses based on Construction Value (Barshan 2003)
- Material Flow based Analysis of Manufactured Housing Production Plant Facility Layout (Banerjee 2003)

- Integration of Production process and Material flow by developing alternative component assemblies in order to produce homes at lower costs within the factory (Sabharwal 2004)

The second part consisted of investigating the home as a designed product and finding ways to improve the design process, so that it can complement the production process. "Whole House" criteria and hybrid house design were explored as a part of this effort. The following theses were produced from this research effort:

- "Whole House" Performance Criteria Framework and its Application (Swarup 2005).
- Alternative Housing Systems: The Hybrid Home (Garcia 2005)

This thesis is also a part of the same research effort.

2.3 Indoor Environment Quality

National Institute for Occupational Safety and Health (NIOSH) investigators have found IEQ problems caused by ventilation system deficiencies, overcrowding, off gassing from materials in the office and mechanical equipment, tobacco smoke, microbiological contamination, and outside air pollutants. NIOSH has also found comfort problems due to improper temperature and relative humidity conditions, poor lighting, and unacceptable noise levels, as well as adverse ergonomic conditions, and job related psychosocial stressors (NIOSH 2005). Based on these findings the parameters for indoor environment quality are categorized into seven topics in this study: Indoor air quality, temperature, humidity, ventilation, lighting, noise and ergonomics.

2.3.1 Indoor Air Quality

The National Health and Medical Research Council defines indoor air as the air within a building occupied for a period of at least one hour by people of varying states of health. Indoor air quality is now considered a significant residential health issue. Current research is pointing towards the fact that indoor air may be more polluted than outside air. Several reasons are attributed to this phenomenon. During the seventies the cost of energy increased by almost ten times due to the energy crisis, triggering research and development initiatives focusing on energy conservation and better envelope design. All these initiatives concentrated on saving energy by decreasing ventilation, thereby reducing the amount of outside air that needs to be heated or conditioned. Reduced ventilation together with increasing use of synthetic building materials has led to a rise in concentrations of indoor pollutants and associated health implications (DoH, Washington 1999). NIOSH has categorized problems associated with poor indoor air quality into (Georgia Tech 1997):

- Inadequate ventilation - 53% of cases
- Inside contaminant source - 15% of cases
- Outside contaminant source - 10% of cases
- Microbial growth - 5% of cases
- Building materials - 4% of cases

2.3.1.1 Indoor air pollutants (DoH, Washington 1999).

Indoor air pollutants can be divided into two broad categories - chemical and biological.

Chemical pollutants

1. Volatile Organic Compounds (VOC), Polycyclic Aromatic Hydrocarbons (PAH)

Concentrations of many VOCs are consistently higher indoors than outdoors. A study by the EPA, covering six communities in various parts of the United States, found indoor levels up to ten times higher than those outdoors — even in locations with significant outdoor air pollution sources, such as petrochemical plants (EPA 1987). Product use (e.g.: chemicals, air fresheners etc.) and occupant activities (e.g.: cooking, smoking) significantly influence the indoor VOC and PAH concentrations and emissions (Van Winkle and Scheff 2001).Temperature influences the emission rate of VOC from indoor materials and products. There are three phases for VOC emissions: the diffusion within the material to the surface, the desorption from the surface and finally the evaporation from the surface. All these processes proportionally increase with the temperature. Additional VOC emissions may result from accelerated chemical reactions due to increase in temperature. Indoor materials may be exposed to higher temperatures than indoor air temperatures due to solar irradiation or floor heating (e.g: carpets, floor tiles) (Van der wal et al. 1997).

1. *Formaldehyde:* Formaldehyde is a colorless, flammable gas with a pungent odor. The major sources of pollution in residences are building materials containing phenol, urea, thiourea or melamine resins. They are found in plywood, glues used in furniture construction, carpets and vinyl attachments. High relative humidity and increased temperatures trigger the degradation of resins containing formaldehyde leading to out-gassing. Negative health effects include irritant effects, sensitization and carcinogenicity and asthmatic conditions (DTIR 1995). NIOSH recommends a 0.1

PPM 15 minute ceiling. Selecting low-VOC products can prevent the problems associated with formaldehyde. Other preventive measures are sealants and fumigation treatments. Nitro-cellulose varnish or water-based polyurethane can be used to coat the materials emitting formaldehyde, thereby sealing the source. The final step should be ventilating with fresh air to dilute the presence of chemical in indoor air (Southface 2002).

2. *Asbestos*

Asbestos containing materials may be present in residences constructed prior to 1977. The most probable locations are old pipe and furnace insulations, vinyl floor tiles, textured paints, roofing materials and home siding. Improper removal and handling of the material aggravates contamination. Asbestos is a known carcinogenic. It can also cause a lung disease called asbestosis. Safe level of exposure for asbestos has not been established. Source removal is the primary control technique to prevent contamination. Damaged areas can also be sealed with heat resistant paints and sealers.

3. *Radon*

Radon gas is a naturally occurring radioactive element found in soils and rocks. It is chemically inert, odorless and colorless. It enters the building through cracks or joints in concrete slabs, sump pits and floor drains. Houses that are built directly on or in the ground have a higher potential for problems. The limit to radon exposure is established as four pico-Curies per liter (4 pCi/l). The primary health effect is the risk of cancer. Sealing radon entry points with appropriate caulking material and covering sumps and drains can reduce contamination. Improved basement or crawlspace ventilation can also significantly reduce the levels of radon. Mitigation systems are available in the market for serious radon problems (Southface 2002).

4. *Carbon monoxide (CO)*

Carbon monoxide is a colorless, odorless gas which is a combustion by-product. The main sources of indoor CO are furnaces, fireplaces, tobacco smoke and automobiles in garages. CO's affinity to bind with hemoglobin, the oxygen-carrying molecule in human blood, is 250 times greater than oxygen. So even low airborne concentrations and long exposure times can result in CO poisoning. The National Ambient Air Quality Standard establishes CO exposure levels at 9 PPM averaged over an eight-hour period, or 35 PPM averaged over one hour. Health effects include headache, dizziness, nausea, unconsciousness, and in severe cases death. Maintaining good ventilation is the primary preventive measure for CO pollution. Active mechanical ventilation for fuel burning appliances can also reduce exposure. CO alarms can warn occupants when carbon monoxide levels become unsafe. Good tight construction practices (envelope and duct systems) can block out carbon monoxide from garages (Energy star 2005).

5. *Carbon Dioxide*

Though not considered as a pollutant, it can affect the general comfort of occupants. Carbon Dioxide is a by-product of respiration and combustion. In order to maintain occupant comfort, indoor levels of carbon dioxide should be preferably below 1000PPM. The effectiveness of ventilation system will be reflected in the indoor levels of carbon dioxide (DTIR 1995).

6. *Nitrogen Oxides*

These are highly toxic and irritating gases mainly emanating from gas burning appliances. Indoor concentrations should not exceed 0.05 PPM. Health effects include headache, dizziness, nausea, respiratory illness and long-term damage to bronchial airway and lung tissues. Harmful concentrations of nitrogen oxides in indoor air can be prevented through good ventilation.

7. *Respirable Suspended Particulates (RSP)*

These are minute organic and inorganic particles suspended in the air, mostly by-products of combustion. The main sources are tobacco smoke, wood smoke and un-vented gas appliances. Though there are no indoor standards for RSP, EPA has established an annual average outdoor standard of 15 ug/m3 (micrograms per cubic meter) for P.M 2.5 type RSP and 50 µg/m3 (micrograms per cubic meter) for P.M 10 type RSP. These particulates are small enough to be inhaled and often carry harmful gases like radon and other substances into the lungs. The health effects include a variety of respiratory illnesses.

Adequate ventilation, source substitution and improving combustion efficiency of household equipments are the main control methods. Textile surface materials may contribute to particle pollution in indoor environment and may emit chemical compounds. This may cause mucosal and allergic symptoms (Jaakkola et al. 1994; Skov et al. 1990). Presence of plasticizers, viscosity modifiers and stabilizers makes PVC materials, a potential source of emissions, which are usually long lasting. Since plasticizers have a high affinity for particles, they are capable of migrating from PVC materials to house dust. Studies show that PVC materials may lead to bronchial obstruction in young children (Jaakkola et al. 1999).

8. *Chemicals used during construction*

These include chemicals used to treat termite and carpenter ants. Some of these chemicals may persist in the home environment for many months or years after application. Most of these chemicals are toxic and have negative health effects.

9. *Ozone*

Ozone is a highly reactive and toxic gas. Equipments that causes ionization of the air or uses ultraviolet light may produce ozone. It is generally found only near the source. Ozone may irritate the eyes and respiratory tract (DTIR 1995).

10. *Unpleasant odors*

Though usually harmless they are considered offensive. Identifying the source and quantifying the smell can be difficult (DTIR 1995).

11. *Other Indoor Pollutants*

- *Lead*

Lead contamination is usually through drinking water and lead based paints. Health effects include slow mental development, learning and behavioral problems, damage to nervous and reproductive systems and high blood pressure. Several tests are available in the market for lead detection. Preventive solutions include replacing painted item or covering over lead based paint (Hawks & Hansen 2002).

<u>Biological pollutants</u>

1. Mold and mildew

When excessive moisture or water accumulates indoors, mold growth will often occur, particularly if the moisture problem remains undiscovered or un-addressed. The main reason for mold infestation is water damage by; water leakage through roofs, rising damp, defective plumbing installations, penetration of cleaning water and condensation (Gravesen et al. 1999). Other reasons include water build into the construction either from hardening concrete; building materials which have been placed on the ground or out in the rain; and parts of the building exposed to rain during the building process (Nielsen 2002).

The products most vulnerable to mold attacks are water damaged, aged organic materials containing cellulose, such as wooden materials, wallpaper, and cardboard. Other susceptible materials are linoleum and insulation materials for plumbing installations (canvas). The deposition of dust and dirt, combined with long-lasting penetration of water, may also lead to fungal growth on inorganic material such as mineral wool (Gravesen et al. 1999). Kiln drying makes the surface of the wood more susceptible to mold growth. OSB, plywood and MDF are more susceptible to mold growth than solid wood, particleboard, acylated wood and wood-polyethylene composites. Materials containing plasticizers [plastics] and resins such as polyethylene, PVC, polyurethanes and fiber glass insulation are vulnerable to mold growth. Waterborne paints also support mold growth (Nielsen 2002).

Presence of water is the key factor in the growth of molds. High relative humidities (RH) are conductive to mold growth. Large local differences in ventilation and surface temperatures is capable of generating micro climates with very high water activity (aw), even in rooms with low relative humidities (RH).The minimal RH for growth on wood-based materials and material containing starch is just below 80% at room temperature, and rises with decreasing temperature. But since molds can grow even in temperatures as low as -7°C, temperature cannot be effectively used to avoid fungal growth in buildings. Transient conditions (fluctuating humidity and temperature: e.g. - bathrooms) greatly influence the mould growth (Nielsen 2002). Temperature and humidity conditions play a critical role in the growth of mold.

The effective way to control indoor mold growth is to control moisture and dampness. Since mold requires high relative humidity, reducing indoor humidity to 40-60 percent can also help in reducing mold growth. Maintaining proper site drainage, waterproofing basement walls and building airtight floors are important (EPA 2005). Mould growth in air filters and in ventilation ducts is a potential health threat, as the ventilation system will act as an effective carrier of the spores. Dust, painted surfaces and fiber glass insulation materials in ventilation ducts may support mold growth (Nielsen 2002). Right sized HVAC systems provide better temperature control while removing excess humidity. Good tight construction practices (envelope and duct systems) can block out moisture from entering the home (Energy star 2005). The better method of solving mold problems is through creating new quality assurance systems, which can be practically implemented during the building process, rather than choosing or developing other materials (Nielsen 2002).

2. *Dust mites and other microorganisms*

   Dust mites can cause allergic reactions and severe asthma attacks. Dust mites need high relative humidity to grow. Reducing indoor humidity can keep dust mite populations in check.

2.3.2 Temperature

Thermal conditions inside buildings can vary considerably with time and spatially within buildings. The effects of temperature on comfort are broadly recognized. Room temperature has potential impacts on prevalence of sick building syndrome symptoms and occupant satisfaction with air quality. Research has shown that there is a linkage between high temperatures and a higher prevalence of sick building syndrome. Low temperatures can induce temporary deterioration in the dexterity of hands (Seppänen et al. 2002). It is suspected that temperature plays a crucial role in the growth of molds (Nielsen 2002).

2.3.3 Humidity

Humidity has significant associations with the concentrations of indoor biological and chemical pollutants (Nielsen 2002, Arens & Baughman 1996a). Humidity promotes growth on indoor surfaces and aids the escalation of mold, dust mite, bacteria and virus populations. It can also affect air borne levels of non-biological pollutants. Spray humidification systems can create problems associated with contaminated aerosols. Correlations between indoor air humidity and health effects are found to be often building-specific. The biotic/health problems associated with any given level of interior air humidity can be different for buildings in different types of climates and for different types of environmental control systems. The factors that affect humidity related health effects are (Arens & Baughman 1996b):

- Outdoor climate.
- Surface properties encountered across rooms and HVAC ducts, which includes associated temperature, hygroscopicity, and air movement.
- Water in cooling and humidification systems.
- Intermittency of operation in cooling systems.
- Other moisture sources like rain penetration, rising damp, and plumbing leaks.

2.3.4 Ventilation

The purpose of ventilation is to bring outdoor air to the occupied zone and remove or dilute indoor generated pollutants. Ventilation air is usually supplied through mechanical ventilation systems or with the aid of natural forces (wind pressure, buoyancy effects, etc.) caused by air temperature differences between indoor and outdoor air. Ventilation air supplied to indoor areas can either be entirely outdoor air or be mixed with re-circulated return air. Studies show that ventilation rates below 10 L/s per person are associated with negative health or perceived air quality outcomes. The relationship between ventilation rates and occupant health is an indirect one (Seppänen et al. 1999). But indoor environmental conditions including air pollutant concentrations are affected by ventilation rates and this may modify occupants' health or perceptions. Studies show that health and perceived air quality will usually improve with increased outside air ventilation (Seppänen et al. 2002). NIOSH investigators have found IEQ problems caused by ventilation system deficiencies and overcrowding (NIOSH 2005).

2.3.5 Lighting

Though lighting is an integral factor in the indoor environment, limited research has been conducted in the area of health effects of lighting. Daylight reduces the incidence of health problems caused by the rapid fluctuations in light output typical of electric lighting (Boyce and Hunter 2003). Studies among school students suggest that classrooms without daylight may upset the basic hormone pattern of children, and this in turn may influence children's ability to concentrate or cooperate. (Plympton et al. 2000). Some studies indicate that day lighting improves student performance (Fisk 2000). Poor indoor lighting may be due to problems like glare, insufficient light, improper contrast, poorly distributed light and flicker. The amount of light we need in an indoor environment varies on the type of surfaces, the individual's vision and the type of task being done (CCOHS 2003).

2.3.6 Noise

Noise problems in a building are usually related to outdoor sources (e.g.: road traffic), indoor sources (e.g.: people and consumer products) or bad acoustics. Excessive exposure to noise can result in hearing loss. It usually develops slowly over a long period of time. The impairment can reach the handicapping stage before an individual is aware of what has happened. Hearing loss can become permanent after continued exposure. Interference with speech communication and other sounds can result in noise-induced annoyance. Noise has the potential to mask important sounds and disrupt communication between individuals in a variety of settings. The effects can vary from a slight irritation to a serious safety hazard involving an accident or even a fatality because of the failure to hear the warning sounds of imminent danger (Suter 1991).

2.4 IEQ and health effects

Health effects of various pollutants in an indoor environment are often a complex function of the properties of pollutants, emission rates and other indoor variables like temperature, humidity and ventilation. Because of this potential health risk posed by any given pollutant can vary among different buildings (Fisk 2000).

2.4.1 Health effects of indoor air pollutants

The lung is the most common site of injury by airborne pollutants. Acute effects, however, may also include non-respiratory signs and symptoms, which may depend upon toxicological characteristics of the substances and host-related factors (EPA et al. 1994).

2.4.2 Health problems caused by biological air pollutants (EPA et al. 1994)

Biological air pollutants are present to some degree in every home. Molds, dust mites, fungus, viruses, bacteria, allergens from other arthropods and pets, protein-containing furnishings (feathers), unusual allergens (e.g., bacterial enzymes, algae) etc. are considered as biological pollutants in indoor environment. Sources of biological air pollutants include outdoor air; human occupants who shed viruses and bacteria; animal occupants (insects and other arthropods, mammals) that shed allergens and indoor surfaces and water reservoirs where fungi and bacteria can grow, such as humidifiers. One of the critical factors that allow biological agents to grow and be released into the air is high relative humidity, which encourages house dust mite populations to increase and allows fungal growth on damp surfaces. Other factors include dampness, inadequate exhaust of bathrooms or kitchen, and components of mechanical heating, ventilating, and air conditioning (HVAC) systems.

Biological agents in indoor air are known to cause three types of human diseases:

i. *Infections - pathogens invade human tissues.*

   Example: *Tuberculosis*; *Legionnaires' disease* (a pneumonia caused by a bacteria called Legionella pneumophila found in close association with cooling systems, whirlpool baths, humidifiers and other sources). Threat of transmission of airborne infectious diseases is increased where there is poor indoor air quality.

ii. *Hypersensitivity diseases - specific activation of the immune system causes disease.*

   Example: *Hypersensitivity pneumonitis*, also called *allergic alveolitis*, is a granulomatous interstitial lung disease caused by exposure to airborne antigens. *Allergic reactions* - range from rhinitis, nasal congestion, conjunctival inflammation, and urticaria to asthma. Studies have established that the prevalence of respiratory symptoms associated with asthma are increased by 20% to 100% among occupants of houses with moisture problems. These moisture and mold problems are common because, it is estimated that 20% of U.S. houses have water leaks. Parental smoking was associated with 20% to 40% increases in asthma symptoms (Fisk 2002). Building factors that have consistent and strong correlation with asthma and allergic respiratory symptoms include moisture problems, house dust mites, molds, cats and dogs, and cockroach infestation. There is evidence that the exposures that cause allergic sensitization often occur early in life and are likely to occur indoors. Therefore the quality of indoor environments may also influence the proportion of the population that is allergic or asthmatic (Fisk 2000).

iii. Toxicosis - biologically produced chemical toxins cause direct toxic effects.

Example: *Humidifier fever* is a flu-like illness marked by fever, headache, chills, myalgia, and malaise. Toxic effects of *mycotoxins* [fungal metabolites] that range from irritation to immunosuppression and cancer.

In addition, exposure to conditions conducive to biological contamination [e.g., dampness, water damage] has been related to nonspecific upper and lower respiratory symptoms (EPA 1994).

2.4.3 Sick building syndrome

Sick building syndrome (SBS) is characterized by the prevalence of acute building-related health symptoms among building occupants, most commonly reported by office workers and teachers. Symptoms include irritation of eyes, nose, and skin, headache, fatigue, and difficulty breathing (Fisk 2000). Risk factors identified with sick building syndrome symptoms include lower ventilation rates, presence of air conditioning, higher indoor air temperatures, increased chemical and microbiological pollutants in the air or on indoor surfaces, debris or moisture problems in HVAC systems, more carpets and fabrics, and less frequent vacuuming (Fisk 2002).

2.4.4 Planning, design and construction measures to improve occupant health

Indoor environmental quality (IEQ) is strongly influenced by a building's design, construction, operation, and maintenance, by the activities of occupants, and by outdoor environmental conditions. Also energy-efficiency measures have the potential to degrade or improve IEQ (Fisk et al. 2002). One approach towards reducing allergy and asthma symptoms via changes in buildings and indoor environments is to control the indoor sources of the agents that cause symptoms. Building design and construction procedures should reduce possibilities of water leaks and moisture problems and decrease indoor humidities. Known reservoirs for allergens, such as carpets for dust mite allergen, can be eliminated or modified. These measures when combined with proper operation and maintenance procedures could effectively reduce the growth of microorganisms indoors. Indoor tobacco smoking can be restricted to isolated, separately-ventilated rooms and pets can be maintained outside of the homes of individuals that react to pet allergens.

Another approach towards reducing allergy and asthma symptoms is to use air cleaning systems or increased ventilation to decrease the indoor concentrations of the relevant pollutants. Technologies that effectively reduce concentrations of airborne particles generated indoors [e.g. better air filtration], should be adopted. Better filtration of the outside air entering mechanically-ventilated buildings is also advisable since, it can also diminish the entry of outdoor allergens into buildings. Filtration is likely to be more effective for the smaller allergenic particles [e.g. cat allergens] than for large particles [e.g. from dust mites] (Fisk 2000). Research demonstrates that increase in ventilation rates in US office buildings would reduce the proportion of office workers with frequent upper respiratory symptoms from 26% to 16% and eye symptoms from 22% to 14% (Fisk 2000). Improvements in HVAC system design and maintenance and positioning of outside air intakes distant from potential pollutant sources, reduces adverse health outcomes among building occupants (Sieber et al. 2002).

Operable windows have two major benefits - occupant can control his environment; energy efficient cooling and ventilation. Two primary risks are increased noise and airborne pollutants from outside (Madsen 2005).

2.5 The "Whole House" approach

Conventional approaches in the home building industry treat each building system separately, often resulting in negative interactions among them (PATH 2001). The "Whole House" approach views the home as a system composed of different components that must work together. The challenge it addresses is to use the synergies among building systems to better the performance of the home (PATH 2003). The origin of concept of "Whole House" can be traced back to the industrial revolution of late 1800's (Swarup 2005). The progression of modern architecture resulted in the use of new building materials, the requirement for the resolution of complex building systems existing within one structure and finally mass production rather than traditional stick built to facilitate and fasten the building process. Since then designers have been experimenting with the issue of integrating complex services as part of a built structure (Russell 1981). Initiatives in United States include Levitt Technology; a proposal for factory built volumetric module housing and Triad; an open plan three bedroom modular house (Fein 1972).

2.5.1 The "Whole House" roadmap

Partnership for Advancement of Technology in Housing (PATH) is a is a partnership with the private sector initiated in the year 1998 when US Congress sanctioned $980,000 to the U.S. Department of Housing and Urban Development (HUD) for work to be conducted under the program. The program sets out roadmaps to promote research in certain key areas that are identified by the expert's panel. One of such roadmaps is the *"Whole House and Building Process Redesign Roadmap"*. PATH program addresses the following issues in the home building industry: quality, durability, environmental performance and affordability of tomorrow's homes.

The "Whole House" roadmap envisions that by the year 2010, home design and construction is efficient, predictable and controllable with a median cycle time of 20 working days from groundbreaking to occupancy. This can result in cost savings that will make homeownership available to ninety percent of the population. The roadmap defines the "Whole House" approach in the context of building systems integration. While the primary concern is to anticipate and resolve conflicts that arise between different building components or systems, it is important to take advantage of the synergies that exist between them. The roadmap also identifies several barriers that hamper innovation and ultimately defer the integration of the "Whole House" approach into mainstream homebuilding. The fragmented nature of the industry; ascendancy of aesthetics and function as primary design considerations; the regulatory process; rigid consumer perceptions and untrained labor are potential candidates. The possible solutions include optimizing design and operation by integrating components and subsystems; integrating component and subsystem functions; simplifying schedule and construction by modifying management approaches and relevant processes; and expanding the use of factory-built assemblies (PATH 2000).

2.5.2 The PATH concept home

The Concept Home is an outgrowth of PATH's '*Technology Roadmap: Whole House and Building Process Redesign*', and '*Technology Scanning*' reports. This concept home demonstrates the objectives of "Whole House" approach and its assimilation into mainstream design of homes. The primary concern is to make the home adaptable to change. The flexible floor plan makes sure this criterion is met. Subsequently, "systems thinking" is implemented to make sure that all building systems function independently – there are no tangled electrical, plumbing or communication lines hidden in the wall. A utility chase organizes the distribution of these independent systems and HVAC throughout the home. This process is expected to facilitate the ease of maintenance and upgrading of the utilities at any point without disturbing the structural fabric of the home. Improved production processes encompassing management systems, information and communications technology, and manufacturing and assembly processes; are expected to improve quality while reducing production time of the home to twenty days. Standardization of measurements and component interfaces is adopted so as to simplify product installation and enhance design flexibility. Use of integrative materials (e.g. - solar panels integrated into the roof) and alternative basic materials (e.g. – electro-textiles, light transmitting concrete) are the other features of the concept home (PATH 2005).

2.6 Green design and construction

The impact of the built environment on the environment and the economy is huge. US construction market commands a sizeable 12.7% of the $10 trillion GDP. Buildings represent 39% of US primary energy use and 70% of electricity consumed. It is estimated that around 40% of raw stone, gravel, sand and 25% of virgin wood goes into building construction (GBFS 2005). Buildings are considered to be major contributors of global warming, since a quarter of the increase in carbon dioxide in atmosphere is attributed to this sector. In addition, current construction practices create 2-2 ½ pounds of solid waste per square foot (LEED Review 2005). Construction industry concerns about the negative impacts of buildings on the environment are forcing the building sector to focus more on the integration of sustainability principles in planning, design and construction. Subsequently, green building design and construction has become a norm in several sectors of the industry in the recent years (Syal & Pillai 2005).

2.6.1 Sustainable development and the green building concept

Sustainable Development can be identified as the philosophy behind the green building concept. A comprehensive definition of Sustainable Development as provided in the Bruntland report by the UN World Commission on Environment and Development, defines the term as " that which meets the needs of the present without compromising the needs of future generations to meet their own needs" (ASTM 2005, Brundtland 1987). Paul Hawken in his book, 'The Ecology of Commerce', resorts to a simple definition for the term: "...leave the world better than you found it, take no more than you need, try not to harm life of the environment, make amends if you do"(Hawken 1993). "Green Building" can be defined as – "a building that provides the specified building performance requirements while minimizing disturbance to and improving the functioning of local, regional, and global ecosystems both during and after its construction and specified service life" (ASTM 2005). According to USGBC, green planning, design and construction comprises the "practices that significantly reduce the negative impact of buildings on environment and occupants" (LEED 2003).

2.7 Summary

Occupant health is related to the quality of indoor environment. Indoor Environment Quality (IEQ) is determined by aspects of Indoor Air Quality (IAQ), temperature, humidity, ventilation, lighting, noise and ergonomics. Presence of indoor chemical and biological pollutants can deteriorate the indoor air quality and negatively affect health, comfort and safety of occupants. Room temperature has potential impacts on prevalence of sick building syndrome symptoms and occupant satisfaction with air quality. While humidity does not directly affect occupant health, it has significant associations with the concentrations of indoor biological and chemical pollutants. The relationship between ventilation rates and occupant health is an indirect one. But indoor environmental conditions including air pollutant concentrations are affected by ventilation rates and this may modify occupants' health or perceptions. Inadequate lighting can affect health and cause discomfort. Noise also is a potential problem in the indoor environment.

The "Whole House" approach views the home as a system composed of different components that must work together. It utilizes the synergies among building systems to better the performance of the home. The "Whole House" roadmap of PATH, envisions that by the year 2010, home design and construction is efficient, predictable and controllable with a median cycle time of 20 working days from groundbreaking to occupancy. The roadmap also identifies several barriers that hamper innovation and ultimately defer the integration of the "Whole House" approach into mainstream homebuilding. The Path Concept Home is an effort that demonstrates the objectives of the "Whole House" approach and its assimilation into mainstream design of homes.

The impact of built environment on the external environment and the economy is huge. Construction industry concerns about the negative impacts of buildings on the environment are forcing the building sector to focus more on the integration of sustainability principles in planning, design and construction. Sustainable Development can be identified as the philosophy behind the green building concept. Green design and construction has environmental, economic and health benefits.

CHAPTER 3

TOOLS AND TECHNIQUES

3.1 Overview

This chapter is a review of the tools and techniques that were utilized for this research. Some of them already exist in literature while others have been developed for this research. The discussion in this chapter is organized around three broad topics – Whole House design and evaluation; Evaluation of Health impacts of planning, design and construction; and Green building design and evaluation. The Whole House topics include (1) Whole House Calculator and (2) Whole House performance criteria framework. The Health Impact Matrix for Planning, Design and Construction of Built Environment constitutes the second topic. The Green Building tools and techniques include: (1) LEED-NC and (2) LEED-H green building rating systems.

3.2 "Whole House" design and evaluation (Swarup 2005, O'Brien 2005)

Traditional construction practices involve discreet optimization of building systems. The drivers in this process are performance and cost. Also during the production stage, the responsibility of design of a home rarely rests on a single person or even a dedicated team that closely coordinates all activities. Typically there are many separate designers in a home including design professional, trade contractors and even suppliers. The sum total of these semi-independent systems of design, engineering, procurement and production, each having discrete standards, goals, and governing regulations; represents the conventional house. This situation often leads to unexpected interactions between building systems that affects the performance and integrity of the house as a whole.

The performance of a home is influenced by the combined interaction of systems internal to the home. These influences can either enhance or reduce performance. The performance reducing influence can be the result of inadequate system compatibility, design integration, poor construction or installation practices, insufficient quality control, or occupant operation. For example, mechanical systems including heating, ventilation and air conditioning, gas and water pipes and vents, and fire protection systems interact with structural systems and negatively impact structural performance. The size of ductwork and piping elements and accommodation for the changes in direction of mechanical and fire protection systems require provision for openings, chases and horizontal bulkheads that impact placement of structural framing. Also large notches and holes placed in framing in order to allow runs of piping and ductwork, reduces the strength of the structural members. This reduction in structural performance may also compromise other aspects of the building such as architectural space reductions. In some cases, the location of large, key elements of the mechanical system such as furnaces can create problems due to the presence of framing conflicts in overhead floors or adjacent walls.

Opposed to this, the "Whole House" approach promotes the idea that the home be viewed as a system composed of different components which work together for improving the overall performance. Each of the parts and processes involved in home production interact with and affect other parts and processes. So interaction between these parts are to be studied in detail and that interacting components be designed for the success of the whole, not just the component. Whole House approach aims at achieving total systems integration. It considers both the end product and the processes that produced it.

Whole House researchers have identified the need to address the complex problem of comparing performance of one house to another. This represents a difficult task for both prospective homebuyers and builders because each house is effectively unique. The complexity arises from the 54,000+ total part count in a house. Taking into account alternatives for each part, different climate conditions, and alternative house designs facing one of various possible compass orientations provides a huge number of combinations for the system. Various trades involved in the production process, alternative production methods and, different objectives of buyers and builders further complicate the problem. This huge number of choices is a considerable barrier in adopting systems approach in housing production. Any tool that aids Whole House design or evaluation for the purpose of comparison should be capable of addressing multiple parameters to support optimization of the design and production process in housing in a systematic way and requires both subjective and objective analysis.

3.2.1 "Whole House" performance calculator (O'Brien 2005)

The Whole House calculator emerged as a tool for the quantitative assessment of the performance of design and production processes, materials and systems, and the interaction between them for the purpose of comparative scoring. It also takes into account characteristics valued by prospective buyers, builders, or other stakeholders involved in residential construction. The large number of choices for materials, processes and components poses a considerable barrier to each builder or buyer applying a fully rational approach to the construction or purchase of a house. The calculator aims to address this issue and helps the builder or buyer make an appropriate selection by analyzing various "what-if" scenarios. The "Whole House" calculator is based on the method developed by the "Battelle Columbus Laboratory" in the United States.

3.2.1.1 The Battelle method

The "Whole House" calculator is based on the method developed by the "Battelle Columbus Laboratory" in the United States. Although referred to the Battelle method in the calculator text it is originally called the Environmental Evaluation System (EES). The method lists seventy-eight parameters based on environmental, social and economic aspects based on their level of importance. These levels of importance are associated with a value between 1 and 1000, and then curves of quality of environment are generated, compared to each parameter. Four categories are defined under which the human environmental is assessed; these are ecology, physical and chemical factors, aesthetic factors and social interest. These four factors are divided into twenty components that are further subdivided into eighty-one parameters. The categories, components and parameters are arranged in descending order. Each category is associated with a relative coefficient of importance from 0 to 1. Finally the relationship between each of the eighty-one parameters and environmental quality are generated based on the afore-mentioned curves. This method has been used successfully to evaluate complex problems from differing points of view. A variation of this method is used to formulate the "Whole House" calculator.

3.2.1.2 Structure of the "Whole House" calculator

A pair of databases driven by lookup functions comprises the calculator. The databases are based on a comprehensive listing of every process, material and component choice that went into the building of the house. This information is derived from specifications of the house and information about design and production process. These are called system choices. The evaluation of a project is conducted in four steps. These are:

i. Inputting objectives defined by the user.
ii. Performance scoring.
iii. Integration scoring.
iv. Deriving final whole House score.

The users of the calculator include homebuilders or homebuyers. First the calculator asks them to identify the attributes in a house that are most important to them. This is input in the calculator as the User Values. The User Values is a listing of attributes that the user can set by order of importance. There are different User Values for homebuilders and homebuyers. Homebuyers using of the calculator complete a form to rank the relative importance of performance characteristics such as: a comfortable home, a healthy home, a dry home, a sturdy home, a safe home, a flexible home and an efficient home. The builders' list includes performance attributes like a durable home, a clear home, a predictable home etc. One hundred points are to be distributed across the User values according to their importance to the user. This weighted score is input into the calculator as User Value Weighting Factors (Uw), which will become percentage multipliers to the performance scores of the System Choices.

The performance of system choices is scored as the next step. For this the house functions are categorized into subsystems in order to split them into parts having a similar performance expectation placed on their design, specification, installation and in-service behavior. In order to reflect the importance of the role each subsystem plays in the function of the house as well as the health and safety of the occupants, weighting factors are applied. These Subsystems Weighting Factors (Sw), which total 100, become multipliers to the performance scores of the System Choices to reflect the importance of their role in the whole house. Weighting factors for houses in different geographic regions signifies the importance of a subsystem's performance in the particular climate. Performance of each System Choice is then scored for a variety of issues like moisture control, system integrity, system part count, regional trade familiarity, environmental impact etc. The performance is scored on a scale of 1 to 5, signifying the range from lowest performance to the highest performance. Finally he System Choice's Performance Score (Ps) is determined by summing up all the scores for different performance issues. The Performance Factor (Pf) is derived by totaling the Performance Score for a given System Choice multiplied by the weighting factor for the subsystem to which it is normally associated. The resulting value is further multiplied by the User Weighting Value (Uw) most closely associated with the given system choice.

$$Pf = ((Ps \times Sw) \times Uw) \qquad \textbf{(Eq 1)}$$

The degree and net effect of the interaction between each System Choice is rated by Interaction Scoring. Interaction between two System Choices can result in improvement or degradation of performance of the two System Choices. The Interaction scoring matrix is made by listing Systems Choices describing a house on a vertical axis and a horizontal axis. The interaction of each System Choice with each of the other System Choices is scored on a scale from +3 to -3 to indicate the degree of improved or degraded performance likely to result from this particular interaction. The System Choice's scores for their interaction with every other System Choice in the house are totaled to calculate that choice's Interaction Score (Is). The Interaction Factor (If) is the reciprocal of the sum of the horizontal and vertical interaction scores of a system choice in the interaction matrix divided by the Total Variance. The resulting value is subtracted from 1 to normalize negative scores.

$$If=1\div(1-(\sum Is\div Tv)) \qquad \textbf{(Eq 2)}$$

The Whole House Score (Whs) is the sum of the products of the Interaction factor (If) multiplied by the Performance Factor (Pf).

$$Whs=\sum(If\times Pf) \qquad \textbf{(Eq 3)}$$

The Whole House score helps to compare different sets of System Choices. A theoretical perfect score is helpful in deciding how close a particular configuration of processes, components and subsystems is to the ideal. The theoretical score is generated by scoring all performance factors as a value of five, all interactions as a value of three and applying the system weighting and user weighting values. Whole House Score a particular configuration of System Choices is divided by the theoretical perfect score generates the percentage of closeness of the actual system to the ideal.

3.2.1.3 Sample calculation with "Whole House" calculator

The sample calculation is performed for a 'typical' house built by a production builder. The performance and interactions scores are intended for demonstration and do not reflect any absolute values. The following assumptions are made prior to the evaluation.

- IRC Code Compliance;
- Mid-Atlantic regional location for decay, weathering, termite infestation probabilities;
- Inland wind exposure;
- Seismic design category "A";
- Radon Zone 1; and
- Climate Zone 10.

For demonstration purposes the *user values* are assumed as the following. Hundred points were divided among seven attributes of the house.

- Comfort 15
- Healthy 10
- Dry 20
- Sturdy 20
- Safe 15
- Flexible 10
- Efficient 10

The subsystems were assigned weighting factors based on the above assumptions.

▪ Process & production design	5
▪ Foundation	15
▪ Superstructure	25
▪ Envelope	15
▪ Interior partitions & finishes	2
▪ Millwork	3
▪ Utility distribution	7
▪ Electrical power & light	10
▪ Sewer & water	5
▪ Thermal systems	13

In the example the typical house is described using 93 system choices:

- Process & production design - 23 system choices (e.g. – purchased design, traditional stick frame, no quality check at end of project etc.)
- Foundation - 7 system choices (e.g. – site cast concrete footing, masonry foundation wall, fiberglass board insulation etc.)
- Superstructure - 4 system choices (e.g. – dimension lumber roof framing)
- Envelope - 16 system choices (e.g. – vinyl siding, no floor ventilation etc.)
- Interior partitions & finishes - 9 system choices (e.g. – drywall substrate, particle board sub-floor, pad and carpet floor finish etc.)
- Millwork - 3 system choices (e.g. – drywall milled wood interior trim)
- Utility distribution - 3 system choices (e.g. – site fabricated trunks and feeders)

- Electrical power & light - 5 system choices (e.g. – wiring is romex, incandescent lighting, electrical system on grid etc.)
- Sewer & water - 7 system choices (e.g. – copper water piping, no cistern etc.)
- Thermal systems - 9 system choices (e.g. – air distribution, point diffusers etc.)

The resulting whole house score was 5,266. This represents 15.81% of the best possible score (33,302) for a house comprising 93 system choices. The best possible scored is arrived by rating all the system choices high on both performance scoring (5 points) and integration scoring (+3).

3.2.2 **"Whole House" performance criteria framework** (Swarup 2005)

The Whole House Criteria Framework is based on building systems integration approach. The criteria framework systematically tabulates all the concepts propagated by the "Whole House" approach and integrates them into the design of a home. The framework follows the LEED format. Expectations from the "Whole House" is categorized into six performance parameters - Spatial flexibility, Thermal performance, Structural integrity, Ease of construction, Ease of maintenance and Sustainability. Building Systems Integration Handbook (BSIH) matrix is used to analyze the interaction possibilities among various systems. System decision models depicting 3-system interactions help to systematically tabulate the intents and associated strategies required for criteria development. A detailed scoring system is built into the framework to rate different strategies. Table 3.1 shows a part of the scoring system. The whole framework has been included in the appendix.

No.		Building systems (Design considerations)	Cr.	Intent				Example strategies
				Thermal performance	Sc.	Total sc.	Sc. x Cr.	Thermal performance
A		**Structure / Env**	4.4					
1		Architectural design		Material thermal performance	5			Foam core panels. High strength OSB
2		Engineering design		Reduction of loss of heat and cold from building envelope	5			Sealing building junctions
				Decreased use of artificial lighting	5			Day lighting design
				Air movement within the home	5			Storage modules serving as partitions with changeable heights for internal air movement
3		Special design consideration						
	a	Active solar design		Use of alternative energy sources	5			Solar panels
	b	Passive solar design		Sunlight in wet areas	5			Day lighting design
				Use of sunlight as per seasonal requirements	5			Collapsible shading devices
		Cumulative score			35	35.00	154.00	

Table 3.1 - Whole House Performance Criteria Framework (source: Swarup 2005)

As the first step, building systems are assigned relative weights based on the level of its effect in the performance of a home. This is followed by a system for rating each strategy based on its level of effectiveness in achieving a particular performance parameter. A consolidated score for each building system, based on the strategies employed, is determined in this manner. This score is adjusted to reflect the relative weights of each building system. The scoring system is based on the "Whole House Calculator". The final score is the sum of all these weighted scores for various building systems. This score is compared against the ideal score of a hypothetical "Whole House". Even though the framework is intended as an effective design tool, this function broadens its scope as a design and evaluation tool for the "Whole House" performance. When three case studies – site built home, factory built home and hybrid home - were compared based on a sample criteria it was found that the latter received the highest score.

3.2.2.1 Sample application of "Whole House" performance criteria

This section demonstrates the application of the "Whole House" Performance criteria on a hybrid home. First each of the seven building systems considered for the exercise is associated with a certain weight that refers to the role of the strategies pertaining to that building system, in the overall performance of the home. The building system that affects the performance of the home to a large degree is given a larger weight than others. The weightage/credit system defines the level of importance of each building system within the complete design of the home. The systems are weighted as a percentage of the total weight of 8.

Structure envelope - 4.4 (55%)

HVAC - 1.28 (16%)

Plumbing - 0.64 (8%)

Electrical - 0.64 (8%)

Communication - 0.32 (4%)

Interior A - 0.48 (6%)

Interior B - 0.24 (3%)

The next step is the scoring of each strategy based on its level of effectives in achieving a particular performance parameter. The scoring will be conducted on a scale of 1-5, where 1 represents the least effective strategy and 5, being the most effective strategy. After scoring each strategy on this scale, a total score is determined under each building system. The weighted score is the product of the total score for each building system and the weight assigned to it. In the case of Structure/ Envelope the scoring was performed like this:

Spatial flexibility – 9 points

Thermal performance – 19 points

Structural integrity – 7 points

Ease of construction – 15 points

Ease of maintenance – 15 points

Sustainable design – 10 points

Total – 75 points

Therefore, weighted Score for Structure/ Envelope = 75 x 4.4 = 330 points.

The sum of weighted scores for all seven building systems is the final score. For hybrid house this was found to be 506 points. This constitutes 67.02% of the ideal Whole House score. The ideal Whole House score of 755 points is calculated by assigning high scores (5 points each) to all the strategies under consideration.

3.3 Evaluation of health impacts of buildings

Planning, design and construction practices often have associated health impacts. The assessment of these health impacts presents a complex problem since a large number of associated elements have to be taken into consideration. Many of these elements are associated with a wide range of direct and indirect health effects. This complex problem demands a systematic process for analyzing various aspects of planning, design and construction; and the cause and effect relationship that the built environment shares with human health.

3.3.1 Health impact matrix for planning, design and construction of built environment

The matrix was developed as a part of this research to systematically evaluate the negative health effects associated with planning, design and construction of built environment. The matrix has three main parts. Table 3.2a, Table 3.2b and Table 3.2c show the three parts of the matrix. The first part links the parameters that define the built environment to causative factors of health effects. The parameters that have been identified for the purpose of this research are: (i) Zoning, (ii) Density, (iii) Land use mix, (iv) Transportation Infrastructure, (v) Pedestrian Infrastructure, (vi) Connectivity, (vii)

Public realm design, (viii) Building design and (ix) Parks/landscaped areas. The second part identifies individual components of these causative factors and their effect on health. The causative factors of health effects have been categorized as: (i) Air pollution, (ii) Water pollution, (iii) Noise pollution, (iv) Variations in microclimate, (v) Solid waste contamination, (vi) Physical inactivity, (vii) Crime and safety issues and (viii) Insecurity. The health effects that are considered for this study include communicable disease, respiratory effects, cardiovascular effects, neurological effects, gastrointestinal effects, effects on skin and exterior organs, birth defects, discomfort, stress, mental illness, accidents and injuries.

The third part of the matrix helps to comparatively evaluate the effects of causative factors on human health. Relative weights are applied to the various categories of health effects. Various life threatening health effects have the highest weight while comfort issues have the lowest weight. Then a scoring system of 0 to 3 is applied to the causative factors on the basis of their effects on health. This signifies the range from no effect to significant health effects. The total of the sores for each of the causative factors help to compare their importance in relation to human health. This information will aid in framing strategies for health performance during the planning, design and construction processes.

3.4 Green building design and evaluation

Green design and construction has environmental, economic and health benefits. Environmental benefits include reduced destruction to natural areas and biodiversity,

Factors of built environment	Air pollution	Water pollution	Noise pollution	Variations in microclimate	Contamination -solid waste	Physical inactivity	Crime/Safety issues	Insecurity
Density This discussion is true only for contiguous urban areas. (If built-up areas are spatially fragmented, density increase is often associated with increase in pollution (e.g. – more vehicle use.) Also, higher density requires much better traffic management, stricter enforcement of parking laws and capital investments in sidewalks and pedestrian overpasses (World Bank 2002).	▪ A person walking up to 12 minutes can easily reach any point in an area of 100 hectares (ha). Typically density of a US suburb is 10 people per ha. - which means any point in that area can be reached by 1,000 people without requiring motorized trips. If the density is 300 people per ha 30,000 people can reach any point in the same area within the same walking time (World Bank 2002).	▪ Spati-ally fragmented density increase and sprawl can lead to water pollution from automobiles (oil, grease, and radiator fluid leaks), auto maintenance/ washing, landscaping, gardening, and pest control (herbicides, pesticides and fertilizers) (Chula Vista 2005). ▪ Nitrogen and phosphorous pollution from home lawn fertilizer can lead to eutrophication and resulting	▪ Density increase in contiguous urban areas can lead to reduced number and duration of automobile trips and reduced car ownership. (Belmont 2002) ▪ This can lead to reduced noise pollution from automobiles.	▪ An expansive form of urban residential development emits more excess radiant energy per parcel than one of urban densification ▪ Low density neighborhoods coexist with expansive lawn areas at the expense of a more extensive tree canopy. Grass tends to exhibit a higher surface temperature than tree canopy and hence increase the	Consolidated waste treatment facilities are possible with higher developmental densities which can reduce risk of contamination from solid waste.	▪ Increase in developmental density combined with mixed land use can improve the vitality of an urban area (Belmont 2002). This can act as an incentive for people to walk rather than travel by car, thereby increasing physical activity. ▪ Dense development often means that destinations are closer and this can lead to more physical activity in	▪ Examples show that high density mixed use neighborhoods report less crime than low density developments. (E.g.: New York's Upper East side). The streets are more live and filled with people, which deter crime (Grogan & Proscio 2000). ▪ Limited automobile use means low flow traffic and this can reduce accidents and fatalities and injuries to pedestrians	High density, mixed use can add to the vitality of a neighbor-hood (Grogan & Proscio 2000). ▪ Safe streets, low flow traffic and presence of people can alleviate feelings of insecurity.

Table 3.2a – Factors of Built Environment

Causative factors-health effects.	Type	Components/effects on humans
Air pollution	Mobile Stationary Area Sources	**Classic pollutants [*'criteria pollutants'* – EPA]:** (EPA 2005, WHO 2000) **Carbon Monoxide**: After being inhaled, CO molecules can enter the bloodstream, where they inhibit the delivery of oxygen throughout the body. Low concentrations can cause dizziness, vision problems, headaches, and fatigue; high concentrations can be fatal. **Lead**: Lead causes damage to the kidneys, liver, brain and nerves, and other organs. Exposure to lead may also lead to osteoporosis (brittle bone disease) and reproductive disorders. Excessive exposure to lead causes seizures, mental retardation, behavioral disorders, memory problems, and mood changes. Low levels of lead damage the brain and nerves in fetuses and young children, resulting in learning deficits and lowered IQ. Lead exposure causes high blood pressure and increases heart disease, especially in men. Lead exposure may also lead to anemia. Some lead-containing chemicals cause cancer. **Ozone**: Ground level ozone is created by a chemical reaction between oxides of nitrogen (NOx) and volatile organic compounds (VOC) in the presence of sunlight. Ozone can irritate lung airways and cause inflammation. Other symptoms include wheezing, coughing, pain when taking a deep breath, and breathing difficulties during outdoor activities. May cause permanent lung damage after long-term exposure. Triggers a variety of health problems even at very low levels including aggravated asthma, reduced lung capacity, and increased susceptibility to respiratory illnesses like pneumonia and bronchitis. **Nitrogen oxides**: React with volatile organic compounds to form ground level ozone. In high doses, smog can harm humans by causing breathing difficulty for asthmatics, coughs in children, and general illness of the respiratory system. It can also cause acid rain. **Sulfur Dioxide:** Can cause temporary breathing difficulty for people with asthma. Longer-term exposures to high levels of SO2 gas and particles cause respiratory illness and aggravate existing heart disease. SO2 reacts with other chemicals in the air to form tiny sulfate particles. These are associated with increased respiratory symptoms and disease and difficulty in breathing. SO2 is a major contributor to acid rain. **Particulate matter**: Particulate matter consists of particles found in the air, including dust, dirt, soot, smoke, and liquid droplets. Health problems include aggravated asthma, increases in respiratory symptoms like coughing, difficult or painful breathing, chronic bronchitis and decreased lung function.(Pope et al. 2000).

Table 3.2b – Factors of Built Environment – Causative Factors

Causative factors	Commu nicable diseases	Respirat o-ry	Cardio-vascular	Neuro-logical	Gastro-intestinal	Others – effects in skin, exterior organs etc.	Birth defects	Discomfo rt	Stress	Mental illness
Air pollution	X	XXX	X	X	X	XXX	X	XXX	XX	X
Water pollution										
Noise pollution										
Variations in microclimate										
Contamination-solid waste										
Physical inactivity										
Crime/Safety issues										
Insecurity										

<u>Legend</u>
X – Minimal, XX – Moderate, XXX - Extensive

Table 3.2c – Factors of Built Environment – Health Effects reduced pollution and solid waste, and reduced depletion of finite sources. Economic benefits include reduction in project and operation costs, enhanced asset value, increased profits, optimized life cycle performance and savings from increase in productivity. Healthier indoor environments are another feature of green buildings. Since on an average Americans spend 80 to 90% of their time indoors the quality of indoor environments is very important for health and quality of life. Potential threats like the Legionnaires disease and sick building syndrome can be avoided through ensuring the quality indoor environment. Green design and construction is also conductive to healthy outdoor environments. Lessened demand for large-scale infrastructure like landfills, water supply, storm water sewers etc. and decreased transportation development will promote healthy outdoor environments (LEED Review 2005). Green design and construction practices strive to address the built environment issue from a whole systems point of view and thereby promote sustainability and environmental responsiveness (Syal & Pillai 2005).

United States Green Building Council (USGBC) is a national non-profit organization that was formed in 1993, which develops and administers the Leadership in Energy and Environmental Design (LEED) green building rating system. USGBC has a diverse membership including building and design professionals, owners, manufacturers, government bodies, environmental groups, research institutions, professional societies and universities. The organization operates on consensus principles. The goal of USGBC is to promote buildings that are environmentally responsible, profitable and healthy places to live and work (LEED Review 2005, LEED 2005a). LEED is a national standard for evaluating high performance, sustainable buildings, developed and administered by USGBC. The development of LEED green building assessment framework is a consensus based and market driven process. LEED's goal is to define 'green building' and establish a common standard of its measurement. The standard aims to promote integrated, whole-building design practices and raise awareness about its benefits. The LEED program is continuously evolving.

Currently, six categories of LEED standards exist in various phases of development (LEED 2005, LEED Review 2005):

- LEED for New Construction (LEED-NC)
- LEED for Existing Buildings (LEED-EB):
- LEED for Commercial Interiors (LEED-CI)
- LEED for Core & Shell (LEED-CS)
- LEED for Homes (LEED-H)
- LEED for Neighborhood Development (LEED-ND)

LEED-NC and LEED-H are described in detail below.

3.4.1 LEED-NC green building rating system

LEED for New Construction and Major Renovations (LEED-NC) is specifically designed for rating commercial and institutional buildings, with a focus on office buildings. LEED-NC has also been applied many other building types like high-rise residential buildings. The point based rating system is categorized into five environmental topics: Sustainable Sites (20% of points), Water Efficiency (7% of points), Energy & Atmosphere (25% of points), Materials & Resources (19% of points), and Indoor Environmental Quality (22% of points). These five categories account for 32 credits and 7 prerequisites amounting to 64 core points. Innovation & Design Process is an additional category, which addresses sustainable building expertise. This category also addresses design measures not covered under the five environmental categories. Five points are available for this category with one point for the participation of a LEED accredited professional in the project, thus making a total of 69 points. Table 3.3 shows the structure of LEED rating system. The full LEED-NC checklist has been included in the appendix.

				Indoor Environmental Quality	15 Points
Y			Prereq 1	**Minimum IAQ Performance**	Required
Y			Prereq 2	**Environmental Tobacco Smoke** (ETS) **Control**	Required
			Credit 1	**Outdoor Air Delivery Monitoring**	1
			Credit 2	**Increased Ventilation**	1
			Credit 3.1	**Construction IAQ Management Plan**, During Construction	1
			Credit 3.2	**Construction IAQ Management Plan**, Before Occupancy	1
			Credit 4.1	**Low-Emitting Materials**, Adhesives & Sealants	1
			Credit 4.2	**Low-Emitting Materials**, Paints & Coatings	1
			Credit 4.3	**Low-Emitting Materials**, Carpet Systems	1
			Credit 4.4	**Low-Emitting Materials**, Composite Wood & Agrifiber Products	1
			Credit 5	**Indoor Chemical & Pollutant Source Control**	1
			Credit 6.1	**Controllability of Systems**, Lighting	1
			Credit 6.2	**Controllability of Systems**, Thermal Comfort	1
			Credit 7.1	**Thermal Comfort**, Design	1
			Credit 7.2	**Thermal Comfort**, Verification	1
			Credit 8.1	**Daylight & Views**, Daylight 75% of Spaces	1
			Credit 8.2	**Daylight & Views**, Views for 90% of Spaces	1

Table 3.3: LEED credit system for Indoor Environment Quality (source: LEED-NC 2.1)

The prerequisites listed in the rating system must be achieved. While each credit is optional, it contributes to the project's point total. Some of these credits are divided into two or more sub-credits with independent or cumulative points. Intent identifies the main goal of the prerequisite or credit. Requirements & Submittals specify the criteria to satisfy the prerequisite or credit, the number of points available, and the documentation required for the LEED application. Potential technologies and strategies for meeting the criteria are also listed for each credit. LEED is a performance-oriented system in which the points are earned for satisfying performance criteria. Four levels of green building certification are available based on the total points earned. They range from 'certified' (26-32 points) to platinum (52-69 points). Silver certification requires 33-38 points and gold, 39-51 points (LEED 2002, LEED 2003). Each of the five categories in the LEED-NC rating system is discussed in detail below.

3.4.1.1 Sustainable sites

Development and construction processes at the construction site often disrupt the local ecology. Pollution from construction activities comprises soil erosion, waterway sedimentation and airborne dust generation. Development of inappropriate sites that are sensitive or restrictive land types causes negative impact on the environment. Greenfields can be protected and habitat and natural resources can be preserved by channeling development to urban areas with existing infrastructure. Rehabilitating damaged sites will also help in confining development to areas that are already developed. Locating the project with consideration of public transport access can reduce impacts related to transportation.

Minimizing parking lot and garage size helps to reduce pollution and land development impacts from single occupancy vehicle use. Designing the building with transportation amenities such as bicycle racks and providing low-emitting and fuel-efficient vehicles with preferred parking for occupants is also beneficial. In greenfield sites, the building should be located carefully to minimize disruption to existing ecosystems. The development footprint must be reduced in order to maximize open space to promote biodiversity. Disruption of natural water hydrology due to increased impervious cover and reduced on-site infiltration can lead to extensive environmental impacts. Pollution of natural water flows by stormwater runoff should be limited and contaminants eliminated. Thermal gradient differences between developed and undeveloped areas can have direct impacts on microclimate and human and wildlife habitat. Light trespass from the building and site reduce nighttime visibility and disrupt nocturnal environments.

The following nine parameters rate the sustainability of the site in LEED-NC: Erosion & Sedimentation Control, Site Selection, Development Density, Brownfield Redevelopment, Alternative Transportation, Reduced Site Disturbance, Stormwater Management, Heat Island Effect and Light Pollution Reduction. Reducing the pollution from construction activities is a necessary prerequisite while fourteen points can be scored for the other eight credits.

3.4.1.2 Water efficiency

It is estimated that 340 billion gallons of fresh water are withdrawn per day from rivers, streams and reservoirs to support residential, commercial, industrial, agricultural and recreational activities in United States, which accounts for about one-fourth of the nation's total supply of renewable fresh water. Around 65% of this amount is discharged back into rivers, streams and other water bodies after use. In addition to this, water is also extracted from underground aquifers. On an annual basis, the water deficit in the United States is currently estimated at about 3,700 billion gallons. Rigorous water reuse strategies have helped to reduce the water use in industrial processes in recent years. Energy Policy Act of 1992 also aided the reduction in water use by mandating the use of water-conserving plumbing fixtures to reduce water use in residential, commercial and institutional buildings. Using large volumes of water is associated with increased maintenance and life-cycle costs for building operations and consumer costs for additional municipal supply and treatment facilities.

Efficient use of water can reduce costs through lower water use fees, lower sewage volumes to treat energy and chemical use reductions, and lower capacity charges and limits. Many water conservation strategies involve either no additional cost or rapid paybacks. Other water conservation strategies such as biological wastewater treatment, rainwater harvesting and gray water plumbing systems often involve more substantial investment. Water efficiency measures in commercial buildings can easily reduce water usage by 30% or more. In a typical 100,000-squarefoot office building, low-flow fixtures coupled with sensors and automatic controls can save a minimum of 1 million gallons of water per year, based on 650 building occupants each using an average of 20 gallons per day. Non-potable water volumes can be used for landscape irrigation, toilet and urinal flushing, custodial purposes and building systems. Utility savings, though dependent on the local water costs, can save thousands of dollars per year, resulting in rapid payback on water conservation infrastructure. In LEED-NC the following three credits rate the efficiency of water use in a project: Water Efficient Landscaping, Innovative Wastewater Technologies and Water Use Reduction. Five possible points are available in this category.

3.4.1.3 Energy and atmosphere

Buildings consume approximately 37% of the energy and 68% of the electricity produced in the United States annually, according to the U.S. Department of Energy. Combustion of fossil fuels produces about 75% of our energy. Production of electricity through the use of fossil fuels such as oil and coal requires extraction, transportation, refining, power generation and distribution. These processes significantly impact the environment in a myriad of adverse ways. For example, conventional fossil-based generation of electricity releases carbon dioxide, which contributes to global climate change. The potential consequences of climate change (rising sea levels leading to coastal floods, severe droughts, heat waves, disease migration) affect communities worldwide. Coal-fired electric utilities emit almost one-third of the country's anthropogenic nitrogen oxide, the key element in smog, and two-thirds the sulfur dioxide, a key element in acid rain. Coal extraction and mining disrupts habitat and can devastate landscapes. Acidic water runoff (acid mine drainage) from coal extraction activities further degrades regional ecosystems. Coal is rinsed with water, which results in billions of gallons of sludge stored in ponds. Coal-fired electric generation plants emit more fine particulate material than any other activity in the United States. The human body is incapable of clearing these fine particles from the lungs. Consequently, particulate materials penetrate deep into the lungs and are contributing factors in tens of thousands of cancer and respiratory illness-related deaths annually. Other energy production technologies include natural gas, nuclear fission and hydroelectric generators. Although its emissions are not as damaging as coal and oil, natural gas is a major source of nitrogen oxides and greenhouse gas emissions. Nuclear power increases the potential for catastrophic accidents and raises significant waste transportation and disposal issues. Hydroelectric generating plants disrupt natural water flows, resulting in disturbance of habitat and depletion of fish populations.

Energy consumption can be dramatically reduced through practices that are economical and readily achievable. Improving the energy performance of buildings lowers operations costs, reduces pollution generated by power plants and other energy-producing equipment, and enhances comfort. Most energy-efficiency measures present an excellent rate of return. It is essential to consider a building's energy load as a whole and to integrate synergistic energy-efficiency measures in order to maximize savings. For example, reduction of energy loads through improved glazing, insulation, daylighting and use of passive solar features may allow the design team to downsize or even eliminate mechanical HVAC systems. LEED recognizes the importance of integrated energy strategies. As a result, most of the prerequisites and credits under this topic are performance-based rather than prescriptive.

LEED-NC rates the energy efficiency of a project on these issues: Fundamental Building Systems Commissioning, Minimum Energy Performance, CFC Reduction in HVAC&R Equipment, Optimize Energy Performance, Renewable Energy, Additional Commissioning, Ozone Depletion, Measurement & Verification and Green Power. The first three are necessary prerequisites while seventeen possible points can be scored on the remaining six credits.

3.4.1.4 Materials and resources

Building materials choices are important in sustainable design because of the extensive network of extraction, processing and transportation steps required to process them. Activities to create building materials pollute the air and water, destroy natural habitats and deplete natural resources. Construction and demolition wastes constitute about 40% of the total solid waste stream in the United States. One of the most effective strategies for minimizing the environmental impacts of material use is to reuse existing buildings. Rehabilitation of existing building shells and non-shell components reduces solid waste volumes and diverts these waste volumes from landfills. It also reduces environmental impacts associated with the production and delivery of new building products. Reuse of an existing building minimizes habitat disturbance and typically requires less infrastructure such as utilities and roads. An effective way to use salvaged non-shell components in new buildings is to specify these materials in construction documents. When new materials are used in buildings, it is important to consider different sources. Salvaged materials can substitute for new materials, save on material costs and perhaps add character to the building. Recycled content materials reuse waste products that would otherwise be deposited in landfills. The use of local materials supports the local economy and reduces the impacts of transportation. The use of rapidly renewable materials and third-party certified wood minimizes the impact of natural resource consumption to manufacture new building materials. In recent years, an increasing number of public and private waste management operations have begun to reduce construction debris volumes by recycling and reusing these materials. Recovery and recycling activities typically involve job site separation into multiple bins or disposal areas. These activities can also take place off-site if space is not available on the project site.

LEED-NC rates the material and resource use in a project on these issues: Storage & Collection of Recyclables, Building Reuse, Construction Waste Management, Resource Reuse, Recycled Content, Regional Materials, Rapidly Renewable Materials and Certified Wood. The first one is a necessary prerequisite while thirteen possible points can be scored on the remaining seven credits.

3.4.1.5 Indoor environmental quality

Americans spend an average of 90% of their time indoors, where levels of pollutants may be two to five times–and occasionally more than 100 times–higher than outdoor levels, according to the U.S. Environmental Protection Agency. In its 1999 Air Quality Guidelines, the World Health Organization states that most of a person's daily exposure to many air pollutants comes through inhalation of indoor air. Many of these pollutants can cause health reactions in the estimated 17 million Americans who suffer from asthma and 40 million who have allergies. The Asthma and Allergy Foundation estimates that asthma cost the U.S. economy $10.7 billion in 1994 alone. Research over the past decade has increased our understanding of the indoor environment, revealing both problems and potential solutions. Major health disasters such as outbreaks of Legionnaires' disease and sick building syndrome have heightened the awareness of indoor air quality for building owners and occupants. An increasing number of legal cases emphasize the need for optimal indoor environmental quality (IEQ) strategies. Such strategies reduce potential liability for design team members and owners, increase the resale value of the building, and increase productivity of building occupants. In fact, case studies suggest that IEQ improvements can increase worker productivity by as much as 16%, resulting in rapid payback for IEQ capital investments (RMI, 1994).

IEQ strategies include issues related to indoor air quality (IAQ) such as increased ratios of filtered outside air, ventilation effectiveness, moisture management, and control of contaminants. Prevention of air quality problems is generally much less expensive than cleaning up after these problems occur. For example, it is inexpensive and sensible to sequence construction activities so that materials are kept dry and those that absorb contaminants are installed after other materials have had the opportunity to off-gas contaminants. Specifying materials that release fewer and less harmful contaminants is even better. Another strategy is to protect air handling systems during construction and perform a building flush-out prior to occupancy. To provide optimal air quality for building occupants over the lifetime of the building, automatic sensors and controls can be integrated with the HVAC system to adjust temperature, humidity, and the percentage of outside air introduced to occupied spaces. Sensors can alert building maintenance staff to potential IAQ problems such as carbon dioxide (CO2) build-up in occupied space. Other IEQ issues to consider include daylighting and lighting quality, thermal comfort, acoustics, occupant control of building systems, and access to views. All of these issues have the potential to enhance the indoor environment and optimize interior spaces for building occupants.

Minimum IAQ Performance and Environmental Tobacco Smoke (ETS) Control are considered are prerequisites in LEED-NC green building rating system. The quality of indoor environment is also rated on these following issues: Carbon Dioxide (CO2) Monitoring, Ventilation Effectiveness, Construction IAQ Management Plan, Low-Emitting Materials, Indoor Chemical & Pollutant Source Control, Controllability of Systems, Thermal Comfort and Daylight & Views. A maximum of fifteen points can be scored for these eight credits.

3.4.1.6 Innovation and design process

Sustainable design strategies and measures are constantly evolving and improving. New technologies are continually introduced to the marketplace and up-to-date scientific research influences building design strategies. The purpose of this LEED-NC category is to recognize projects for innovative building features and sustainable building knowledge. Occasionally, a strategy results in building performance that greatly exceeds those required in an existing LEED credit. Other strategies may not be addressed by any LEED prerequisite or credit but warrant consideration for their sustainability benefits. Finally, expertise in sustainable building is essential to the design and construction process. All of these issues are rewarded in this category.

3.4.2 LEED-H green homes rating system.

LEED for homes is focused on transforming the mainstream home building industry towards more sustainable practices. LEED for Homes aims to incorporate the following best-practice environmental features in homes: efficient use of energy resources; efficient use of water resources; efficient use of land resources; efficient use of building construction resources and enhanced indoor environmental quality. It is developed as a point based rating system based on building performance in seven broad areas. These are Location and Linkages (10% of points), Sustainable Sites (13% of points), Water Efficiency (11% of points), Indoor Environmental Quality (13% of points), Materials and Resources (22% of points), Energy and Atmosphere (27% of points) and Home Owner Awareness (1% of points). These seven categories account for 41 credits amounting to 104 core points. Four points are available for innovation in design process, thus making a total of 108 points. Some of these credits are mandatory while the others are optional. Variations due to changes in climate zones are accounted for in the rating system. Three precipitation zones are considered: Dry (< 20 inches/year), Normal (20-40 inches/year) and Wet (> 40 inches/year). Intents, mandatory and optional requirements, verification process, synergies and tradeoffs, rationale behind intent, strategies, and relevant resources define each credit. There are four levels of certification available, ranging from 'certified' (30 points) to platinum (90 points). Silver certification requires 50 points and gold, 70 points (LEED 2005b). The Indoor Environmental Quality category of LEED for homes is discussed in detail below.

3.4.2.1 Indoor environmental quality

The goal of rating this aspect in homes is to enhance the quality of indoor environment with the purpose of safeguarding the health of the home's occupants. This category in LEED-H has 10 credits among which some are wholly or partly mandatory:

1. ENERGY STAR with Indoor Air Package
2. Combustion Venting
3. Humidity Control
4. Outdoor Air Ventilation
5. Local Exhaust
6. Supply Air Distribution
7. Supply Air Filtering
8. Contaminant Control
9. Radon Protection
10. Vehicle Emissions Protection

Fourteen possible points can be scored in this section. There are two optional pathways for scoring in IEQ credits in this category. One option is to score ten possible points on the first credit by completing all of the requirements of EPA's ENERGY STAR Indoor Air Package. If this option is considered then credits 2, 3, 9, 10 and parts of 4, 5, 6, 7 and 8 must be skipped. The other option is to go through all credits from 2 through 10 individually for the maximum possible of fourteen points. The ten credits in this section is discussed in detail below.

Credit #1- ENERGY STAR with Indoor Air Package: The intent is to improve overall quality of indoor environment by installing an approved bundle of air quality measures. The ENERGY STAR with Indoor Air Package is a comprehensive set of indoor air quality measures that includes ventilation, source control, and source removal measures. All of the requirements of EPA's ENERGY STAR Indoor Air Package are to be completed for scoring this credit.

Credit #2 - Combustion Venting: The intent here is to minimize leakage of combustion gases into occupied space of home. Indoor air quality may be adversely affected by leakage of combustion exhaust gases into the home. Direct- or power- venting reduces the risk of combustion gases being drawn into the home when negative pressure occurs in the home. This credit is divided into two sub-credits and each of them is mandatory. The first sub-credit requires the designing and installation of HVAC and DHW combustion equipment with closed combustion if equipment is located inside the building envelope installing a CO monitor on each floor of the home. The second sub-credit mandates the proper design and installation of fireplace or no fireplace at all.

Credit #3 - Humidity Control: The intent is to provide a comfortable thermal environment in the home. Occupant comfort may be adversely affected by very high or very low humidity levels in the home. High humidity levels may also foster mold growth. If points are to be scored for this credit, moisture loads and need for a central humidity control system should be analyzed. Install humidity control system should be installed where needed to maintain humidity ratios below 0.012 (lb. water vapor / lb. dry air).

Credit #4 - Outdoor Air Ventilation: The intent is to protect occupants from indoor pollutants by ventilating with outdoor air. Occupant health and comfort may be adversely affected by poor ventilation in a home. Without adequate outdoor air ventilation, humidity, odors, and pollutants may accumulate within the home. This credit is divided into three sub-credits in which the first is mandatory and other two optional. Designing and installing a whole building ventilation system that complies with ASHRAE standard 62.2.4 comprises the mandatory sub-credit. Additional points can be scored by installing a dedicated outdoor air supply system that complies with ASHRAE Standard 62.2 and provides for heat transfer between the incoming outdoor air streams and exhaust air streams and has fully ducted supply and exhaust. Third-party testing of outdoor air flow rate into the home constitutes the third optional sub-credit.

Credit #5 - Local Exhaust: The intent is to remove indoor pollutants in kitchens and bathrooms. Odors, pollutants, and moisture may accumulate in kitchens and baths that have poor local exhaust. This credit is also divided into three sub-credits in which the first is mandatory and remaining two optional. The first sub-credit mandates the design and installation of local exhaust systems in bathrooms and kitchen per ASHRAE Standard 62.2, and use of ENERGY STAR labeled exhaust fans. The optional sub-credit requires installation of occupancy sensor or automatic humidistat controller or timer for bath exhaust fans to operate fan either for a timed interval after occupant leaves room or until humidity level is reduced. The third optional sub-credit requires third-party test of each of these systems.

Credit #6 - Supply Air Distribution: The intent is to ensure supply air is distributed adequately to conditioned spaces. The rationale is that occupant Comfort may be adversely affected by inadequate air distribution to each room in a home. This credit is divided into two sub-credits. The first sub-credit requires performing ACCA Manual D duct design calculations and installing ducts accordingly, and ensuring that every room has adequate return air flow or installing ductless space conditioning system. The second sub-credit requires testing total supply air flow rates in each room of home using a flow hood, and adjusting the flow rates using balancing dampers to ensure that supply air flow rates are within +/- 15% (or +/- 10 cfm) of calculated values from ACCA Manual J. The former is mandatory while the latter is optional.

Credit #7 - Supply Air Filtering: The intent is to remove particulate matter from supply air system. Inadequate air filtration may have adverse health effects. Improved air filters will help to remove more particles from the supply air stream. This credit is also divided into three sub-credits in which the first is mandatory and remaining two optional. The first sub-credit mandates the installation of air filters >/= MERV 8 and ensuring that air handlers can maintain adequate pressure, or installation of a ductless space conditioning system. Additional points can be scored by installing air filters >/= MERV 10 and ensure that air handlers can maintain adequate pressure. The third optional sub-credit requires the installation of HEPA air filters, and ensuring that air handlers can maintain adequate pressure.

Credit #8: Contaminant Control: The intent is to protect occupants from exposure to contaminants. Indoor air quality may be adversely affected by contaminants brought into home by occupants. Walk-off mats trap some of the dirt at the entryway that would otherwise be tracked into the home. Central vacuums exhaust collected dust and particulates to the outdoors.

Seal off ducts during construction OR clean HVAC ducts and coils before occupancy. This credit is further divided into three sub-credits in which the first is mandatory and remaining two optional. Designing and installing permanent walk-off mats at each entry, or installing central vacuum system with exhaust to the outdoors is mandatory. The optional second sub-credit requires third party testing for contaminant concentration prior to occupancy. Measuring and reporting concentration levels for listed contaminants comprises the third optional sub-credit.

Credit #9: Radon Protection: The intent here is to protect occupants from exposure to radon gas, and other ground contaminants. Occupant health may be adversely affected by the presence of radon gas. The first part of this credit mandates that if home is located in EPA Region 1, radon mitigation system must be designed and installed. The second part which is optional requires that if the home is NOT located in EPA Region 1, radon resistant construction techniques should be employed in its design and construction.

Credit #10 - Vehicle Emissions Protection: The intent is to protect occupants from exposure to car emissions. The rationale is that occupant health may be adversely affected by car emissions leaking from garage into home. This credit has two mandatory and one optional sub-credit. The first sub-credit mandates no air handling equipment, return ducts or un-sealed supply ducts in garage. Installation of CO detector in any occupied rooms above the garage and tightly sealing shared surfaces between garage and conditioned spaces is mandatory as per the second sub-credit. Points can be scored for the third sub-credit by installing minimum 100 cfm exhaust fan rated for continuous operation with automatic timer control linked to occupant sensor, light switch, or garage door opening/closing mechanism; or by avoiding contact of garage with conditioned spaces.

3.5 Analytic Hierarchy Process (AHP)

The Analytic Hierarchy Process (AHP) is a multiple criteria decision-making technique. This technique allows subjective as well as objective factors to be considered in the decision-making process. The user is allowed to assign relative weights in a logical manner for all factors involved in the decision making process through pair-wise relative comparison of those factors. The use of AHP entails the development of a tree-like hierarchical structure of the factors involved. The first step in AHP is to make a pair-wise comparison of all the elements belonging to the same level of hierarchy. The elements are then pair-wise compared with respect to an element in a higher level of the same hierarchy to show the relative importance of each element of the lower level with respect to that element in the higher level. A matrix of comparison is formed in which each element is an outcome of the pair wise comparison of all factors involved. A scale of relative importance is used for the purpose of pair wise comparison. The final step is to compute the vector of priorities. The vector of priorities outlines the relative weights of the elements of matrix considering their strength on influencing the main criterion with respect to which they are being compared. It is computed by normalizing the columns in the matrix of comparison and then adding the elements in each resulting row and dividing this sum by the number of elements in the row (Hass & Meixner 2005, Dey 2002).

In this thesis the AHP is adopted to determine the relative importance of building systems in respect to the health performance attributes and also the relative importance of each of these attributes. It should be noted that the application of AHP in this thesis is limited, since the process of assigning relative importance scores during pair wise comparison of building systems is based on author's knowledge of the subject. The application of AHP in assigning relative weights for building systems and attributes of IEQ is discussed in detail in Chapter 5 with an example.

3.6 Summary

This chapter is a review of the tools and techniques that were utilized for this research. The first two tools discussed in this chapter aids in the design and evaluation of the "Whole House". The Whole House Performance Calculator is a tool for the quantitative assessment of the performance of design and production processes, materials and systems, and the interaction between them for the purpose of comparative scoring. The Whole House Performance Criteria Framework aids in developing the criteria for the design and construction of home by adopting the concept of building systems integration. Sample application of these tools has been demonstrated as a part of this chapter.

Health impact matrix for planning, design and construction of built environment helps to systematically evaluate the negative effects associated with the built environment. The LEED green building criteria of USGBC has also been discussed in as a part of this chapter. The LEED-NC and LEED for homes rating systems have been discussed in detail. Finally the Analytic Hierarchy Process (AHP) has been discussed.

CHAPTER 4

HEALTH PERFORMANCE CRITERIA FRAMEWORK

4.1 Overview

This chapter includes a detailed description of the framework for health performance criteria for homes, based on LEED guidelines and building systems integration. The format and scoring system used are based on the Whole House Performance Criteria Framework (Swarup 2005), the Whole House Calculator (O'Brien et al. 2005) and LEED green building criteria (LEED 2003) which were discussed in Chapter 3.

The development of the health performance criteria framework comprises a series of steps starting with the analysis of health issues associated with indoor environments. Two different matrices have been developed for this analysis. They are described in detail in the following section. These health issues are then traced back to various physical, chemical and biological interactions in the indoor environment. The health performance of a home can be improved by implementing the building systems integration approach that will eliminate negative interactions while promoting synergistic associations between various building components. The negative interactions and synergistic associations are identified by studying the various physical, chemical and biological interactions; involved building systems and health performance attributes. The building systems and various health performance attributes are also defined as a part of the process. This analysis is then utilized to develop broad goals that will promote health performance of homes. Strategies are developed based on the goals that will promote the health performance.

The health performance criteria helps to evaluate the strategies during the design and construction stage based on two attributes – performance and interaction. The framework helps to score strategies based on their ability to insure health performance of homes and the degree of synergism that exists between various implemented strategies. This will insure health performance of homes devoid of negative interactions that will affect the performance of homes.

4.2 Health matrix based on LEED requirements

Indoor environment and external environment are interconnected. The LEED green building criteria utilizes the systems approach in an effort to minimize environmental damage attributable to buildings, while enhancing occupant health, safety and comfort. So in an effort to study the health impacts of buildings the LEED criteria was selected as a starting point. The health impacts of LEED for New Construction (LEED-NC) and LEED for Homes (LEED-H) green building criteria (LEED 2003, LEED 2005) are analyzed by means of a health matrix. LEED-NC and LEED-H have been discussed in detail in Chapter 3. The LEED health matrix was developed as a part of this thesis to systematically relate each of the LEED credits to direct and indirect health effects on the building occupants. It is a step by step method for analyzing the health impacts of LEED green building criteria and then associate them with interactions and possible solutions through building systems integration. The intents of each credits is analyzed in detail to associate it to relevant direct and indirect health effects. Supporting literature connects the intent with direct and indirect health effects.

4.2.1 The LEED-NC health matrix

The LEED-NC (LEED 2003) health matrix has five columns for each LEED credit. The first column lists the intent and rationale of a particular LEED credit. For example the intent of "Credit 2 – Ventilation Effectiveness" in the Indoor Environmental Quality section of LEED-NC, is to protect occupants from indoor pollutants by ventilating with outdoor air. Health effects and supporting literature comprises the second major column, which has two subsections. The first subsection lists the direct health effects associated with the particular LEED-NC credit, and the second one lists the indirect health effects. Direct health effects are more physiological in nature while indirect health effects address comfort problems and latent physiological effects. For example the direct health effect for the previously mentioned credit can be irritant effects or cancer associated with indoor air pollutants, since ventilation is the transport mechanism for many of these pollutants. Perceived air quality of air polluted by human bio-effluents and tobacco smoke is an indirect effect associated with ventilation rate. The third column in the health matrix comprises of broad guidelines from LEED to achieve the stated intent. The fourth column lists possible positive and negative interaction scenarios associated with the particular intent. The information in this column is extracted from LEED criteria and other sources. For example when designing for outdoor air ventilation, the interactions arising due to natural air leakage through the envelope should be considered. This is important from both health and energy perspectives. The last column in the LEED-NC health matrix lists the building systems integration aspects associated with that particular credit. A section of the actual matrix developed has been included in Table 4.1 and the complete framework is provided in the Appendix.

4.2.2 The LEED-H health matrix

The LEED-H (LEED 2005) health matrix follows the same format of the LEED-NC health matrix. But it is focused on the Indoor Environmental Quality section of LEED-H criteria and is more comprehensive in nature when compared to the LEED-NC health matrix. LEED-H has been discussed in detail in the Chapter 3. The Indoor Environmental Quality section of the LEED-H criteria has 10 credits and these have been systematically analyzed in the matrix to associate them to direct and indirect health effects. A section of the actual matrix developed has been included in Table 4.2 and the complete framework is provided in the Appendix.

4.3 Health impacts of green buildings on occupants

The direct health impacts include respiratory ailments from inhaling air pollutants, decreased lung function, asthma, severe allergic reactions; nonspecific hypersensitivity, bronchitis, pneumonia; mutagenicity and carcinogenicity; eye, nose and throat irritation, changes in skin temperature; headaches, fatigue, lethargy disorientation, visual distortion, nausea; hypersensitivity pneumonitis, Legionnaires' disease pulmonary hemorrhage, rheumatic diseases; toxic and systemic effects; eyestrain, eye irritation; skin irritation and rashes, erythema (skin redness); reproductive problems; cardiovascular effects; musculoskeletal problems; sleep disturbance, hearing problems; disruption of human circadian clock and stress related problems. In worst cases even death can result. The indirect health impacts include a range of comfort issues, perceived air quality, ability to concentrate, productivity, annoyance, interference with communication and effects on

LEED checklist item	LEED intent	Health Effects and Supporting literature		LEED broad guidelines	LEED: Specific design and construction procedures	Building systems: D/C/M/I aspects
Credit 3.1: Construction IAQ Management Plan: (During Construction)	Prevent indoor air quality problems resulting from the construction/renovation process in order to help sustain the comfort and well-being of construction workers and building occupants.	▪ Construction and renovation projects may present a wide range of situations where release of contaminants and pollutants occurs and the indoor air quality (IAQ) of the building is adversely affected. ▪ Indoor air contaminants generated by construction activities include vapors, particles and microbial aerosols. ▪ Workers in the industry can be exposed to these pollutants and subsequent negative health effects.	No indirect health effect.	Develop and implement an Indoor Air Quality (IAQ) Management Plan for the construction and pre-occupancy phases of the building as follows: ▪ During construction meet or exceed the recommended Design Approaches of the Sheet Metal and Air Conditioning National Contractors Association (SMACNA) IAQ Guideline. ▪ Protect stored on-site or installed absorptive materials from moisture damage. ▪ If air handlers must be used during construction, filtration media with a Minimum Efficiency Reporting Value (MERV) of 8 must be used at each return air grill, as determined by ASHRAE 52.2-1999. ▪ Replace all filtration media immediately prior to occupancy.	▪ Adopt an IAQ management plan to protect the HVAC system during construction, control pollutant sources and interrupt contamination pathways. ▪ Sequence the installation of materials to avoid contamination of absorptive materials such as insulation, carpeting, ceiling tile and gypsum wallboard.	▪ Adequate planning and communication prior to the construction phase. ▪ Specify materials with minimal contaminant generation. ▪ Site construction related equipment should be located away from the building access areas and from air intakes. ▪ Modify air intakes with adequate filtration. ▪ Provide negative pressure in work areas and filter any air discharged outside. ▪ Test and monitor ventilation and exhaust airflow for suspected contaminant particles and gases during construction (Kuehn 1998). ▪ Schedule construction/installation.

Table 4.1: LEED-NC health matrix

LEED checklist item	LEED Intent & Rationale	Health Effects and Supporting literature		LEED broad guidelines	LEED: Interaction Scenarios
		Direct Effects	Indirect Effects		
Credit 4: Outdoor Air Ventilation	**Intent**: Protect occupants from indoor pollutants by ventilating with outdoor air. **Rationale**: Occupant health and comfort may be adversely affected by poor ventilation in a home. Without adequate outdoor air ventilation, humidity, odors, and pollutants may accumulate within the home.	▪ Outdoor air ventilation dilutes the indoor generated pollution. But ventilation is also the transport mechanism for indoor air pollutants into the building. Exposure to pollutants in indoor air may cause a variety of health effects ranging from irritant effects to cancer. ▪ Ventilation may dilute the concentration or disperse airborne virus or bacteria that can cause infectious diseases. ▪ Indoor humidity is influenced by ventilation rates. Very high humidity indoors is associated with an increased growth of microorganisms such as mold, bacteria and dust mites (ECA 2003). ▪ Moisture damage and microbial growth in buildings have been associated with a number of health effects including respiratory symptoms (Bornehag et al. 2001). ▪ Mold exposure is associated with risk of asthma.	▪ Outdoor air ventilation dilutes the indoor generated pollution. But ventilation is also the transport mechanism for indoor air pollutants into the building. Exposure to pollutants in indoor air may cause a variety of health effects ranging from perception of unwanted odors to other comfort problems (ECA 2003). ▪ There is a strong association between ventilation and comfort (as indicated by perceived air quality (Wargocki et al. 2002). ▪ Ventilation rate is an effective method of improving the perceived quality of air polluted by human bio-effluents and tobacco smoke(Cain et al. 1983). ▪ Ventilation rate is an effective method of improving the perceived quality of air.	▪ Design and install a whole building ventilation system that complies with ASHRAE Standard 62.2.4. Alternative (e.g.: passive) ventilation designs should also be considered. ▪ Install dedicated outdoor air supply system that complies with ASHRAE Standard 62.2, AND provides for heat transfer between the incoming outdoor air stream and exhaust air streams (except in very mild and dry climates), AND has fully ducted supply and exhaust. ▪ Third-party testing of outdoor air flow rate into the home.	▪ Natural air leakage through the envelope contributes to the overall ventilation rate of the home. From a health perspective, it is important to not "under-ventilate" a home. ▪ However, from an energy perspective, it is also important not to over-ventilate a home. In extreme hot or cold climates, it can cost up to 2 dollars per year to condition each additional cfm of outside air brought into a home.

Table 4.2: LEED-H health matrix

social behavior (Southface 2002, Hawks & Hansen 2002, DoH Washington 1999, Jaakkola et al. 1999, LHC 1990).

4.3.1 Relevant physical, chemical and biological interactions and processes

Health impacts associated with buildings, as identified using the LEED health matrices can be traced back to various physical, chemical and biological interactions and processes. Literature study done as a part of Chapter 2 will help to map the connection between health effects and these interactions. Physical and chemical interactions involve air flow, air mixing and energy transfer through envelope induce changes in temperature, humidity ventilation effectiveness, airborne level of indoor pollutants, condensation, sorption, volatilization and dissolution processes, hydrolysis, photolysis, redox reactions etc. Biological interactions are often moisture related and involve microbial growth. Many of these processes are often interrelated and the effects they cause are a result of combined action (Arens & Baughman 1996a, Arens & Baughman 1996b). The detailed analysis of these physical, chemical and biological interactions associated with indoor environment helps to better understand the issue of health performance of homes.

4.3.2 Health performance attributes

Through literature study seven attributes have been identified for defining the health performance of a home. They include:

- *Indoor Air Quality - Presence of Indoor air pollutants*: This includes both chemical (VOC, nitrogen oxides, carbon dioxide, carbon monoxide asbestos etc.) and biological (mold, pollen, dust mites) pollutants in indoor home environments.

- *Temperature*: Room temperature has a crucial role in the health and comfort performance of homes.
- *Humidity/moisture*: Correlations exist between indoor air humidity and health performance of homes. This attribute is also important from a comfort point of view. Moisture in the indoor environment is an important variable to be considered when designing healthy homes.
- *Ventilation*: Literature study done in Chapter 2 suggests that ventilation has a very crucial role in maintaining a health and comfortable indoor environment.
- *Lighting*: Lighting is an integral factor of indoor environment and hence is inextricably related to the health performance of homes. Daylighting possess superior qualities over typical electrical lighting.
- *Acoustics*: Noise related problems have significant impacts on health performance of homes.
- *Ergonomic Design and Safety issues*: Defective design can result in hazards and discomfort.

All of these attributes are discussed in detail as a part of Chapter 2.

4.4 Defining building systems

The research effort in this thesis involves the improvement of health performance of homes by implementing building systems integration principles to counter the effect of negative interactions in homes. So it is necessary to define the building systems, which must be integrated in the design of a home. The following six building systems have been determined for the purpose of this thesis, from the perspective of health performance.

This definition of building systems closely follows the method adopted in the Whole House Performance Criteria Framework (Swarup 2005):

- Envelope - That part of the building that protects the occupants from climate and other natural forces. In most cases it also provides stability to the home and allows it to stand.
- Heating Ventilation and Cooling (HVAC) - The building system that tempers the living environment for comfort.
- Plumbing - The building system that provides water supply to all outlets.
- Electrical/Communication - The building system that provides electrical supply to run all home appliances and support systems. It also includes communication supply such a phone, cable and Internet.
- Lighting - The building system that provides both artificial and natural lighting inside the home. Artificial lighting systems include light fixtures and natural lighting systems include windows, skylights, light wells etc.
- Interior– The building system that make up the interior of the home, composed of movable elements including finishes and furnishings like furniture, movable storage, carpet, drapes etc. It also includes elements that are visible from the inside of the home and are in some manner connected to the structure or the envelope like partition walls, ceilings etc.

4.4.1 Health performance goals

These goals are framed with the intent of improving the health performance of a home. These goals require the application of the building systems integration concepts in the design and construction of a home. These goals are developed by analyzing the following factors:

- Health/comfort effects identified using LEED matrices
- Relevant Physical, Chemical and Biological interactions and processes
- Attributes of health performance involved in a particular interaction

An example scenario will adequately explain the development of these goals. When we look at "Credit 2 – Humidity Control" in the Indoor Environmental Quality section of the LEED-H criteria, several associated health effects can be observed. Humidity levels are associated with respiratory ailments, hypersensitivity pneumonitis and asthma. Humidity levels can also influence local thermal comfort. These effects can be traced back to physical, chemical and biological processes in the indoor environment. Elevated humidities in the indoor environment can be traced back to moisture infiltration through envelope due to temperature and vapor gradients between indoor and outdoor environments; moisture released in bathroom and kitchen due to occupant activities like showering and cooking; rise of dampness through the structure; faulty mechanical equipment; or condensation of water vapor in homes due to microclimate formation. Moisture may be retained inside building materials due to their non-breathable nature.

Humidity levels can influence growth and spread of biotic agents including pathogens, mold, mites etc and release of aerosols and VOCs from building materials. Formaldehyde off gassing from pressed wood products is related to levels of humidity. In most cases interactions induced by humidity are also a function of temperature. So the health performance attributes involved in this scenario include humidity/moisture, temperature and presence of indoor pollutants. The health performance goals developed to achieve better health performance for this scenario include the following: reducing moisture infiltration through envelope; reducing moisture infiltration through structure; reducing interior moisture levels through mechanical equipment; reducing interior moisture levels by controlling occupant activities; preventing condensation in homes; preventing chances of biotic growth in the indoor environment; and preventing chances of VOC release in the indoor environment associated with humidity. The framework of the goal development analysis involving the above mentioned example has been included in Table 4.3.

4.4.2 Building systems Design/Construction/Integration strategies

The building systems design/construction/integration strategies are developed from the health performance goals developed in the last section. The strategy is the process that will be employed to achieve the goal. These strategies are compiled through literature studies done as a part of Chapter 2. These strategies take into account health performance and integration potential between building systems. By analyzing the health performance goals and driving processes behind IEQ issues, the relevant building systems that require design/construction/integration treatment are identified. The intent is to improve health performance through design/construction/integration strategies that will enhance synergistic associations. For example, to address the goal of reducing the moisture infiltration into the structure through envelope two building systems have been identified as relevant – envelope and HVAC. Two strategies involving these two building systems are available to achieve the goal: tight envelope construction to prevent moisture infiltration; and maintaining high pressure inside buildings to prevent moisture infiltration. Table 4.3 explains the strategy development process in greater detail with an example. Figure 4.1 depicts the model adopted for generating the health performance goals and building systems design/construction/integration strategies.

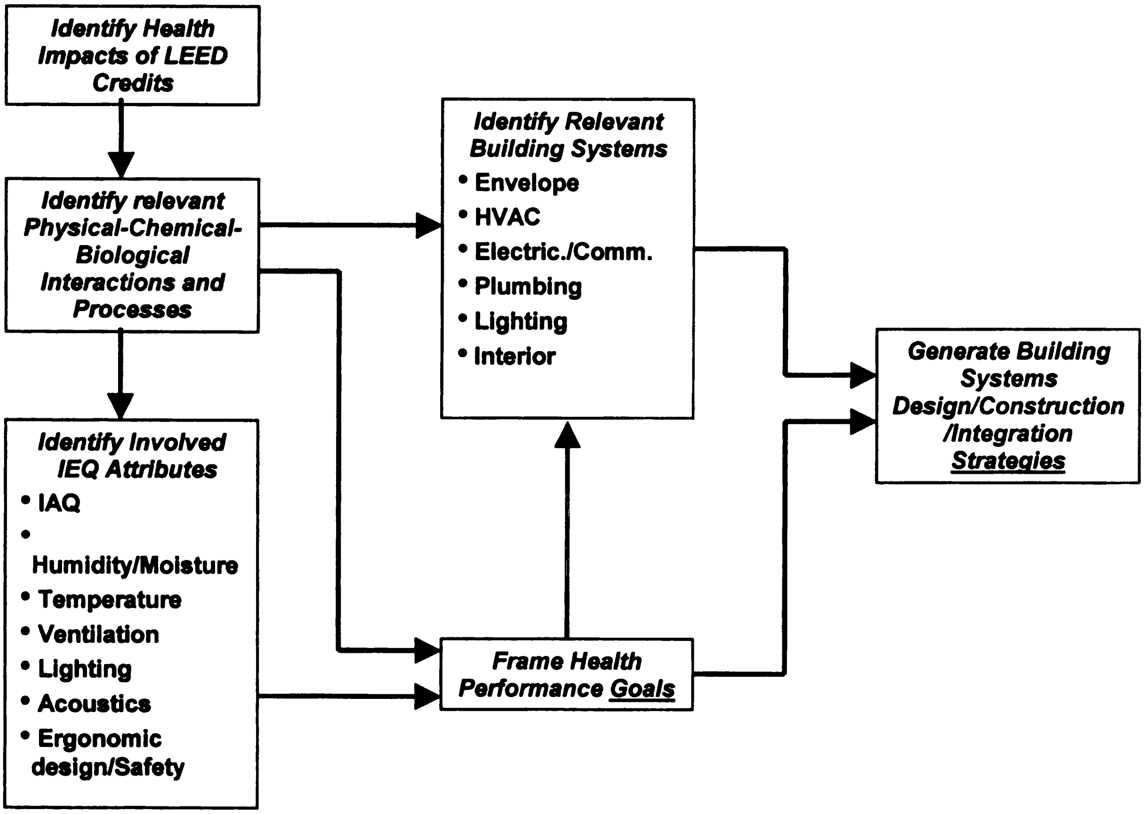

Figure 4.1: Model for generating health performance goals and building systems D/C/I strategies

4.5 Health performance criteria framework

The Health Performance Criteria Framework is integrated into the broader Whole House Performance Criteria Framework (Swarup 2005). This framework is based on the LEED guidelines. Some features of the Whole House Calculator (O'brien et al. 2005) are also utilized for developing the Health Performance Criteria Framework. The Whole House

Health Impacts	Relevant P-C-B interactions and processes	Involved IEQ attributes	Health Performance goals and involved building systems	Building systems design/construction/integration strategies
CREDIT: HUMIDITY CONTROL ▪ Infectious diseases caused by pathogens. ▪ Asthma caused by mites, mold and animal dander. ▪ Hypersensitivity pneumonitis caused by fungi and bacteria. ▪ Respiratory ailments caused by aerosols. ▪ Susceptibility to biological and non-biological pollutants. ▪ Local thermal comfort. ▪ Perception of IAQ. ▪ Static electricity hazards.	▪ Pathogens colonize in moist environments and become airborne given proper conditions. ▪ Growth and spread of biotic agents under elevated humidities. ▪ Dust collected in humid areas promotes biotic growth. ▪ Fungi can produce VOC that can be harmful for health. ▪ Formaldehyde off gassing from pressed wood products is related to levels of humidity. ▪ Nitrogen and sulphur dioxide present in indoor environment react with water on indoor surfaces to form aerosols. ▪ Moisture infiltration through envelope due to temperature and vapor gradients between indoor and outdoor environments.	**IAQ** **Humidity/moisture** **Temperature** **Ventilation** **Lighting** **Acoustics** **Ergo. design/safety**	▪ Reduce moisture infiltration (air). Envelope HVAC ▪ Reduce moisture infiltration (structure). Envelope HVAC Electrical Plumbing Communication Interior ▪ Reduce humidity/moisture levels in homes. HVAC ▪ Reduce moisture level in homes (occupant activities). HVAC	▪ Tight envelope construction to prevent moisture infiltration. ▪ Maintain high pressure inside buildings to prevent moisture infiltration through external air. ▪ Slope roof to prevent moisture infiltration. ▪ Roof overhang. ▪ Foundation waterproofed and insulated to prevent moisture infiltration and dampness. ▪ Reduce service duct runs through envelope. ▪ Properly design electrical fixtures in the exterior. ▪ Soil grading to be done away from the building. ▪ Site drainage. ▪ Gutter positions. ▪ Protect building materials from the elements during construction. ▪ HVAC to maintain proper humidity levels. HVAC system design should take into account moisture due to infiltration and occupant activities. ▪ Bathrooms and kitchens mechanically vented. ▪ Bathroom/kitchen venting should take into account problems due to negative pressure.

Table 4.3: Framework for generating Health performance goals and Building systems D/C/I strategies

Performance Criteria Framework and Whole House Calculator have been discussed in detail in Chapter 3. This framework will help to systematically tabulate all the goals and strategies that go into the design and construction of a healthy home. The main intent is to evaluate a particular combination of strategies chosen for designing and construction of a healthy home. The evaluation is attained by means of a scoring system which takes into account the health performance potential of a particular strategy and its degree of synergism compared to other prospective strategies. For the purpose of evaluation the concept of an ideal healthy home is introduced. This ideal "Whole House" epitomizes the situation where all involved building systems work synergistically, thereby enhancing the health performance of the home and avoiding any negative interaction.

4.5.1 Structure of the health performance criteria framework

The proposed framework has two sections – one for compiling health performance goals and the other one for building systems design/construction/integration strategies. The goals section lists all building elements against the seven health performance attributes identified in the previous section. Each health performance goal is to be compiled against the particular building system and the performance attribute to which it is more associated with. For each building system the goals are segregated into two design considerations: architectural design and engineering design. Architectural design consideration involves specifics, such as space usage in terms of placement of units and arrangement of partitions. Engineering design encompasses all services design issues. The health performance goal specified under each design consideration for each building system is then associated with a building systems design/construction/integration strategy in the next section of the framework. The strategies are specific to the user and may be tabulated as per the individual expertise. The strategies section has provisions for scoring the performance and interaction potentials of each listed strategy. Figure 4.2 and Figure 4.3 shows in detail the structure of Health Performance Criteria Framework. The complete framework is included in the appendix.

4.5.2 Scoring system for the health performance criteria framework

Each building systems design/construction/integration strategy is scored for performance and interaction. Performance score of a strategy denotes its ability to deliver the required health performance. Interaction score denotes the degree of synergism of that particular strategy in combination with other strategies. The scoring system is modified from the "Whole House Calculator" and the "Whole House Performance Criteria Framework". Each building system and attribute of IEQ is associated with a certain weight that refers to the role of the strategies pertaining to that building system or the attribute, in the overall performance of the home. The building system or attribute that affects the performance of the home to a large degree is given a larger weight than others. The weightage/credit system defines the level of importance of each building system within the complete design of the home. Analytic Hierarchy Process (AHP) is adopted to determine the weightage of each the building system in respect to the health performance parameters. The application of AHP in assigning relative weights for building systems and attributes of IEQ is discussed in detail in Chapter 5 with an example.

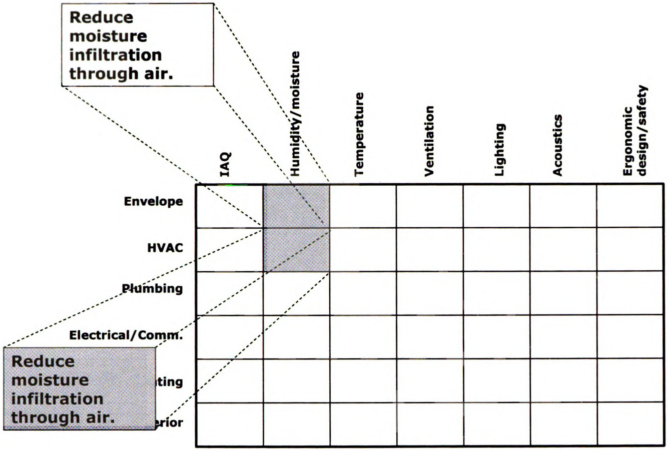

Figure 4.2 - Health Performance Criteria Framework - Health performance goals

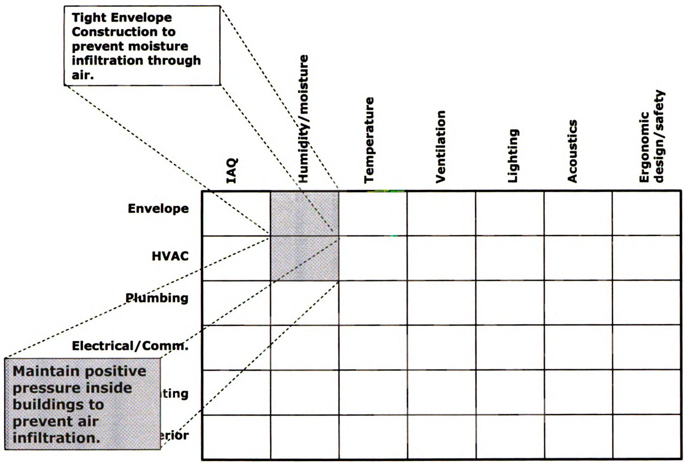

Figure 4.3 - Health Performance Criteria Framework - Building systems D/C/I strategies

Performance scoring

The performance scoring (*Ps*) in Health Performance Criteria Framework follows the same format of Whole House Performance Criteria Framework. The scoring will be conducted on a scale of 1-5, where 1 represents the least effective strategy and 5, being the most effective strategy. The weighted performance factor (*Pf*) for a particular strategy is the product of the performance score (Ps), the weightage of the building system and the weightage of attribute of IEQ it is associated with.

Pf = *Ps* X *relative weight of building system* X *relative weight of attribute of IEQ* **(Eq 1)**

Interaction scoring

The interaction scoring in Health Performance Criteria Framework is adapted from Whole House Calculator. Each of the strategies is compared with the other strategies for identifying synergistic interactions. The strategies are grouped as synergistic combinations and dyssynergistic combinations to determine the interaction score. A synergistic combination will result in an improvement in the health performance of homes. A dyssynergistic combination will result in degradation in the health performance of homes. The combinations are scored on a scale from 1 to 5. The scoring system for the combinations is as follows:

1 represents a combination which results in a major degradation of health performance.

2 represents a combination which results in a minor degradation of health performance.

3 represents a combination which has no effect on health performance.

4 represents a combination which results in a minor improvement of health performance.

5 represents a combination which results in a major improvement of health performance.

Intermediate values represent degrees of performance degradation or improvement. After scoring each strategy on this scale, a total score is determined for each strategy (*Is*) by obtaining the average of all the individual combination interaction scores.

$$Is = \frac{\sum \text{interaction scores of combination involving a particular strategy}}{\text{number of combinations involving that particular strategy}} \qquad \textbf{(Eq 2)}$$

Whole House Health Performance Score (Hs)

The Whole House Health Performance Score is obtained in two steps. The performance factor *(Pf)* of each strategy is multiplied with its interaction score *(Is)*. These values for all the strategies are summed up together to obtain the Whole House Health Performance Score (*Hs*).

$$Hs = \sum (Pf \text{ X } Is) \qquad \textbf{(Eq 3)}$$

The resultant value is compared with the score of the ideal "Healthy home". This is obtained by assigning a performance score of 5 and an interaction score of 5 for all the strategies. This will give the user an idea of how close the case study design comes to being an ideal "Healthy home" design. The ideal score has been calculated as 6680.

4.6 Summary

This chapter discusses in detail the development of the Health Performance Criteria Framework. The LEED matrices for identifying the health impacts of buildings are discussed in the first section. The identified health effects were then traced back to several physical, chemical and biological interactions associated with the indoor environment. These interactions were then linked to health performance attributes. This analysis was used to develop health performance goals and building systems design/construction/integration strategies. The health performance criteria framework is developed with the intent to systematically compile these goals and strategies. A scoring system was developed to evaluate the effectiveness of the strategies in achieving health performance. Finally the ideal "Health house" score was developed to compare individual scores of case study houses.

CHAPTER 5

FEEDBACK AND CASE STUDY APPLICATIONS

5.1 Overview

In Chapter four, the Health Performance Criteria Framework was presented as a planning and evaluation tool for the health performance of homes. In this chapter the framework will be applied to three case study homes and feedback will be obtained from industry experts. The three case studies include a site built home, a factory built home and a combination of both – the hybrid home. All three of them are assumed to be LEED certified homes and will employ the strategies outlined in the LEED rating system for homes. The scoring system that was developed as a part of the last chapter will be applied to these case study homes and a final health performance score will be obtained. These scores will be compared to the ideal health performance score of a hypothetical healthy home to ascertain the effectiveness of strategies employed in these homes in ensuring the health and comfort of occupants. The case studies will help in measuring how the performance of the strategies employed in the design and construction of homes and various interactions between them will impact the health and comfort of occupants.

5.2 Sample "Health Performance Criterion"

A sample health performance criterion has been developed based on LEED for homes guidelines. This criterion will be applied to the three case study homes to evaluate their health performance. This criterion has five components:

1. Building systems: These six building systems have been identified and defined as a part of Chapter 4. These are Envelope, HVAC, Plumbing, Electrical and Communication, Lighting and Interior systems.

2. Design considerations: Each building system is further defined in terms of two major design considerations – architectural and engineering. The architectural design consideration includes all general design related issues, such as space usage in terms of placement of units and arrangement of partitions. Engineering design encompasses all services design issues and any other special considerations.
3. Health performance attributes: These seven attributes have been identified and established through literature study conducted as a part of Chapter 2. They collectively determine the quality of the indoor environment and thereby the health and comfort of occupants. The attributes include aspects of Indoor Air Quality (presence of indoor air pollutants), Humidity/Moisture, Temperature, Ventilation, Lighting, Acoustics and Ergonomic Design/Safety.
4. Goals for improving the health performance: These goals have been extracted from the analysis of health/comfort impacts associated with the LEED for Homes green building rating system. They are listed against the respective building system and health performance attributes discussed above in the goals section of the criteria.
5. Strategies for improving the health performance: These strategies aim to improve the health and comfort of occupants by employing the concept of building systems integration. These strategies were developed based on the goals for improving the health performance discussed above. Seventy strategies have been defined for the purpose of evaluating the health performance of case study homes. These strategies will be rated based on their

effectiveness in improving the health performance and the various interactions between them.

5.3 Scoring system for the sample criterion

The scoring system used here is based on the "Whole House Calculator" and the "Whole House Performance Criteria Framework". This system has been discussed in detail in Chapter 4. Weighting factors are applied to both the health performance attributes and the building systems that will highlight the importance of each of them in the health performance of a home. Analytic Hierarchy Process (AHP) is adopted to determine the weightage of each of the building system in respect to the health performance attributes and also the relative importance of each of these attributes. This process has been demonstrated here for the sake of conducting the cases studies. It is based on the author's understanding of the relative importance of various building systems and health performance attributes.

5.3.1 Relative weights of building systems and health performance attributes

The use of AHP requires the development of a tree-like hierarchical structure of all the factors involved. Analytic Hierarchy Process allows the user to assign relative weights in a logical manner through pair-wise relative comparison of these factors. The Health Performance Criterion has a three tier hierarchy. The lower tier consists of all the building systems, the middle one includes all the health performance attributes and the upper one is the health performance of the home. The first step in AHP is to make a pair-wise comparison of all the elements belonging to the same tier of hierarchy. The elements are pair-wise compared with respect to an element in a higher tier of the same hierarchy to show the relative importance of each element of the lower tier with respect to that element in the higher tier (Hass & Meixner 2005). Here the building systems in the lower tier are pair-wise compared to determine their level of impact on each of the health performance attributes. For example the 'envelope' will be compared pair-wise to the remaining five building systems to determine its impact on humidity/moisture performance. Further each of the health performance attributes will be compared against each other to determine their relative importance for the health performance of the home. For example the 'humidity/moisture' performance will be compared with the rest of the six attributes to decide its relative importance in ensuring the health and comfort of occupants. For the purpose of pair-wise comparison the following scale is used.

Intensity	Definition	Explanation
1	Equal importance	Two activities contribute equally to the object
3	Moderate importance	Slightly favors one over another
5	Essential or strong importance	Strongly favors one over another
7	Demonstrated importance	Dominance of the demonstrated importance in practice
9	Extreme importance	Evidence of favoring one over another of highest possible order of affirmation
2, 4, 6, 8	Intermediate values	When compromise is needed

Table 5.1: Scale of relative importance for pair-wise comparison (Dey 2002)

For example, while comparing 'x' and 'y' for criterion 'a', if 'x' has essential importance over 'y' intensity level 5 is chosen. So if (x,y) represent the relative importance of 'x' against 'y' for criterion 'a', then (x,y) = 5 and (y,x) = 0.2.

The various steps in AHP employed for establishing the relative importance of the factors in the Health Performance Criterion are detailed out below. First the six building systems are pair-wise compared to determine their levels of impact on each of the health performance attributes. For example, the following matrix shows the pair-wise comparison of envelope, HVAC, plumbing, electrical/communication, lighting and interior systems to determine their levels of impact on the health performance attribute of IAQ - presence of indoor pollutants.

IAQ - presence of indoor pollutants

	Envelope	HVAC	Plumbing	Electrical	Lighting	Interior
Envelope	1	0.33	5	5	5	1
HVAC	3	1	5	7	5	3
Plumbing	0.2	0.2	1	3	3	0.33
Electrical	0.2	0.14	0.3	1	1	0.2
Lighting	0.2	0.2	0.3	1	1	0.33
Interior	1	0.3	3	5	3	1

Table 5.2: Matrix of comparison for building systems affecting IAQ

The next step in AHP is to calculate the sum of all elements in a column and divide each element in that column by this sum. This process is known as normalizing the column. The normalized matrix looks as follows:

IAQ - presence of indoor pollutants

	Envelope	HVAC	Plumbing	Electrical	Lighting	Interior
Envelope	0.18	0.15	0.34	0.23	0.28	0.17
HVAC	0.54	0.46	0.34	0.32	0.28	0.51
Plumbing	0.04	0.09	0.07	0.14	0.17	0.06
Electrical	0.04	0.06	0.02	0.05	0.06	0.03
Lighting	0.04	0.09	0.02	0.05	0.06	0.06
Interior	0.18	0.14	0.21	0.23	0.17	0.17

Table 5.3: Normalized matrix for building systems affecting IAQ

The final step in AHP is to add all the elements in a row of the normalized matrix and divide it by the number of elements in that row. The new value obtained is the relative weight for the building system represented by that row. The relative weights for the six building systems are shown in the following table:

IAQ - presence of indoor pollutants

	Envelope	HVAC	Plumbing	Electrical	Lighting	Interior
Relative Weights	0.22	0.41	0.09	0.04	0.05	0.18

Table 5.4: Relative weights for building systems affecting IAQ

The steps outlined above are conducted for the rest of the health performance attributes and relative weights are obtained. These are shown in the following table. The relative weights are rounded off to the nearest multiple of 5 and then multiplied by 10. So effectively 10 points are distributed among the six building systems for each of the health performance attribute, in accordance to their relative weights.

	Envelope	HVAC	Plumbing	Electrical	Lighting	Interior
IAQ	2.00	4.00	1.00	0.50	0.50	2.00
Humid./Moisture	2.50	2.50	1.50	0.50	0.50	2.50
Temperature	2.50	4.00	0.50	0.50	0.50	2.00
Ventilation	2.00	4.00	1.00	0.50	0.50	2.00
Lighting	2.00	0.50	0.50	0.50	3.50	3.00
Acoustics	3.50	1.50	1.00	0.50	0.50	3.50
Ergo./safety	3.00	1.00	1.00	1.00	1.00	3.00

Table 5.5: Adjusted relative weights for building systems affecting health performance attributes

The process is continued for the next level of hierarchy to establish the relative importance of the health performance attributes with respect to the health performance of the home. These values are shown in the following table.

	Health Performance of the Home						
	IAQ	Humidity/ Moisture	Temperature	Ventilation	Lighting	Acoustics	Ergono. Des./ Safety
Relative weights	3.50	2.00	1.50	1.50	0.50	0.50	0.50

Table 5.6: Adjusted relative weights for attributes affecting the health performance of a home.

While scoring a particular strategy for performance, the relative weight of the building system and the health performance attribute to which it is most associated, is taken into consideration. The product of relative weights of the building system and the health performance attribute will adequately reflect the effect of the strategy's performance on the overall health performance of the home.

5.4 Case study applications

This section deals with the application of the sample "Whole House" performance criterion developed to three distinct case studies, site-built home, factory-built home and finally hybrid home. A major homebuilder has provided the case studies for the site-built home and the hybrid home. Both homes are based on the same design but have different approaches to construction. For the factory-built home case study, a hypothetical, double section factory built home similar to the other two case studies was developed. The rating associated with each strategy is based on the understanding of the researcher but will be corroborated with a discussion of the specific strategy used within the design.

5.4.1 LEED assumptions

All the case study homes are assumed to be LEED homes. Several assumptions are made so that they will satisfy the LEED for homes rating system. These are discussed in detail below. The credits that have significant impact on health and comfort of occupants are given more importance.

It is assumed that all of the case study homes are located in a LEED certified neighborhood with minimum disturbance to the site. The other assumptions are listed below.

- Rainwater harvesting system and grey water re-use system will be installed.
- Very high efficiency plumbing fixtures will be used throughout the homes.
- A CO monitor will be installed on each floor of home.

- HVAC and DHW combustion equipment with closed combustion is installed if equipment is located inside the building envelope.
- Direct venting installed in kitchen.
- Humidity control system will be installed.
- Whole building ventilation system that complies with ASHRAE Standard 62.2 will be installed.
- Dedicated outdoor air supply system that complies with ASHRAE Standard 62.2 and that which provides for heat transfer between the incoming outdoor air stream and exhaust air streams and that which will have fully ducted supply and exhaust will be installed.
- Local exhaust systems in bathrooms and kitchen per ASHRAE Standard 62.2 will be installed.
- Timer for bath exhaust fans to operate fan for a timed interval after occupant leaves room.
- HEPA air filters will be installed and ducts will be sealed off during construction.
- Permanent walk-off mats to be installed at each entry.
- Home is NOT located in EPA Region 1, so only radon resistant construction techniques are to be installed.
- No air handling equipment, return ducts or un-sealed supply ducts are located in the garage. There is also a 100 cfm exhaust fan rated for continuous operation with garage door opening/closing mechanism.
- No extra lumber may be used for purely aesthetic purposes.
- Space joists & studs greater than 16"OC with two stud corners.

- Headers have been sized for actual loads.
- Design roof pitch/eave width to 24" module.
- It is assumed that all the building materials or products have been extracted, harvested, recovered and manufactured, within 500 miles of the home.
- A detailed durability plan is in place.
- Environmentally preferable products are used throughout the home with reduced jobsite waste.
- Insulation is installed in such a way so as to minimize thermal bridging.
- Air leakage rate from envelope will be </= 0.25 ACH.
- Windows exceed requirements for ENERGY STAR labeled windows by 10%.
- Air leakage rate from air ducts will be </= 3.0 CFM at 25 PA per 100 square feet of conditioned floor area.
- HVAC equipment exceeds requirements for ENERGY STAR labeled HVAC by 10 percent.
- Water heating system is optimized for energy performance.
- Energy efficient lighting and appliances will be installed.
- It is assumed that refrigerants that reduce ozone depletion will be used.
- Home owners' education process will be completed.

5.4.2 Site built home

The specifications for the case study design are as follows: Basement: Footprint except garage includes walkout light well. First floor: 2 car garage, formal living and dining, family room, kitchen, powder and laundry room. Second floor: 3 bedroom, master suite and 2 baths. The gross square footage is 4198 square feet for the entire home. The HVAC and plumbing specifications and electrical drawings have been provided as well as framing and foundation plans. Communication and interior plans shall be assumed standard; it is also assumed that no specialized furniture design is recommended and no moveable partitions are used. None of the additional options have been considered for the analysis; only the basic option has been used. Regular timber framing with wooden studs (2 x 4), 16 inches on center with gypsum board is used for the superstructure; and pre-engineered roof trusses are used for the floors and the roof. Cast in place foundation walls are used for the basement. Electrical and HVAC distribution is largely through the floor and through a vertical mechanical chase running from the basement to the second floor. The specifications for the HVAC ducting include mastic and duct tape as insulation to be installed on all the corners. The ducting used is flex duct that is easier to install. An optional zoned HVAC system has also been specified, and all supply air registers openings on exterior walls are specified to be insulated with rigid urethane insulation board (R12). The design also specifies use of low 'E' glass for all skylights, and all doors and windows are to be insulated. The design does specify that most openings should be oriented East/West, which may not be the most desirable orientation in terms of passive solar design strategies.

All strategies within the Health Performance Criteria are scored with respect to the information associated with the design and assumptions made based on LEED for homes. The scoring for each strategy is subjective and is based on the understanding of the user, in this case the author. Both performance scoring and interaction scoring are conducted as discussed in Chapter 4. Interaction scoring is done by grouping strategies in synergistic and dyssynergistic combinations. A synergetic combination improves the performance of all the component strategies leading to an improvement in one or more health performance attribute. A dyssynergistic combination impairs the performance of component strategies leading to degradation in one or more health performance attribute. The interaction scoring scale ranges from 1-5, where 1 represents the least preferable dysergistic effect and 5 represents the most preferable synergistic effect. For example, the strategies involving exterior water management, prevention of moisture infiltration through structure, moisture control in home and home owner education comprise a synergetic combination for site built home. The exterior water management systems and design features of the envelope including sloping roof, overhangs, gutters, downspouts and site sloping efficiently wards off moisture from the external envelope. Adequate steps have been taken to prevent moisture infiltration through the structure – the foundation has been properly treated and the joint between the foundation and the structure has been secured against moisture entry. The HVAC system meets the humidity requirements reducing the condensation potential inside homes. All these strategies coupled with home owner awareness about humidity/moisture issues in a home comprise a synergistic combination that improves the humidity/moisture performance of home. Related health and comfort effects include growth of biological agents and perceived air quality. This synergistic combination has been given 4 points for interaction in the criteria for site built homes.

The health performance score for the site-built home is 2870.37. With respect to the ideal score of 6680 as stated before, this represents 42.96% of the ideal Health Performance score based on the "Whole House" and LEED concepts. The completed criterion sheet for the site-built home has been included in Appendix.

5.4.3 Factory built home

The case study design for the factory-built home was developed from the case study design for the site-built home. It is designed as a double section home with each section being 16" wide as per the HUD codes. The home is designed as a single storey unit such that it can be transported with ease. No special additions have been made to the design, as the basic specifications remain the same. The design specifications are as follows; the first section includes a family room, dining, and kitchen that are part of the open plan with an additional powder room and utility room with a rear access. The second section includes the master bedroom, bath and walk in closet, with two additional rooms that share one bath. The first section is 16 feet wide and 48 feet long and the second section is 16 feet wide and 39 feet long. The specifications are assumed to be the same as the original design for the site-built home. It is assumed that the sections are built on a chassis that is used to transport the home to the site. Standard specifications have been based on the body of knowledge generated by the research team at MSU and Purdue University on manufactured housing under the NSF research grants.

The health performance score for the factory-built home is 3147.27. With respect to the ideal score of 6680 as stated before, this represents 47.11% of the ideal Health

Performance score based on the "Whole House" and LEED concepts. The completed criterion sheet for the factory-built home has been included in Appendix.

5.4.4 Hybrid home

The hybrid home case study design was similar to the site-built home as well and was provided by the same major homebuilder. The architectural design specifications in this case are the same as the site-built home, and so are the plans. The only difference is the construction process and the materials used. These are based on the components produced by the major homebuilder at their privately owned factory facility. There are four basic components that the factory manufactures; foundation walls, structurally insulated wall panels (SIP) with windows attached, floor trusses with complete assemblies and steel studs for internal partitions. These are manufactured as per the specifications of the design and then transported to the site on specially designed trailers to enhance ease of construction at site. The OSB (Oriented Strand Board) used for the SIP's is specially designed to have equal strength in both axes such that it is easy to use; it also makes it possible to attach windows without adding headers, thereby reducing the manufacturing time improving and structural integrity immensely. Another special addition is a specially manufactured insulation strip which is used for door and window openings, further reducing any loss of heat and cold from within the home during its lifetime, thereby increasing the inherent efficiency of the HVAC system. The component has been designed and manufactured by the major homebuilder and is due to be patented. The roof systems are pre-manufactured roof trusses that are subcontracted. Several other possibilities to standardize the production of a home are being considered.

The health performance score for the hybrid home is 3467.06. With respect to the ideal score of 6680 as stated before, this represents 51.9% of the ideal Health Performance score based on the "Whole House" and LEED concepts. The completed criterion sheet for the hybrid home has been included in Appendix.

5.4.5 Comparison of the criterion application on three case studies

The design of the site built, factory built and the hybrid home are similar in nature, in order to maintain the consistency of the case studies. It is assumed that the specifications are standard and the quality of construction is satisfactory for all three case studies. It is also assumed that all the homes meet the LEED criteria. Since the specifications for all three designs are similar, a large part of the scoring was similar. The decisions regarding the scoring of each strategy were partly based on an understanding of the specification and partly on whether a particular goal was given enough consideration at the time of the design. Hybrid home received the highest health performance scores followed by the factory built home. The site built home received the lowest score. The results of case study applications are compiled in the table below.

Home type	Score	Percentage
Ideal healthy home	6680	100.00
Site built home	2870.37	42.96
Factory Built home	3147.27	47.11
Hybrid home	3467.06	51.90

Table 5.7: Comparison of health performance scores for case study homes

Except for envelope and HVAC systems there are no major differences in the scores received by the three homes. These are the major observations:

- Impact of envelop tightness on IAQ (presence of indoor pollutants), Humidity/moisture performance, Temperature comfort, Ventilation and Acoustical performance. Tighter envelope warrants better health performance of homes.
- Impact of material selection on almost all attributes of health performance of homes.
- Impact of negative pressure in homes on IAQ (presence of indoor pollutants), temperature comfort and humidity/moisture performance. Negative pressure in homes can be attributed to defective design of HVAC system, impaired performance of HVAC equipment, local exhaust and other types of direct venting. Development of negative pressure deteriorates performance.
- Impact of humidity control on IAQ (presence of indoor pollutants) and Temperature comfort.
- Impact of contaminant control during construction and occupation phases on IAQ (presence of indoor pollutants).
- Impact of plumbing, electrical/communication and lighting installations on the exterior envelope, on Humidity/moisture performance and IAQ (presence of indoor pollutants).
- Impact of building layout on Ventilation, Temperature comfort and Lighting performance. Site specific building layout enhances these aspects.

- Impact of layout of interiors and interior fixtures on Temperature comfort, Ventilation effectiveness and Lighting performance.
- Impact of home owner education on all attributes of health performance of homes. Home owner education can significantly improve the health performance of homes.

From the case study applications it can be observed that the major difference in scores is related to envelope and HVAC architectural and engineering considerations. Both the hybrid home and the factory built home received relatively high scores on these aspects. The factory-built home and the hybrid home take advantage of the tighter envelope construction affected through prefabricated parts and modular design. Especially in the case of hybrid home, the component design and the use of special materials and products provides it with enhanced envelope performance. Special insulation strip installed with the window openings allows for better thermal performance for the interior, consequently enhancing the thermal efficiency of the HVAC system and the humidity/moisture performance of the home. The factory built home has an added advantage, since it avoids the garage-living space interface. Control of contaminants during construction is another key feature of factory built homes due to the controlled production environment inside the factory. Site specific design enhances the ventilation, day-lighting and temperature comfort aspects of both the hybrid and site built home. In all three cases the engineering and design considerations for the other building systems excluding envelope, received similar scores. This is because these building systems are designed and placed in relatively the same manner for all three types of home.

5.5 Feedback on the health performance criteria framework

The effectiveness of the research outputs were reviewed with the help of feedback from selected industry professionals. The survey set from the industry professionals was based on their involvement with LEED pilot homes and expertise in the field of sustainable construction. A total of three industry personnel were interviewed. The feedback was obtained in two stages; the first stage being the initial development phase of the framework, while the second stage being the finalization of the framework. During the first stage interviews, the responses were organized based on a predetermined list of questions; although discussions were open and certain general observations were made and noted by the researcher. During the second stage, a summary of the research outputs and their development process were sent to the selected professionals and suggestions for improvement were obtained.

5.5.1 First stage feedback – general observations

During this stage the industry experts were probed regarding the importance of health performance in sustainable construction. The main topic of discussion was related to the appropriateness of health performance as one of the major aspects of green construction. The responses of the industry community clearly show that health performance is crucial and it is employed as one of the main selling points of sustainable and healthy construction. They were convinced that LEED criteria for homes had considerable benefits for occupant health and comfort. They all agreed that the LEED criteria for homes was still in the development phase and much more research is needed on the health aspects and healthy lifestyle associated with green buildings. There was consensus upon the preeminence of health as one of the key aspects of LEED.

5.5.2 Second stage feedback – general observations

Research outputs and their development process were sent to the selected professionals and they were asked to review the framework. The industry experts agreed that Health Performance Criteria Framework is applicable to the green building industry especially since the system measures the relative quality of each system to occupant health. They felt that the format of the framework was effective and easy to use. Most of the concerns expressed by the subject experts are technical in nature rather than broad concerns related to the structure and organization of the framework, as can be expected out of an industry community. These have been discussed in detail below.

Occupant Lifestyle

Homeowner education as it relates to the health of the structure should be a very important consideration in the design and construction of homes. Occupant lifestyle can have a negative impact on the health of a structure. Maintenance, cleaning, adjustment and future product selection are all important to maintaining a healthy structure. Plugged dryer vents, dirty furnace filters, toxic chemical cleaning products, all the responsibility of the occupant, may lead to health issues in the structure. Furnace-mounted humidifiers are a prime example. If not serviced every other week they can produce mold, bacteria and respirable silica dust. Homeowners should be given training regarding the operation and adjustment of systems installed in a home and should be educated about the importance of maintenance and future product selection.

Product Selection

A structure has a lot of materials installed that, under the wrong circumstance, can become health problems. Cellulose and fiberglass insulation are prime examples. Normally these products are thought to be contained in areas outside the thermal envelope. Wind washing, structural settlement and/or construction deficiencies can bring these irritants into the living environment. Cellulose insulation, installed in an attic can enter the living environment through partition walls, electrical fixtures, exhaust vents and HVAC systems. The dust is respirable and becomes air borne from wind washing or pressure differences between living environment and the attic. Cellulose is usually composed of recycled newsprint that contains inks and chemical additives that can compromise the health of the occupants. During the design and construction of homes care must be taken that products that have a potential impact on occupant health are installed in a manner that ensures health and safety. The option would be to select products that are stable and unlikely to migrate once installed.

Positive pressure in homes

Maintaining a slight positive pressure in homes is crucial for occupant health and temperature comfort. A slight positive pressure will ensure that untreated external air is not unintentionally introduced into the indoor environment. Air leakage from outside may bring in pollutants and humidity that will affect the quality of indoor air and create health problems for occupants. It will also affect HVAC system performance resulting in problems related to thermal comfort.

5.6 Summary

In this chapter a sample criteria of health performance of homes has been applied to three case study homes and feedback was obtained from industry experts on the effectiveness of the criteria. The case study applications utilized a site built home, a factory built home and a hybrid home. All the floor plans were similar and it was assumed that all the three types of homes had specifications not very different from each other. It was also assumed that all the homes were LEED for homes certified. The scoring system of the health performance criteria framework helped to rate the health performance of these homes. Then these scores were compared against the ideal scores of a hypothetical "healthy home". The hybrid home received the highest health performance score followed by the factory built home. The site built home received the lowest scores. Feed back from industry experts were obtained as a part of this chapter. All of them agreed that occupant health and comfort is an important aspect of green buildings. The industry experts felt that Health Performance Criteria Framework is applicable to the green building industry especially since the system measures the relative quality of each system to occupant health. Their suggestions were incorporated while finalizing the framework.

CHAPTER 6

SUMMARY & CONCLUSIONS

6.1 Overview

Health performance of homes has received much attention lately. Various studies point to the effects of the design of a home on aspects of Indoor Environment Quality, thereby impacting the health and comfort of occupants (Levin 1989, Fisk et al 2002). Presence of indoor chemical and biological pollutants is a decisive factor in residential occupant health performance (DoH, Washington 1999). Combined with this aspect, less than optimal performance in temperature comfort, humidity/moisture control, ventilation effectiveness, lighting, acoustics and ergonomic design/safety has the potential to seriously undermine the indoor environmental quality (IEQ) of homes. Research has associated indoor environmental quality with occupant health and comfort (Fisk 2005, Wood 2003). Building systems fail to function efficiently due to negative interactions leading to development of deficiencies in the performance of home. The "Whole House" approach is rooted on the idea of building systems integration in design, construction and maintenance of homes. The adoption of the "Whole House" approach can assist in the understanding and subsequently, improving the health and environmental performance of homes (O'Brien et al. 2005, Swarup 2005). Indoor environmental quality is intrinsically related to the quality of external environment and the impact of buildings on the overall environment needs to be understood in a proper perspective. The concept of 'Green Buildings" promotes the idea of sustainable buildings with limited environmental and human health impacts.

This research effort focused on developing a design and evaluation tool for health performance of homes by analyzing the health impacts associated with LEED green building criteria. The Health Performance Criteria Framework was developed as the design and evaluation tool. The concept of building systems integration was utilized in the development of this framework. The framework helps to categorically list the building systems integration strategies and conduct "what if" scenarios on health performance during the design development of a home. The tool is also quite useful in evaluating an existing home for health performance. Since all the strategies are scored for individual performance and interaction with other strategies, the framework is expected to help the user in obtaining a realistic score for the health performance of a home.

Chapter 1 presented the goals and objectives that the author aimed to achieve, along with a detailed methodology and the need for this research. Chapter 2 focuses on study of literature associated with various aspects of indoor environmental quality, LEED green building criteria and the "Whole House" concept. Indoor environmental quality is associated with health impacts on occupants. The health impacts range from issues related to comfort to carcinogenic effects. The studies done as a part of this chapter have traced the health and comfort effects associated with indoor environment back to various physical, chemical and biological interactions in the indoor environment. Several attributes that define Indoor Environmental Quality have also been identified as a part of this study. These attributes include Indoor air quality – presence of indoor pollutants, Temperature, Humidity/moisture, Ventilation, Lighting and Noise. Maintenance of acceptable levels for these attributes is necessary for a healthy indoor environment. The LEED green building rating system propagated by USGBC is also discussed in this chapter. The criteria discussed in this chapter include LEED-NC, LEED for Homes and

LEED-ND. Literature on various aspects of the "Whole House" concept and building systems integration have also been reviewed as a part of this chapter.

The third chapter is a review of the tools and techniques that will be utilized for this research. Some of them already exist in literature while others have been developed for this research. The discussion in this chapter is organized around three broad topics – Whole House design and evaluation; Evaluation of Health impacts of planning, design and construction; and Green building design and evaluation. The Whole House topics include (1) Whole House Calculator and (2) Whole House performance criteria framework. The Health Impact Matrix for Planning, Design and Construction of Built Environment constitutes the second topic. The Green Building tools and techniques include: (1) LEED-NC and (2) LEED-H green building rating systems.

Chapter 4 includes a detailed description of the framework for health performance criteria for homes, based on LEED guidelines and building systems integration. The framework development process begins with systematically analyzing the health impacts of LEED green building criteria. Two health matrices have been developed for this purpose in this chapter – the LEED-NC health matrix and the LEED-H health matrix. The LEED-NC health matrix analyzes the health impacts related to all the credits in the LEED-NC criteria, while the LEED-H health matrix focuses on health impacts associated with indoor environmental quality. These health impacts are then associated with relevant physical, chemical and biological interactions, health performance attributes and building systems. These factors are analyzed and health performance goals based on building systems integration concepts are developed. These goals help in the choice of appropriate health performance strategies based on building system integration concepts. A scoring system has been developed as a part of this chapter to rate each strategy for its effectiveness in ensuring health performance of the home and interaction with other strategies.

Chapter 5 involves the application of a sample health performance criterion to three case study homes. The sample criterion based on LEED for homes was used to evaluate the health performance of a site built home, factory built home and a hybrid home. Through the case study application it was established that the hybrid home achieved better health performance. Also feedback was obtained from industry experts regarding the effectiveness of the Health Performance Criteria Framework as a tool in design and evaluation of health performance of homes.

6.2 Summary

This section includes the steps carried out to achieve the goals and objectives set out for this research.

6.2.1 Objective 1

Define the attributes of a healthy home with focus on IEQ

Step 1: Literature review of all four aspects related to the research.

1. *"Whole House" and building systems integration.*
2. *"LEED" green building criteria.*

3. *Health impacts associated with Indoor Environmental Quality (IEQ).*
4. *Physical, chemical and biological interactions in buildings, related to occupant health.*

This was accomplished through the literature review conducted in chapter 1 and 2. Relevant literature related to all the four aspects was reviewed as a part of this step.

Step 2: Identify attributes that define Indoor Environmental Quality.

Based on literature review conducted as a part of chapter 1 and 2, the attributes that determine the quality of the indoor environment were identified and analyzed from the perspective of health performance of a home. Seven attributes were identified as a part of this research: Indoor Air Quality (presence of indoor pollutants), Humidity/moisture, Temperature, Ventilation, Lighting, Acoustics and Ergonomic design/safety issues. These attributes define the Indoor Environmental Quality (IEQ) and thereby the health performance of a home. Relationship of these attributes to various physical, chemical and biological interactions in the indoor environment has also been reviewed as a part of this step.

6.2.2 Objective 2

To explore "Whole House" and "LEED" approaches for health impacts.

Step 3: Define all applicable building systems.

All relevant building systems/sub systems have been defined from the perspective of health performance of homes. Six building systems have been identified for the purpose of this research. They include Envelope, HVAC, Plumbing, Electrical/Communication, Lighting and Interior systems.

Step 4: Review health impacts of "LEED" criteria.

Literature study was conducted to identify the health impacts of LEED criteria related to:

a. LEED for new construction.
b. LEED for homes, with emphasis on indoor environment quality.

Two categories of health impacts associated with buildings have been reviewed:

1. Direct impacts on health (e.g. – indoor pollutant concentrations leading to respiratory problems and allergic effects)
2. Indirect impacts on health (e.g. – humidity leading to feelings of discomfort)

Two health matrices have been developed as a part of this step to categorically organize health impacts associated with LEED credits and the related building systems design, construction and integration strategies.

Step 5: Develop a framework for associating health impacts related to Indoor Environment Quality (IEQ) with physical, chemical, biological interactions and relevant attributes of IEQ.

A framework has been developed as a part of this step to effectively link health effects associated with Indoor Environment Quality with physical, chemical and biological interactions in the indoor environment; and attributes of IEQ. This step is only relevant for attributes that can be controlled from a design point of view. These attributes have been identified as a part of Step 2. The framework has been designed in such a way that it can specifically address health impacts associated with LEED credits.

Step 6: Establish a model for generating systems integration strategies to improve the health performance of homes.

A model has been developed to allow the user to generate or choose strategies involving the integration of various building systems to improve the health performance of a home. With the aid of this model, the user can make informed decisions regarding the integration when two or more building systems need to be integrated with each other in order to improve performance related to a particular attribute of IEQ. The model will help to frame health performance goals using the framework developed as a part of Step 5. Involved building systems/subsystems can then be identified and systems integration strategies can be generated.

6.2.3 Objective 3

Develop a health performance criteria framework for homes. The format for the framework will be based on the one developed for "Whole House" performance (Swarup 2005). The existing format will be expanded to incorporate the health performance scoring system.

Step 7: Probe expansion potential of the existing "Whole House" performance criteria framework to include health performance.

The existing "Whole House" performance criteria framework has been expanded to integrate the health performance of homes. The expanded framework incorporates attributes of Indoor Environmental Quality as the parameters for evaluating health performance. Six building systems have been included in the framework with each of them being further defined on the basis of architectural and engineering design considerations. The framework allows the categorical listing of health performance goals and building systems Design/Construction/Integration (DCI) strategies while developing the health performance criteria. During criteria development, health performance goals can be tabulated based on the specific design considerations for each building system in order to fulfill each of the seven performance attributes. Strategies can then be listed to correspond to particular health performance goals.

Step 8: Frame a scoring system for evaluating health performance.

The scoring system that has been framed for the purpose of evaluating health performance rates each of the listed strategies in the criteria on two separate aspects – performance and interaction. Performance scoring helps to evaluate the capability of individual systems Design/Construction/Integration strategies to maintain an ideal indoor environment. The system integration strategies will be scored against the attributes that determine the quality of indoor environment. The interaction scoring accounts for the positive and negative interactions while choosing strategies. This is achieved by grouping strategies into synergistic and dyssergistic combinations and scoring them for their effect on IEQ. Relative weights have also been assigned to building systems and IEQ attributes so as to reflect their importance in the health and comfort of occupants.

Step 9: Case study application of the scoring system for health performance and development of an example criteria.

An example criterion has been formulated to demonstrate the usage of the framework. The sample criteria was then applied to three case study homes – site built home, factory built home and hybrid home. All the homes were assumed to be LEED for homes certified. Basic design and specifications were considered similar for all three case studies. The points scored by each of these homes when evaluated against the sample criterion were compared to the ideal "Healthy House" score, which is a hypothetical score, based on all strategies being most effective in achieving the set of performance attributes defined. The hybrid home achieved better health performance scores followed by the factory built home.

Step 10: Feedback and finalize the health performance criteria framework.

Feedback on the health performance criteria framework was obtained through interviews with industry professionals involved in healthy and sustainable housing initiatives. The industry experts agreed that Health Performance Criteria Framework is applicable to the green building industry especially since the system measures the relative quality of each system to occupant health. Most of the concerns expressed by the subject experts are technical in nature rather than broad concerns related to the structure and organization of the framework. Necessary changes were incorporated and the framework has been finalized.

6.3 Conclusions and inferences

This section focuses on the conclusions and inferences made based on the research conducted. The health effects associated with LEED credits have been extensively reviewed in this thesis. It can be concluded that even though the LEED criteria has health and comfort benefits for building occupants, there is still great scope for improvement. Presently LEED green building rating system has sustainability as its main focus, with health and affordability being added benefits. This can be partly attributed to the fact that the green building movement emerged as a result of concerns about environmental impacts of buildings involving energy and resource inefficiency. This research has substantiated the importance of building design, construction and building systems integration on the health and comfort of occupants. It can also be concluded that integrative design measures focusing on synergistic associations of building systems can greatly enhance health performance while making the buildings more affordable and sustainable.

Several strategies that are discussed in the main body of the research are crucial in ensuring the health and comfort of occupants. Envelope tightness can be regarded as one of the most important factors in the health performance of a home. This holds true for both direct health effects and indirect health effects related to comfort. Envelop tightness can prevent the entry of untreated air, moisture and pollutants like radon, which may impact the indoor air quality and functioning of the HVAC system. Unfiltered/untreated air may contain pollutants from the external environment and can cause health problems for occupants. Moisture in the air that leaks into the interior can create condensation problems which can aid the growth of biological agents in the indoor environment. Air infiltration can also result in thermal discomfort since it may impact the functioning of HVAC systems. Maintaining envelop tightness together with a slight positive pressure is a very effective strategy to prevent indoor environment quality problems related to pollutants, thermal comfort etc. Local exhaust systems and direct venting systems are an area of concern related to envelope tightness. The operation of local exhaust systems may create conditions of negative pressure inside the home and can lead to pollutant entry and back drafting.

Another area of crucial importance in health performance of a home is material selection. Many building products used presently contain VOCs and other harmful chemicals which can impact indoor air quality. Also building elements containing materials like fiberglass and cellulose can disintegrate with time and get distributed indoors which can cause severe health problems. It is very important to choose materials which are stable and durable with less harmful chemical content. Humidity influences VOC release from building materials during phases of construction and occupancy. Retained humidity in building materials can also result in growth of biological agents which can severely impact indoor air quality. Selecting permeable materials and finishes can avoid such problems. It can be inferred that proper material selection combined with humidity control is crucial in ensuring the quality of indoor environment in homes.

Though indoor environment quality issues associated with occupant activities is not in the scope of this research, it is crucial for occupant health. One area of concern is household chemicals. Cleaning chemicals and air fresheners release sizeable amounts of aerosols into the air. This can affect indoor environment quality and result in health problems. Occupant activities like showering and cooking can cause release of large amounts of moisture in a home. This can promote biotic growth and hence degrade air quality. Proper maintenance of homes combined with homeowner education can limit these problems.

6.4 Areas of future research

This section deals with the list of future research directions that are related to the domain of this research effort. In the author's opinion these ideas are promising directions with considerable potential for fundamental and applied research. Some research efforts are already underway on these topics, but since these topics are interdisciplinary, they require a more comprehensive and multi-faceted research approach involving experts from all related fields.

1. Health effects of life style changes associated with green design and construction.

The research effort undertaken as a part of this thesis investigated the link between green buildings and occupant health. The analysis of health impacts associated with green buildings has substantiated the hypothesis that green design and construction has a positive influence on occupant health. Most of the current research focuses on the direct health impacts (e.g.: allergic effects, asthma etc.) and indirect effects related to comfort of occupants. But there are indications that built environment has the potential to induce life style changes and associated health effects in communities. For example automobile oriented street design discourages physical activity. Automobile dependent life style devoid of any physical activity has a negative impact on the health of community. Conversely, neighborhoods which incorporate the principles of compact development, walkability, connectivity, mixed use and diversity promotes physical activity and social interaction which has a pronounced effect on physical and mental health of members of the community (Frank et al. 2003). Since the main concern of the 'green building' concept is to promote sustainability and occupant health, it is worthwhile to investigate whether green design and construction has the potential to induce healthy lifestyle changes in a community.

2. Expansion of health performance criteria framework

The next step can be the expansion of the health performance criteria framework to include the effects of design of a home or neighborhood on the mental and social health of individuals in a community. The current research deals mostly with the physical health of occupants of a home. The attributes that are crucial to the physical, mental and social health of individuals of a community should be identified through research and associated with health performance goals and strategies. Likewise the building systems section of the framework should be expanded and redefined to include design elements that can influence mental and social health of individuals in a community.

3. Cost estimation of healthy home

From a construction management point of view it is crucial to understand the cost implications of a healthy home. The construction of a healthy home utilizes particular building materials, methods and integration strategies that make it different from a traditional home. If cost is connected to health, then the future home user can choose the level of health performance that is expected out of a home.

4. Risk analysis of health performance scores

Using the framework, a detailed criterion can be developed that will help to score a particular home for health performance. But it is important to understand the precise health implications of a particular health performance score for a home. The comprehensive criterion could be reviewed by a panel of experts for analyzing the risk associated with a particular score. This will make the scoring system more objective and can help in the development of a set of prescriptive guidelines and recommended scores for health performance.

5. Bionics and building systems design/construction/integration

Bionics or biomimetics applies the methods and systems found in nature to the study and design of engineering systems. The development of dirt and water-repellent paint from the observation of the behavior of surface of the lotus flower plant (the lotus effect) is a classical example. Natural systems are highly optimized and efficient due to millions of years of evolutionary pressure (Rechenberg 2005, ESA 2006).

Living systems function efficiently by working as interacting wholes to counter any external or internal disruptions. All the component parts of a living system work under the concept of integrated systems, under the interdependencies and interactions of subsystems (Miller 1978). The "Whole House" concept and building systems integration strives to improve performance of buildings by reducing negative interactions among component parts and planning for positive interactions. The study of living systems, especially the human body, has great potential for applications in building systems design/construction/integration. The systems integration concepts as manifested in living systems are worth emulating in building technology field, since they have been perfected by millions of years of evolutionary forces.

APPENDICES

APPENDIX A

"Whole House" Performance Criteria Framework

No.		Building systems (Design considerations)	Credit	Intent										
				Spatial flexibility	Sc.	Thermal performance	Sc.	Structural Integrity	Sc.	Ease of const.	Sc.	Ease of maint.	Sc.	Sustainable design
A		**Structure**												
1		Architectural design												
2		Engineering design												
3		Special design consideration												
	a	Active solar design												
	b	Passive solar design												
		Cumulative score												
B		**Envelope**												
1		Architectural design												
2		Engineering design												
3		Special design consideration												
	a	Active solar design												
	b	Passive solar design												
		Cumulative score												
C		**HVAC**												
1		Architectural design												
	a	Comfort requirements												
2		Engineering design												
3		Special design consideration												
	a	Choice of Fuel												
	b	Passive design techniques												
	c	Indoor Air Quality (ventilation)												
		Cumulative score												
D		**Plumbing**												
1		Architectural design												
2		Engineering design												
3		Special design consideration												
	a	Water conservation												
	b	Fuel requirements												
		Cumulative score												

A

B

A

Example Strategies						Information resources / Professional expertise				
Spatial flexibility	Thermal performance	Structural Integrity	Ease of const.	Ease of maint.	Sustainable design	Spatial flexibility	Thermal performance	Structural Integrity	Ease of const.	Ease of maint.

B

C

No.		Building systems (Design considerations)	Credit	Intent										
				Spatial flexibility	Sc.	Thermal performance	Sc.	Structural Integrity	Sc.	Ease of const.	Sc.	Ease of maint.	Sc.	Sustainable design
E		**Electrical**												
1		Architectural design												
2		Engineering design												
3		Special design consideration												
	a	Energy requirements												
		Cumulative score												
F		**Communication**												
1		Architectural design												
2		Engineering design												
3		Special design consideration												
	a	Integrative design												
		Cumulative score												
G		**Interior (Type A)**												
1		Architectural design												
2		Engineering design												
3		Special design consideration												
	a	Energy requirements												
		Cumulative score												
H		**Interior (Type B)**												
1		Architectural design												
2		Engineering design												
3		Special design consideration												
	a	Flexible space design												
		Cumulative score												
		Final score												

D

C

Example Strategies						Information resources / Professional expertise				
Spatial flexibility	Thermal performance	Structural Integrity	Ease of const.	Ease of maint.	Sustainable design	Spatial flexibility	Thermal performance	Structural Integrity	Ease of const.	Ease of maint.

D

APPENDIX B

LEED-NC Checklist (LEED 2005)

LEED-NC Version 2.2 Registered Project Checklist

Prereq 1	**Construction Activity Pollution Prevention**		Required
Credit 1	**Site Selection**		1
Credit 2	**Development Density & Community Connectivity**		1
Credit 3	**Brownfield Redevelopment**		1
Credit 4.1	**Alternative Transportation**, Public Transportation Access		1
Credit 4.2	**Alternative Transportation**, Bicycle Storage & Changing Rooms		1
Credit 4.3	**Alternative Transportation**, Low-Emitting and Fuel-Efficient Vehicles		1
Credit 4.4	**Alternative Transportation**, Parking Capacity		1
Credit 5.1	**Site Development,** Protect of Restore Habitat		1
Credit 5.2	**Site Development,** Maximize Open Space		1
Credit 6.1	**Stormwater Design,** Quantity Control		1
Credit 6.2	**Stormwater Design,** Quality Control		1
Credit 7.1	**Heat Island Effect,** Non-Roof		1
Credit 7.2	**Heat Island Effect,** Roof		1
Credit 8	**Light Pollution Reduction**		1

Credit 1.1	**Water Efficient Landscaping**, Reduce by 50%		1
Credit 1.2	**Water Efficient Landscaping**, No Potable Use or No Irrigation		1
Credit 2	**Innovative Wastewater Technologies**		1
Credit 3.1	**Water Use Reduction**, 20% Reduction		1
Credit 3.2	**Water Use Reduction**, 30% Reduction		1

Prereq 1	**Fundamental Commissioning of the Building Energy Systems**		Required
Prereq 2	**Minimum Energy Performance**		Required
Prereq 3	**Fundamental Refrigerant Management**		Required
Credit 1	**Optimize Energy Performance**		1 to 10
Credit 2	**On-Site Renewable Energy**		1 to 3
Credit 3	**Enhanced Commissioning**		1
Credit 4	**Enhanced Refrigerant Management**		1
Credit 5	**Measurement & Verification**		1
Credit 6	**Green Power**		1

Prereq 1	**Storage & Collection of Recyclables**	Required
Credit 1.1	**Building Reuse**, Maintain 75% of Existing Walls, Floors & Roof	1
Credit 1.2	**Building Reuse**, Maintain 100% of Existing Walls, Floors & Roof	1
Credit 1.3	**Building Reuse**, Maintain 50% of Interior Non-Structural Elements	1
Credit 2.1	**Construction Waste Management**, Divert 50% from Disposal	1
Credit 2.2	**Construction Waste Management**, Divert 75% from Disposal	1
Credit 3.1	**Materials Reuse**, 5%	1
Credit 3.2	**Materials Reuse**,10%	1
Credit 4.1	**Recycled Content**, 10% (post-consumer + ½ pre-consumer)	1
Credit 4.2	**Recycled Content**, 20% (post-consumer + ½ pre-consumer)	1
Credit 5.1	**Regional Materials**, 10% Extracted, Processed & Manufactured Regiona	1
Credit 5.2	**Regional Materials**, 20% Extracted, Processed & Manufactured Regiona	1
Credit 6	**Rapidly Renewable Materials**	1
Credit 7	**Certified Wood**	1

Prereq 1	**Minimum IAQ Performance**	Required
Prereq 2	**Environmental Tobacco Smoke** (ETS) **Control**	Required
Credit 1	**Outdoor Air Delivery Monitoring**	1
Credit 2	**Increased Ventilation**	1
Credit 3.1	**Construction IAQ Management Plan**, During Construction	1
Credit 3.2	**Construction IAQ Management Plan**, Before Occupancy	1
Credit 4.1	**Low-Emitting Materials**, Adhesives & Sealants	1
Credit 4.2	**Low-Emitting Materials**, Paints & Coatings	1
Credit 4.3	**Low-Emitting Materials**, Carpet Systems	1
Credit 4.4	**Low-Emitting Materials**, Composite Wood & Agrifiber Products	1
Credit 5	**Indoor Chemical & Pollutant Source Control**	1
Credit 6.1	**Controllability of Systems**, Lighting	1
Credit 6.2	**Controllability of Systems**, Thermal Comfort	1
Credit 7.1	**Thermal Comfort**, Design	1
Credit 7.2	**Thermal Comfort**, Verification	1
Credit 8.1	**Daylight & Views**, Daylight 75% of Spaces	1
Credit 8.2	**Daylight & Views**, Views for 90% of Spaces	1

Credit 1.1	**Innovation in Design**: Provide Specific Title	1
Credit 1.2	**Innovation in Design**: Provide Specific Title	1
Credit 1.3	**Innovation in Design**: Provide Specific Title	1
Credit 1.4	**Innovation in Design**: Provide Specific Title	1
Credit 2	**LEED® Accredited Professional**	1

Project Totals (pre-certification estimates)	69 Points

APPENDIX C

LEED-NC Health Matrix

LEED-NC Version 2.1

Sustainable Sites

LEED checklist item	LEED intent	Health Effects and Supporting literature		LEED broad guidelines	LEED: Specific design and construction procedures	Building systems: D/C/M/I aspects
		Direct	Indirect			
Prereq. 1: **Erosion and sedimentation control**	Control erosion to reduce negative impacts on water and air quality.	▪ Link between atmospheric soil dust and the occurrence of respiratory problems (Owens 2004)	▪ Increased levels of nitrogen and phosphorus in water (Al-Kaisi et al. 2003) ▪ Can restrict oxygen transport in the human bloodstream & cause illness (WRI 2002).	▪ Prevent pollution of air with particulate matter. ▪ Preventing loss of topsoil during construction through erosion.	▪ Erosion and sediment control plan for construction ▪ Employ erosion control strategies – seeding, mulching, earth dikes, sediment traps etc.	▪ Avoid sensitive sites. ▪ Minimum footprint for building. ▪ Construction methods those are less likely to cause erosion problems.
Credit 1: **Site Selection**	Avoid development of inappropriate sites and reduce the environmental impact from the location of a building on a site.	No direct health effect.	No indirect health effect.	▪ Do not develop buildings, roads or parking areas on portions of sites are prime farmland or on land which prior to acquisition for the project was public parkland unless land of equal or greater value as parkland is accepted in trade by the public landowner.	▪ During the site selection process, give preference to those sites that do not include sensitive site elements and restrictive land types. ▪ Select a suitable building location and design the building with the minimal footprint to minimize site disruption. ▪ Strategies include stacking the building program, tuck under	None.

					parking, and sharing facilities with neighbors.	
Credit 2: Urban Redevelopment (Development Density)	Channel development to urban areas with existing infrastructure, protect greenfields and preserve habitat and natural resources.	No direct health effect.	▪ Higher urban temperatures due to heat island formation as cities replace natural land cover with pavement, buildings etc (due to denser development). Extremely hot weather can result in illness (EPA 2005).	▪ Increase localized density to conform to existing or desired density goals by utilizing sites that are located within an existing minimum development density of 60,000 square feet per acre (two story downtown development).	▪ During the site selection process, give preference to urban sites.	▪ Roofing materials with high albedo values or high solar reflectance index reduce heat island effect (Gray & Finster 1999). ▪ Intensive or extensive green roofs also reduce heat island effect (England et al. 2004).
Credit 3: Brownfield Redevelopment	Rehabilitate damaged sites where development is complicated by real or perceived environmental contamination, reducing pressure on undeveloped land.	No direct health effect.	No indirect health effect.	▪ Develop on a site documented as contaminated or classified as brownfield by a local, state or federal agency. ▪ Effectively remediate site contamination.	▪ During site selection process, give preference to brownfield sites. ▪ Identify tax incentives and property cost savings. ▪ Develop and implement a site remediation plan using strategies such as pump-and-treat, bioreactors, land farming and in-situ remediation.	None.
Credit 4.1: Alternative transportation (Public transport. Access)	Reduce pollution and land development impacts from automobile use.	▪ High automobile traffic emits pollutants – gases and particulates (ESRU 2005). Air pollutants	No indirect health effect.	▪ Locate project within 1/2 mile of a commuter rail, light rail or subway station or 1/4 mile of two or more public or campus bus lines usable by building occupants.	▪ Perform a transportation survey of future building occupants to identify transportation needs. ▪ Site the building near mass transit.	Air pollutants from automobile emissions enter the building through infiltration. Intakes for ventilation must be provided in places where pollution

		associated with vehicle emissions can cause serious health problems including respiratory ailments (DoE-WA 2005).				levels are lowest – away from busy streets or at the rear end of building (ESRU 2005). ▪ Flexible positioning of air intake for ventilation.
Credit 4.2: Alternative transportation (Bicycle storage and Changing rooms)	Reduce pollution and land development impacts from automobile use.	▪ High automobile traffic emits pollutants – gases and particulates (ESRU 2005). Air pollutants associated with vehicle emissions can cause serious health problems including respiratory ailments (DoE-WA 2005).	▪ Physical activity reduces the risk of heart disease, stroke, diabetes, hypertension, depression, cancer, osteoporosis, and improves well being. Cycling is a good physical activity and is as effective as a training program (TSHG 2000).	▪ For commercial or institutional buildings, provide secure bicycle storage with convenient changing/shower facilities (within 200 yards of the building) for 5% or more of regular building occupants. ▪ For residential buildings, provide covered storage facilities for securing bicycles for 15% or more of building occupants in lieu of changing/shower facilities.	▪ Design the building with transportation amenities such as bicycle racks and showering/changing facilities.	Air pollutants from automobile emissions enter the building through infiltration. Intakes for ventilation must be provided in places where pollution levels are lowest – away from busy streets or at the rear end of building (ESRU 2005). ▪ Flexible positioning of air intake for ventilation. ▪ Building ground floor to include provisions for showering/changing rooms near bicycle racks. ▪ Provision for storage facilities for bicycles (covered – optional).
Credit 4.3: Alternative	Reduce pollution and land	▪ Automobiles using traditional	No indirect health effect.	▪ Provide alternative fuel vehicles for 3% of	▪ Provide transportation amenities such as	Air pollutants from automobile emissions

transportation (Alternative fuel vehicles)	development impacts from automobile use.	fuels emit large amounts of pollutants – gases and particulates (ESRU 2005). Air pollutants associated with vehicle emissions can cause serious health problems including respiratory ailments (DoE-WA 2005).		building occupants AND provide preferred parking for these vehicles. ▪ Install alternative-fuel refueling stations for 3% of the total vehicle parking capacity of the site.	alternative fuel refueling stations and carpool/vanpool programs. ▪ Consider sharing the costs and benefits of refueling stations with neighbors.	enter the building through infiltration. Intakes for ventilation must be provided in places where pollution levels are lowest – away from busy streets or at the rear end of building (ESRU 2005). ▪ Flexible positioning of air intake for ventilation. ▪ Provision for alternative-fuel refueling stations in buildings.
Credit 4.4: Alternative transportation (Parking capacity)	Reduce pollution and land development impacts from single occupancy vehicle use.	No direct health effect.	▪ High automobile traffic emits pollutants – gases and particulates (ESRU 2005). Air pollutants associated with vehicle emissions can cause serious health problems including respiratory ailments (DoE-WA 2005).	▪ Size parking capacity to meet, but not exceed, minimum local zoning requirements ▪ Add no new parking for rehabilitation projects. AND ▪ Provide preferred parking for carpools or vanpools capable of serving 5% of the building occupants	▪ Minimize parking lot/garage size. ▪ Share parking facilities with adjacent buildings.	None.

Credit 5.1: Reduced site disturbance (Protect or restore open space)	Conserve existing natural areas and restore damaged areas to provide habitat and promote biodiversity.	No direct health effect.	No indirect health effect.	▪ On greenfield sites, limit site disturbance including earthwork and clearing of vegetation to 40 feet beyond the building perimeter, 5 feet beyond primary roadway curbs, walkways and main utility branch trenches, and 25 feet beyond constructed areas with permeable surfaces. ▪ On previously developed sites, restore a minimum of 50% of the site area (excluding the building footprint) by replacing impervious surfaces with native or adapted vegetation.	▪ Perform a site survey to identify site elements and adopt a master plan for development of the project site. ▪ Select a suitable building location and design the building with a minimal footprint to minimize site disruption. ▪ Strategies include stacking the building program, tuck-under parking and sharing facilities with neighbors. ▪ Establish clearly marked construction boundaries to minimize disturbance of the existing site and restore previously degraded areas to their natural state.	None.
Credit 5.2: Reduced site disturbance (Development footprint)	Conserve existing natural areas and restore damaged areas to provide habitat and promote biodiversity.	No direct health effect.	No indirect health effect.	▪ Reduce the development footprint (defined as entire building footprint, access roads and parking) to exceed the local zoning's open space requirement for the site by 25%. ▪ For areas with no local zoning requirements (e.g., some university campuses and military bases), designate open space area adjacent to the building that is equal to	▪ Perform a site survey to identify site elements and adopt a master plan for development of the project site. ▪ Select a suitable building location and design the building with a minimal footprint to minimize site disruption. ▪ Strategies include stacking the building program, tuck-under parking and sharing facilities with neighbors.	None.

				the development footprint.	▪ Establish clearly marked construction boundaries to minimize disturbance of the existing site and restore previously degraded areas to their natural state.	
Credit 6.1: Stormwater management (Rate and Quantity)	Limit disruption and pollution of natural water flows by managing stormwater runoff.	No direct health effect.	▪ Storm water runoff can contain toxic chemicals, oil and grease, pesticides, metals, pathogens and other contaminants that are a major source of water pollution and that can pose a threat to public health (IL-EPA 2002).	▪ If existing imperviousness is less than or equal to 50%, implement a stormwater management plan that prevents the post-development 1.5 year, 24 hour peak discharge rate from exceeding the pre-development 1.5 year, 24 hour peak discharge rate. ▪ If existing imperviousness is greater than 50%, implement a stormwater management plan that results in a 25% decrease in the rate and quantity of stormwater runoff.	▪ Design the project site to maintain natural stormwater flows by promoting infiltration. ▪ Specify garden roofs and pervious paving to minimize impervious surfaces. ▪ Reuse stormwater volumes generated for non-potable uses such as landscape irrigation, toilet and urinal flushing and custodial uses.	▪ Green roofs will reduce stormwater runoff (England et al. 2004). ▪ Avoid low-density developments as it disturbs the soil over larger land areas, accelerating transport of sediment and associated pollutants into water bodies (Gaffield et al. 2003). ▪ Avoid stripping the protective vegetation cover from construction sites as it accelerates soil erosion (Gaffield et al. 2003).
Credit 6.2: Stormwater management (Treatment)	Limit disruption of natural water flows by eliminating stormwater runoff, increasing on-site infiltration	No direct health effect.	▪ Storm water runoff can contain toxic chemicals, oil and grease, pesticides, metals,	▪ Construct site stormwater treatment systems designed to remove 80% of the average annual post-development total suspended solids and	▪ Design mechanical or natural treatment systems such as constructed wetlands, vegetated filter strips and bioswales to treat the site's stormwater.	None.

	and eliminating contaminants.		pathogens and other contaminants that are a major source of water pollution and that can pose a threat to public health (IL-EPA 2002).	40% of the average annual post-development total phosphorous based on the average annual loadings from all storms less than or equal to the 2-year/24-hour storm.		
Credit 7.1: Heat island effect (non roof)	Reduce heat islands to minimize impact on microclimate and human and wildlife habitat.	▪ Extremely hot weather can result in illness including physiological disruptions and organ damage and even death. ▪ VOCs and nitrogen oxides react in the presence of sunlight and high temperatures to produce ozone. Ozone can lead to aggravated asthma and respiratory ailments (EPA 2005).	No indirect health effect.	▪ Provide shade. ▪ Use light-colored/high-albedo materials ▪ Open grid pavement for at least 30% of the site's non-roof impervious surfaces, including parking lots, walkways, plazas, etc. ▪ Place a minimum of 50% of parking spaces underground or covered by structured parking; ▪ Use an open-grid pavement system (less than 50% impervious) for a minimum of 50% of the parking lot area.	▪ Shade constructed surfaces on the site with landscape features and minimize the overall building footprint. ▪ Replace constructed surfaces (i.e. roof, roads, sidewalks, etc.) with vegetated surfaces such as garden roofs and open grid paving. ▪ Specify high-albedo materials to reduce the heat absorption.	▪ Light colored envelops for buildings - high albedo values (Gray & Finster 1999). ▪ Design sidewalks and roads with open grid paving. ▪ Lowering the heat island effect through envelope modifications means lesser air condition loads (Envelope-HVAC integration).
Credit 7.2: Heat island effect (roof)	Reduce heat islands to minimize impact on microclimate and human and	▪ Extremely hot weather can result in illness including physiological	No indirect health effect.	▪ Use 'ENERGY STAR' compliant (highly reflective) AND high emissivity roofing for a minimum of 75% of the	▪ Use 'ENERGY STAR' compliant products. ▪ Install high-albedo and vegetated roofs to reduce heat absorption.	▪ Roofing materials with high albedo values or high solar reflectance index reduce heat island

	wildlife habitat.	disruptions and organ damage and even death. ▪ VOCs and nitrogen oxides react in the presence of sunlight and high temperatures to produce ozone. Ozone can lead to aggravated asthma and respiratory ailments (EPA 2005).		roof surface. ▪ Install a green roof for at least 50% of the roof area. Combinations of high albedo and vegetated roof can be used providing they collectively cover 75% of the roof area.		effect (Gray & Finster 1999). ▪ Roofing materials with high infrared emittance and good convective heat transfer properties reduce heat island effect (Gray & Finster 1999). ▪ Intensive or extensive green roofs also reduce heat island effect (England et al. 2004). ▪ Lowering the heat island effect through envelope modifications means lesser air condition loads (Envelope-HVAC integration).
Credit 8: Light pollution reduction.	Eliminate light trespass from the building and site, improve night sky access and reduce development impact on nocturnal environments.	▪ Daily entrainment of the human circadian clock is vital for good human health. Studies suggest that the proper use and color of indoor and outdoor lighting is important to human health (Pauley 2004).	No indirect health effect.	▪ Meet or provide lower light levels and uniformity ratios than those recommended by the Illuminating Engineering Society of North America (IESNA). ▪ The maximum candela value of all interior lighting shall fall within the building.	▪ Adopt site lighting criteria to maintain safe light levels while avoiding off-site lighting and night sky pollution. ▪ Minimize site lighting where possible and model the site lighting using a computer model. ▪ Technologies to reduce light pollution include full cutoff luminaries, low-reflectance surfaces and low angle spotlights.	▪ Design of lighting fixtures should be such that it will minimize interference with normal circadian rhythms in humans (Pauley 2004).

Water Efficiency

Credit 1.1: **Water Efficient Landscaping** (reduce by 50%)	Limit or eliminate the use of potable water for landscape irrigation.	No direct health effect.	▪ The increased use of minimally treated household grey water for landscaping irrigation represents a small potential increased risk of waterborne pathogen transmission to the humans through contact recreation, due to the presence of enteric viruses and cyst-forming protozoa (Lee and Jones-Lee 1993). *	▪ High efficiency irrigation technology. ▪ Use captured rain or recycled site water for irrigation by 50% over conventional means.	▪ Perform soil /climate analysis to determine appropriate landscape types. ▪ Design the landscape with indigenous plants. ▪ Use high efficiency irrigation systems. ▪ Use stormwater/grey water for irrigation.	None.

- **Most of the literature suggests that negative health effects from the use of recycled grey water/stormwater for landscaping is minimal.*
- The tertiary treatment of wastewater significantly reduces the presence of enteric pathogens and cysts (Lee and Jones-Lee 1993).

Credit 1.2: **Water Efficient Landscaping** (no potable use or no irrigation)	Limit or eliminate the use of potable water for landscape irrigation.	No direct health effect.	▪ The increased use of minimally treated household gray water for landscaping irrigation represents a small potential increased risk of waterborne pathogen transmission to the humans through contact recreation, due to the presence of enteric viruses and cyst-forming protozoa (Lee and Jones-Lee 1993). *	▪ Use ONLY captured rain or recycled site water. ▪ Do not install permanent landscape irrigation systems.	▪ Perform soil /climate analysis to determine appropriate landscape types. ▪ Design the landscape with indigenous plants. ▪ Use stormwater/grey water for irrigation.	None.

- **Most of the literature suggests that negative health effects from the use of recycled grey water/stormwater for landscaping is minimal.*
- The tertiary treatment of wastewater significantly reduces the presence of enteric pathogens and cysts (Lee and Jones-Lee 1993).

Credit 2: **Innovative Wastewater Technologies.**	Reduce generation of wastewater and potable water demand, while increasing the local aquifer recharge.	No direct health effect.	No indirect health effect.	▪ Reduce the use of municipally provided potable water for building sewage conveyance by a minimum of 50%. ▪ Treat 100% of wastewater on site to tertiary standards.	▪ Specify high-efficiency fixtures and dry fixtures such as composting toilets and waterless urinals.	None.

- *Innovative wastewater technologies: From the intent and guidelines it is not clear how the local aquifer recharge is attained.*

Credit 3.1: **Water Use Reduction.** (20% reduction)	Maximize water efficiency within buildings to reduce the burden on municipal water supply and wastewater systems.	No direct health effect.	No indirect health effect.	▪ Employ strategies that in aggregate use 20% less water than the water use baseline calculated for the building (not including irrigation) after meeting the Energy Policy Act of 1992 fixture performance requirements.	▪ Estimate the potable and non-potable water needs for the building. ▪ Use high efficiency fixtures, dry fixtures such as composting toilets, waterless urinals and occupant sensors to reduce the potable water demand.	None.
Credit 3.2: **Water Use Reduction.** (30% reduction)	Maximize water efficiency within buildings to reduce the burden on municipal water supply and wastewater systems.	No direct health effect.	No indirect health effect.	▪ Employ strategies that in aggregate use 30% less water than the water use baseline calculated for the building (not including irrigation) after meeting the Energy Policy Act of 1992 fixture performance requirements.	▪ Estimate the potable and non-potable water needs for the building. ▪ Use high efficiency fixtures, dry fixtures such as composting toilets, waterless urinals and occupant sensors to reduce the potable water demand.	None.

Energy and Atmosphere

Prereq. 1: **Fundamental Building Systems Commissioning**	Verify and ensure that fundamental building elements and systems are designed, installed and calibrated to operate as intended.	▪ Studies indicate that building systems that are not installed or operating properly can lead to IAQ problems which has adverse health effects ranging from headaches and fatigue to severe allergic reactions. Commissioning can lead to a healthy environment in buildings (PECI 1998).	▪ Building systems that are not installed or operating properly can lead to lower levels of comfort for occupants (PECI 1998).	▪ Engage a commissioning team that does not include individuals directly responsible for project design or construction management. ▪ Review the design intent and the basis of design documentation. ▪ Incorporate commissioning requirements into the construction documents. ▪ Develop and utilize a commissioning plan. ▪ Verify installation, functional performance, training and operation and maintenance documentation. ▪ Complete a commissioning report.	▪ Include commissioning requirements in bid documents and task the commissioning agent to produce a commissioning report once commissioning activities are completed.	Higher levels of: ▪ Mechanical systems integration. ▪ Electrical systems integration. ▪ Fire safety systems integration. ▪ Security systems integration. ▪ Miscellaneous building systems integration.

- *A lot of building systems integration possibilities. This should be a major component of whole house design.*

Prereq. 2: **Minimum Energy performance.**	Establish the minimum level of energy efficiency for the base building and systems.	No direct health effect.	No indirect health effect.	▪ Design the building to comply with ASHRAE/IESNA Standard 90.1-1999 or the local energy code, whichever is more stringent.	▪ Design the building envelope and systems to maximize energy performance. ▪ Use a computer simulation model to assess the energy performance and identify the most cost effective energy measures. ▪ Quantify energy performance compared to the baseline building.	▪ Tight building envelope. ▪ Better integration of envelope and mechanical systems to achieve energy efficiency.
Prereq. 3: CFC Reduction in HVAC&R Equipment.	Reduce ozone depletion.	*No direct health effect.	▪ Reactive chlorine released from the CFCs causes degradation of stratospheric ozone. This leads to an increase in the amount of ultraviolet radiation (UVB band) reaching earth's surface. UV induced health effects include skin cancer and cataract (de Gruijl 2000).	▪ Zero use of CFC-based refrigerants in new base building HVAC&R systems. ▪ When reusing existing base building HVAC equipment, complete a comprehensive CFC phase-out conversion.	▪ For new buildings, specify new HVAC equipment that uses no CFC refrigerants. ▪ When reusing existing HVAC systems, conduct an inventory to identify equipment that uses CFC refrigerants and adopt a replacement schedule for these refrigerants.	None.

- *NIOSH alerts that working with CFC in confined spaces may cause death by cardiac arrhythmia or asphyxiation. But the reported incidents occurred in industrial type facilities and involved large quantities of CFC (NIOSH 1989).

Credit 1: **Optimize Energy Performanc e.**	Achieve increasing levels of energy performance above the prerequisite standard to reduce environmental impacts associated with excessive energy use.	No direct health effect.	▪ Reactive	▪ Reduce design energy cost compared to the energy cost budget for energy systems regulated by ASHRAE/IESNA Standard 90.1-1999 (without amendments), as demonstrated by a whole building simulation using the Energy Cost Budget Method. ▪ Separate meters (accounting) may be created in the energy simulation program for regulated and non-regulated energy uses in the building.	▪ Design the building envelope and building systems to maximize energy performance. ▪ Use a computer simulation model to assess the energy performance and identify the most cost-effective energy efficiency measures. ▪ Quantify energy performance as compared to a baseline building.	▪ Better building systems integration to optimize energy performance (e.g.: mechanical systems and envelope integration, lighting systems and interior integration). ▪ Building systems integration modeling to optimize energy performance.

- *Energy efficiency should be treated as a separate performance parameter (apart from sustainability) for whole house and studied in detail. (Building systems integration together with building systems commissioning, to achieve maximum energy efficiency.)*

Credit 2.1, 2.2, 2.3: **Renewable Energy** (5%, 10%, 20%).	Encourage and recognize increasing levels of on-site renewable energy self supply in order to reduce environmental impacts associated with fossil fuel energy use.	No direct health effect.	No direct health effect.	▪ Supply at least 5%-10%-20% of the building's total energy use (as expressed as a fraction of annual energy cost) through the use of on-site renewable energy systems.	▪ Assess the project for non-polluting and renewable energy potential including solar, wind, geothermal, low-impact hydro, biomass and bio-gas strategies.	▪ Changes in building design to incorporate the renewable energy facilities (building orientation, slope of roof etc.)

Credit 3: **Additional Commissioning**	Verify and ensure that the entire building is designed, constructed and calibrated to operate as intended.	No direct health effect.	No direct health effect.	Implement or have a contract in place to implement the following additional commissioning tasks: ▪ A commissioning authority independent of the design team shall conduct a review of the design prior to the construction documents phase. ▪ An independent commissioning authority shall conduct a review of the construction documents near completion of the construction document development and prior to issuing the contract documents. ▪ An independent commissioning authority shall review the contractor submittals. ▪ Provide the owner with a single manual that contains the information required for re-commissioning building systems.	▪ Engage the commissioning authority early in the design phases.	None.

Credit 4: Ozone Protection.	Reduce ozone depletion and support early compliance with the Montreal Protocol.	No direct health effect.	▪ Reactive chlorine released from the CFCs causes degradation of stratospheric ozone. This leads to an increase in the amount of ultraviolet radiation (UVB band) reaching earth's surface. UV induced health effects include skin cancer and cataract (de Gruijl 2000).	▪ Install base building level HVAC and refrigeration equipment and fire suppression systems that do not contain HCFCs or Halons.	▪ When reusing buildings, inventory existing building systems using refrigerants and fire suppression chemicals and replace those that contain HCFCs or Halons. ▪ For new buildings, specify refrigeration and fire suppression systems that use no HCFCs or Halons.	None.
Credit 5: Measurement and Verification.	Provide for the ongoing accountability and optimization of building energy and water consumption performance over time.	No direct health effect.	No indirect health effect.	Install continuous metering equipment for the following end-uses: ▪ Lighting systems and controls ▪ Constant and variable motor loads ▪ Variable frequency drive (VFD) operation ▪ Chiller efficiency at variable loads (kW/ton) ▪ Cooling load ▪ Air and water economizer and heat recovery cycles ▪ Air distribution static pressures and ventilation	▪ Model the energy and water systems to predict savings. ▪ Design the building with equipment to measure energy and water performance. ▪ Draft a Measurement & Verification Plan to apply during building operation that compares predicted savings to those actually achieved in the field.	None.

				air volumes ▪ Develop a Measurement and Verification plan that incorporates the monitoring information from the above end-uses and is consistent with Option B, C or D of the 2001 International Performance Measurement & Verification Protocol (IPMVP) Volume I: Concepts and Options for Determining Energy and Water Savings.		
Credit 6: Green Power	Encourage the development and use of grid-source, renewable energy technologies on a net zero pollution basis.	No direct health effect.	No direct health effect.	▪ Provide at least 50% of the building's electricity from renewable sources by engaging in at least a two-year renewable energy contract.	▪ Determine the energy needs of the building and investigate opportunities to engage in a green power contract with the local utility. Green power is derived from solar, wind, geothermal, biomass or low-impact hydro sources. Green power may be procured from a Green-e certified power marketer, a Green-e accredited utility program, through Green-e certified Tradable Renewable Certificates, or from a supply that meets the Green-e renewable power definition.	None.

Materials & Resources

Prereq. 1: **Storage & Collection of Recyclables**.	Facilitate the reduction of waste generated by building occupants that is hauled to and disposed of in landfills.	No direct health effect.	No indirect health effect.	▪ Provide an easily accessible area that serves the entire building and is dedicated to the separation, collection and storage of materials for recycling including paper, corrugated cardboard, glass, plastics and metals.	▪ Designate an area for recyclable collection and storage that is appropriately sized and located in a convenient area. ▪ Identify local waste handlers and buyers for glass, plastic, office paper, newspaper, cardboard and organic wastes. ▪ Instruct occupants on building recycling procedures. ▪ Employ cardboard balers, aluminum can crushers, recycling chutes and other waste management technologies to further enhance the recycling program.	▪ Provision in the design for a conveniently located recyclable collection and storage facility. ▪ Design provision for recycling chutes and associated storage/collection facility.
Credit 1.1: Building Reuse: (Maintain 75% of Existing Walls, Floors and Roof).	Extend the life cycle of existing building stock, conserve resources, retain cultural resources, reduce waste and reduce environmental impacts of new buildings as they	No direct health effect.	No indirect health effect.	▪ Maintain at least 75% of existing building structure and shell (exterior skin and framing, excluding window assemblies and non-structural roofing material).	▪ Reuse of existing buildings, including structure, shell and non-shell elements. ▪ Remove elements that pose contamination risk to building occupants and upgrade outdated components such as windows, mechanical systems and plumbing	▪

	relate to materials manufacturing and transport.				fixtures. ▪ Quantify the extent of building reuse.	
Credit 1.2: Building Reuse: (Maintain 100% of Existing Walls, Floors and Roof).	Extend the life cycle of existing building stock, conserve resources, retain cultural resources, reduce waste and reduce environmental impacts of new buildings as they relate to materials manufacturing and transport.	No direct health effect.	No indirect health effect.	▪ Maintain an additional 25% (100% total) of existing building structure and shell (exterior skin and framing, excluding window assemblies and nonstructural roofing material).	▪ Reuse of existing buildings, including structure, shell and non-shell elements. ▪ Remove elements that pose contamination risk to building occupants and upgrade outdated components such as windows, mechanical systems and plumbing fixtures. ▪ Quantify the extent of building reuse.	▪
Credit 1.3: Building Reuse: (Maintain 100% of Shell/Structure and 50% of Non-Shell/Non-Structure).	Extend the life cycle of existing building stock, conserve resources, retain cultural resources, reduce waste and reduce environmental impacts of new buildings as they relate to materials manufacturing and transport.	No direct health effect.	No indirect health effect.	▪ Maintain 100% of existing building structure and shell (exterior skin and framing, excluding window assemblies and non-structural roofing material) AND at least 50% of non-shell areas (interior walls, doors, floor coverings and ceiling systems).	▪ Reuse of existing buildings, including structure, shell and non-shell elements. ▪ Remove elements that pose contamination risk to building occupants and upgrade outdated components such as windows, mechanical systems and plumbing fixtures. ▪ Quantify the extent of building reuse.	▪

Credit 2.1: Construction Waste Managemen t: (Divert 50% From Landfill).	Divert construction, demolition and land clearing debris from landfill disposal. Redirect recyclable recovered resources back to the manufacturing process. Redirect reusable materials to appropriate sites.	No direct health effect.	No indirect health effect.	▪ Develop and implement a waste management plan, quantifying material diversion goals. ▪ Recycle and/or salvage at least 50% of construction, demolition and land clearing waste.	▪ Establish goals for landfill diversion and adopt a construction waste management plan to achieve these goals. ▪ Recycle land clearing debris, cardboard, metal, brick, concrete, plastic, clean wood, glass, gypsum wallboard, carpet and insulation. ▪ Designate a specific area on the construction site for recycling and track recycling efforts throughout the construction process. ▪ Identify construction haulers and recyclers to handle the designated materials.	▪ Develop and implement a construction waste management plan that establishes goals, means, methods and types of materials to be recycled. ▪ Construction site planning to incorporate a conveniently positioned area for recycling efforts. ▪ Adopt construction methods that generate less waste.
Credit 2.2: Construction Waste Managemen t: (Divert 75% From Landfill).	Divert construction, demolition and land clearing debris from landfill disposal. Redirect recyclable recovered resources back to the manufacturing process. Redirect reusable materials to appropriate sites.	No direct health effect.	No indirect health effect.	▪ Develop and implement a waste management plan, quantifying material diversion goals. ▪ Recycle and/or salvage at least 75% of construction, demolition and land clearing waste.	▪ Establish goals for landfill diversion and adopt a construction waste management plan to achieve these goals. ▪ Recycle land clearing debris, cardboard, metal, brick, concrete, plastic, clean wood, glass, gypsum wallboard, carpet and insulation. ▪ Designate a specific area on the construction site for recycling and track recycling efforts throughout the	▪ Develop and implement a construction waste management plan that establishes goals, means, methods and types of materials to be recycled. ▪ Construction site planning to incorporate a conveniently positioned area for recycling efforts. ▪ Adopt construction

					construction process. ▪ Identify construction haulers and recyclers to handle the designated materials.	methods that generate less waste.
Credit 3.1: Resource reuse: (5%).	Reuse building materials and products in order to reduce demand for virgin materials and to reduce waste, thereby reducing impacts associated with the extraction and processing of virgin resources.	No direct health effect.	Reused building materials may have less VOC content harmful to health, when compared to new building materials?	▪ Use salvaged, refurbished or reused materials, products and furnishings for at least 5% of building materials.	▪ Identify opportunities to incorporate salvaged materials into building design and research potential material suppliers. ▪ Consider salvaged materials such as beams and posts, flooring, paneling, doors and frames, cabinetry and furniture, brick and decorative items.	▪ Specify salvaged materials wherever possible if it satisfies the structural, functional and aesthetic requirements.
Credit 3.2: Resource reuse: (10%).	Reuse building materials and products in order to reduce demand for virgin materials and to reduce waste, thereby reducing impacts associated with the extraction and processing of virgin resources.	No direct health effect.	Reused building materials may have less VOC content harmful to health, when compared to new building materials?	▪ Use salvaged, refurbished or reused materials, products and furnishings for at least 10% of building materials.	▪ Identify opportunities to incorporate salvaged materials into building design and research potential material suppliers. ▪ Consider salvaged materials such as beams and posts, flooring, paneling, doors and frames, cabinetry and furniture, brick and decorative items.	▪ Specify salvaged materials wherever possible if it satisfies the structural, functional and aesthetic requirements.

Credit 4.1: Recycled content: 5% (post-consumer + 1/2 post-industrial).	Increase demand for building products that incorporate recycled content materials, therefore reducing impacts resulting from extraction and processing of new virgin materials.	No direct health effect.	Recycled building materials may have less VOC content harmful to health, when compared to new building materials?	▪ Use materials with recycled content such that the sum of post-consumer recycled content plus one-half of the post-industrial content constitutes at least 5% of the total value of the materials in the project. ▪ Recycled content materials shall be defined in accordance with the Federal Trade Commission document, Guides for the Use of Environmental Marketing Claims, 16 CFR.	▪ Establish a project goal for recycled content materials and identify material suppliers that can achieve this goal. ▪ During construction, ensure that the specified recycled content materials are installed and quantify the total percentage of recycled content materials installed.	▪ Specify recycled content materials wherever possible if it satisfies the structural, functional and aesthetic requirements.
Credit 4.2: Recycled content: 10% (post-consumer + 1/2 post-industrial).	Increase demand for building products that incorporate recycled content materials, therefore reducing impacts resulting from extraction and processing of new virgin materials.	No direct health effect.	Recycled building materials may have less VOC content harmful to health, when compared to new building materials?	▪ Use materials with recycled content such that the sum of post-consumer recycled content plus one-half of the post-industrial content constitutes at least 10% of the total value of the materials in the project. ▪ Recycled content materials shall be defined in accordance with the Federal Trade Commission document, Guides for the Use of Environmental Marketing Claims.	▪ Establish a project goal for recycled content materials and identify material suppliers that can achieve this goal. ▪ During construction, ensure that the specified recycled content materials are installed and quantify the total percentage of recycled content materials installed.	▪ Specify recycled content materials wherever possible if it satisfies the structural, functional and aesthetic requirements.

Credit 5.1: Regional materials: (20% manufactured regionally).	Increase demand for building materials and products that are extracted and manufactured within the region, thereby supporting the regional economy and reducing the environmental impacts resulting from transportation.	No direct health effect.	No indirect health effect.	▪ Use a minimum of 20% of building materials and products that are manufactured regionally within a radius of 500 miles.	▪ Establish a project goal for locally sourced materials and identify materials and material suppliers that can achieve this goal. ▪ During construction, ensure that the specified local materials are installed and quantify the total percentage of local materials installed.	None.
Credit 5.2: Regional materials: (50% manufactured regionally).	Increase demand for building materials and products that are extracted and manufactured within the region, thereby supporting the regional economy and reducing the environmental impacts resulting from transportation.	No direct health effect.	No indirect health effect.	▪ Of the regionally manufactured materials documented for MR Credit 5.1, use a minimum of 50% of building materials and products that are extracted, harvested or recovered (as well as manufactured) within 500 miles of the project site.	▪ Establish a project goal for locally sourced materials and identify materials and material suppliers that can achieve this goal. ▪ During construction, ensure that the specified local materials are installed and quantify the total percentage of local materials installed.	None.
Credit 6: Rapidly Renewable Materials	Reduce the use and depletion of finite raw materials and long-cycle renewable materials by	No direct health effect.	Most rapidly renewable building materials may have high VOC content that can affect health?	▪ Use rapidly renewable building materials and products (made from plants that are typically harvested within a ten-year cycle or shorter) for 5% of the total value of	▪ Establish a project goal for rapidly renewable materials and identify materials and suppliers that can achieve this goal. ▪ Consider materials such	▪ Specify rapidly renewable materials wherever possible if it satisfies the structural, functional and aesthetic requirements.

	replacing them with rapidly renewable materials.			all building materials and products used in the project.	as bamboo flooring, wool carpets, straw board, cotton batt insulation, linoleum flooring, poplar OSB, sunflower seed board, wheatgrass cabinetry and others. ▪ During construction, ensure that the specified rapidly renewable materials are installed.	
Credit 7: Certified Wood.	Encourage environmentally responsible forest management.	No direct health effect.	No indirect health effect.	▪ Use a minimum of 50% of wood-based materials and products, certified in accordance with the Forest Stewardship Council's Principles and Criteria, for wood building components including, but not limited to, structural framing and general dimensional framing, flooring, finishes, furnishings, and nonrented temporary construction applications such as bracing, concrete form work and pedestrian barriers.	▪ Establish a project goal for FSC-certified wood products and identify suppliers that can achieve this goal. ▪ During construction, ensure that the FSC-certified wood products are installed and quantify the total percentage of FSC certified wood products installed.	▪ Specify FSC certified wood based materials and products wherever possible.

Indoor Environmental Quality

Prereq. 1: **Minimum IAQ Performance:**	Establish minimum indoor air quality (IAQ) performance to prevent the development of indoor air quality problems in buildings, thus contributing to the comfort and well being of the occupants.	▪ Health effects associated with indoor environment include eye, nose and throat irritation; headaches, fatigue and lethargy; upper respiratory symptoms; and skin irritation and rashes. 'Sick building syndrome' refers to the excess prevalence of this collection of symptoms. 'Building-related illness' refers to a different set of diseases including hypersensitivity pneumonitis and Legionnaires' disease. Other health effects include symptoms of allergies and asthma, respiratory illnesses, and toxic and systemic effects with known causes (e.g.	No indirect health effect.	▪ Meet the minimum requirements of voluntary consensus standard ASHRAE 62-1999, Ventilation for Acceptable Indoor Air Quality, and approved Addenda using the Ventilation Rate Procedure.	▪ Design the HVAC system to meet the ventilation requirements of the referenced standard. ▪ Identify potential IAQ problems on the site and locate air intakes away from contaminant sources.	▪ Proper design, installation, commissioning, operation and maintenance of HVAC systems. ▪ Building systems commissioning to be implemented. ▪ Implementation of preventive maintenance procedures (ASHRAE 2001). ▪ Previous land use evaluation and testing for soil contaminants may be undertaken. ▪ The location of parking areas, vehicle access areas and high traffic areas relative to building openings and air intakes is identified as an issue for consideration as the building mass is developed. ▪ Landscape areas to enhance the outdoor air requirements. ▪ Low-emitting materials for the envelope and the interior finishes (ATS 1997). ▪ Air intakes for

		carbon monoxide poisoning). Implementation of advanced and available Indoor Air Quality knowledge, technologies and practices could significantly improve indoor environments, health and comfort. (ASHRAE 2001).				ventilation to be located away from busy streets or at the rear end of building (ESRU 2005). ▪ Proper integration of HVAC and envelope systems to avoid problems related to moisture buildup and associated microbial growth.
Prereq. 2: Environmental tobacco Smoke Control	Prevent exposure of building occupants and systems to Environmental Tobacco Smoke (ETS).	Environmental tobacco smoke (ETS) is also called second-hand smoke or passive smoke. ETS consists of particulate matter and vapor phase. Chemicals known to be present in ETS can be (Allwright et al. 2002): ▪ Cancer-causing ▪ Irritating to the eyes and to the lungs, resulting in respiratory problems ▪ Cause reproductive problems or harm the unborn child ▪ Have effects on the cardiovascular	No indirect health effect.	Zero exposure of non-smokers to ETS by either: ▪ Prohibiting smoking in the building and locating any exterior designated smoking areas away from entries and operable windows; OR ▪ Providing a designated smoking room designed to effectively contain, capture and remove ETS from the building. At a minimum, the smoking room must be directly exhausted to the outdoors with no recirculation of ETS-containing air to the non-smoking area of the building, enclosed with impermeable deck-to-	▪ Prohibit smoking in the building. ▪ Provide separate smoking rooms with isolated ventilation systems.	▪ Provision for designated smoking rooms in the building or exterior smoking areas in the building. ▪ Proper ventilation of designated smoking areas. ▪ Building systems integration issues arising from separate ventilation/exhaust and negative pressure to be employed in the designated smoking rooms/areas.

		system. ▪ Children in ETS environment are susceptible to asthma, bronchitis, pneumonia, sudden infant death syndrome (SIDS) and ear Infections (US EPA 2004).		deck partitions and operated at a negative pressure compared with the surrounding spaces of at least 7 PA (0.03 inches of water gauge). ▪ Performance of the smoking rooms shall be verified by using tracer gas testing methods as described in the ASHRAE Standard 129-1997.		
Credit 1: Carbon Dioxide (CO2) Monitoring	Provide capacity for indoor air quality (IAQ) monitoring to help sustain long-term occupant comfort and well being.	▪ Exposure to carbon dioxide concentrations above 20,000 ppm can affect respiratory function and cause excitation followed by depression of the central nervous system (general discomfort). Higher concentrations of CO2 can cause headache, dizziness, sweating, restlessness, disorientation, irritability, discomfort and visual distortion. Concentrations greater than 100,000 ppm can	No indirect health effect.	▪ Install a permanent carbon dioxide (CO2) monitoring system that provides feedback on space ventilation performance in a form that affords operational adjustments. Refer to the CO2 differential for all types of occupancy in accordance with ASHRAE 62-2001, Appendix D.	▪ Design the HVAC system with carbon dioxide monitoring sensors and integrate these sensors with the building automation system (BAS).	▪ Carbon dioxide monitoring sensors to be installed in occupied spaces. ▪ Active integration of carbon dioxide sensors with HVAC system (dampers) so as to maintain indoor carbon dioxide levels similar to outdoor air (Keen 2004).

		cause impaired hearing, nausea, vomiting, unconsciousness and even death (CCOHS 1997). ▪ Dangerous CO2 levels as outlined by OSHA is >5,000 ppm for an extended time period and >30,0000 ppm for a period of 15 minutes. But these levels are a rare occurrence in a standard building environment. ▪ CO2 is monitored as an indicator to indoor air quality. When CO2 levels exceed 1000 ppm, it is assumed that other pollutants also exceed safe levels (Keen 2004).				
Credit 2: Ventilation Effectivenes s	Provide for the effective delivery and mixing of fresh air to support the safety, comfort and well-being of building occupants.	Sick building syndrome (SBS) is associated with occupancy in buildings and is characterized by the following: eye, nose and throat irritation; erythema (skin redness);	No indirect health effect.	▪ For mechanically ventilated buildings, design ventilation systems that result in an air change effectiveness (Eac) greater than or equal to 0.9 as determined by ASHRAE 129-1997. ▪ For naturally ventilated	▪ Design the HVAC system and building envelope to optimize air change effectiveness. ▪ Air change effectiveness can be optimized using a variety of ventilation strategies including displacement ventilation, low-velocity ventilation,	▪ HVAC – Envelope (right sizing of HVAC equipment) integration for optimizing air change effectiveness. ▪ Adoption of effective ventilation strategies.

		headache; nonspecific hypersensitivity; nausea and dizziness, difficulty in concentration; and difficulty in breathing. Inadequate ventilation is one of the causes of sick building syndrome. The rate of ventilation affects indoor environmental conditions including air pollutant concentrations that, in turn, can modify the occupants' health or perceptions. Studies show that ventilation rates below 10 Ls-1 per person were associated with significant worsening in one or more health or perceived air quality outcomes. Some other studies show that increases in ventilation rates above 10 Ls-1 per person, up to		spaces demonstrate a distribution and laminar flow pattern that involves not less than 90% of the room or zone area in the direction of air flow for at least 95% of hours of occupancy.	plug-flow ventilation such as under floor or near floor delivery, and operable windows. ▪ Test the air change effectiveness of the building after construction.	▪ Building systems commissioning.

		approximately 20 Ls-1 per person, were associated with further significant decreases in the prevalence of SBS symptoms (Seppänen 1999)				
Credit 3.1: Construction IAQ Management Plan: (During Construction)	Prevent indoor air quality problems resulting from the construction/renovation process in order to help sustain the comfort and well-being of construction workers and building occupants.	▪ Construction and renovation projects may present a wide range of situations where release of contaminants and pollutants occurs and the indoor air quality (IAQ) of the building is adversely affected. ▪ Indoor air contaminants generated by construction activities include vapors, particles and microbial aerosols. ▪ Workers in the industry can be exposed to high levels of these pollutants and subsequent a range of negative health effects unless reasonable precautions are taken at the	No indirect health effect.	Develop and implement an Indoor Air Quality (IAQ) Management Plan for the construction and pre-occupancy phases of the building as follows: ▪ During construction meet or exceed the recommended Design Approaches of the Sheet Metal and Air Conditioning National Contractors Association (SMACNA) IAQ Guideline for Occupied Buildings. ▪ Protect stored on-site or installed absorptive materials from moisture damage. ▪ If air handlers must be used during construction, filtration media with a Minimum Efficiency Reporting Value (MERV) of 8 must be used at each return air grill, as determined by ASHRAE 52.2-1999.	▪ Adopt an IAQ management plan to protect the HVAC system during construction, control pollutant sources and interrupt contamination pathways. ▪ Sequence the installation of materials to avoid contamination of absorptive materials such as insulation, carpeting, ceiling tile and gypsum wallboard.	▪ Adequate planning and communication prior to the construction phase. ▪ Specify materials with minimal contaminant generation. ▪ Site construction related equipment should be located away from the building access areas and from air intakes. ▪ Modify air intakes with adequate filtration. ▪ Provide negative pressure in work areas and filter any air discharged outside. ▪ Test and monitor ventilation and exhaust airflow for suspected contaminant particles and gases during construction (Kuehn 1998). ▪ Schedule construction/installation sequence so as to avoid contamination of absorptive materials.

		building site. ▪ In case these pollutants penetrate adjacent occupied buildings or occupied areas of a renovated building, adverse health effects among the occupants can be seen (Kuehn 1998).		▪ Replace all filtration media immediately prior to occupancy. Filtration media shall have a Minimum Efficiency Reporting Value (MERV) of 13, as determined by ASHRAE 52.2-1999 for media installed at the end of construction.		▪ JIT construction.
Credit 3.2: Construction IAQ Management Plan: (Before Occupancy)	Prevent indoor air quality problems resulting from the construction/renovation process in order to help sustain the comfort and well-being of construction workers and building occupants.	▪ Construction and renovation projects may present a wide range of situations where release of contaminants and pollutants occurs and the indoor air quality (IAQ) of the building is adversely affected. ▪ Indoor air contaminants generated by construction activities include vapors, particles and microbial aerosols. ▪ Workers in the industry can be exposed to high levels of these pollutants and subsequent a	No indirect health effect.	Develop and implement an Indoor Air Quality (IAQ) Management Plan for the pre-occupancy phase as follows: ▪ After construction ends and prior to occupancy conduct a minimum two-week building flush out with new Minimum Efficiency Reporting Value (MERV) 13 filtration media at 100% outside air. After the flush out, replace the filtration media with new MERV 13 filtration media, except the filters solely processing outside air. OR ▪ Conduct a baseline indoor air quality testing procedure consistent	▪ Prior to occupancy, perform a two-week building flush out or test the contaminant levels in the building.	▪ Include IAQ monitoring in the building systems commissioning process. ▪ Schedule adequate out gassing time for new paints, carpets adhesives and other materials prior to occupancy. ▪ Perform two-week building flush out with 100% outside air. ▪ Schedule construction/installation sequence so as to avoid contamination of absorptive materials. ▪ JIT construction.

		range of negative health effects unless reasonable precautions are taken at the building site. ▪ In case these pollutants penetrate adjacent occupied buildings or occupied areas of a renovated building, adverse health effects among the occupants can be seen (Kuehn 1998).		with the United States Environmental Protection Agency's current Protocol or Environmental Requirements, Baseline IAQ and Materials, for the Research Triangle Park Campus, Section 01445.		
Credit 4.1: Low-Emitting Materials: (Adhesives & Sealants)	Reduce the quantity of indoor air contaminants that are odorous, potentially irritating and/or harmful to the comfort and well-being of installers and occupants.	▪ Newly installed adhesives & sealants emit volatile organic compounds (VOC). ▪ Researchers have reported that increased concentrations of indoor VOCs are often associated with increased occupant health complaints. ▪ Immediate negative health effects include physiological irritation - inflammation of exposed skin,	No indirect health effect.	▪ The VOC content of adhesives and sealants used must be less than the current VOC content limits of South Coast Air Quality Management District (SCAQMD) Rule #1168 AND ▪ All sealants used as fillers must meet or exceed the requirements of the Bay Area Air Quality Management District Regulation 8, Rule 51.	▪ Specify Low-VOC materials in construction documents. ▪ Ensure that VOC limits are clearly stated in each section where adhesives and sealants are addressed.	▪ Specify application of only the minimum amounts of these materials necessary for satisfactory completion of each installation task. ▪ Require that adhesives have the lowest possible content of toxic or irritating VOCs. ▪ Ensure that maximum ventilation is supplied during and after application of these products. ▪ Implement building bake-out process. The purpose of a building bake-out is to "artificially age"

		eyes, and mucous membranes - and stress reactions to the perceived chemical - tearing of the eyes; runny nose; stinging, itching, or tingling feelings in exposed tissues; changes in skin temperature; headache; and drowsiness. ▪ Delayed health effects, include risk of asthma, other chronic respiratory illnesses, reproductive effects and carcinogenic effects (Alevantis 1996).				building materials and products by accelerating emissions of residual solvents. It involves elevating the temperature of an unoccupied, newly constructed or remodeled building to between 95F and 102F while supplying a fixed amount of ventilation, and flushing out the building with the maximum possible ventilation after completion of the process (Alevantis 1996).
Credit 4.2: Low-Emitting Materials: (Paints & Coatings)	Reduce the quantity of indoor air contaminants that are odorous, potentially irritating and/or harmful to the comfort and well-being of installers and occupants.	▪ Newly installed paints & coatings emit volatile organic compounds (VOC). ▪ Researchers have reported that increased concentrations of indoor VOCs are often associated with increased occupant health complaints.	No indirect health effect.	▪ VOC emissions from paints and coatings must not exceed the VOC and chemical component limits of Green Seal's Standard GS-11 requirements.	▪ Specify Low-VOC paints and coatings in construction documents. ▪ Ensure that VOC limits are clearly stated in each section where paints are addressed.	▪ Minimize the use of solvent-based paints indoors. ▪ Require that paints & coatings have the lowest possible content of toxic or irritating VOCs. ▪ Ensure that maximum ventilation is supplied during and after application of paints. ▪ Implement building bake-out process. The purpose of a building

		▪ Immediate negative health effects include physiological irritation - inflammation of exposed skin, eyes, and mucous membranes - and stress reactions to the perceived chemical - tearing of the eyes; runny nose; stinging, itching, or tingling feelings in exposed tissues; changes in skin temperature; headache; and drowsiness. ▪ Delayed health effects, include risk of asthma, other chronic respiratory illnesses, reproductive effects and carcinogenic effects (Alevantis 1996).				bake-out is to "artificially age" building materials and products by accelerating emissions of residual solvents. It involves elevating the temperature of an unoccupied, newly constructed or remodeled building to between 95F and 102F while supplying a fixed amount of ventilation, and flushing out the building with the maximum possible ventilation after completion of the process (Alevantis 1996).
Credit 4.3: Low-Emitting Materials: (Carpet)	Reduce the quantity of indoor air contaminants that are odorous,	DIRECT EFFECTS ▪ Newly installed paints & coatings emit volatile organic compounds (VOC).	INDIRECT EFFECT. No indirect health effect.	▪ Carpet systems must meet or exceed the requirements of the Carpet and Rug Institute's (CRI) Green Label Indoor Air Quality Test Program.	▪ Specify Low-VOC carpet products and systems in construction documents. ▪ Ensure that VOC limits are clearly stated where carpet systems are	▪ Specify carpets having CRI's indoor air quality label. ▪ Conditioning of carpets may be done prior to shipment, after delivery or after installation.

	potentially irritating and/or harmful to the comfort and well-being of installers and occupants.	▪ Researchers have reported that increased concentrations of indoor VOCs are often associated with increased occupant health complaints. ▪ Immediate negative health effects include physiological irritation - inflammation of exposed skin, eyes, and mucous membranes - and stress reactions to the perceived chemical - tearing of the eyes; runny nose; stinging, itching, or tingling feelings in exposed tissues; changes in skin temperature; headache; and drowsiness. ▪ Delayed health effects, include risk of asthma, other chronic respiratory illnesses, reproductive effects and carcinogenic effects.			addressed.	▪ Specify low VOC products for carpet assembly constitents like adhesives used for its installation, padding, seaming and "floor-prep" compounds, and the underlayment or substrate. ▪ Ensure that maximum ventilation is supplied during and after installation of carpets. ▪ Implement building bake-out process. The purpose of a building bake-out is to "artificially age" building materials and products by accelerating emissions of residual solvents. It involves elevating the temperature of an unoccupied, newly constructed or remodeled building to between 95F and 102F while supplying a fixed amount of ventilation, and flushing out the building with the maximum possible ventilation after completion of the process (Alevantis 1996).

Credit 4.4: Low-Emitting Materials: (Composite wood)	Reduce the quantity of indoor air contaminants that are odorous, potentially irritating and/or harmful to the comfort and well-being of installers and occupants.	▪ Formaldehyde is a colorless flammable gas with a pungent odor found in the resins in composite wood products. ▪ High relative humidity and increased temperatures trigger the degradation of resins containing formaldehyde leading to out gassing. ▪ Negative health effects include irritant effects, sensitization, carcinogenicity and asthmatic conditions (DTIR 1995).	No indirect health effect.	▪ Composite wood and agrifiber products must contain no added urea-formaldehyde resins.	▪ Specify wood and agrifiber products that contain no added urea-formaldehyde resins.	▪ Specify low-formaldehyde-emitting products meeting HUD, HPVA, and NPA's guidelines. ▪ Consider completely sealing all exposed surfaces, including any penetrations, with a coating of nitro cellulose varnish or water based polyurethane to minimize emissions. ▪ Specify low VOC composite wood products. ▪ Implement building bake-out process. The purpose of a building bake-out is to "artificially age" building materials and products by accelerating emissions of residual solvents. It involves elevating the temperature of an unoccupied, newly constructed or remodeled building to between 95F and 102F while supplying a fixed amount of ventilation, and flushing out the building with the maximum possible ventilation after completion of the process (Alevantis

						1996). ▪ Avoid moisture contamination of composite wood product prior to installation.
Credit 5: Indoor Chemical & Pollutant Source Control	Divert construction, demolition and land clearing debris from landfill disposal. Redirect recyclable recovered resources back to the manufacturing process. Redirect reusable materials to appropriate sites.	▪ There is growing evidence that indoor surface pollution (contamination deposited on surfaces in office buildings) has an important role in sick building syndrome. ▪ Building users contribute to indoor surface pollution through dirt, particulates, microorganisms, skin scales, debris from clothing etc. ▪ The health effects of indoor surface pollutants are amplified by the adsorption of gases and vapors, both inorganic and organic (Raw et al. 1993). ▪ Cleaning and disinfecting chemicals can cause Reactive Airway Dysfunction	No indirect health effect.	Design to minimize pollutant cross-contamination of regularly occupied areas: ▪ Employ permanent entryway systems (grills, grates, etc.) to capture dirt, particulates, etc. from entering the building at all high volume entryways. ▪ Where chemical use occurs (including housekeeping areas and copying/ printing rooms), provide segregated areas with deck to deck partitions with separate outside exhaust at a rate of at least 0.50 cubic feet per minute per square foot, no air re-circulation and maintaining a negative pressure of at least 7 PA (0.03 inches of water gauge). ▪ Provide drains plumbed for appropriate disposal of liquid waste in spaces where water and	▪ Design separate exhaust and plumbing systems for rooms with contaminants to achieve physical isolation from the rest of the building. ▪ Install permanent architectural entryway systems such as grills or grates to prevent occupant borne contaminants from entering the building.	▪ Provision for separate exhaust and plumbing systems for designated areas. ▪ Issues related to building systems integration arising from these isolated systems. ▪ Entryway design for effective blocking/removal of occupant borne contaminants at the source itself.

		Syndrome, asthma and hypersensitivity syndrome. ▪ People exposed to floor stripping and floor-polishing chemicals experience headaches, eye irritation, dizziness, nausea, difficulty in concentrating, fatigue, asthma attacks, respiratory infections, hypersensitivity pneumonitis, and nose, throat and skin irritation (HCWH 2004).		chemical concentrate mixing occurs.		
Credit 6.1: Controllability of Systems: (Perimeter Spaces)	Provide a high level of thermal, ventilation and lighting system control by individual occupants or specific groups in multi-occupant spaces (i.e. classrooms or conference areas) to promote the productivity, comfort and	▪ Individual occupant control of temperature and ventilation aims to provide each occupant with clean air direct to the breathing zone. Thus occupants' well being and satisfaction can be increased as a result of improved air quality (minimized air borne	▪ Occupants' productivity and satisfaction can be increased as a result of improved air quality, thermal comfort and control over the immediate environment (Melikov 2005).	▪ Provide at least an average of one operable window and one lighting control zone per 200 square feet for all regularly occupied areas within 15 feet of the perimeter wall.	▪ Design the building with occupant controls for airflow, temperature and lighting. ▪ Strategies to consider include lighting controls, task lighting and operable windows.	▪ Installing individual or specific group occupant controls for thermal, ventilation and lighting systems. ▪ Issues related to building systems integration arising from occupant controls for thermal, ventilation and lighting systems. ▪ Façade modification for incorporating operable windows.

	wellbeing of building occupants.	transmission of infectious agents detrimental to health), thermal comfort and control over the environment (Melikov 2005). ▪ Insufficient lighting can cause accidents, eyestrain, headaches and musculoskeletal problems from adopting a poor posture to compensate for inadequate light. Excessive lighting causes eyestrain, eye irritation, associated headaches and fatigue (WHSC 2002). Occupant's comfort can be increased by controllability of lighting systems.				
Credit 6.2: Controllability of Systems: (Non-perimeter Spaces)	Provide a high level of thermal, ventilation and lighting system control by individual occupants or specific groups in multi-occupant spaces (i.e.	▪ Individual occupant control of temperature and ventilation aims to provide each occupant with clean air direct to the breathing zone. Thus occupants' well being and	▪ Occupants' productivity and satisfaction can be increased as a result of improved air quality, thermal comfort and control over the immediate	▪ Provide controls for each individual for airflow, temperature and lighting for at least 50% of the occupants in non-perimeter, regularly occupied areas.	▪ Design the building with occupant controls for airflow, temperature and lighting. ▪ Strategies to consider include task lighting and under floor HVAC systems with individual diffusers.	▪ Installing individual or specific group occupant controls for thermal, ventilation and lighting systems. ▪ Issues related to building systems integration arising from occupant controls for thermal, ventilation and lighting systems.

	classrooms or conference areas) to promote the productivity, comfort and wellbeing of building occupants.	satisfaction can be increased as a result of improved air quality (minimized air borne transmission of infectious agents detrimental to health), thermal comfort and control over the environment (Melikov 2005). ▪ Insufficient lighting can cause accidents, eyestrain, headaches and musculoskeletal problems from adopting a poor posture to compensate for inadequate light. Excessive lighting causes eyestrain, eye irritation, associated headaches and fatigue (WHSC 2002). Occupant's comfort can be increased by controllability of lighting systems.	environment (Melikov 2005).			▪ Personalized ventilation systems involving under floor HVAC systems and individual diffusers (Melikov 2005).

Credit 7.1: Thermal comfort: (Compliance with ASHRAE 55-1992)	Provide a thermally comfortable environment that supports the productivity and well-being of building occupants.	▪ Humidity control is crucial in suppressing mold growth. Negative health effects associated with molds include allergic reactions, asthma and other respiratory complaints (EPA 2005). ▪ High temperatures and relative humidity can trigger VOC out gassing from building materials leading to bad air quality and associated negative health effects (DTIR 1995).	▪ Occupants' productivity and satisfaction can be increased as a result of improved air quality, thermal comfort and control over the immediate environment (Melikov 2005).	▪ Comply with ASHRAE Standard 55-1992, Addenda 1995, for thermal comfort standards including humidity control within established ranges per climate zone. ▪ For naturally ventilated buildings, utilize the adaptive comfort temperature boundaries, using the 90% acceptability limits as defined in the California High Performance Schools (CHPS) Best Practices Manual, Appendix C - A Field Based Thermal Comfort Standard for Naturally Ventilated Buildings, Figure 2.	▪ Establish temperature and humidity comfort ranges and design the building envelope and HVAC system to maintain these comfort ranges.	▪ Integration of HVAC and envelope systems (right sizing of HVAC equipment). ▪ Better envelope design and insulation.
Credit 7.2: Thermal comfort: (Permanent monitoring system)	Provide a thermally comfortable environment that supports the productivity and well-being of building occupants.	▪ Humidity control is crucial in suppressing mold growth. Negative health effects associated with molds include allergic reactions, asthma and other respiratory complaints (EPA 2005). ▪ High temperatures and relative humidity can trigger VOC	▪ Occupants' productivity and satisfaction can be increased as a result of improved air quality, thermal comfort and control over the immediate environment (Melikov 2005).	▪ Install a permanent temperature and humidity monitoring system configured to provide operators control over thermal comfort performance and the effectiveness of humidification and/or dehumidification systems in the building.	▪ Establish temperature and humidity comfort ranges and design the building envelope and HVAC system to maintain these comfort ranges. ▪ Install and maintain a temperature and humidity monitoring system in the building to automatically adjust building conditions as appropriate.	▪ Integration of HVAC and envelope systems (right sizing of HVAC equipment). ▪ Installation of a temperature and humidity monitoring system.

		out gassing from building materials leading to bad air quality and associated negative health effects (DTIR 1995).				
Credit 8.1: Daylight and Views: (Daylight 75% of Spaces)	Provide for the building occupants a connection between indoor spaces and the outdoors through the introduction of daylight and views into the regularly occupied areas of the building.	▪ Increased use of daylight for activities can reduce eyestrain. ▪ Daylight has greater probability of maximizing visual performance than most forms of electric lights. ▪ Daylight reduces the incidence of health problems caused by the rapid fluctuations in light output typical of electric lighting (Boyce and Hunter 2003). ▪ Studies among school students suggest that classrooms without daylight may upset the basic hormone pattern of children, and this in turn may influence children's ability	▪ Physiologically daylight and view are desired (Boyce and Hunter 2003).	▪ Achieve a minimum Daylight Factor of 2% (excluding all direct sunlight penetration) in 75% of all space occupied for critical visual tasks. ▪ Spaces excluded from this requirement include copy rooms, storage areas, mechanical plant rooms, laundry and other low occupancy support areas. Other exceptions for spaces where tasks would be hindered by the use of daylight will be considered on their merits.	▪ Design the building to maximize interior day lighting. ▪ Strategies to consider include building orientation, shallow floor plates, increased building perimeter, exterior and interior permanent shading devices, high performance glazing and photo-integrated light sensors. ▪ Predict day lighting via calculations or model day lighting strategies with a physical or computer model to assess foot-candle levels and daylight factors achieved.	▪ Spread out the building; so as to achieve maximum perimeter and associated day light. ▪ Design the façade so as to achieve maximum day lighting for the interiors. ▪ Consider filtered day lighting from the roof. ▪ Orienting the building in the site so as to achieve maximum day lighting. ▪ Integration of interiors with building envelope for improved day lighting.

		to concentrate or cooperate. (Plympton et al. 2000).				
Credit 8.2: Daylight and Views: (Views for 90% of Spaces)	Provide for the building occupants a connection between indoor spaces and the outdoors through the introduction of daylight and views into the regularly occupied areas of the building.	▪ Windows that provide a view out as well as daylight can reduce stress (Boyce and Hunter 2003).	▪ Physiologically daylight and view are desired (Boyce and Hunter 2003).	▪ Achieve direct line of sight to vision glazing for building occupants in 90% of all regularly occupied spaces. Examples of exceptions include copy rooms, storage areas, mechanical, laundry and other low occupancy support areas.	▪ Design the building to maximize view opportunities.	▪ Spread out the building; so as to achieve maximum perimeter and associated views. ▪ Design the façade so as to achieve maximum views. ▪ Better landscaping to improve views. ▪ Orienting the building in the site so as to make use of available views.

APPENDIX D

LEED-H Health Matrix

LEED-H Version 1.72

Indoor Environment Quality

LEED checklist item	LEED Intent & Rationale	Health Effects and Supporting literature		LEED broad guidelines	LEED: Interaction Scenarios	Systems integration aspects
		Direct Effects	Indirect Effects			
Credit 1: ENERGY STAR with Indoor Air Package	**Intent**: Improve overall quality of indoor environment by installing an approved bundle of air quality measures. **Rationale**: The ENERGY STAR with Indoor Air Package is a comprehensive set of indoor air quality measures that includes ventilation, source control, and source removal measures.	▪ REFER Credits 2-10.	▪ REFER Credits 2-10.	▪ Complete all of the requirements of EPA's ENERGY STAR Indoor Air Package.	▪	▪ REFER Credits 2-10.
Credit 2: Combustion Venting	**Intent**: Minimize leakage of combustion gases into occupied space of home.	▪ Combustion smoke contains carbon monoxide. It reduces the ability of blood to carry oxygen to body tissues. High exposures can lead to death. Lower levels can aggravate	▪	▪ Design and install HVAC and DHW combustion equipment with closed	▪	▪

	Rationale: Indoor air quality may be adversely affected by leakage of combustion exhaust gases into the home. Direct- or power- venting reduces the risk of combustion gases being drawn into the home when negative pressure occurs in the home.	heart and circulatory diseases, lower birth weights and lead to increased deaths of newborns. ▪ Combustion smoke especially woodsmoke contains particulate matter less than 2.5 microns in diameter and get collected in the lungs. They can cause structural and chemical changes in the lungs. Other toxic and cancer causing compounds can attach to the particulates and enter the lungs at the same time (WSDE 2004). ▪ There is evidence that the levels of fine particulate matter in the air are associated with the risk of death from cardiovascular and respiratory illnesses (Samet et al. 2004). ▪ Woodsmoke contains irritants – phenols, aldehydes, quinines, nitrogen oxides and sulphur oxides. These can contribute to health problems in respiratory tract. Exposure can lead to inflammation of respiratory tract, pulmonary edema, other allergic reactions and contribute to long-term health effects. ▪ Woodsmoke increases the risk of lower respiratory tract		combustion (i.e., direct vented or power-vented exhaust) if equipment is located inside the building envelope, AND Install a CO monitor on each floor of home. ▪ Design and install fireplace per requirements in Table IEQ2-A, OR install no fireplace.		

		infections like bronchiolitis and pneumonia in young children. ▪ Woodsmoke contains mutagenic material. ▪ Woodsmoke posses significant cancer threat and many of its components are suspected human carcinogens (e.g.: benzopyrene), co-carcinogens and cilia-toxic agents (WSDE 2004). ▪ A causal relationship exists between elevated wood smoke levels and adverse respiratory health outcomes in young children (Larson & Koenig 1994). ▪ Nitrogen dioxide emissions resulting from the use of domestic gas appliances is associated with respiratory symptoms or a diminished lung function in children and adults (Garrett et al. 1998, Jarvis et al. 1996). ▪ A relationship exists between relatively high Nitrogen dioxide exposure and an enhanced bronchial responsiveness and inflammatory reaction to inhaled allergens (Tunnicliffe et al. 1994).				
Credit 3: Humidity Control	**Intent:** Provide a comfortable thermal	▪ No direct health effects from humidity per se. BUT	▪ Humidity significantly affects local thermal comfort. Local thermal discomfort can	▪ Analyze moisture loads and need for a	▪ Water leakage through building	▪ Humidity control equipment

	environment in the home. **Rationale:** Occupant comfort may be adversely affected by very high or very low humidity levels in the home. High humidity levels may also foster mold growth.	▪ Known health effects related to high humidity are primarily caused by the growth and spread of biotic agents under elevated humidities, and humidity interactions with non-biotic pollutants, such as formaldehyde (Arens & Baughman 1996). ▪ A few pathogens causing infectious diseases can colonize abundantly within moist environments outside the human body and become airborne given proper conditions (Flannigan 1992). ▪ The majority of patients suffering from asthma are allergic to dust mites, mold, and/or animal dander (Berglund et al. 1992). ▪ Non-allergic immunologic responses like hypersensitivity pneumonitis can be triggered by fungi and bacteria. They occur as a result of repeated pollutant exposures (Burge 1988). ▪ Many fungi produce VOCs that may be respiratory irritants and probably contributing factor to sick-building-type symptoms in microbially contaminated buildings (Bjurman 1993; Sorenson 1989).	be due to the insufficient cooling of the mucous membrane in upper respiratory tract, resulting from high temperature and humidity of air (Toftum et al. 1998). ▪ Humidity affects the perception of indoor air quality (Fang et al. 1998). ▪ Low humidity can result in the drying out of nasal and throat membranes, leading to discomfort. ▪ Dehumidification can result in static electricity in buildings which can be hazardous.	central humidity control system. Install humidity control system where needed to maintain humidity ratios below 0.012 (lb. water vapor / lb. dry air) per Section 5.2.2 of ASHRAE Standard 55-2004.	envelopes can be another major cause of indoor environmental problems (e.g., mold). The LEED points for improved foundation, exterior wall, and roof water management water are included in Materials and Resources credit 4, Durability plan.	should be selected to maintain maximum humidity levels based on the summer design indoor air temperature. ▪ Adding humidity may waste energy and in some cases has been shown to be unhealthy and may have adverse affects on durability (LEED 2005). ▪ Studies show that moisture transfer between indoor air and the hygroscopic structure significantly reduces the peak indoor humidity. Hygroscopic

		▪ The rate of formaldehyde off gassing from pressed-wood products is sensitive to a number of factors, including humidity (Gammage 1990; Meyer 1986). Formaldehyde is classified by the USEPA as a probable carcinogen. ▪ Nitrogen and sulfur oxides present in indoor environment react with water on indoor surfaces to form acid aerosols (Leaderer et al. 1993). Their acidic nature, reactivity, and aqueous solubility suggest that respiratory damage is possible (Brauer et al. 1993). ▪ Occupant's susceptibility to biological and non-biological pollutants may also be a function of humidity, primarily at low humidities, when respiratory ailments result from dry mucous membranes (Green 1985).				structure with a permeable interior coating is able to significantly improve warm respiratory comfort and perceived air quality (PAQ) during occupation. In general, a hygroscopic structure will reduce the peak values of indoor humidity, but as heat and moisture transfer are coupled, the indoor temperature will increase when moisture accumulates in the hygroscopic structure and decrease when moisture is

						dried from the structure. As humidity is important for warm respiratory comfort and PAQ, the net result is that comfort levels increase (Simonson et al. 2002).
Credit 4: Outdoor Air Ventilation	**Intent:** Protect occupants from indoor pollutants by ventilating with outdoor air. **Rationale:** Occupant health and comfort may be adversely affected by poor ventilation in a home. Without adequate outdoor air ventilation, humidity, odors, and pollutants may accumulate within the home.	▪ Outdoor air ventilation dilutes the indoor generated pollution. But ventilation is also the transport mechanism for indoor air pollutants into the building. Exposure to pollutants in indoor air may cause a variety of health effects ranging from irritant effects to cancer. ▪ Ventilation may dilute the concentration or disperse airborne virus or bacteria that can cause infectious diseases. ▪ Indoor humidity is influenced by ventilation rates. Very high humidity indoors is associated with an increased growth of microorganisms such as mold, bacteria and dust mites (ECA 2003). ▪ Moisture damage and microbial growth in buildings have been associated with a	▪ Outdoor air ventilation dilutes the indoor generated pollution. But ventilation is also the transport mechanism for indoor air pollutants into the building. Exposure to pollutants in indoor air may cause a variety of health effects ranging from perception of unwanted odors to other comfort problems (ECA 2003). ▪ There is a strong association between ventilation and comfort (as indicated by perceived air quality (Wargocki et al. 2002). ▪ Ventilation rate is an effective method of improving the perceived quality of air polluted by human bio-effluents and tobacco smoke(Cain et al. 1983).	▪ Design and install a whole building ventilation system that complies with ASHRAE Standard 62.2.4. Alternative (e.g.: passive) ventilation designs should also be considered. ▪ Install dedicated outdoor air supply system that complies with ASHRAE Standard 62.2, AND provides for heat transfer between the incoming	▪ Natural air leakage through the envelope contributes to the overall ventilation rate of the home. From a health perspective, it is important to not "under-ventilate" a home. ▪ However, from an energy perspective, it is also important not to over-ventilate a home. In extreme hot or cold climates,	▪ Material selection to avoid VOC and maintenance of proper humidity levels may reduce the demand for outside air ventilation, thereby saving energy (Wargocki et al 2002). ▪ Outdoor air supply rates required for indoor environments depend on the load of pollutants

		number of health effects including respiratory symptoms (Bornehag et al. 2001). ▪ Various diseases associated with mold exposure include an increased risk of asthma development and exacerbation as well as clusters of hypersensitivity pneumonitis, pulmonary hemorrhage in infants and rheumatic diseases (Nevalainen & Seuri 2005). ▪ Ventilation rates below 0.5 ach in homes can increase the rate of infestation of house dust mites due to increase in humidity in cold dry climates (Wargocki et al. 2002). Studies have linked house dust mite infestation with allergy (Andersen & Korsgaard, 1986) ▪ Exposure to environmental tobacco smoke (ETS) and to radon decay products have been linked with an increased risk of developing lung cancer. Ventilation rates affect the indoor concentrations of ETS and radon (ECA 2003). ▪ Increasing the total outdoor air change rate reduces the time available for chemical reactions indoors between	▪ Ventilation rate is an effective method of improving the perceived quality of air polluted due to emissions from building materials (Knudsen et al. 1998). ▪ Human well-being and capacity to concentrate attention are reduced when carbon dioxide (CO_2) concentration in the air increases up to 3000 p.p.m (Kajtar et al. 2003). Ventilation rates affect CO_2 concentrations (Seppanen & Fisk 2004). ▪ Ventilation is one of the links between the outdoor and the indoor environment and it easily transmits noise. Noise can also be produced by the ventilation system itself. Health effects of noise include effects on performance, annoyance, interference with communication and effects on social behavior (ECA 2003).	outdoor air stream and exhaust air streams (except in very mild and dry climates), AND has fully ducted supply and exhaust. ▪ Third-party testing of outdoor air flow rate into the home.	it can cost up to 2 dollars per year to condition each additional cfm of outside air brought into a home. ▪ Substantial energy savings can be achieved by using heat recovery equipment for the outdoor air brought into a home. The LEED points for the energy savings from heat recover have been included in this credit.	indoors (Wargocki et al 2002). The design of ventilation rates to be based on all pollution loads present indoors. ▪ Night-time ventilative cooling in both hot and moderate climates provides an energy efficient way for indoor temperature control (Seppanen & Fisk 2004). ▪ Outdoor air ventilation must take into account the infiltration through envelope. Interaction between envelope and outdoor air supply. ▪ Outdoor air

		outdoor ozone and volatile organic compounds (VOCs), which can produce other compounds often more adverse for human health and comfort than their precursors (Weschler & Schields, 2000). ▪ Ventilation is needed to dilute the VOC concentrations in indoor environment to the acceptable levels (Seppanen & Fisk 2004). ▪ Combustion is the source of nitrogen oxides and carbon monoxide in indoor environment. Both of them have negative health effects. Proper ventilation can reduce the indoor concentration of these gases (Seppanen & Fisk 2004). ▪ Sources of outdoor local pollution include regional industrial pollution, pollution from vehicles and pollution emissions from adjacent buildings. These pollutants can enter the building through outdoor air ventilation. ▪ Ventilation is one of the links between the outdoor and the indoor environment and it easily transmits noise. Noise can also be produced by the ventilation system itself.				supply affects humidity indoors. Interaction between humidifiers and supply air. ▪ Some ventilation systems, especially those incorporating air to air heat recovery systems, cannot function correctly unless the building is virtually completely airtight.

		Background noise, from outside, from inside the building or from installations can have a tremendous impact on this communication and with that on social live. Health effects of noise include hearing loss, sleep disturbance, cardiovascular and psycho-physiological effects (ECA 2003). ▪ Pollen is usually carried indoors with ventilation air and is an allergen. Some plant allergens are present substantially in particles smaller than 1 μm and is difficult to filter out (Seppanen & Fisk 2004). ▪ Ventilation has also an impact on the outdoor pollution level. Ventilation related energy use may represent up to 50% of the total energy use of a building (ECA 2003).				
Credit 5: Local Exhaust	**Intent:** Remove indoor pollutants in kitchens and bathrooms. **Rationale:** Odors, pollutants, and moisture may accumulate in	▪ Showering and cooking are activities that increase the humidity levels in a home. ▪ Very high humidity indoors is associated with an increased growth of microorganisms such as mold, bacteria and dust mites (ECA 2003). ▪ Microbial growth in	▪ Humidity affects the perception of indoor air quality (Fang et al. 1998). Showering and cooking are activities that increase the humidity levels in a home. ▪ Odors from kitchen and bathrooms can lead to discomfort.	▪ Design and install local exhaust systems in bathrooms and kitchen per ASHRAE Standard 62.2, AND use ENERGY STAR labeled exhaust	▪	▪

	kitchens and baths that have poor local exhaust.	buildings has been associated with a number of health effects including respiratory symptoms (Bornehag et al. 2001). ▪ Various diseases associated with mold exposure include an increased risk of asthma development and exacerbation as well as clusters of hypersensitivity pneumonitis, pulmonary hemorrhage in infants and rheumatic diseases (Nevalainen & Seuri 2005). ▪ Nitrogen dioxide emissions resulting from the use of domestic gas appliances is associated with respiratory symptoms or a diminished lung function in children and adults (Garrett et al. 1998, Jarvis et al. 1996). ▪ A relationship exists between relatively high Nitrogen dioxide exposure and an enhanced bronchial responsiveness and inflammatory reaction to inhaled allergens (Tunnicliffe et al. 1994). ▪ Some cooking oil fumes are found to contain mutagenic compounds. Exposure to the emitted fumes of cooking oils increases the risk of contracting lung cancer		fans, except for exhaust fans serving multiple bathrooms. ▪ Install occupancy sensor, OR automatic humidistat controller, OR timer for bath exhaust fans to operate fan either for a timed interval after occupant leaves room or until humidity level is reduced. ▪ Perform third-party test of each exhaust air flow rate from the home – for compliance with Std 62.2 requirements.		

		(Chiang et al 1997). ▪ Common food preparation processes, frying, broiling and baking, can give rise to air pollutants that are known to be mutagenic and carcinogenic (Lofroth 1994).				
Credit 6: Supply Air Distributio n	**Intent:** Ensure supply air is distributed adequately to conditioned spaces. **Rationale:** Occupant Comfort may be adversely affected by inadequate air distribution to each room in a home.	▪ Increased airflow rate with filtered outdoor air in the building improves indoor air quality (Kruger & Kraenzmer 1996). This has positive health benefits. ▪ Duct systems that are undersized, are pinched, or have numerous bends and turns may lead to low air flow rates and high air velocities. Poorly designed and installed duct systems can induce back drafting of flue gases from combustion appliances into living spaces (USDoE 2003).	▪ Right-sizing ducts with a compact system layout helps to ensure that the proper amount of air is distributed to each room at a comfortable temperature. This can result in a more consistent level of comfort throughout a house (USEPA 2000). ▪ Properly sizing the ducts for required air flow improves the ability of the heating and cooling equipment to distribute air properly with minimum noise (USEPA 2000). Duct systems that do not distribute air properly throughout the house may make some rooms too hot and others too cold. ▪ Risk of draught increases if the air is not supplied through more, or larger, supply devices (Kruger & Kraenzmer 1996). ▪ Poor indoor air quality can reduce the performance (Wyon 2004).	▪ Perform ACCA Manual D duct design calculations and install ducts accordingly, AND ensure that every room has adequate return air flow (through use of either multiple returns or transfer grills), OR install ductless space conditioning system (e.g., hydronic heat with passive ventilation system per Section 4.1.2 of ASHRAE Standard 62.2.) ▪ Test total supply air flow rates in each room of home using a flow hood, AND	▪ Space heating and cooling loads are room air flow rates must be calculated using ACCA Manual J in Environment & Atmosphere credit 6.1 - Space heating and cooling. ▪ Ducts installation should be visually inspected in Environment & Atmosphere credit 2 – Insulation, during the pre-drywall insulation inspection.	▪

				adjust using balancing dampers to ensure that supply air flow rates are within +/- 15% (or +/- 10 cfm) of calculated values from ACCA Manual J.		
Credit 7: Supply Air Filtering	**Intent:** Remove particulate matter from supply air system. **Rationale:** Inadequate air filtration may have adverse health effects. Improved air filters will remove more particles from the supply air stream.	▪ Particulate matter consists of particles found in the air, including dust, dirt, soot, smoke, and liquid droplets. Health problems include aggravated asthma, increases in respiratory symptoms like coughing, difficult or painful breathing, chronic bronchitis and decreased lung function. (EPA 2005, WHO 2000). ▪ There is evidence that the levels of fine particulate matter in the air are associated with the risk of death from cardiovascular and respiratory illnesses (Samet et al. 2004). ▪ Other toxic and cancer causing compounds can attach to the particulates and enter the lungs (WSDE 2004). ▪ Pollen is usually carried indoors with ventilation air and is an allergen (Seppanen	▪	▪ Install air filters >/= MERV 8 and ensure that air handlers can maintain adequate pressure (and air flow), OR install a ductless space conditioning system (e.g., a hydronic heating systems). ▪ Install air filters >/= MERV 10 and ensure that air handlers can maintain adequate pressure (and air flow). OR ▪ Install HEPA air filters, and ensure that air handlers can	▪	▪

		& Fisk 2004). ▪ Loaded filters and poorly maintained HVAC systems can cause adverse health effects (Seppanen & Fisk 2004).		maintain adequate pressure (and air flow).		
Credit 8: Contaminant Control	**Intent:** Protect occupants from exposure to contaminants. **Rationale:** Indoor air quality may be adversely affected by contaminants brought into home by occupants (e.g., on shoes). Walk-off mats trap some of the dirt at the entryway that would otherwise be tracked into the home. Central vacuums exhaust collected dust and particulates to the outdoors.	▪ Exposure to formaldehyde can cause burning of eyes, tightness in chest and headaches. Severe effects include sensitization, asthmatic attacks, depression, and death. Formaldehyde exposure has been associated with menstrual disorders. Exposure can cause an individual to become sensitive to a wide variety of other chemicals that were previously not problematic (Bower 1993). Formaldehyde has been identified as a potential occupational carcinogen (NIOSH 1981). ▪ There is evidence that the levels of fine particulate matter in the air are associated with the risk of death from cardiovascular and respiratory illnesses (Samet et al. 2004). ▪ Other toxic and cancer causing compounds can attach to the particulates and enter the lungs (WSDE 2004). ▪ The presence of Volatile	▪ Formaldehyde has a pungent odor which can cause discomfort.	▪ Seal off ducts during construction OR clean HVAC ducts and coils before occupancy. ▪ Design and install permanent walk-off mats at each entry, OR install central vacuum system with exhaust to the outdoors. ▪ Hire third party to test for contaminant concentration prior to occupancy. Measure and report concentration levels for contaminants.	▪ Products with low VOC emissions greatly benefit indoor air quality. The LEED points for such products are included in Materials & Resources credit 5 - Environmentally Preferable Products.	▪ The rate of formaldehyde off gassing from pressed-wood products is sensitive to a number of factors, including humidity (Gammage 1990; Meyer 1986).

		Organic Compounds (VOC) in indoor air, has been associated with adverse health effects such as sensory irritation, odor and the more complex set of symptoms comprising the Sick Building Syndrome. A possible link between increase in prevalence of allergies and exposure to elevated concentrations of VOC's has been suggested (Andersson et al. 1997).				
Credit 9: Radon Protection	**Intent:** Protect occupants from exposure to radon gas, and other ground contaminants. **Rationale:** Occupant health may be adversely affected by the presence of radon gas.	▪ Radon is found in the soil in some geographic regions. When radon filters through the ground and enters the house, it undergoes a radioactive process. These decay products are associated with an increased risk of developing lung cancer. ▪ Synergistic responses: The combined effect of radon and Environmental Tobacco Smoke is greater than the sum of individual effects. Radon tends to cling to particulates in cigarette smoke and as a result of this much more radon is inhaled into the lungs (Berglund et al. 1992, Bower 1993).	▪	▪ If home is located in EPA Region 1, design and install radon mitigation system. ▪ If home is NOT located in EPA Region 1, design and build home with radon resistant construction techniques.	▪	▪ Controlling radon progeny in the air space of houses may be divided into three principal categories: (1) preventing radon infiltration (basement pressurization, basement sealing, sub-slab depressurization, choice of building materials); (2) diluting the

						radon and radon progeny within the house (air-to-air heat exchanger, ventilation); and (3) using air cleaning systems for direct removal (filtration, mixing fan, electric field methods, radon adsorption, and ion generator) (Li & Hopke 1992). ▪ Install a ground contaminant protection system which provides the following basic benefits (LEED 2005): - Improved drainage below slab; - Sealed cracks and

						holes to prevent penetration; - Reduced negative pressure in basement.
Credit 10: Vehicle Emissions Protection	**Intent:** Protect occupants from exposure to car emissions. **Rationale:** Occupant health may be adversely affected by car emissions leaking from garage into home.	▪ Many pollutant sources are commonly stored or used in residential attached garages such as gasoline-fired engines (automobiles, lawnmowers, etc.), paints, and solvents. Pressure differences across air leakage paths between the garage and adjoining living space can result in the transport of these contaminants to the living space (NIST 2003). ▪ Vehicle emissions in the attached garage do have a measurable impact on the indoor air quality of houses with attached garages. Pollutants include carbon monoxide, carbon dioxide, nitrogen oxide, volatile organic compounds and carbonyl compounds (Graham et al. 2004). ▪ Vehicles parked in attached garages of homes are one of the important sources of toxic organic compounds such as benzene in indoor air (Gammage & Matthews	▪ Human well-being and capacity to concentrate attention are reduced when carbon dioxide (CO_2) concentration in the air increases up to 3000 p.p.m (Kajtar et al. 2003).	▪ No air handling equipment, return ducts or un-sealed supply ducts in garage. ▪ CO detector in any occupied rooms above the garage AND tightly seal shared surfaces between garage and conditioned spaces, including these measures: Weather-stripped doors, All penetrations sealed, All connecting floor/ceiling joist bays sealed, Paint walls/ceilings & Seal all cracks at the base of walls ▪ Install minimum 100 cfm exhaust fan rated for continuous	▪	▪

		1988). ▪ Carbon Monoxide molecules can enter the bloodstream on inhalation, where they inhibit the delivery of oxygen throughout the body. Low concentrations can cause dizziness, vision problems, headaches, and fatigue; high concentrations can be fatal (Bower 1993). ▪ Benzene is an established cause of leukemia in adults, especially acute non-lymphocytic leukemia (International Agency for Research on Cancer 1982). ▪ Nitrogen dioxide emissions are associated with respiratory symptoms or a diminished lung function in children and adults (Garrett et al. 1998, Jarvis et al. 1996). ▪ A relationship exists between relatively high Nitrogen dioxide exposure and an enhanced bronchial responsiveness and inflammatory reaction to inhaled allergens (Tunnicliffe et al. 1994).		operation with automatic timer control linked to occupant sensor, light switch, or garage door opening/closing mechanism. OR ▪ No garage in contact with conditioned spaces.		

APPENDIX E

Case study application: Site built home

			1							2		
			IAQ - Presence of Indoor Pollutants		Performance Score (x)	Interaction Score (y)	Relevant Interactions	Performance Factor (a*b*x)	Whole House Score	Humidity/ moisture		Performance Score
			3.50							2.00		
	Envelope											
	(Weight.)		2.00							2.50		
A	Arch. Design Consideration		Garage-Living spaces interface.	Attached garage and hence there is threat from vehicle emissions.	2	2.3	A1-A4, A1-B2, A1-B4, A1-C1, A1-C6, A1-C7, A1-O1, A1-U1, A1-V7	14	32.2	Exterior water management systems.	Sloping roof has been provided. Design requirements followed for overhangs, gutters and downspouts are satisfactory.	3
B			Material selection - environmentally preferable products	Low VOC products used for roof/ wall insulation.	3	4.5	A2-B1-T1-T2, B1-B3, B1-D2-E2-G2-H2-I4-LI, B1-H4	21	94.5	Material selection - environmentally preferable products	Permeable materials and finishes used. Ease of maintenance been considered.	3

				3							4			
				STRATEGIES										
				Attributes of Indoor Environmental Quality (IEQ)										
Interaction Score	Relevant Interactions	Performance Factor	Whole House Score	**Temperature**		Performance Score	Interaction Score	Relevant Interactions	Performance Factor	Whole House Score	**Ventilation**		Performance Score	Interaction Score
				1.50							*1.50*			
				2.50							**2.00**			
3.14	A2-A5, A2-B1-T1-T2, A2-C4, A2-D2-E2-G2-D7, A2-E1, A2-E3, A2-O2-R2	15	47.1	Material thermal performance.	The minimum code requirement have been enforced with gypsum board on 2x4s, siding and insulation. This may not be effective as alternative materials like foam core panels, SIPs etc.	3	1.75	A3-C3-D3-G3-O2-R2, A3-C6, A3, T2, A3-U1	11.3	19.7	Natural ventilation	Room layout, partition wall and window positions have somewhat compromised scope for natural ventilation.	2	2
3.5	A1-B2, B2-D2-E2-G2-H2-I4-L1, B2-H4, B2-T1	15	52.5	Selection of windows.	High efficiency windows add to thermal comfort.	5	4	A5-B3, B1-B3, B3-E3, B3-J3, B3-T1, C1-B3-G3-I5-O3-R3	18.8	75	Position of outdoor air intake.	This strategy has been considered so as to avoid contaminant intake.	3	4

			5							6			
Relevant Interactions	Performance Factor	Whole House Score	Lighting		Performance Score	Interaction Score	Relevant Interactions	Performance Factor	Whole House Score	Acoustics		Performance Score	Interaction Score
			0.50							0.50			
			2.00							3.50			
A1-A4, A4-D4, A4-I3, A4-U1	6	12	Day lighting	This strategy has been considered and is effective in ensuring moderate daylighting.	3	2.8	A2-A5, A5-A7-E3-U5, A5-B3, A5-I5, A5-T5	3	8.4				
A1-B4, B4-I1-H4	9	36						0	0				

			7							
Relevant Interactions	Performance Factor	Whole House Score	**Ergonomic design & safety**		Performance Score	Interaction Score	Relevant Interactions	Performance Factor	Whole House Score	**Final score**
			0.50							
			3.00							
	0	0	Layout of living spaces.	Perceived as adding to the comfort of occupants.	4	3.4	A5-A7-E3-U5, A7-C7, A7-E3, A7-T3, A7-U5	6	20.4	
	0	0						0	0	

C	Building Systems	Engg. Design Consideration	Prevent air infiltration.	Only moderately tight envelope can be achieved for a site built home since prefabricated parts & modular design are not employed.	2	1.67	A1-C1, C1-H4, C1-G3, C1-B3-G3-I5-O3-R3, C1-T1	14	23.4	Prevent moisture infiltration through air	Only moderately tight envelope can be achieved for a site built home since prefabricated parts & modular design are not employed.	2
D			Contaminant control during construction	Contaminant control difficult since the unit is assembled at the open site.	2	1	D1-T1	14	14	Prevent moisture infiltration through structure	Joint between foundation and structure is not susceptible.	4
E			Radon Protection	Radon mitigation system has been installed.	5	4.5	A2-E1	35	158	Moisture control inside the home.	HVAC system meets humidity requirements. Since attic ventilation is not specified condensation may occur.	3
									322			

2	C2-C4, C2-T1, C2-T2	10	20	Insulation	Meets grade II specs. As per National Home Energy Rating Standards. Will help minimize thermal bridging.	4	2	A3-C3-D3-G3-O2-R2	15	30	Attic ventilation	No provision for attic ventilation. This can result in ice dam formation and moisture infiltration.	1	1.67
4	A2-D2-E2-G2-D7, B1-D2-E2-G2-H2-I4-LI, B2-D2-E2-G2-H2-I4-L1	20	80	Air leakage through envelope	Only moderately tight envelope can be achieved for a site built home since prefabricated parts & modular design are not employed.	2	2	A3-C3-D3-G3-O2-R2, D3-G3, D3-I3	7.5	15	Operable windows.	Operable windows enhance ventilation effectiveness, thermal comfort and control of indoor pollutants.	5	4
3.5	A2-D2-E2-G2-D7, B1-D2-E2-G2-H2-I4-LI, B2-D2-E2-G2-H2-I4-L1, C4-E2-G2	15	52.5	Solar design	Some consideration has been given for this strategy and hence it is moderately effective.	2	4	A2-E3, A5-A7-E3-U5, A7-E3, B3-E3	7.5	30				
			252							**170**				

A2-C4, C2-C4, C4-E2-G2	3	5.01	Artificial lighting.	Only minimum requirements have been met. Artificial lighting has not been integrated with daylighting.	2	2	C5-T5-U5	2	4	Spacing of structural members and selection of wall sheathing.	Limited sound performance offered by 16 inch OC spacing of studs and OSB covered walls.	2	2
A4-D4	15	60						0	0				
	0	0						0	0				
		113							**12.4**				

A1-C6, A3-C6, C6-L6	3.5	7	Safety issues.	Safety issues have been addressed.	4	4	A1-C7, A7-C7, C7-D7	6	24	
	0	0	Home owner education.	This strategy has been considered.	5	4	A2-D2-E2-G2-D7, C7-D7	7.5	30	
	0	0						0	0	
		7							**74.4**	**950.18**

U		Material selection and installation - other health hazards	Some materials like cellulose and fiberglass are prone to disintegration and likely to migrate to living spaces. They are potential irritants and health hazards. This factor has not been considered during material selection.	1	1.33	A3-U1, A4-U1, T1-U1-V7-W7-X7	7	9.31			
V	Engg. Design Consideration						0	0			
W							0	0			
X							0	0			
								51.3			

		0	0						0	0				
		0	0						0	0				
		0	0						0	0				
		0	0						0	0				
			13.4							6				

			Position of furniture & fixtures.	Position of furniture and fixtures to complement lighting. It is assumed that this has been taken into consideration.	4	3.33	A5-A7-E3-U5, A7-U5, C5-T5-U5	6	19.98				
								0	0				
								0	0				
								0	0				
									22.23				

	0	0								
	0	0	Ease of maintenance.	This strategy has not been considered.	1	1.5	A1-V7, T1-U1-V7-W7-X7	1.5	2.25	
	0	0	Home owner education.	This strategy has been considered.	5	1	T1-U1-V7-W7-X7	7.5	7.5	
	0	0	Safety issues.	Safety issues have been addressed.	4	1	T1-U1-V7-W7-X7	6	6	
		21							**15.8**	**129.64**
HEALTH PERFORMANCE SCORE BASED ON "WHOLE HOUSE" & "LEED" APPROACHES										**2870.37**

APPENDIX F

Case study application: Factory built home

				1							2		
			IAQ - Presence of Indoor Pollutants		Performance Score (x)	Interaction Score (y)	Relevant Interactions	Performance Factor (a*b*x)	Whole House Score	Humidity/ moisture		Performance Score
			3.50 (a)							2.00		
	Building Systems	Envelope										
		(Weight.)	2.00 (b)							2.50		
A		Arch. Design Consideration	Garage-Living spaces interface.	No attached garage and hence reduced threat from vehicle emissions.	5	4.5	A1-A4, A1-O1	35	158	Exterior water management systems.	Sloping roof has been provided. Minimum design requirements have been followed for overhangs, gutters and downspouts	2
B			Material selection - environmentally preferable products	Low VOC products used for roof/ wall insulation.	3	3.5	A2-B1-T1-T2, B1-B3, B1-D2-E2-G2-H2-I4-LI, B1-H4, B1-C2-D2-E2-G2-H2-L1-O2-R2	21	73.5	Material selection - environmentally preferable products	Permeable materials and finishes used. Ease of maintenance been considered.	2

				3							4			

STRATEGIES

Attributes of Indoor Environmental Quality (IEQ)

Interaction Score	Relevant Interactions	Performance Factor	Whole House Score	Temperature		Performance Score	Interaction Score	Relevant Interactions	Performance Factor	Whole House Score	Ventilation		Performance Score	Interaction Score
				1.50							*1.50*			
				2.50							2.00			
2.33	A2-A5, A2-B1-T1-T2, A2-C4, A2-D2-E2-G2-D7, A2-E1, A2-E3, A2-O2-R2	10	23.3	Material thermal performance.	Only minimum code requirement have been enforced with gypsum board on 2x4s, siding and insulation.	3	1.66	A3-C3-D3-G3-O2-R2, A3-C6, A3, T2, A3-U1	11.3	18.7	Natural ventilation	Room layout, partition wall and window positions have somewhat compromised scope for natural ventilation.	2	2
3	A1-B2, B2-D2-E2-G2-H2-I4-L1, B2-H4, B2-T1, B2-C2-D2-E2-G2-H2-L1-O2-R2	10	30	Selection of windows.	High efficiency windows add to thermal comfort.	5	4.16	A5-B3, B1-B3, B3-E3, B3-J3, B3-T1, C1-B3-G3-I5-O3-R3, B3-C6	18.8	78	Position of outdoor air intake.	In factory built homes this factor is not site specific and hence may lead to contaminant intake.	1	4

			5							6			
Relevant Interactions	Performance Factor	**Whole House Score**	**Lighting**		Performance Score	Interaction Score	Relevant Interactions	Performance Factor	**Whole House Score**	**Acoustics**		Performance Score	Interaction Score
			0.50							***0.50***			
			2.00							**3.50**			
A1-A4, A4-D4, A4-I3, A4-U1	6	12	Day lighting	In factory built homes this factor is not site specific and hence may be ineffective in ensuring maximum daylighting.	1	2	A2-A5, A5-A7-E3-U5, A5-B3, A5-I5, A5-T5	1	2				
B4-I1-H4	3	12						0	0				

Relevant Interactions	Performance Factor	Whole House Score	Ergonomic design & safety		Performance Score	Interaction Score	Relevant Interactions	Performance Factor	Whole House Score	Final score
			7							
			0.50							
			3.00							
	0	0	Layout of living spaces.	Minimum requirements have been achieved.	3	3	A5-A7-E3-U5, A7-C7, A7-E3, A7-T3, A7-U5	4.5	13.5	
	0	0						0	0	

U			Material selection and installation - other health hazards	Some materials like cellulose and fiberglass are prone to disintegration and likely to migrate to living spaces. They are potential irritants and health hazards. This factor has not been considered during material selection.	1	1	A3-U1, A4-U1, T1-U1-V7-W7-X7	7	7			
V		Engg. Design Consideration						0	0			
W								0	0			
X								0	0			
									59.5			

		0	0						0	0				
		0	0						0	0				
		0	0						0	0				
		0	0						0	0				
			12.5							3				

			Position of furniture & fixtures.	Position of furniture and fixtures to complement lighting. It is assumed that this has been taken into consideration.	4	2.6	A5-A7-E3-U5, A7-U5, C5-T5-U5	6	15.6				
								0	0				
								0	0				
								0	0				
									17.85				

	0	0								
	0	0	Ease of maintenance.	This strategy has not been considered.	1	2	A1-V7, T1-U1-V7-W7-X7, T6-V7	1.5	3	
	0	0	Home owner education.	This strategy has been considered.	5	1	T1-U1-V7-W7-X7	7.5	7.5	
	0	0	Safety issues.	Safety issues have been addressed.	4	1	T1-U1-V7-W7-X7	6	6	
		5.25							16.5	114.60
HEALTH PERFORMANCE SCORE BASED ON "WHOLE HOUSE" & "LEED" APPROACHES										**3147.27**

APPENDIX G

Case study application: hybrid home

			1							2		
			IAQ - Presence of Indoor Pollutants		Performance Score (x)	Interaction Score (y)	Relevant Interactions	Performance Factor (a*b*x)	Whole House Score	Humidity/ moisture		Performance Score
			3.50							2.00		
	Building Systems	**Envelope**										
		(Weight.)	2.00							2.50		
A		Arch. Design Consideration	Garage-Living spaces interface.	Attached garage and hence there is threat from vehicle emissions.	2	2.88	A1-A4, A1-B2, A1-B4, A1-C1, A1-C6, A1-C7, A1-O1, A1-U1, A1-V7	14	40.3	Exterior water management systems.	Sloping roof has been provided. Design requirements followed for overhangs, gutters and downspouts are satisfactory.	4
B			Material selection - environmentally preferable products	Low VOC products used for roof/ wall insulation.	3	4.5	A2-B1-T1-T2, B1-B3, B1-D2-E2-G2-H2-I4-LI, B1-H4, B1-C2-D2-E2-G2-H2-L1-O2-R2	21	94.5	Material selection - environmentally preferable products	Permeable materials and finishes used. Ease of maintenance been considered.	3

STRATEGIES

Attributes of Indoor Environmental Quality (IEQ)

Interaction Score	Relevant Interactions	Performance Factor	Whole House Score	Temperature (3)		Performance Score	Interaction Score	Relevant Interactions	Performance Factor	Whole House Score	Ventilation (4)		Performance Score	Interaction Score
				1.50							1.50			
				2.50							2.00			
3.57	A2-A5, A2-B1-T1-T2, A2-C4, A2-D2-E2-G2-D7, A2-E1, A2-E3, A2-O2-R2	20	71.4	Material thermal performance.	Special strength OSB and alternative materials - SIPs - have been used. A special insulating strip has been used to insulate the door and window openings.	5	2.67	A3-C3-D3-G3-O2-R2, A3-C6, A3, T2, A3-U1	18.8	50.1	Natural ventilation	Reorganization of spaces is possible due to component assembly design. So it is easy to integrate natural ventilation.	4	3
2.75	A1-B2, B2-D2-E2-G2-H2-I4-L1, B2-H4, B2-T1, B2-C2-D2-E2-G2-H2-L1-O2-R2	15	41.3	Selection of windows.	High efficiency windows add to thermal comfort.	5	3.4	A5-B3, B1-B3, B3-E3, B3-J3, B3-T1, C1-B3-G3-I5-O3-R3, B3-C6	18.8	63.8	Position of outdoor air intake.	This strategy has been considered so as to avoid contaminant intake.	3	4

			5							6			
Relevant Interactions	Performance Factor	Whole House Score	Lighting		Performance Score	Interaction Score	Relevant Interactions	Performance Factor	Whole House Score	Acoustics		Performance Score	Interaction Score
			0.50							0.50			
			2.00							3.50			
A1-A4, A4-D4, A4-I3, A4-U1	12	36	Day lighting	This strategy has been considered and is effective in ensuring moderate daylighting.	3	2.8	A2-A5, A5-A7-E3-U5, A5-B3, A5-I5, A5-T5	3	8.4				
A1-B4, B4-I1-H4	9	36						0	0				

			7							
Relevant Interactions	Performance Factor	Whole House Score	**Ergonomic design & safety**		Performance Score	Interaction Score	Relevant Interactions	Performance Factor	Whole House Score	**Final score**
			0.50							
			3.00							
	0	0	Layout of living spaces.	Perceived as adding to the comfort of occupants.	4	3.4	A5-A7-E3-U5, A7-C7, A7-E3, A7-T3, A7-U5	6	20.4	
	0	0						0	0	

U			Material selection and installation - other health hazards	Some materials like cellulose and fiberglass are prone to disintegration and likely to migrate to living spaces. They are potential irritants and health hazards. This factor has not been considered during material selection.	1	1.5	A3-U1, A4-U1, T1-U1-V7-W7-X7	7	10.5			
V		Engg. Design Consideration						0	0			
W								0	0			
X								0	0			
									63			

				48							15			
				0	0						0	0		
				0	0						0	0		
				0	0						0	0		
				0	0						0	0		

			Position of furniture & fixtures.	Position of furniture and fixtures to complement lighting. It is assumed that this has been taken into consideration.	4	3.3	A5-A7-E3-U5, A7-U5, C5-T5-U5	6	19.8				
								0	0				
								0	0				
								0	0				
									22.05				

	0	0								
	0	0	Ease of maintenance.	This strategy has been considered.	4	1.5	A1-V7, T1-U1-V7-W7-X7, T6-V7	6	9	
	0	0	Home owner education.	This strategy has been considered.	5	1	T1-U1-V7-W7-X7	7.5	7.5	
	0	0	Safety issues.	Safety issues have been addressed.	4	1	T1-U1-V7-W7-X7	6	6	
		21							**22.5**	**191.55**
HEALTH PERFORMANCE SCORE BASED ON "WHOLE HOUSE" & "LEED" APPROACHES										**3467.06**

REFERENCES

(Abu Hammad 2001) - Abu Hammad, A. (2001). "Simulation Modeling for Manufactured Housing Processes." Masters Thesis, University of Cincinnati. Cincinnati, OH.

(Abu Hammad 2003) - Abu Hammad, A. (2003). "DSS for Manufactured Housing Production Process and Facility Design." PhD Thesis, University of Cincinnati. Cincinnati, OH.

(Allwright et al. 2002) - Allwright, S., McLaughlin, J., Murphy, D., Pratt, I., Ryan, M., Smith, A. (2002), "Report on The Health Effects of Environmental Tobacco Smoke (ETS) in The Workplace." Health and Safety Authority and the Office of Tobacco Control, Ireland. URL: http://ie.osha.eu.int/publications/tobacco_report.pdf, (viewed in July 2005).

(Al-Kaisi et al. 2003) - Al-Kaisi, M., Hanna, M., Licht, M.(2003). "Soil Erosion & Water Quality." Iowa State University Extension, Ames, IW. URL: http://www.extension.iastate.edu/Publications/PM1901E.pdf, (viewed in June 2005).

(Arens & Baughman 1996a) - Arens, E., Baughman, A. (1996). "Indoor Humidity and Human Health: Part I – Literature Review of Health Effects of Humidity-Influenced Indoor Pollutants." ASHRAE Transactions, 102(1).

(Arens & Baughman 1996b) - Arens, E., Baughman, A. (1996). "Indoor Humidity and Human Health: Part II – Buildings and their systems." ASHRAE Transactions, 102(1).

(ASHRAE 2001) - American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE), Position Document (2001), "Indoor Air Quality Position Document." URL: http://xp20.ashrae.org/ABOUT/IAQ_papr01.htm, (viewed in July 2005).

(ASTM 2005) - American Society for Testing and Materials Standard E2114-05a (2005), "Standard Terminology for Sustainability Relative to the Performance of Buildings." ASTM International, West Conshohocken, PA.

(ATS 1997) - American Thoracic Society (ATS) (1997), "Achieving Healthy Indoor Air: Report of the ATS Workshop: Santa Fe, New Mexico, November 16-19, 1995." American Journal Of Respiratory And Critical Care Medicine, 156 (3), S32-S64.

(Banerjee 2003) - Banerjee, D. (2003). "Material Flow based Analysis of Manufactured Housing Production Plant Facility Layout." Masters Thesis, Construction Management Program, Michigan State University. East Lansing, MI.

(Barista 2005) - Barista, D. (2005). "Hilton experiments with 'allergy resistant' hotel rooms." Building Design & Construction, 7.

(Barriga 2003) - Barriga, M. Edgar. (2003) "Manufactured Housing Industry: Material Flow and Management." Masters Thesis, Purdue University. West Lafayette, IN.

(Barshan 2003) - Barshan, A. (2003). "Methodology for Evaluating and Ranking Manufactured Houses based on Construction value" Masters Thesis, Construction Management Program, Michigan State University. East Lansing, MI.

(Bass et al. 2003) - Bass, B., Economou, V., Lee, C., K., Perks, T., Smith, S., Queenie Yip, Q. (2003). "The Interaction Between Physical and Social-Psychological Factors in Indoor Environmental Health." Environmental Monitoring and Assessment, 85(2): 199 - 219.

(Blair et al. 1999) - Blair, Steven N., Brodney, Suzanne (1999), "Effects of physical inactivity and obesity on morbidity and mortality: current evidence and research issues." Medicine & Science in Sports & Exercise. 31(11) Supplement 1:S646.

(Bornehag et al. 2004) - Bornehag, C. G., Sundell, J., Bonini, S., Custovic, A., Malmberg, P., Skerfving, S., Sigsgaard, T., and Verhoeff, A. (2004). "Dampness in buildings as a risk factor for health effects, EUROEXPO: a multidisciplinary review of the literature (1998-2000) on dampness and mite exposure in buildings and health effects." Indoor Air, 14(4), 243-257.

(Boyce & Hunter 2003) - Boyce, P., Hunter, C., (2003), "The benefits of daylight through windows." Lighting Research Center, Rensselaer Polytechnic Institute, NY. URL: http://www.lrc.rpi.edu/programs/daylighting/pdf/DaylightBenefits.pdf, (viewed in July 2005).

(Brundtland 1987) - The Brundtland Report, (1987), United Nations General Assembly document A/42/427, World Commission on Environment and Development.

(CCOHS 1997) - Canadian Centre for Occupational Health and Safety (1997), "Health Effects of Carbon Dioxide Gas." URL: http://www.ccohs.ca/oshanswers/chemicals/chem_profiles/carbon_dioxide/health_cd.html, (viewed in July 2005).

(Chen & Millar 1999) - Chen J. and Millar W. (1999), "Health effects of physical activity." Statistics Canada, Catalogue 82-003, Health Reports 11(1).

(Chitla 2002) - Chitla, V. (2002). "Performance Assessment Of Planning Processes During Manufactured Housing Production Operations Using Lean Production Principles." Masters Thesis, Construction Management Program, Michigan State University. East Lansing, MI.

(CPHA 2004) - Canadian Public Health Association (2004), "FAQs on the Health Effects of Air Pollution." URL: http://www.cpha.ca/cleanair/FAQ.pdf, (viewed in July 2005).

(de Gruijl 2000) - de Gruijl, F., (2000), "Health effects from the sun's ultraviolet radiation." Global Change & Human Health, 1(1), 26-40.

(Dey 2002). Dey, P. (2002). Department of Management Studies, University of West Indies, Barbados, West Indies. "Benchmarking project management practices of Caribbean organizations using analytic hierarchy process." Benchmarking: An International Journal, 9(4).

(DoH Washington 1999) - DoH Washington. (1999). "Indoor Air Quality – Primer." Division of Environmental Health, Washington State Department of Health, Olympia, WA. URL: http://www.doh.wa.gov/ehp/ts/IAQ/IAQPRIME.pdf, (viewed in June 2005).

(DTIR 1995) - Department of Training and Industrial Relations (DTIR), Queensland government, Australia (1995). "Indoor Air Quality." URL: http://www.whs.qld.gov.au/guide/gde21.pdf (viewed in June 2005).

(Energy star 2005) - Energy star (2005). "Better Homes through Assured Indoor Air Quality." Builder Guide, http://www.energystar.gov/ia/partners/bldrs_lenders_raters/downloads/BuilderGuide4C.pdf (viewed in June 2005).

(England et al. 2004) - England, E., Morgan, B.,Usrey, L.,Greiner, M.,Bleckmann, C. (2004). "Vegetated Roofing Technology: An Evaluation." Research Paper, International Life Cycle Assessment and Life Cycle Management Conference - 2004 (InLCM/LCA), URL: http://www.lcacenter.org/InLCA2004/papers/England_E_paper.pdf (viewed in July 2005).

(EPA 1987) - U.S. Environmental Protection Agency (1987). "Project Summary: The Total Exposure Assessment Methodology (TEAM) Study." EPA-600-S6-87-002, Office of Acid Deposition, U.S. EPA, Washington, D.C.

(EPA 1994) - EPA, ALA, CPSC, and AMA. (1994). "Indoor Air Pollution: An Introduction for Health Professionals." EPA 402-R-94-007, United States Environmental Protection Agency, Washington, D.C.

(EPA 2005a) - U.S. Environmental Protection Agency (2005). "A brief guide to mold, moisture and your home." U.S. EPA, Washington D.C, http://www.epa.gov/mold/moldresources.html#Introduction%20to%20Molds (viewed in June 2005).

(EPA 2005b) - U.S. Environmental Protection Agency (2005), "Drinking Water Contaminants." Fact sheet, URL: http://www.epa.gov/safewater/hfacts.html (viewed in October 2005).

(EPA 2005c) – U.S. Environmental Protection Agency Website, URL: http://www.epa.gov (viewed in October 2005).

(ESA 2006) - European Space Agency (2006), Advanced Concepts Team Biomimetics Website. URL: http://www.esa.int/gsp/ACT/biomimetics/index.htm (viewed in December 2005).

(ESP 2005) – Environmental Science and Policy - ESP 801 (2005). "Physical chemical and biological processes of the environment," Course material, Michigan State University, East Lansing, MI.

(ESRU 2005) - Energy Systems Research Unit, "Indoor and Outdoor Air Quality." Courseware, Class 16387, Environmental Engineering Science, University of Strathclyde, Glasgow, URL - http://www.esru.strath.ac.uk/Courseware/Class-16387/6-indoor-outdoorAQ.pdf (viewed in July 2005).

(Fein 1972) - Fein, G. (1972). "The Evaluation of the Technical and Spatial Aspects of Selected Types of Pre-fabricated Modular Construction." Masters Thesis, Michigan State University, East Lansing, MI.

(Fisk & Rosenfeld 1997) - Fisk W. and Rosenfeld A. (1997). "Estimates of improved productivity and health from better indoor environments." Indoor Air 1997; 7: 158-72.

(Fisk 2000) - Fisk, W. (2000). "Health and Productivity Gains From Better Indoor Environments and Their Relationship with Building Energy Efficiency." Annual review of energy and the environment, 25, 537-566.

(Fisk 2002) - Fisk, W. (2002). "How IEQ affects Health, Productivity." ASHRAE Journal, May 2002, 56-58.

(Fisk et al. 2002) - Fisk, W., Brager, G., Brook, M., Burge, H., Cole, J., Cummings, J., Levin, H., Loftness, V., Logee, T., Mendell, M., Persily, A., Taylor, S., and Zhang, J. (2002). "A Priority Agenda for Energy-Related Indoor Environmental Quality Research." Indoor Air 2002, The 9th International Conference on Indoor Air Quality and Climate, Monterey, California.

(Fisk 2005) - Fisk, W. (2005). "Impact of Indoor Environmental Quality on Health and Productivity and Implications for Building Design and Operation." Engineering Sustainability 2005 Conference, University of Pittsburgh, PA.

(Frank et al. 2003) – Frank, L., Engelke, P., Schmid, T. (2003). "Health and Community Design." Island Press, Washington, DC.

(Gaffield et al. 2003) - Gaffield, S., Goo, R., Richards, L. and Jackson, R., (2003), "Public Health Effects of Inadequately Managed Stormwater Runoff." American Journal of Public Health, 93(9),1527-1533.

(Galea et al. 2005) - Galea, S., Ahern, J., Rudenstine, S., Wallace, Z., Vlahov, D. (2005), "Urban built environment and depression: a multilevel analysis." Journal of Epidemiology and Community Health; 59:822–827.

(GBFS 2005) - Green Building Fact Sheet (2005), United States Green Building Council, URL: https://www.usgbc.org/FileHandling/show_general_file.asp?DocumentID=871 (viewed in Sept 2005).

(Gravesen et al. 1999) - Gravesen, S., Nielsen, P., Iversen, R., and Nielsen, K. (1999). "Microfungal Contamination of Damp Buildings - Examples of Risk Constructions and Risk Materials." Environmental Health Perspectives 107(3).

(Gray & Finster 1999) - Gray, K., Finster, M. (1999) "The Urban Heat Island, Photochemical Smog, and Chicago: Local Features of the Problem and Solution," Urban Heat Island Pilot Project(UHIPP), United States Environmental Protection Agency, Washington DC. URL: http://www.epa.gov/heatisld/resources/pdf/the_urban_heat_island.pdf (viewed in July 2005).

(Hass & Meixner 2005) - Haas, R. and Meixner, O. (2005). "A guide to analytic hierarchy process." University of Natural Resources and applied Life Sciences, Vienna. URL: http://www.boku.ac.at/mi/ahp/ahptutorial.pdf (viewed in December 2005).

(Hawken 1993) - Hawken, P. (1993), "The Ecology of Commerce: A Declaration of Sustainability." HarperCollins Publishers, New York, NY.

(Hawks & Hansen 2002) - Hawks, L., and Hansen, A. (2002). "How to purchase a healthy home." Electronic publishing, Utah State University extension. http://extension.usu.edu/files/homipubs/hh06.pdf (viewed in June 2005).

(Jaakkola et al. 1994) - Jaakkola, J., Tuomaala, P., and Seppanen, O. (1994). "Textile wall materials and sick building syndrome." Archives of Environmental Health, 49(3), 175-81.

(Jaakkola et al. 1999) - Jaakkola, J., Oie, L., Nafstad, P., and Botten, G. (1999). "Interior surface materials in the home and the development of bronchial obstruction in young children in Oslo, Norway." American Journal of Public Health, 82(2), 188-92.

(Jeong 2003) - Jeong, Jae G. (2003). "Supply Chain Analysis and Simulation Modeling for the Manufactured Housing Industry." Masters Thesis, Purdue University. West Lafayette, IN.

(Keen 2004) - Keen, J., (2004) "Carbon dioxide monitoring", GreenBuild Tech Bulletin, Department of Architectural Engineering & Construction Science, Kansas State University, KS. URL: http://www.edcmag.com/FILES/HTML/PDF/2005_01-GBTB-CO2_Monitoring.pdf (viewed in July 2005).

(Klepeis et al. 2001) - Klepeis, N., Nelson, W., Ott, W., Robinson, J., Tsang, A., Switzer, P., Behar, J., Hern, S., and Engelmann, W. (2001). "The National Human Activity Pattern Survey (NHAPS) - A Resource for Assessing Exposure to Environmental Pollutants." Environmental Health Sciences, School of Public Health, University of California at Berkeley Berkeley, CA.

(Koeleian et al. 2005) – Keoleian, G., Blanchard, S. and Reppe, P. (2001), "Life Cycle Energy, Costs and strategies for Improving a Single Family House." Journal of Industrial Ecology 4 (2) p 135-156.

(Krupat 1985) - Krupat, E. (1985), "People in Cities: The Urban Environment and its Effects." London, Cambridge University Press.

(Kuehn 1998) - Kuehn, T., (1998), "Construction and Renovation Impact on Indoor Air Quality." Indoor Air Quality Newsletter, 1(1), University of Minnesota.

(Lee & Jones-Lee 1993) - Lee, G. and Jones-Lee, A. (1993), "Public Health Significance of Waterborne Pathogens in Domestic Water Supplies and Reclaimed Water." Report to state of California Environmental Protection Agency Comparative Risk Project, Berkeley, CA. URL: http://www.gfredlee.com/phealthsig_080801.pdf (viewed in July 2005).

(LEED 2002) - LEED Green Building Rating System for New Construction and Major Renovations (LEED-NC) Version 2.1, (2002), United States Green Building Council, Washington, DC.

(LEED 2003) - LEED Reference Package for New Construction and Major Renovations Version 2.1, (2003), United States Green Building Council, Washington, DC.

(LEED Review 2005) - LEED-NC Technical Review Workshop Manual (2005), United States Green Building Council, Washington, DC.

(LEED 2005a) - Leadership in Energy and Environmental Design (2005), United States Green Building Council, URL: http://www.usgbc.org/DisplayPage.aspx?CategoryID=19, (viewed in Sept 2005).

(LEED 2005b) - LEED Rating System for Pilot Demonstration of LEED for Homes Program (LEED-NC) Version 1.72, (2005), United States Green Building Council, Washington, DC.

(LEED 2005c) – LEED for Neighborhood Developments backgrounder (2005), United States Green Building Council, Washington, DC.

(Levin 1989) - Levin H. (1989). "Building materials and indoor air quality." Occupational Medicine, 4(4):667-93.

(LHC 1990) – LHC (1990). "Sick Building Syndrome: Causes, Effects and Control." London Hazard Center, London, UK.

(Madsen 2005) - Madsen, J. (2005). "A breath of fresh air." Buildings, 26.

(Mehrotra 2002) - Mehrotra, N. (2002). "Facilities Design Process of a Manufactured Housing Production Plant." Master's Thesis, Construction Management Program, Michigan State University. East Lansing, MI.

(Melikov 2005) - Melikov, A., (2005), "Development and evaluation of air terminal devices for personalized ventilation", International Centre for Indoor Environment and Energy, Department of Mechanical Engineering, Technical University of Denmark. URL: http://www.ie.dtu.dk/ResResults.asp?ID=16 (viewed in July 2005).

(Miller 1978) – Miller, J. (1978). "Living Systems." McGraw-Hill, Inc., New York.

(NAHB 2004) - NAHB Green Home Building Guidelines-version 1 (2004), National Association of Home Builders, Washington D.C.

(Nielsen 2002) - Nielsen, K. F. (2002). "Mould growth on building materials - Secondary metabolites, mycotoxins and biomarkers," Ph.D. Thesis, Technical University of Denmark, Denmark.

(NIOSH 1989) - National Institute for Occupational Safety and Health (1989), "Preventing Death from Excessive Exposure to Chlorofluorocarbon 113 (CFC-113)." DHHS Publication No. 89-109, URL - http://www.cdc.gov/niosh/89-109.html (viewed in July 2005).

(NIOSH 2005) - National Institute for Occupational Safety and Health (2005). "NIOSH Safety and Health Topic: Indoor Environmental Quality." National institute for occupational safety and health, URL: http://www.cdc.gov/niosh/topics/indoorenv/ (viewed in November 2005).

(NPS 2005) - Ongoing & Emerging Issues Fact Sheet (2005), North Carolina On-Site Wastewater Non-Point Source (NPS) Pollution Program, Raleigh, NC.

(O'Brien et al. 2005) - O'Brien, M., Wakefield, R., and Nowak, M. (2005). "A Preliminary Method to Develop a Calculator for Evaluating Physical Design Characteristics and Whole House Performance Scoring." U.S. Department of Housing and Urban development, Office of Policy Development and Research, Washington, D.C.

(Owens 2004) - Owens, P., (2004). "The link between soil erosion and diffuse contamination of water and air." Environment Directorate - General , European Commission, Brussels. URL: http://www.sednet.org/materiale/eu_sts.pdf (viewed in June 2005).

(PATH 2000) - Partnership for Advancing Technology in Housing (2000). "Partnership for Advancing Technology in Housing: Year 2000 Progress Assessment of the PATH Program." Commission on Engineering and Technical Systems (CETS).

(PATH 2001) - Partnership for Advancing Technology in Housing (2001). "Whole House and Building Process Redesign." NAHB Research Center and Partnership for Advancing Technologies in Housing, U.S. Department of Housing and Urban Development, Washington D.C.

(PATH 2003) - Partnership for Advancing Technology in Housing (2003). "Whole House and Building Process Redesign." PATH Technology Road map, Partnership for Advancing Technologies in Housing and Newport Partners, U.S. Department of Housing and Urban Development, Washington D.C.

(PATH 2005) - Partnership for Advancing Technology in Housing website. (2005). "Concept Home." URL: http://www.pathnet.org/sp.asp?id=11175, (viewed in November 2005).

(Pauley 2004) - Pauley, S. (2004). "Lighting for the Human Circadian Clock," International Dark-Sky Association, Tucson, AZ., URL: http://www.darkskysociety.org/handouts/pauley.pdf (viewed in July 2005).

(PECI 1998) - Portland Energy Conservation, Inc., (1998), "Building commissioning: A guide to quality assurance", U.S. Department of Energy Rebuild America Guide Series, URL - http://www.rebuild.org/attachments/guidebooks/commissioningguide.pdf (viewed in July 2005).

(Plympton et al. 2000) - Plympton, P., Conway, S., Epstein, K., (2000), "Day lighting in Schools: Improving Student Performance and Health at a Price Schools Can Afford." Paper Presented at the American Solar Energy Society Conference, Madison, Wisconsin. URL: http://www.nrel.gov/docs/fy00osti/28049.pdf, (viewed in July 2005).

(Raw et al. 1993) - Raw, G., Roys, M., Whitehead, C., (1993). "Sick Building Syndrome: Cleanliness is Next to Healthiness", Indoor Air, 3, 237-245.

(Rechenberg 2005) - Rechenberg, I. (2005). Bionics – Building on Bio-Evolution, Bionics Tutorial, Bionics & Evolutiontechnique at the Technical University Berlin. URL: http://lautaro.bionik.tu-berlin.de/institut/xstart.htm (viewed in December 2005).

(Russell 1981) - Russell, B. (1981). Building Systems Industrialization and Architecture, John Wiley & Sons Inc., NY.

(Sabharwal 2004) - Sabharwal, A. (2004). "Integration of Manufactured Housing Production Process and Facility Layout Design." Masters Thesis, Construction Management Program, Michigan State University. East Lansing, MI.

(Senghore 2001) - Senghore, O. (2001). "Production and Material Flow Process Model for Manufactured Housing Industry." Masters Thesis, Construction Management Program, Michigan State University. East Lansing, MI.

(Seppänen et al. 1999) - Seppänen, O., Fisk, W., and Mendell, M. (1999). "Association of Ventilation Rates and CO2 Concentrations with Health and Other Responses in Commercial and Institutional Buildings." Indoor Air, 9, 226-52.

(Seppänen et al. 2002) - Seppänen, O., Fisk, W., and Mendell, M. J. (2002). "Ventilation Rates and Health." ASHRAE Journal, 44(8), 56-58.

(Sieber et al. 2002) - Sieber, W., Petersen, M., Stayner, L., Malkin, R., Mendell, M., Wallingford, K., Wilcox, T., Crandall, M., and Reed, L. (2002). "HVAC Characteristics and Occupant Health." ASHRAE Journal, September 2002.

(Southface 2002) - Southface Energy Institute (2002). "Indoor Air Quality - sources, controls, testing." http://www.southface.org/web/resources&services/publications/factsheets/4airqual.pdf (viewed in June 2005).

(Sundell & Nordling 2003) - Sundell, J. and Nordling, E. (2003), European interdisciplinary networks on indoor environment and health, Report no. 2003:32, National institute of public health, Sweden.

(Skov et al. 1990) - Skov, P., Valbjorn, O., and Pedersen, B. (1990). "Influence of indoor climate on the sick building syndrome in an office environment. The Danish Indoor Climate Study Group." Scandinavian journal of work, environment & health, 16(5), 363-71.

(Swarup 2005) - Swarup, L. (2005). "Whole House Performance Criteria Framework and its Application." Maters Thesis, Michigan State University, East Lansing, MI.

(Syal et al. 2002) - Syal, M. and Mehrotra, M. (2002). "Manufactured Housing Trends and Building Codes." Research Report, Construction Management Program, Michigan State University, East Lansing, MI.

(Syal et al. 2004) - Syal, M. and Hastak, M. (2004). "Whole House Production: Integration of Factory-built and Site-built Construction", Housing Research Agenda Workshop paper, Focus Area 5, URL: http://www.pathnet.org/sp.asp?id=12201 (viewed in Dec 2004).

(Syal & Pillai 2005) - Syal, M. and Pillai, G. (2005). "Green and Holistic Planning, Design and Construction." US-India Symposium on Housing and Urban Infrastructure, New Delhi, India.

(Suter 1991) - Suter A., (1991). "Noise and Its Effects", Administrative Conference of the United States, URL: http://www.nonoise.org/library/suter/suter.htm#extent (viewed in October 2005).

(Van der wal et al. 1997) - Van der wal, J., Hoogeveen, A., and Wouda, P. (1997). "The Influence of Temperature on the Emission of Volatile Organic Compounds from PVC flooring, Carpet, and Paint." Indoor Air, 7, 215-21.

(Van Winkle & Scheff 2001) - Van Winkle, M., and Scheff, P. (2001). "Volatile Organic Compounds, Polycyclic Aromatic Hydrocarbons and Elements in the Air of Ten Urban Homes." Indoor Air, 11, 49-64.

(WHO 2000) - Air Quality Guidelines (2000). Second Edition, WHO Regional Publications, European Series No.91, World Health Organization Regional Office for Europe, Denmark.

(WHSC 2002) - WHSC (2002), "Lighting Hazards." Resource lines hazard bulletin, Workers Health and Safety Centre, Ontario, Canada. URL: http://www.whsc.on.ca/Publications/hazardbulletins/winter01-02/lighting.pdf (viewed in July 2005).

(Wood 2003) - Wood, R. (2003). "Improving the Indoor Environment fot Health, Well-being and Productivity." AILA NSW conference, 2003, Sydney, Australia.