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"WHOLE HOUSE" PERFORMANCE CRITERIA FRAMEWORK AND ITS APPLICATION

By

Lori Swarup

A THESIS

Submitted to
Michigan State University
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ABSTRACT

"WHOLE HOUSE" PERFORMANCE CRITERIA FRAMEWORK AND ITS APPLICATION

By
Lori Swarup

It is difficult to affect change in a complex industry such as home building. This is due to fragmentation of the industry, lack of new techniques and involvement of a large number of trades in the building process. Therefore, the inefficiencies, which are inbuilt into the production process, have remained. Each building system is dealt with separately such that there are inevitable negative interactions among them.

The "Whole House" approach promotes the idea that the home be viewed as a system that is composed of different components which must work together and therefore comes across as a credible direction to take with the intent of revolutionizing the homebuilding industry in the long run. The challenge it addresses is to use the synergies among building systems to better the performance of the home. Integrative systems thinking or systems integration is fundamental to the generation of a design and in the approach to its implementation. The aim is to be able to achieve both, total system unification and complete independence while designing for flexible programming.

A "Whole House" performance criteria (WHPC) framework was developed through research, based on the building systems integration approach, which assists the user in systematically tabulating the building systems interactions. The WHPC framework was then used to develop a sample "Whole House" criterion which was applied to three case study designs one each for site-built, factory-built and hybrid home to determine which design comes closest to being an ideal "Whole House" design.

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i. Structure + Plumbing + Interior B
j. Structure + Electrical + Communication
k. Structure + Electrical + Interior A
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Chapter 1 – Introduction

1.1 Overview

Provision of adequate housing has been a primary concern in all societies and over the years, various attempts have been made to address this need. The most significant among them has been the mass production movement or the industrial revolution (Reidelbach 1982). Manufactured homes (MH), which are mass-produced within a controlled factory facility, have been the leaders among the factory-built housing sector within the United States. The average square foot cost of a manufactured house is 10 to 35% less than a comparable site-built house (MHI 2005). It has also been observed that the multi section home shipments have been increasing steadily (MHI 2005).

Previous research funded by the National Science Foundation (NSF) at Michigan State University (MSU) and Purdue University, studied the present MH production process and the assembly plant, in order to make the process more efficient (Banerjee 2003). The next step in the overall goal of being able to *"produce homes, faster, at lower costs and with high quality"* is to question the very design of the home in order to make it more efficient.

This next logical transition has been termed the "Whole House" approach. 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 then (2) uses that 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).

Since the 1920s, builders have tried to develop housing that could be mass constructed. Many housing approaches stimulate "systems thinking" in design, construction and maintenance of homes and a blurring of the lines between industrialized and traditional construction. The beginning of "Whole House" can be traced back to the late 1940's with the introduction of mass productions concepts such as Levittown. This was a community of 17,450 detached homes built within four years in Pennsylvania (Martin 2004). Among the few national attempts to encourage housing technology research in the last decade, Partnership for Advancing Technology in Housing (PATH) is the only program that was instituted in 1994 to address a variety of residential construction sectors and performance traits. Through its efforts to improve the design and construction industry as a whole, known as the National Construction Goals, PATH was formally launched by the White House and U.S. Congress in 1998. While other federal programs, such as the U.S. Department of Energy's Building America and the DOE/Environmental Protection Agency's Energy Star, explore the specific contribution of "Whole House" and "systems thinking" approaches to issues of energy and resource consumption, PATH addresses multiple characteristics of housing performance (Martin 2004).

Before moving further into the discussion regarding "Whole House" and the need for research on the topic, it is important to state the definitions of the various housing forms. For the purpose of this thesis the following definitions for site-built homes , factory-built homes and hybrid homes will be applicable:

- Site-Built homes – Housing constructed mostly at the home site (Senghore 2001).

- Factory-Built homes – Homes built largely within a factory facility on an assembly line and partly assembled on site. The major kinds of factory built homes are as follows: modular, panelized and manufactured homes. Previous research conducted at MSU and Purdue focused on Manufactured homes, which are built according to the HUD code within a factory facility as a single, or a double section for the complete home (Senghore 2001).
- Hybrid homes – Homes that are completed as an integration of site-built with one or more forms of factory-built homes. There have been many attempts in the past to hybridize home production, among them, the "on-site" factory concept (Cohen 2003), where the factory facility is mobile and is set up on the site itself, and the on-going research on the design of hybrid homes (Garcia 2005).

Although the body of knowledge and approaches to this concept are diverse and manifold, it is the author's understanding that "sustainable design" is an important inference of the "Whole House" approach. Sustainable design is the design of a home, which is environmentally responsive in terms of overall energy consumption and construction materials. In other words, it is a design that has minimal negative impact on global resources.

1.2 Need statement

Research has been conducted so far with focus on improving the production process of a factory-built home as well as the supply chain and the layout design of the production facility (Hammad 2001, Senghore 2001, Chitla 2002, Mehrotra 2002,Banerjee 2003, Barriga 2003, Barshan 2003, Sabharwal 2004). In addition to the production

aspect, it is also important to consider other aspects of housing design and construction. Overall performance of the house, as well as ease of preconstruction through the reduction of players involved, construction and maintenance are important issues.

It is difficult to affect change in a complex industry such as home building. This is due to fragmentation of the industry, lack of new techniques and involvement of a large number of trades in the building process. As a result, assimilation of new technology is slow and geographically scattered leaving the homebuilding industry unchanged for a long period of time. Inefficiencies, which are inbuilt into the production process, have remained. Each building system is dealt with separately, consequently negative interactions among them are inevitable and systems integration techniques must be adopted (PATH 2001). Systems do not function efficiently leading to increased energy consumption for the home. As part of systems integration, it is also important to address responsible energy consumption and reduced environmental impact. It is estimated that the residential building industry accounts for 20% of all energy consumption in the United States (Koeleian 2005). It is important to address these deficiencies and develop a process, which will allow the product to be more efficient. "Whole House" redesign, which focuses on building systems integration, seems to be a reasonable direction to take.

1.2.1 "Whole House" as an option

The "Whole House" approach promotes the idea that the home be viewed as a system composed of different components which must work together. It is the author's belief that the "Whole House" approach is not revolutionary, for developers have made isolated attempts over the years. But the idea of bringing all these concepts together is

revolutionary at this time; it may not be a viable option in the distant future. At present the "Whole House" approach comes across as a credible direction to take in order to revolutionize the homebuilding industry in the long run. The challenge it addresses is to use the synergies among building systems to better the performance of the home (PATH 2003). Integrative systems thinking or systems integration is fundamental to the generation of a design and in the approach to its implementation. The aim is to be able to achieve both total system unification and complete independence while designing for flexible programming (Rush 1986). The integrative system must achieve a design, so that the failure of one building system may not affect any other. The proposed research is an attempt to streamline and systemize the building systems integration.

1.2.2 Need for development of the criterion

At present, the literature relevant to the "Whole House" approach is fragmented, and understanding of the approach is also incomplete. As a consequence, the process of implementation of "Whole House" is unclear.

Research has been focused on developing a framework, which will form the basis for effective design, building and maintenance of a "Whole House". This would also help in rethinking of the industry approach to design and construction of a home. The intent of the proposed research is to develop a "Whole House" performance criteria framework, based on the building systems integration approach. This will assist in systematically tabulating all the concepts propagated by the "Whole House" approach and integrating them into the design of a home. Since no such criteria exist in literature (PATH 2003,

Martin 2004), the output of the proposed research will be seen as a unique addition to this field.

The author acknowledges the presence of other important issues dealt within the purview of "Whole House", such as site and consumer related factors. These factors will not be included within the scope of this thesis. Moreover, certain aspects such as chemical and biological process and their impact on indoor air quality will be discussed as future research areas.

1.3 Overall goal and objectives

The overall goal of the research is the "development of a "Whole House" performance criteria framework and its application to site-built, factory built and hybrid housing."

1.3.1 Objectives

1. To map the evolution of the "Whole House" approach.
2. To develop "systems integration models" in order to demonstrate systems interactions and their impact on each other.
3. To develop a "Whole House" performance criteria framework.
4. To develop a sample "Whole House" criterion and apply it to site-built, factory-built and hybrid case study homes.
5. To review the "Whole House" performance criteria framework based on feedback from researchers and industry personnel.

1.4 Research scope and uniqueness

Previously, research has been conducted to model the MH production and material flow process and to develop and implement simulation models in order to identify the bottlenecks in this process. In addition, various aspects of production facility layout, components assembly design, and supply chain management were explored. The following research will be outside the realm of the production facility and will be intended to address the issues relating to building systems integration within the overall "Whole House" design. The author acknowledges that other aspects such as site and consumer related factors as well as, indoor air quality relating to chemical and biological aspects also exist and these topics will be addressed as a part of future research.

The understanding of "Whole House" has been based on the definition laid out by the Whole House Roadmap, and therefore the proposed research will be restricted to the identification of interactions of major building systems. Suitable performance parameters, which relate to the performance expectations from identified building systems, will be determined through research. The performance parameters defined here are not considered as an exhaustive list. Many other parameters may exist, but for the purpose of this thesis the major parameters have been included.

The author's intent is to address the issue of residential design with a "Whole House" approach. This will include both site-built and factory-built homes, where factory-built homes are generic to all types of homes built within a factory facility, such as manufactured, panelized, and modular homes. The sample criterion developed through this research will be reviewed through feedback from researchers and industry

professionals, and inferences will be drawn regarding the most effective use of this criterion.

1.5 Methodology

The proposed research will be conducted using the following research steps. Each research objective will be associated with one or more of the steps. The specific objectives have been indicated in the form of a model in Figure 1.1.

1.5.1 Objective 1

To map the evolution of the "Whole House" approach.

Step 1 – Conduct Literature Review.

1. Origin of "Whole House" (Before 1990's) –
    a. The industrial revolution and design of buildings thereof (Russell 1981, Dietz, Cutler 1971)
    b. Evolution of modular design (Gilbert 1984)
    c. Historical reference to the evolution of factory built housing and Operation Breakthrough (Fein 1972)
2. Recent developments
    a. HUD history and formation of PATH (Martin 2004, PATH 2000)
    b. Whole House roadmap (PATH 2003)
    c. NSF Research Agenda workshop focus group (Martin 2004)
3. Related examples
    a. Concept home from PATH (PATH, URL 2004)

b. Zero energy home (ZEH) design (ZEH 2004)

c. Open building concepts and their relation to the "Whole House" approach. Detailed references and discussion are included in Chapter 2.

d. Leadership in Energy and Environmental Design (LEED) – it is anticipated that the framework developed through this research is akin to the LEED specifications (LEED 2002).

4. Tools and techniques

a. Systems integration tools used to help determine the type and extent of integration required. Detailed discussion and references are included in Chapter 3.

b. Mechanical Electrical and Plumbing (MEP) integration and building systems design. Detailed discussion and references are included in Chapter 3.

c. Recycled content materials, bio based materials and alternative framing materials, which replace lumber. Integrative materials, allowing for integration of uses; for example structured wiring, which integrate wiring for telephone, data and video communication. Detailed discussion and references are included in Chapter 3.

d. Energy efficient design techniques. Detailed discussion and references are included in Chapter 3.

e. Management tools and other contributors such as Lean design, supply chain management, consumer perception. Detailed discussion and references are included in Chapter 3.

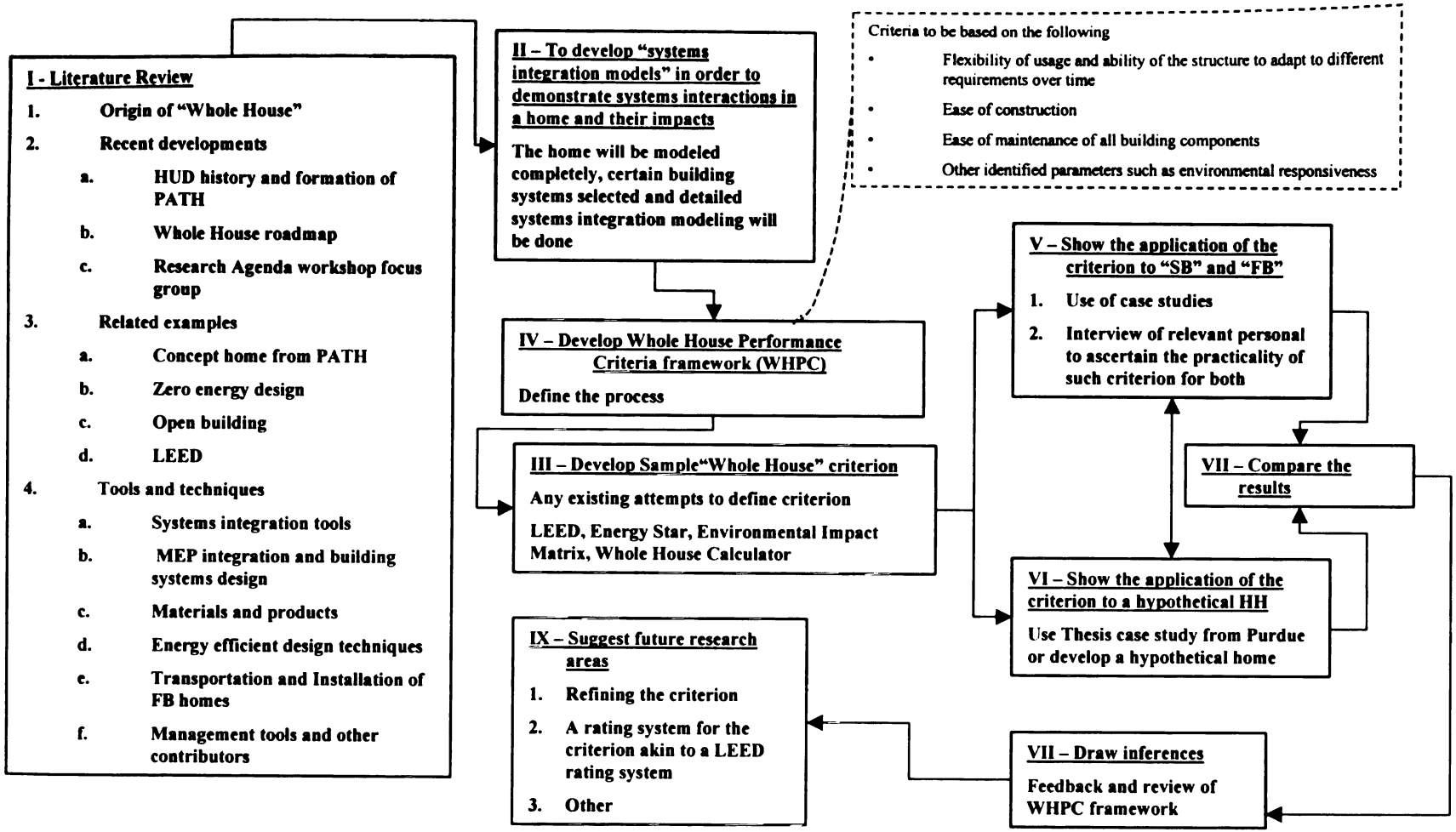

Figure 1.1: Research methodology

1.5.2 Objective 2

To develop "systems integration models" in order to demonstrate systems interactions and their impacts on each other.

The following methodology Steps 2 to 5 will be completed in order to accomplish Objective 2, based on the modeling techniques described in Chapter 4.

Step 2 – Model the "Whole House" as an overall systems integration model.

This step consists of modeling the complete home at a macro level. This includes all the building components such as the substructure, envelope, mechanical – electrical – plumbing, HVAC and communication. This will be accomplished using the BSIH matrix. It was determined that developing Building Systems Integration Handbook (BSIH) matrixes for 2-system and 3-system interactions will provide the information required, although the actual number of combinations can be many more when considering eight building systems.

Step 3 – Determine performance parameters.

The performance parameters reflect the expectations from a "Whole House" design and were based on the following:

- Flexibility of usage and ability of the structure to adapt to different requirements over time
- Ease of construction
- Ease of maintenance of all building components
- Other identified parameters such as environmental responsiveness

Step 4 – Understand the impact of "systems interactions" among the selected building components.

This was accomplished by generating "systems decision models" for each set of building system interactions based on the predetermined performance parameters. The understanding of the systems interactions generated here forms the basis for the sample "Whole House" performance criterion framework. It was determined that the systems decision models developed for 2-system interactions are redundant and therefore the models will be completed for all 58 possible 3-system interactions only.

1.5.3 Objective 3

To develop a "Whole House" performance criteria framework.

Step 5 – Review any existing attempts to define similar frameworks.

The following were identified as existing attempts, which will guide the production of the "Whole House" performance criteria framework.

1. LEED – It is the most widely accepted set of guidelines for design and construction of sustainable buildings. The LEED criterion is comprehensive in its approach taking into account everything from site specifics to the materials used in the building. The criterion specify credits, which must be met in order to receive the minimum certification or the silver, gold or platinum certification based on the number of credits received (LEED 2002).
2. Energy Star – The guidelines specify the design process to be employed for achieving the Energy Star label based on the geographical location of a home (Energy 2003).

3. Environmental Impact Matrix (EIM) – The matrix is a tool developed by the Design Work Group West Michigan Sustainable Business Forum. It is a rating system that can be used as a template for rating environmental impact and can be used by product developers for a wide variety of products and companies (DFE 1999).
4. Whole House Calculator – The "Whole House" calculator is a scoring system that allows the user to determine whether the design of a home comes close to being an ideal "Whole House" design based on a set of performance scores. The research is presently being conducted at the Housing Research Center at Virginia Tech University (O'Brien et al 2005).

Step 6 – Review and determine the appropriate option and formulate the framework.

Three options were considered for the framework; the first originating from the EIM (DFE 1999), another originating from the "Decision Selection Method" (DSM 2005) and the last based on the LEED guidelines format (LEED 2002). It was determined that the LEED format was more comprehensive and allowed the user to systematically tabulate all the information required.

1.5.4 Objective 4

To develop a sample "Whole House" criterion and apply it to site-built, factory-built and hybrid case study homes.

Step 7 – To develop a sample "Whole House" performance criterion.

The sample criterion was formulated to demonstrate the usage of the framework. It is a consequence of the framework, which is intended to be sufficiently flexible to include

individual requirements and is therefore subjective to the researcher. The sample criterion has three major sections based on which the building systems are defined; the intents relating to each performance parameter when looking at one specific building system, the strategies used to achieve these, and the information resources required. The information resources are based on the literature review conducted.

Step 8 - To demonstrate the application of the sample criterion to site-built, factory-built and hybrid case study homes.

This was accomplished through the application of the sample criterion on three case studies one specific to each site-built, factory-built and hybrid case study homes. The drawings and specifications for the site-built and hybrid home case studies were obtained through a major homebuilder. The factory-built home case study was modified from the design of the same home. The application of the sample criterion refers to a set of scores attributed to the strategies employed in the design and construction of each home and their effectiveness with respect to the performance parameters specified through research.

1.5.5 Objective 5

To review the "Whole House" performance criteria framework based on feedback form researchers and industry personnel.

Step 9 - To compare the results obtained for the three case study homes.

The results were obtained in the form of points for each case study. These points were then compared to the ideal "Whole House" score, which is the total number of points obtained hypothetically if all strategies are considered highly effective. The results were expressed as a percentage of the ideal score and then compared.

Step 10 – Feedback on the "Whole House" performance criterion framework and its applications.

Feedback on the criterion was obtained through interviews with involved researchers, in the production of the "Whole House Roadmap" and participants of the "Whole House" focus area at the NSF Research Agenda Workshop, and with industry professionals involved in the hybrid and innovative approaches to housing.

1.6 Expected outcomes and deliverables

The expected outcomes of this research will be as follows:

1. The organization of literature relevant to the "Whole House" approach.
2. The systems interactions model for a complete home.
3. Detailed systems interaction models for the identified building components.
4. A sample "Whole House" performance criteria framework.
5. A sample "Whole House" performance criterion and its application to site-built, factory-built and hybrid homes.

The intent of the research is to set forth a framework for the development of a sample performance criterion and not an accurate "Whole House" performance criterion itself. The author concedes the criterion may take many forms based on individual differences and therefore the accuracy of the criterion itself is not in question. It is expected that this research will serve as a basis for further research into the development of a comprehensive "Whole House" performance criterion.

1.7 Summary

The anticipated impacts on the industry through the proposed research would be manifold. Through the use of the "Whole House" approach, the building process from design to commissioning would be streamlined. The attempt is to integrate the process of building systems design such that the process is rendered much more efficient. The proposed research touches upon the issue of responsible environmental design, which is fast becoming a global concern.

The "Whole House" approach seems most appropriate in addressing the above-mentioned issues. Although the origins of "Whole House" are not new the term has been coined recently through the research conducted by PATH and as such, further research must be attempted. The term includes within its purview all aspects of design, management, construction and postconstruction issues. The approach would be most valuable if assimilation in everyday construction can be achieved. This research is intended to be an early attempt at addressing "Whole House" through the building systems integration approach.

Chapter 2 – Literature Review – "Whole House" Evolution

2.1 Overview

According to NAHB analysis of department of commerce statistics - the median cost of houses increased by 32% from 1992 to 1997 while the median salaries increased by only 24% (PATH 2001). The Manufactured Housing (MH) industry has been one of the largest proponents of affordable housing in the past, and thus previous research has been focused on further reducing the cost incurred during production within the factory facility.

The following research is a continuing academic exploration, from the improvement of the MH factory facility design and production process set out by the National Science Foundation (NSF) in the form of research grants awarded over the past six years. This research seeks to explore beyond the factory facility and to address issues that relate to the overall performance of the home including site-built, factory-built and any hybrid of the two forms. In an effort to identify technological advancements in the home building industry, *Partnership for Advancement in Housing* (PATH) released the *Whole House and Building Process Redesign Roadmap* (PATH 2003). This chapter includes the evolutionary process of the "Whole House" approach. Specific milestones, which have been responsible for the generation of the concept, will be discussed.

2.2 Results of prior NSF research

NSF has funded two projects so far (Grant CMS-0080209: Modeling of Manufactured Housing Production and Material Utilization and Grant CMS-0229856:

Manufactured Housing Production Process Analysis and Facility Layout) at Michigan State University and Purdue University/University of Cincinnati. These projects focus on MH production, facility layout, and material supply chain process, along with an effort to define "Whole House" production (Syal et al 2004).

The main aim of the first research project was to model the MH production and material flow process and to develop and implement simulation models in order to identify the bottlenecks in this process. In addition, preliminary aspects of production facility layout were explored. As part of this research project and other related research efforts at Michigan State University and Purdue University/University of Cincinnati, the following theses and reports were produced.

- Production and Material Flow Process Model for Manufactured Housing Industry (Senghore 2001).
- Simulation Modeling for Manufactured Housing Processes (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).

Until the intervention of NSF, limited research work has been completed in the area of manufactured housing. Moreover, there have not been many research attempts, which encompass both MH production improvement and overall supply chain efficiency. However, through the NSF-PATH projects efficient production process and material flow

management in MH as well as innovative factory layouts were investigated and developed.

In terms of building process optimization, a simulation model was developed for a generic MH factory to identify process bottlenecks, which constrain productivity (Hammad 2001). It was determined that the industry can benefit from the use of more modern equipment, such as faster cranes and a less labor intensive way of moving materials from feeder to main stations (Senghore 2001). At the same time, production optimization was investigated considering factory layout optimization. Following this, space and proximity requirements in a production plant were developed as a process model and detailed steps involved in the layout design generation process were compiled (Mehrotra 2002, Banerjee 2003). Most recently, as part of a PhD Thesis at Purdue University, an Activity-Streamlining Model (ASM) was developed for MH operations using the critical path method that was tested via simulation on four factory design alternatives such as, the spine, the J-shape, the central layout, and the U-shape. These alternative designs offer productivity improvement as much as two, three, and four times, respectively, when compared to the existing U-shape systems (Hammad 2003).

Jeong analyzed the characteristics of the current supply chain in the MH industry at the macro level and identified significant process bottlenecks with regard to process time from order to installation of a MH unit. It was determined that streamlining of the information flow plays an important part in the overall performance of the supply chain parties. Broad adoption of information technologies by the MH industry was also recommended (Jeong 2003).

As part of the second research project, investigators have completed work on detailed aspects of production facility layout and supply chain management. The completed work has resulted in the following theses and reports.

- 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).

2.3 Introduction to "Whole House"

The notion of the "Whole House" approach was pushed in the late 1940s with the introduction of mass production concepts, Levitt and Sons constructed 17,450 detached homes at Pennsylvania within a span of four years (Wright 1981). HUD's 1969 launch of Operation Breakthrough in response to US housing shortages added an impetus towards the "Whole House" approach. Operation Breakthrough was instituted to invite innovative models for mass producible housing, and many concept designs were submitted. The complete list of conceptual designs submitted to HUD can be found in the

book entitled *Housing systems proposals for Operation Breakthrough* (HUD 1970). Created to encourage "new technology, improving architectural design, using the full range of labor skills and overcoming building code, zoning, and labor constraints," these systems incorporated all aspects of the design and construction process, including zoning assessments, multiple-use designs, streamlined mass-produced building materials, and expedited construction methods (Martin 2004).

2.3.1 History of "Whole House"

This section deals with the evolution of the "Whole House" approach. It is apparent that this idea is not novel. The concepts have existed since the Industrial Revolution, but the term "Whole House" was coined later, while assimilating all these fragmented tools and concepts. The discussion begins with the origin of the concepts and then continues with a discussion of initiatives, which deal specifically with the "Whole House" approach. Similar initiatives over the world will also be discussed in brief to give the reader an understanding of the extent of the "Whole House" presence in the world community.

2.3.2 Origin of "Whole House" (before 1990's)

The origin of the concepts, which are part of the "Whole House" approach, can be traced back to the industrial revolution. A large impetus towards the inclusion of these concepts into mainstream homebuilding was the "Operation Breakthrough" initiated by HUD. These two initiatives are discussed in this section in some detail.

2.3.2.1 Industrial Revolution

Though the Industrial Revolution started in Great Britain in the late 18th century, it spread rapidly to Europe and the U.S.A. The most prominent example of the impact of the industrial revolution in the United States is the city of Chicago. The Great Chicago fire in the year 1871 gave designers an impetus to design the loop anew and the buildings built there in the late 1800's are high-rise complex structures.

The progression of modern architecture saw in its wake the use of new materials, such as steel, to design structures, 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. Designers have been experimenting with the issue of integrating complex services as part of a built structure. This was achieved by using shell structures for roof and floor slabs, which provided the building with structural integrity, as well as a convenient location of electrical, and HVAC runs. The shell structures served the purpose of sound and heat insulation between floors as well. The intent was to integrate services with the building structure to economize space, along with increasing the efficiency and facilitating ease of access to building services (Russell 1981).

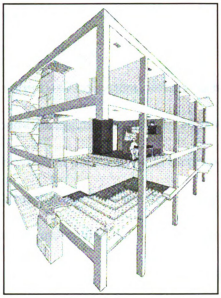

Figure 2.1: Building systems integration (Russell 1981)

2.3.2.2 Operation Breakthrough

Operation Breakthrough, was an initiative by the federal government to promote research and development in housing in the 1970s. It was started in the summer of 1969 under the leadership of George Romney, Secretary of the United States Department of Housing and Urban Development (HUD). All proposals were sorted into two categories: (a) complete housing systems that were essentially ready for production and (b) advanced components and concepts of software or approaches needing further research (Fein 1972). Due to lack of technical expertise and experience this particular approach was not as successful as anticipated and failed to meet its overall objective of promoting new technologies in housing. In spite of the perceived failure, several technologies were identified and promoted. This laid the foundation for the development of the Partnership for Advancing Technology in Housing (PATH), again an initiative of the U.S. government (PATH 2000).

2.3.3 Similar initiatives across the world

Germany (Fein 1972)

- Null-Punkt (Zero point) – The system derives its name from the mode of connecting the load-bearing members. In this system points of least stress or zero stress occur at the weakest points and that the maximum stress occurs at the point of maximum structural strength. Since these components were designed to be prefabricated, the system would be easy to transport and relatively light for ease of handling.
- Okal-House system – The system was designed to produce 2,000 units per year. It dealt with the production of prefabricated components, being flexible enough to be able to be arranged in fifty different housing designs.

United Kingdom (Fein 1972)

- Mark 45 – The system was built to permanent specifications and structures were completely extendible and relocatable. It was essentially a panel system and used external wall panels and structural steelwork.

Switzerland (Fein 1972)

- Norm-Modul system – The system was made up of three principal members, the column with its variants, the beam, and the decking elements with thermal insulation incorporated within them. The mechanical systems were distributed in the basement and from there, carried up in ducts, which ran through a core in the building. The design was on a 1.2 meter grid so that partitions could be planned as per requirements.

France (Fein 1972)

- Fiorio system – This system was designed using load bearing walls, with a hollow burnt clay core, which took advantages of the lightness and thermal insulation qualities of clay products. Each panel consisted of an external layer of concrete with a self-cleaning external finish. All units were designed to be prefabricated in the factory and then transported to the site where they were set on trailers designed to place the units vertically.

United States (Fein 1972)

- Levitt Technology – Proposal for a factory built volumetric module housing system with flexibility in unit arrangement and floor plans. There were two basic modular types: wet modules included baths, kitchens, and heating and air conditioning units. Dry modules were essentially living spaces; wood framed sectionalized housing modules that were factory produced.
- Triad – A 3 bedroom modular house produced by Hodgson Houses consisting of two modules; one, which included the living areas. The plan here was open without any partition walls. The other was a bedroom wing, which was separated and thus quiet. Inserted between the two was a glass ended entry and dining unit. The house included insulation and utilities, major kitchen appliances, plus interior and exterior finishing.

2.3.4 Partnership for Advancement of Technology in Housing (PATH)

PATH is a partnership with the private sector initiated in the year 1998 when Congress sanctioned $980,000 to HUD for work to be conducted by PATH, $10 million has been appropriated since. The overall goal of PATH is:

> *"To stimulate the public and private sectors to develop and use new technologies that could improve the performance and reduce the costs of American homes"*

The aspects of home building researched are materials, products, tools and equipment, subsystems, and systems that are incorporated into houses and the home construction process. The PATH program seeks to achieve many goals:

- Improved durability of materials and components
- Reduced carbon emissions through reduced energy use
- Reduced water use
- Reduced construction waste
- Increased use of recycled, engineered, or alternative construction materials
- Increased use of renewable energy
- Improved disaster resistance
- Improved safety for construction workers

The program sets out roadmaps to promote research in certain key areas that are identified by the panel of experts. One such roadmap is the *Whole House and Building Process Redesign Roadmap*. All of the objectives described above have come together to form the "Whole House" thought process (PATH 2000).

2.3.5 The Whole House Roadmap

The *Whole House and Building Process Redesign Roadmap* was prepared by Newport Partners LLC for HUD, Office of Policy Development and Research under the PATH initiative (PATH 2003). PATH has come about to address the following issue; *improve quality, durability, environmental efficiency, and affordability of tomorrow's homes*. Following this objective research is conducted on relevant subjects, so that they may be addressed more thoroughly. Several roadmaps have been developed in the past to facilitate this objective. With the same intention the Whole House Roadmap was initiated in 2001 and finally completed and submitted in August of 2003. The roadmap begins with a view of what the "Whole House" approach is understood to be; it then proceeds to detail specific visions, goals and objectives, along with the methods for achieving these. Finally it suggests some future research areas, which may be looked into. The "Whole House" vision is defined by the roadmap as follows:

> *"By 2010, home design and construction is efficient, predictable, and controllable with a median cycle time of 20 working days from groundbreaking to occupancy with resulting cost savings that make homeownership available to 90 percent of the population. Homebuyers are pleased with the product since the homes have fewer defects and builders and subcontractors improve margins through the sale of more homes."*

The "Whole House" approach is largely defined in the context of the "systems approach". The systems approach, or systems integration, suggests that the home be viewed as a system comprised of several different components and participants. The key to "Whole House" redesign is to anticipate and resolve conflicts that arise between these

components at the outset so that the design and construction process will be rendered more efficient. It is also important to take advantage of the synergies or interactions between two or more building systems; for example, integrated communications wiring which is now available and is referred to as "Structured wiring"; we shall discuss and many other products in detail in Chapter 3. The systems approach is not new to construction; designers have been exploring possibilities such as structural designs, which incorporate wiring and plumbing systems within them.

The roadmap recognized several barriers to the inclusion of "Whole House" concepts into mainstream homebuilding. The industry is fragmented and this situation is not conducive to innovation. Aesthetics and function appear to be primary consideration for the design of homes, whereas durability, energy efficiency, or systems design seems to be secondary. The regulatory process and consumer perception hamper innovation, since small homebuilders do not want to take risks. Certain objectives have been set out to address the above-mentioned issues. These are:

- Integrating various subsystems or components to optimize design and operation
- Integrating functions of various components or subsystems in a home
- Modifying the management approach and/or other processes to simplify the schedule, reduce negative interdependencies and simplify construction
- Expanding the use of factory-built assemblies including whole-building systems.

This research is based largely on the understanding of the "Whole House" approach set out by the Whole House roadmap. The focus will be on building systems integration.

2.3.6 PATH Research Agenda Workshop

To further research ideas upon the "Whole House" approach, the NSF-PATH housing research agenda workshop was organized and executed in Florida in February 2004. Position papers were submitted by 45 housing researchers under five focus areas (1) Construction Management and Production; (2) Structural Design and Materials; (3) Building Enclosures, Energy, and Indoor Air Quality (IAQ); (4) Housing Technology, Community and the Economy; and (5) Systems Interactions and "Whole House" Approach.

For the purpose of this research we shall focus Area 5, which refers to the "Whole House" approach. Under this title the following research papers were most significant:

- "Building the whole greater than the sum of its parts: contextual zing 'whole house' technologies and initiatives" Focus area summary paper (Martin 2004).
- "Whole House Production: Integration of Factory-built and Site-built Construction" (Syal et al 2004).
- "Automated Construction by Contour Crafting – Related Robotics and Information Technologies" (Khoshnevis 2004).
- "Bio-Based Composite Materials for Whole House Design: Potential Applications and Research Needs" (Shenton et al 2004).
- "Whole House Design Through the Application of Multi-functional Precast Panels" (Ellis et al 2004).

2.3.7 The PATH concept home

The PATH concept home is an attempt to demonstrate the objectives of the "Whole House" approach and its realistic inception into mainstream design of homes. An architectural model of the home was created to demonstrate these concepts. The model was displayed at Portland, Oregon, and at the 2005 International Builders' Show at Orlando, Florida.

The primary objective to be accomplished by the home is that it should be able to adapt to change and thus a flexible floor plan has been designed, which can be changed as per the changing requirements of the occupants. The next step is to make sure that all building systems function independently, so that there are no tangled electrical, communication and plumbing lines hidden within the walls. This is referred to as the "systems thinking" or the "Whole House" approach. After having separated the building systems it is important to organize their distribution through the home, and for this purpose a utility chase is incorporated that includes electrical, HVAC, communication and plumbing services within one space. This process will facilitate the ease of maintenance and upgrading of the utilities at any point without disturbing the structural fabric of the home. The home also integrates the use of factory built components with site built technologies using the most optimum of the two to reduce the production time, traditionally six to nine months, to 20 days. Finally it propagates the use of integrative materials; for example, the roof incorporates solar panels as part of the envelope, as well as an electricity-generating device.

The concept home has been referred to as the home of the future *"which evolves with its occupants"* and is made up of *"moveable walls"*. It is a step towards a "Whole

House" design and demonstrates the practical applicability of the techniques propagated thereby (PATH, URL 2004f).

2.4 Factory-Built homes

Factory-built homes are defined as those homes that are built, either partially or as a whole, within a factory facility and then transported to a site where they are assembled. These homes have proven to be affordable alternatives to housing in the United States. The development has been rapid and now many manufacturers offer consumers a variety of choices, which make the product all the more attractive. The genesis of this kind of home is from the "mobile homes" concept, which was further improved to form the Manufactured, Modular and Panelized homes (Senghore 2001).

2.4.1 Manufactured

At the outset all factory-built homes were referred to as mobile homes. As the factory-built housing industry matured and both products and production process became more sophisticated, distinctions were made among the types of factory-built homes. The name was coined in the year 1980 by the federal government when all industrialized housing came to be referred to as "Manufactured homes" or "HUD code homes". These are factory-built home units, which can be built either as a single section, or a double section, based on the space requirements. These sections are then transported in entirety to the specific site. The share of manufactured housing among all factory-built housing is relatively large. It was estimated that in the year 1998 the percentage of affordable

housing covered by MH was 22.7%, since then the numbers have decreased but not substantially (Banerjee 2004, MHI 2000).

A manufactured home is a unit that is mostly completed in a factory setting. The manufactured home goes through five different stages in the assembly line within the manufacturing facility, starting from station one, where the chassis is assembled, to the final station where the home is finally cleaned up and ready to be delivered at site. These homes meet the HUD codes, and resemble the site-built homes to a large extent (Banerjee 2004).

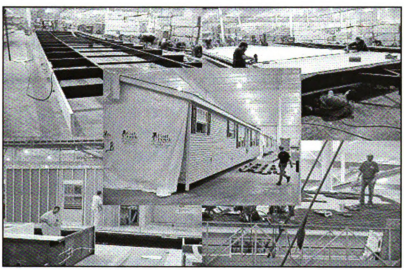

Figure 2.2: Manufactured Housing Factory (Banerjee 2003)

2.4.2 Modular

Defined as non-residential structures that are 60 to 100 percent factory-built, commercial modular buildings are designed so that they can be constructed at one location, the factory, and then used by occupants at another location where the building is to be placed. Although originally used to design commercial buildings, the technology is also used in the housing sector. The word "modular" describes a construction method

where individual modules stand-alone or are assembled together to make up larger structures (MOD URL 2004a).

Primarily, four stages make up modular construction. First, design approval by the end user and any regulating authorities; second, assembly of module components in a controlled environment; third, transportation of modules to a final destination; and fourth, erection of modular units to form a finished building. These homes are built as per manufacturers predetermined designs, along with client input (MOD URL 2004b). Modular homes relate to a larger extent to traditional stick built homes, which increases their overall popularity. This is because it is possible to affect more complex designs through the stacking of several boxed units that can be designed and completed within a factory. These homes must meet state or local building codes at the parent site.

2.4.3 Panelized

Panelized homes are defined as homes where panels are built as flat units that represent a whole wall with windows, doors, wiring and outside siding. These are constructed in the factory and then transported to the site and assembled. Panelized homes must meet the state or local building codes specific to their location (Senghore 2001).

Exterior wall panels are constructed on a horizontal wall table. Working on the flat surface, all the panels for one side of the house are built together. The wall panels are framed with studs and plywood. Windows are installed in the panels at the factory facility when the wall is flat on the table, so considerable time is saved on the site. Wall panels are available in two forms, "open" wall panels for buildings with less post and beam

frame, or occasionally in areas where "closed" panels are not approved. Although the same construction system is used open panels are shipped with no inside finish or insulation; hence, the term, "open", whereas "closed" panels have insulation and interior finish installed. The roof panels consist of rafters, insulation, exterior plywood top, and interior finish fabricated to panel sizes. For the roof panels, the frame is built, then a vapor retarder, insulation, and the interior ceiling finish is installed. The panels are vented, providing an air space running from the vent strip at the bottom to the ridge vent at the peak. Panelized housing is not as popular as manufactured or modular housing; it represented only 6.3 % of the total share of factory built housing according to a 1998 census (Banerjee 2004).

2.4.4 History

The concept of modular systems came into existence in the early 1960's. Created by Le Corbusier, the "modular is a measuring tool based on the human body and mathematics"(Fein 1972). Along with Le Corbusier, other architects such as Moshe Safdie promoted the concept. Moshe Safdie is possibly one of the beginning thinkers of prefabrication and ease of construction through design. His name is indivisibly attached to the Montreal Fair – Expo 67 and his exhibition there of the Habitat. I quote the designer: (Gilbert 1984)

> *"...in order to take the 75% of building into a factory you have to deal not with the panels but with volumes of space. You had to fabricate cells of space in the factory and put your mechanical services, plumbing, bathrooms whatever else there was into them in an assembly line procedure. You would then assemble the*

modules on site and if connections were simple you would have a 95% factory produced building"

Component sizes needed to be standardized so that there is no waste of material during fabrication. The Modular Number pattern based on this principle called for a range of basic product sizes based on the elimination of prime numbers and their multiples starting with 7.

1,2,3,4,5,6,8,9,10,12,15,16,18,20,24,27,30,32,36,40,45,48,54,60,64,72,80,90, 96,108,120

Figure 2.3: Numbers contained in the Modular Number pattern up to 120 (Russell 1981)

The concept of standardization was translated into factory produced components, or boxed units, which were assembled on site, thereby cutting down construction time. Factory fabrication and assembly of compatible subsystems results in the production of three dimensional space modules which are complete or partially complete and can be used to form entire buildings that require varying degrees of on-site finishing (Russell 1981).

2.5 Recent developments

This section deals with other schools of thought on building design that feed into the "Whole House" approach. Open building concepts, Lean construction and Zero energy homes all contribute in some manner to the concepts inherent to the "Whole House" approach. It is important to discuss all these developments in order to have a

complete understanding of the entirety of the "Whole House" approach and, therefore, the expectations of such as a design.

2.5.1 Open building

Residential Open Building is an integrative approach to design, financing, construction, fit-out and long-term management processes of residential buildings. The intent is to analyze the processes in all their complexities to determine appropriate tools and techniques to complete a design in an organized manner. Open building lends itself to adaptation and ease of construction. The intent is to extend the usability of the product (the built structure) over its lifetime, inasmuch as the structure is able to adapt to new uses during its lifetime. The early realizations of this approach were spearheaded by John Habraken, who was a young Dutch architect. He published a small volume titled "Supports: An Alternative to Mass Housing" which is a translation from the original 1962 text (Habraken 1972). He noted that mass housing had altered the relationship of a dweller with his environment. Habraken believed that it was important to consider the lack of personal relationship with a dwelling environment as perpetrated by the industrial revolution. The intent was to be able to give the dwellers a reasonable degree of choices as to the interior placement of their particular unit; thus, the aspect of mass production could be interposed with the notion of individual choice (Kendall 2000).

2.5.1.1 Decision making parameters in open building

The following objectives are set out by Open building adopters (Kendall 2000):

- The users choice during design.

- The building process is a team effort and must be coordinated as so.
- All building systems are replaceable and can be integrated – The concept of the Fit-out.
- All building systems and the building as a whole must be able to assimilate change.
- The built environment is the product of an ongoing design process, which transforms periodically. There is a dynamic approach to the built form and design.
- The distinct levels of intervention must be recognized such as:
    - Urban level decisions involve the public realm which includes built form and space, infrastructure requirements such as local amenities, roads, parking, utility, setbacks, street furniture and so on.
    - Support (base building) level involves those parts of the building, which are common to all occupants such as the base building.
    - Infill (fit-out) level includes the interior structural aspects of the built structure, which is sustained for a period of 10-20 years.
    - Layout level is as the name suggests, the internal layout of the building unit.

2.5.1.2 Key concepts

The following statements are the key concepts for the open building approach (Kendall 2000):

- Levels – The intent is to design according to the distinct decision-making levels defined as above. The theory of levels takes into account that several parties have several levels of control between the phases of the building.
- Supports – The supports include the shared utilities of the built structure, such as building structure and façade, staircases, electrical, and HVAC.
- Infill – These systems are used to infill an existing support system. They include complex mechanical systems.
- Unbundling decision-making – The concept is to divide the building into distinct bundles of technology. Here the systems integration aspect relating to building systems comes into play.
- Capacity – The idea of capacity includes designing the form to be an open-ended and dynamic fabric and designing space or form (at multiple scales) with built-in capacity to accommodate more than one "program of function" over time.
- Sustainability – The issue of sustainable design or environmentally responsive design must be taken into consideration as well.

2.5.2 Sustainable development

In 1987 the United Nations World Commission on Environment and Development report entitled "Our Common Future" formalized the use of sustainable development by providing the first definition (DFE 1999):

> *"meeting the needs of the present without compromising the ability of future generations to meet their own needs."*

The notion of equity associated with the use of natural resources was not only extended not only to physical areas but also among generations of inhabitants. As we begin to realize that we are using natural resources at a rate, which cannot equal the renewal process, we must include processes that reduce the waste of energy in any form. As of the present, the homebuilding industry has been left far behind in its ability to embrace this very important requirement. As a result, only about 10% of new homes in the United States are built significantly above the minimum efficiency standards (Koeleian 2005).

2.5.3 Zero energy homes

A Zero Energy Home (ZEH) combines state-of-the-art, energy-efficient construction and appliances with commercially available renewable energy systems such as solar water heating and solar electricity. This combination can result in net zero energy consumption. A ZEH, like most houses, is connected to the utility grid, but can be designed and constructed to produce as much energy as it consumes on an annual basis. With its reduced energy needs and renewable energy systems, a ZEH can, over the course of a year, give back as much energy to the utility as it takes (DOE 2004). Researchers plan to carry this even further by defining the next stage for such a design would be to generate enough energy to give back to the local grid over and above its own usage capacity; these are referred to as Net Positive homes.

Zero Energy Homes have a number of advantages over traditionally built homes; they provide improved comfort conditions for the occupants, since the energy-efficient building envelope reduces temperature fluctuations and, as such, is more reliable during

blackouts. There is added financial security since the home generates its own energy it protects the user from fluctuations in energy prices. And of course environmental sustainability since a ZEH saves energy and reduces pollution (ZEH 2004).

2.5.4 Lean construction

Lean construction is a derivative of the original Lean production system envisioned by Henry Ford for improving the productivity of the Ford Motor Plant. The Lean vision revised on the concept of mass production in order to include within it aspects such as consumer specific design, continuous improvement, error proof management and just in time are the founding beds of this philosophy. The Lean construction philosophy also stems from these very dictates of maximizing value and minimizing waste. The primary propagator of this thought process was the book The Machine That Changed The World (Womack et al. 1990). Lean construction may be defined as follows (Womack et al 1996):

> *"Lean construction is a production management based project delivery system emphasizing the reliable and speedy delivery of value. It challenges the generally accepted belief that there is always a trade between time, cost and quality."*

2.5.4.1 Key concepts

The following concepts are key to the Lean construction philosophy (LC 2004):

- Project Delivery is the simultaneous design of the facility and its production process concurrently so as to determine the design as per the performance requirement from the production process.

- Value engineering, or value to the customer, is defined, created and delivered throughout the life of the project.
- Performance is based on maximizing value and minimizing waste at the project level.
- Decision-making is decentralizing through transparency and empowerment. This means providing project participants with information on the state of the production systems and empowering them to take action.
- Action is coordinated through pull and continuous flow as opposed to traditional schedule driven push, with its over-reliance on central authority and project schedules to manage resources and coordinate work.
- Control is defined as making things happen. Planning system performance is measured and improved to assure reliable workflow and predictable project outcomes.

2.5.5 Supply Chain Management

With the introduction of the "Whole House" approach to the home building process, it will be necessary to reconsider the alignment of the supply chain. This is essential to render the entire process efficient. Technological advancements and recommendations can only be successful if the supply chain has the ability to mould itself to serve best within the prevailing circumstances. It will be essential to recommend updated supply chain characteristics, along with means and methods to integrate the supply chain with the "Whole House" process model.

The inception of the currently prevailing supply chain is associated with the housing boom after the World War II. After the Housing Act was passed in the year 1949, almost one million new low-cost housing units were commissioned for construction; at this time, the importance of a fast and reliable supply chain became apparent. It is predicted that 75% of the home building will be carried out by the 20 largest homebuilders in the industry by the year This hypothesis is questionable, simply because the infrastructure, in this particular case the supply chain, is not adequate at present to fulfill the demands of organizations that continue to grow larger. Initial forays into expanding the domain of access were achieved by the introduction of the web-based supply chain. Quote:

> *"Davidow and Malone (1992) in their visionary book, "The Virtual Corporation," predicted that information processing capabilities would result in a business revolution."*

It has been recognized in academic circles that the use of information technology (IT) will provide "value-adding solutions to remove waste and latency from supply chains" (John et al 2004).

2.6 Existing attempts at developing a criterion

The following guidelines are most widely accepted as guidelines for the design and construction of energy efficient homes. Both LEED and Energy Star guidelines are comprehensive and address all the issues relating to design and construction of a home. It is the author's opinion that the LEED guidelines are more comprehensive in the sense that they take into account site specifics, along with materials and performance of the

built structure. The LEED guidelines format will serve as a point of departure for the sample "Whole House" criterion. This section includes other concepts, which may lend themselves to the formulation of the sample criterion, such as the Environmental Impact matrix, the "Whole House calculator" (which is a recent addition to the body of knowledge) and other contributors.

Finally the author feels it is important to recognize the existence of attempts made by the EPA to promote energy efficiency in construction in the form of the CTSA and the Federal guidelines. The Federal guidelines are significant because they are the first comprehensive recognition of requirements for sustainable design for federal buildings. This might lead to a wider acceptance of "green building" or "sustainable building".

2.6.1 Leadership in Energy and Environmental Design (LEED)

The LEED certification standard is a product of the US Green Building Council (USGBC). It is the most extensive and well-recognized certification standard, which distinguishes green building design. The intent is to outline design guidelines, along with a design-training program toward sustainable design. The formal mission statement set out for the LEED guidelines by the USGBC is as follows (LEED 2002):

> *"LEED encourages and accelerates global adoption of sustainable green building and development practices through the creation and implementation of universally understood and accepted standards, tools and performance criteria."*

The LEED certification is processed along two different levels, the Horizontal products are main LEED products which span the full range of possible building types and phases in the life of a building, whereas Vertical products are specific technical

features of the buildings or the processes that take place within them that demand special treatment. In these instances, a LEED Application Guide gives specific advice on how to apply LEED and also on any special exceptions or interpretations that can be used to deal with specific problems or simply to assist an application. The certification standard is given out at 4 distinct levels of compliance:

- LEED Certified projects achieve 40% or more of the Core Credits
- LEED Silver projects achieve over 50% of the Core Credits
- LEED Gold projects achieve over 60% of the Core Credits
- LEED Platinum projects achieve over 80% of the Core Credits

The general characteristics of the sections specified for the LEED guidelines for New Construction & Major Renovations (LEED-NC) Version 2.1 (LEED 2002) have been simplified in the form of a matrix developed by the author depicted in part in Figure 3, the complete matrix is included as part of Appendix A.

No	Description	Credit	Intent	Strategies	Requirements
A	**Sustainable Sites**	**14**			
P1	Erosion and Sedimentation Control	Prerequisite (1)	Control erosion to reduce negative impacts on water and air quality.	Consider employing strategies such as temporary and permanent seeding, mulching, earth dikes, silt fencing, sediment traps and sediment basins.	Must follow EPA Document No. EPA 832/R-92-005 (September 1992), Storm Water Management for Construction Activities, Chapter 3, or local erosion and sedimentation control standards and codes, whichever is more stringent.
C1	Site Selection	1	Avoid development of inappropriate sites and reduce the environmental impact from the location of a building on a site.	Design of footprint to minimally impact the site, tuckunder parking, and sharing facilities with neighbors.	Must not develop on Prime farmland, wetland and parkland as defined by the US govt, land with elevation lower than 5ft from the 100-year flood as defined by FEMA, and that which is specific to a particular habitat
C2	Development Density	1	Channel development to urban areas with existing infrastructure, protect greenfields and preserve habitat and natural resources.	During the site selection process, give preference to urban sites.	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
C3	Brownfield Redevelopment	1	Rehabilitate damaged sites where development is complicated by real or perceived environmental contamination, reducing pressure on undeveloped land.	During the 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	Develop on a site documented as contaminated (by means of an ASTM E1903- 97 Phase II Environmental Site Assessment) OR on a site classified as a brownfield by a local, state or federal government agency.

Figure 2.4: Matrix of specifics for LEED criterion

2.6.2 Energy Star

Energy Star is a nationally recognized, voluntary program designed to identify and promote energy efficient products, new homes and buildings to consumers and businesses across the United States, developed by the Environmental Protection Agency (EPA). Homes that are independently verified to be at least 30% more energy efficient than homes built to the 1993 national Model Energy Code or 15% more efficient than the state energy code, whichever is more stringent.

The design, manufacturing, installation and certification procedures are described below in the form of steps specified (Energy 2003):

- Step 1 - Select the climate region where the home will be cited based on the Figure specified by the Energy Star guidelines.
- Step 2 - Select an Energy Star design package which is specified in tabular form set out by the EPA: (1) select the climate region (2) select the duct leakage level that the plant can hope to achieve (3) select the type of heating equipment (4) finally select the appropriate U values or the Solar Heat Gain Coefficient (SOGC).

The following specifics are stated in the matrix to be followed in order to achieve the Energy Star rating.

- Maximum Duct leakage - Refers to the amount of leakage from an air distribution duct as measured using a "Duct Blaster".
- Minimum Heating Equipment Efficiency - Electric heat pumps – ARI (Air-Conditioning and Refrigeration Institute). Here the performance specification to be considered is the HSPF (Heating Seasonal Performance Factor). Fossil

fuel-burning furnaces – GAMA (Gas Appliance Manufacturers Association). Here the performance specification to be considered is the AFUE (Annual Fuel Utilization Efficiency).

- Maximum U value - Refers to the ability of the home's envelope to resist heat flow. This value should be calculated such that all surfaces that impact energy use are considered.
- Solar heat gain coefficient (SHGC) - Refers to the ability of the window to block solar heat from entering the home. The higher the SHGC the more solar heat is transmitted through the window.
- Minimum Hot Water Equipment Efficiency – Energy efficiency of the hot water heater measured in terms of Energy Factor.
- Thermostat Type – Programmable thermostat.
- Minimum Cooling Equipment Efficiency - Equipment rating as certified by ARI and published in the ARI Directory of Certified Unitary Products. Air conditioners and heat pumps in the cooling mode are rated in terms of Seasonal Energy Efficiency Ratio (SEER).
- Heat Recovery Ventilator - A heat recovery ventilator (also called an air-to-air heat exchanger) is a ventilation system that consists of two separate air-handling systems; one collects and exhausts stale indoor air and the other draws in fresh outdoor air and distributes it throughout the home. At the core of an HRV is a heat transfer module. Both the exhaust and fresh air streams pass through this module, and the heat from the exhaust air is used to preheat the fresh air stream. Only the heat is transferred; the two air streams remain

physically separate. Typically, an HRV is able to recover 70-80 % of the heat from the exhaust air and transfer it to the incoming air. This dramatically reduces the energy needed to heat fresh air to a comfortable temperature.

2.6.3 Environmental Impact Matrix

The "Environmental Impact Matrix" (EIM) is a tool developed by the Design Work Group West Michigan Sustainable Business Forum as a rating system to evaluate progress toward achieving sustainability in new products and services. The goal in creating the matrix was to establish a system that can be used as a template for rating environmental impact. It is usable by product developers for a wide variety of products and companies (DFE 1999).

The idea is based on Life Cycle Thinking (LCT), which is a unique way of addressing environmental problems from a systems perspective. In this way of thinking, a product or service system is evaluated or designed with a goal of reducing potential environmental impacts over its entire life cycle. Put simply, the LCT results are qualitative in nature whereas the Life cycle analysis (LCA) results are quantitative (DFE 1999).

It is important to understand the strengths and weaknesses of the tool before using it. The strengths of the Environmental Impact Matrix are as follows:

- It is easy to use, straightforward and logical.
- If used consistently, it will provide a measure of product-to-product improvements.

- It is a self-analysis and enabling tool to help a company reduce its environmental impact over time.
- The total score is useful as a comparative environmental impact measurement between similar internal products.

The weaknesses are as follows:

- It cannot be used as a complete Life Cycle Assessment.
- Hard data may not be available to support each company's index values, in which case experience and judgment should prevail.

The procedure to implement this tool is as follows:

1. Step One: First, in the horizontal rows list all the various materials, sub-processes, etc. that go into a product or service. List one product or service per EIM, using multiple pages as necessary.
2. Step Two: Assign a value range using internal company goals, objectives, or definitions to determine least impact and worst impact. The matrix uses a range of 0 to 5 range but the user should feel free to adjust numeric values to better reflect company goals or priorities. If an environmental aspect is not relevant, a zero rating may be used.
3. Step Three: The physical weight of each component should be recorded in the Physical Weight column. It may be beneficial to include all material needed including waste, not just the material in the final product.
4. Step Four: Go across the matrix for each line item component, add each impact value, and record the sum in the Subtotal Column.

5. Step Five: Multiply the subtotal by the weight and record for each line item component.
6. Step Six: Record the final score in the Final Score space.

The intent of the matrix is to allow the developer to perform "what if" scenarios based on current production practice to determine the least environmental impact score.

2.6.4 The "Whole House" calculator

The "Whole House" calculator is a quantitative model, which allows the user to determine whether the design of a home is close to being a "Whole House" design. The research is being conducted at the Housing Research Center at Virginia Tech University (O'Brien et al. 2005). The calculator is a tool that takes into account the processes, products and materials used to design, engineer, and construct a house. Then the calculator uses performance scores for each characteristic of the house that are customized by the requirement of the prospective buyer or builder and then modified by the way the materials and processes interact with each other to arrive at a "whole house score". This *whole house score* is compared to the ideal whole house score for the same home in percentile. The user may then conduct analysis to determine which design is closest to being a "Whole House" design. The "Whole House" calculator serves as a comparison tool rather than a design tool. It does not assist the user in designing a "Whole House" but rather in determining whether a pre-designed home fits the performance requirements of a "Whole House" (O'Brien et al. 2005).

The Battelle Method that is described below serves largely as the scoring system for this approach and acts as the skeleton for the "Whole House Calculator". Both the

choice of the buildings systems and the kinds of interactions are the opinion of the authors. The credits assigned to building systems as well as the scoring of the interactions are based on the researchers' understanding. The authors intend to conduct a process of validation through the review of this report by an experts' panel. However at this time the "Whole House Calculator" may be viewed as an industry model rather than pure academic research.

2.6.4.1 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. A variation of this method is used to formulate the "Whole House" calculator.

2.6.5 Other contributors

This section includes some of the methods found during literature review that may prove useful in the formulation of the criteria in the future. It is the author's opinion that at this time the methods stated in this section are in their inception stages and may require some more relevant research before they are useful. Also these methods were not directly useful for the study in question, since the "Cleaner Technology Substitute Assessment" method addresses the use of chemicals in the industry and the federal guidelines are primarily a federal document that recognizes the impact of environmentally conscious design and seeks to assimilate these methods in the mainstream homebuilding industry.

2.6.5.1 Cleaner Technology Substitute Assessment (CTSA)

The Cleaner Technology Substitute Assessment (CTSA) is a methodology for evaluating the comparative risk, performance, cost, and resource conservation of alternatives to chemicals currently used by specific industry sectors. This is developed by the U.S. Environmental Protection Agency (EPA) Design for the Environment (DfE) Program, the University of Tennessee Center for Clean Products and Clean Technologies, and other partners in voluntary, cooperative, industry-specific pilot projects. The relevant terminology used is described below (EPA 2004):

- A Cleaner Technologies Substitutes Assessment (CTSA) is a repository for all of the technical information developed by a DfE project, including risk, competitiveness (i.e., performance, cost, regulatory status, market availability), and conservation data. A use cluster is a product- or process-specific application in which a competing set of

chemical products, processes, or technologies can substitute for one another to perform a particular function.

- A substitute or an alternative is any traditional or novel product, technology, or process that performs a particular function.
- A substitutes tree is a graphical depiction of: (1) the alternative chemical products, technologies, or processes that make up the use cluster; and (2) their relationship to each other within the functional category defined by the use cluster.
- An information module is a standard analysis or set of data on the substitutes. Information modules are designed to build on or feed into one another to form an assessment of the substitutes.

2.6.5.2 Federal guidelines

It is important to point out the existence of this federal document as it acknowledges the fact that green building or sustainable design has become an important and accepted aspect of construction today. The DRAFT Federal Guide for Green Construction Specs is being developed by EPA in a partnership with the Federal Environmental Executive and the Whole Building Design Guide, to help Federal building project managers meet various mandates as established by statute and Executive Orders, as well as, EPA and DOE program recommendations. The Federal Guide for Green Construction specifications read as a legal document that must be referred to for the design of Federal building projects. This document has been discussed for the purpose of documentation and was recognized as a significant contribution in the field of guidelines development for the design of environmentally responsive buildings. In the author's view

the document provides a legal basis for the design of federal buildings and is a compilation of energy guidelines such as LEED, Energy Star and local code. The document comprises of several sections, which range from administrative requirements to site preparation, and finally commissioning (WBDG 2004).

2.6 Summary

The building industry has gone through a series of evolutionary steps, some identified as steps towards the "Whole House" approach. With the evolution in the early 90's in building construction and the complexities of buildings constructed, it became incumbent upon designers to develop procedures to render the design and building process more integrated. Building systems gained a new significance in the overall design due to the magnitude and complexity. New building systems, such as fire retardants and HVAC, were introduced.

For the purpose of this research, the association has been restricted to home building although the author does not deny the possibility of the extension of this approach to all form of design and construction. The approach to such design is referred to as the "systems approach", which states that the home be looked upon as a system which incorporates several components within it. The systems approach extends itself from the relationship of parties involved in the construction process to the actual interaction between the different building systems within a single home unit. Finally the "Whole House" approach looks into sustainable design such that materials and appliances used within a home do not affect the environment adversely. Performance requirements in terms of energy consumption are also an important characteristic.

The present research is an attempt to develop a framework for the development of a sample "Whole House" criterion, which will help users to identify as well as design, homes following the "Whole House" approach. In order to formulate this criterion, the author has identified the LEED and Energy Star guidelines as possible take-off points for the format of the sample criterion since these are already accepted criteria for sustainable development and design. Also, the formats provide required information in an organized and comprehensive manner to the user. In the author's opinion the LEED guidelines are comprehensive and may form a satisfactory basis for the design of the sample "Whole House" criterion.

Chapter 3 - Literature Review – Tools and Techniques

3.1 Overview

The previous chapter focused on the history of the "Whole House" concept. In this chapter the review will focus on tools and techniques, which have been introduced over the years, as parts of the body of knowledge relevant to "Whole House". The following tools and techniques are recent introductions and have not been assimilated into the main stream for the large part. The discussion in this chapter is based on the following topics: (1) Systems integration modeling tools, which focus on determining the extent and kind of integration required. (2) Mechanical electrical plumbing (MEP) integration techniques. (3) Identification of all building systems present within a home, such as HVAC, plumbing, electrical, fire protection, communication, and home automation systems. Here the review will be based on better performance through change in design or type of fuel. (4) The chapter concludes with a review of tools that will assist in determining the performance of a "Whole House" design.

3.2 Systems Integration tools

The total systems approach or system integration is concerned with the logical selection of materials and methods in order to obtain value in terms of the functioning model rather than the use of any specific technology or material. Building subsystems must be integrated such that each subsystem remains separately accessible along with serving a dual purpose. For example, a hollow tube structural column may serve as an air duct, or a shaped floor deck structural member may function as a light coffer. An analysis

of needs, accessibility, available resources and methods for joining different building systems provides a substantial range of options. In developing a sequence for selecting specific approaches the focus should be the performance requirements for the building during its lifetime (Ezra 1989, Fein 1972).

This section deals with the concept of systems integration and possible means and methods to achieve the same. The modeling techniques included in this section are from the book entitled The Building Systems Integration Handbook by Richard Rush (Rush 1986). Rush begins by dividing the home into four components, together referred to as the "four function model". This constitutes the four distinct building systems that comprise the design and functioning of a built structure (Rush 1986).

1. Structure – That part of a built space that transfers loads to the foundation and supports the envelope of the building to provide integrity.
2. Envelope – That part of the structure, which protects the user from the natural elements and the interior from damage.
3. Mechanical – All building systems, which make it possible for the user to temper the indoor environment of the built structure. This includes building systems such as HVAC, plumbing, electrical, fire protection, and communication.
4. Interior – Those parts of the building visible when inside the building. This may include exposed ducts or electrical raceways, carpeting etc.

The four-function model may be viewed as a simplified format to facilitate understanding, but for the purpose of research this model will be expanded to include each building system separately. The separate building systems will be discussed in greater detail later in the chapter.

3.2.1 Building Systems Integration Handbook (BSIH) matrix

The Building Systems Integration Handbook (BSIH) matrix is a tool used to determine the extent of integrative design required for any two or more building systems. Although Rush formulates the BSIH matrix for the four-function model only, it is possible to extend this format to include individual building systems. The author will follow the academic model for the BSIH matrix with modifications specific for the analysis. The matrix compares any two or more building systems for the levels of integration they have among each other. The levels of integration specified here are (Rush 1986):

1. Remote – when two systems do not touch physically.
2. Touching – when two systems are in contact although there is no permanent connection.
3. Connected – when two systems are permanently attached by some means.
4. Meshed – when two systems are interrelated and occupy the same space. This is a more restrictive relationship than the connected relationship.
5. Unified – when two systems are no longer apart but use the same material or method to perform different functions

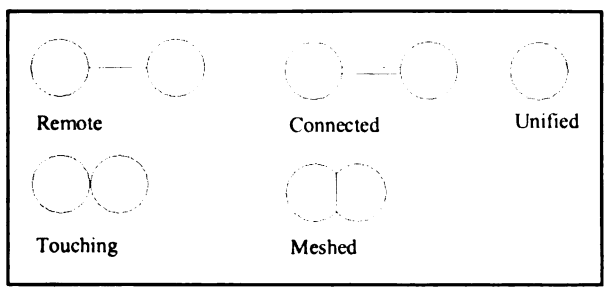

Figure 3.1: Levels of integration (Rush 1986)

Figure 3.1 is a representation of the BSIH matrix; the shaded sections represent the types of integration existing between two systems. The model allows the designer to ascertain the extent of the relationship between the components of the four-function model. The author proposes the extension of this matrix to take into account relationships between distinct building systems, which are at present combined within the mechanical aspect of the four-function model. The determination of specific building systems to be studied will be included in further chapters.

	Remote	Touching	Connected	Meshed	Unified
Str + Env					
Str + Mec					
Str + Int					
Env + Mec					
Env + Int					
Mec + Int					

Figure 3.2: BSIH matrix (Rush 1986)

3.2.2 Performance parameters

The next step is to define the performance requirements from a design; these are termed as the performance parameters and refer to the expectations from a "Whole House" design. Each strategy finally decided upon must accomplish some or all of the performance requirements or parameters. Rush defines the following performance

parameters: spatial, thermal, air quality, acoustics, visual and building integrity (Rush 1986). Performance parameters may be defined as per individual requirements and may vary. For the purpose of this research, specific parameters will be determined in later chapters.

3.2.3 Systems decision models

After having determined performance parameters, the intent is to systematically formulate all physical decisions that need to be taken when integrating two or more building systems taking into account the performance requirements from the building systems. For example Systems decisions for HVAC systems relating to spatial performance may be regarding the size, volume, form, configuration, expansion capability, material and ornament for service generators such detailed decision parameters may be defined relating to each performance criterion. These decision parameters may be depicted in the form of a flow chart as in Figure 3.1. This chart shall be referred to as the "systems decision model". The above-mentioned models allow the designer, in this case the author, to tabulate the requirements of the identified building systems integration (Rush 1986). An example is provided in Figure 3.3.

3.3 Mechanical Electrical Plumbing (MEP) Integration

This section will focus on the prevailing method for integrating mechanical, electrical and plumbing operations within one system. Since separate qualified individuals deal with all these building systems, the integration is for the most part cosmetic and not integrative. The integration process is linear and is largely concerned

with solving individual problems relating to each building system rather than integrative design. Attempts have been made to address this shortcoming and one such attempt will be discussed in this section. The MEP integration model developed as a computer modeling technique by Korman (Korman 2001) aims at rendering the integration process much more cyclic and integrative design oriented.

3.3.1 Sequential Comparison Overlay Process (SCOP)

Current practice for MEP coordination is executed after the preliminary design and placement of essential building systems and sizing has been completed. At this stage specific routing of each building system has not been specified. Later each specialty design consultant will complete the design, including checking for clearances, architectural requirements and any other constraints.

Drafting software is employed and coordination is affected though manual overlay of the architectural drawings and the drawings for the specific building systems. The overlay process generally used is refereed to as Sequential Comparison Overlay Process (SCOP). This is an iterative process of sequentially overlaying multiple drawings of various trades. The logical sequence followed for the overlay process is as follows; (1) architectural drawings (2) HVAC dry (3) HVAC wet (4) plumbing (5) fire protection (6) and electrical. This is in essence a linear process and problems identified at the time of coordination are solved through a meeting of all design disciplines involved in the design of the building (Korman 2001).

3.3.2 The Korman Model

In the age of information technology the use of integrative software renders the process of integrating building systems much more cyclic than linear, and the iterative steps can be completed without impediment. At the present time most design drawings are completed on CAD software, and as such, integration is a real prospect. An academic computer based model has been developed at Stanford University which allows the decision making to be cyclic rather than linear (Korman 2001). For the purpose of this research, the procedure for the development of the model, rather than the model itself, will be important; and as such the viability of the model will not be discussed.

The researcher identified three main criteria to be considered for effective MEP coordination and integration was affected leading from here: operations and maintenance, design criterion and intent and finally construction issues. This defines the input required for the integration. The input output model has been defined as in Figure 3.2.

The input for the model starts with what the author refers to as "product models". These were three-dimensional drawings produced by all contractors for their own specific building system. These product models were prepared in the 3D CAD software. The final "geometric model" integrates all the product models to form the complete image of the built structure. Along with the physical information some non-physical information related to the project, such as cost, material type, equipment sizes, installation time and installation sequence, access space, and frequency were also required. The database for the coordination contained some of this information but user specific databases may also be developed.

Control for the coordination model was achieved through an integrated knowledge database. This database included information regarding system function and performance, insulation and clearance, fabrication, installation, start-up, testing, accessibility and safety. The tool abstracts the data from the geometric model and this data serves as a comparison base in determining the type of interferences and further recommendations to resolve such interferences.

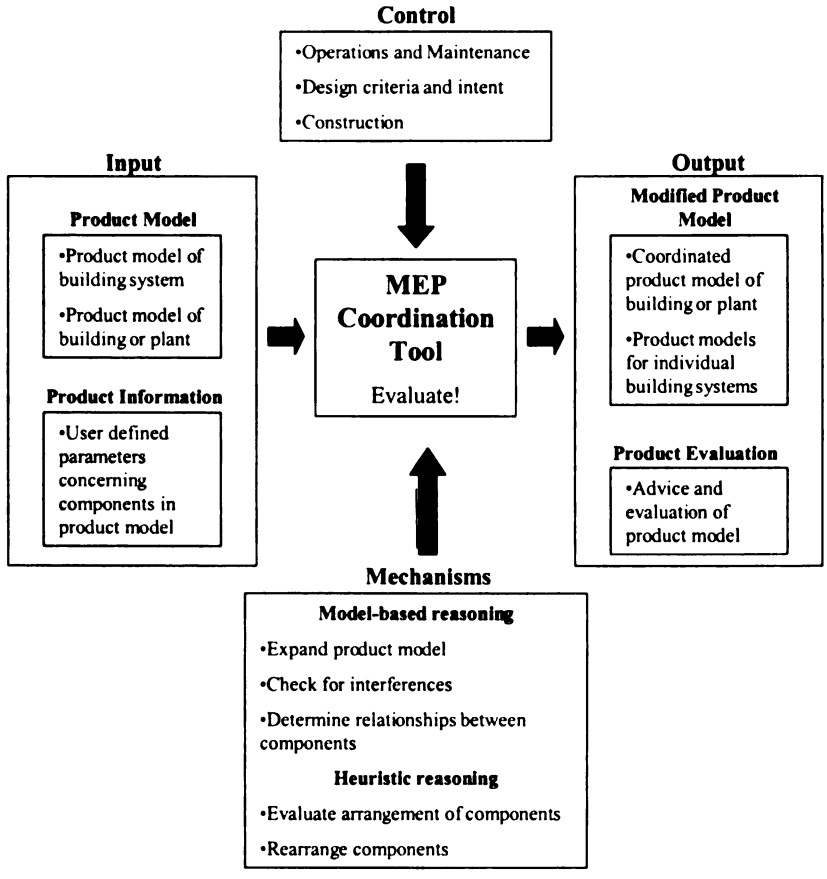

Figure 3.3: Systems architecture for MEP integration (Korman 2001)

The output of the MEP coordination model is a coordinated product model. The applicability of this tool is evident in its capability to eliminate any kind of meeting

requirements for all specialty contractors, thus saving the design team substantial time, which is reflected in cost savings. The software tool is not viable for commercial use as of now and is limited in its capabilities to interface several kinds of drafting software. The author of the research has conducted two case studies to demonstrate the practical use of the software (Korman 2001).

3.4 Building systems

This section will review all identified building systems prevalent within a home design. The review will be based on design techniques, material, methods and fuel alternatives identified that might aid in improving the performance of the building system. Integrative design and products, which integrate more than one usage, will also be discussed.

3.4.1 Heating Ventilation and Air Conditioning (HVAC)

The HVAC systems is that part of the building system that tempers the environment and renders it comfortable for the user. It also helps in maintaining the indoor air quality of the home, which is imperative for the health of the occupants. The following sections will focus on the design techniques, distribution methods, and control systems that can be employed to better the performance of the system.

3.4.1.1 HVAC design techniques

- High efficiency gas furnace – The core aspect that renders these furnaces more efficient than traditional designs is that they are able to condense the water vapor

from the exhaust gases and capture the heat of condensation. Condensing furnaces are expensive because they require corrosion resistant materials, but they can have efficiencies as high as 97% (PATH 1999). High efficiency furnaces receive the Energy star for appliances and are an excellent option. Although initial costs might be comparatively higher, these are offset by overall savings.

- Heat recovery ventilator (HRV) - Also referred to as an air-to-air heat exchanger, it is a ventilation system that consists of two separate air-handling systems: one that collects and exhausts stale indoor air and the other draws in fresh outdoor air and distributes it throughout the home. At the core of an HRV is a heat transfer module. Both the exhaust and fresh air streams pass through this module, and the heat from the exhaust air is used to preheat the fresh air stream. Only the heat is transferred; the two air streams remain physically separate (Energy 2003).
- Whole House ventilators – Since hot air rises the intention is to release the heat trapped in the roof hollow or attic area. This is essentially a large fan installed in the attic or stairwell which pulls hot air from the living areas into the attic and then releases it to the atmosphere through ventilators, due to decrease in pressure fresh air is pulled in through the windows. This is a fairly simple technique to reduce cooling loads in milder climates (ZEH 2004).
- Radiant barriers – Light reflective materials are installed on the roof to reflect excess heat so that the house is not heated through absorbing ambient heat. Several kinds of materials might be used; foil, paint coatings and chips. This again is a fairly simple technique, which reduces cooling loads (ZEH 2004).

3.4.1.2 HVAC distribution systems

Measures must be taken to improve the performance of existing distribution systems in order to realize the maximum efficiency of the energy used to run the system. New and improved performance systems are available today to replace traditional distribution systems, which may not be as effective. The following section discusses some of these options.

- Older air distribution systems must be rehabilitated by sealing the supply duct to minimize the loss of conditioned air. According to a HUD study, leaky ductwork increases energy by 30%. This may also cause air pressure problems which results in drafts and uneven room temperature. Water distribution systems may be rehabilitated by adding foam-based insulation to seal the return pipes. The author feels it is important to mention the possibility of rehabilitation of existing HVAC systems, we will not go into greater detail on this issue although since the present research does not look into rehabilitation (PATH 1999).
- Mini duct HVAC system – This is comprised of small diameter flexible ductwork that can be run through drywall along studs and joists without having to cut through them. Equipment costs may be higher for this system although system performance and ease of installation and replaceability are aspects to be considered (PATH 1999).
- Radiant heating and cooling panels – These systems run hot or cold water through piping embedded in the floor or a wall panel. These piping systems can be easily embedded into the structural floor at the time of manufacture without the need for installation on site. These systems are presently not very cost effective, since they are

not popularly used in building design and thus are expensive to design and manufacture (Ezra 1989, ZEH 2004).

3.4.1.3 HVAC zoning controls

In the present day scenario, zoning controls become more and more pertinent in terms of increasing the efficiency of the HVAC system. HVAC "smart" zoning technology consists of dampers and electronic controls that attach to standard central air systems. By providing controlled damping at the base of each branch duct, multiple zones can save energy and increase occupant comfort and convenience. Quite simply temperature and flow of air can be controlled over a multitude of spaces as per usage required and so all piping will not be conducting the same amount of energy whether or not it is needed (PATH URL 2004e).

This can be considered as a step towards systems integration, which allows for more flexibility in design and installation. The flexibility, which is now built into the system allows for energy efficiency in usage.

3.4.1.4 HVAC fuels

Solar energy is fast becoming one of the most attractive sources of energy for all building systems, primarily because it is an abundant natural resource without many adverse effects. Passive systems use building orientation and construction materials to enhance natural processes to collect, store, and distribute heat, while active systems employ pumps and/or fans. Photovoltaic (PV) systems convert solar energy directly to DC power, which is inverted to AC power for home use. Installation costs and product

costs are high and returns are a long way into the future, so this is yet not a viable alternative for lower income housing (Energy URL 2004b).

3.4.1.5 Indoor Air Quality

Indoor materials and appliances that release gases or particles into the air that are undesirable for human consumption are the primary cause of indoor air quality problems in homes. Inadequate ventilation is one of the primary problems, since the home then does not have enough outdoor air to dilute emissions from indoor sources and vent these out of the home. High temperature and humidity levels due to inadequate ventilation and faulty HVAC ducting can also increase concentrations of some pollutants.

There are many sources of indoor air pollution in any home which include combustion sources such as oil, gas, kerosene, coal, wood, and tobacco products. Materials and furnishings used within the home such as asbestos-containing insulation, wet or damp carpet, and cabinetry or furniture made of certain pressed wood products. Certain household cleaning products and outdoor sources such as radon, pesticides, and outdoor air pollution also pose a problem.

Energy Star provides users with instructions regarding remodeling of homes with special consideration for indoor air quality. This includes procedures on how to handle recognized indoor pollutants such as lead, moisture, inadequate ventilation, asbestos, mold, volatile organic compounds, paints and combustion materials (EPA URL 2005).

3.4.2 Plumbing / Sewer

The plumbing and the sewer system serve three primary functions, first the distribution of hot and cold water, second the collection and disposal of wastewater and black water or soil waste, and finally collections and disposal of storm water. Piping for these systems may use any or a combination of the following processes: gravity drained waste systems; as the name suggests, the piping uses the gravitational pull and is sloped downward towards the city mains. Pumped waste systems may be used where the level of the piping is below the level of the city lines such that it needs to be pumped up. Pressure driven systems use the difference in pressure to pull water through hot and cold water pipes. The possibility of the integration of plumbing stacks or cores with other utility systems, along with simplification of the design process, is also a prime concern. In the present industry environment, the following approaches lend themselves to better performance of plumbing systems.

3.4.2.3 Distribution design

- Aluminum-Plastic Composite Water Piping – The piping is a multipurpose pressure piping that can be used for hot and cold-water distribution and is suited to both indoor floor heating or outer snowmelt systems. The material is lightweight, flexible, corrosion resistance and the strength is enhanced since the plastic core is laminated on both interior and exterior edges by an aluminum piping. The product can operate at pressures ranging from 90 to 300 pounds per square inch (psi) and can withstand operating temperatures of up to 210 degrees Fahrenheit. The flexibility of the pipe

lends itself to ease in design. It can be installed within floors and ceilings and can also be snaked through walls (PATH URL 2004h).

- Drain water heat recovery – A heat recovery device is attached to existing waste water drains to capture the heat from the waste water, which is then used to preheat the hot water for usage around the home. Storage-type units have a tank containing a reservoir of clean water, drain water flows through a spiral tube at the bottom of the heat storage tank, and water in the tank warms and rises to the top. Water heater intake water is preheated by circulation through a coil in the top of the tank. The system is designed so it does not lose stored heat to cold wastewater. Non-storage units have a copper heat exchanger that replaces a vertical section of a main waste drain such that the warm water flows down the waste drain. Incoming cold supply water flows through a spiral copper tube wrapped around the copper section of the waste drain where heat is picked up by the cold supply water and is sent to the cold side of the fixtures (i.e. shower) or to the water heater. Some non-storage units exchange heat between the drainpipe and the incoming cold water supply line by a horizontal heat exchange device that thermally connects the drainpipe and the cold water supply tube. Initial installation costs are not very high and thus this is a recommended method to achieve better energy performance for a home (PATH URL 2004l).

3.4.2.4 Water conservation

- Rainwater harvesting – This is the process of forming catchments for the rainwater logged on roofs and other surfaces so that instead of allowing runoff the water may be

channeled toward a common pool and used for non-potable water requirements or potable uses after treatment. If followed, this approach can be substantially beneficial in reducing the water requirements of a community. The system is constituted of a catchment area which is primarily the roof, a rain water conveyance system including gutters and leaders, holding areas that can be any kind of storage device such as cisterns) a roof-wash system (usually the first 10 -20 gallons of rain are diverted from the cistern, a delivery system which includes pumps, and finally a treatment system which is constituted of filters and/or purifiers. Systems can be custom designed or retrofitted as per the requirements. Figure 3.3 is a pictorial representation of the system requirements.

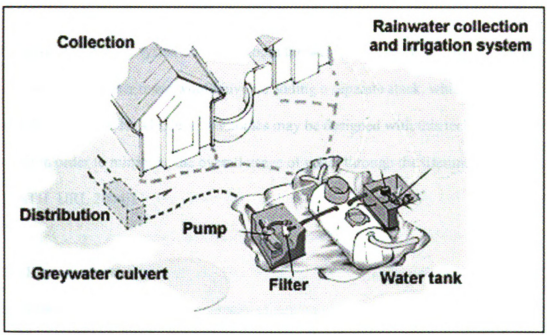

Figure 3.4: Rainwater harvesting system requirements (Toolbase 2004)

Installation costs vary tremendously based on the requirements of the user and the quality of water supplied in the area. It is important to stress at this point the need to

design with permeable surfaces on the ground so that it is possible to harvest underground water and replenish it through rainwater percolation. Tarred or mettled surfaces must be avoided and paved surfaces should be encouraged (PATH URL 2004k).

- Greywater reuse - This process extends itself from the rainwater harvesting procedure. Building water refuse through plumbing systems is of two kinds; wastewater and black water or soil waste. Wastewater is the water from baths and sinks; the intent is to be able to reuse this water for non-potable uses such as irrigation and recycling through the wastewater stack. A Greywater reuse system generally consists of a three-way diverter valve, a treatment assembly such as a sand filter, a holding tank, a bilge pump, and an irrigation or leaching system. Since most traditional plumbing systems combine both the wastewater and black water stacks including Greywater reuse would involve adding a separate stack, which may lead to space constraints. Newly designed homes may be designed with this technique in mind in order to minimize the overall usage of water through the lifetime of the home (PATH URL 2004j).

3.4.3 Electrical systems

Electrical systems are the mainstay of any built structure and possibly the largest contributor to energy usage and costs over the lifetime of the home. It will be beyond the scope of this research to discuss the details of an electrical system, therefore in the following section the author restricts the documentation to technology lending itself to integrative design.

3.4.3.3 Distribution design

- Electrical raceways – Running wires through wall cavities is a cumbersome process and at some level compromises the structural integrity of the home. Electrical raceways make it possible to run the wiring of a home independent of the built structure, thus making it easier to install and access the wiring in the event of a breakdown. These raceways are PVC baseboards, which come in white and laminate finish to blend into the décor, and these can be mounted easily on drywalls. There are several advantages to this product; it is easy to install, no special tools or expertise are required, and is relatively inexpensive. A combination of electrical and communication wiring can also be run through the same raceways (PATH URL 2004d).
- Power line networking – An ordinary AC electrical outlet can be converted into a network port, without drilling through walls. A device is plugged into an electrical outlet referred to as the "node". No software is required to complete the connection, although the home must be wired for a broadband connection. One device is connected directly into the cable/DSL modem or the router though which the broadband service comes, and the power cord is plugged into any AC outlet. Next, an identical device is connected to separate power outlet, which is connected to the PC (PLN 2005).

3.4.3.4 Alternative fuel

- Solar electricity – Solar energy or energy derived from sunlight can be utilized within the home in two forms, passive energy and active energy. Passive solar energy is in

the form of heat absorbed by the building envelope during the daytime, along with the use of natural lighting rather than artificial lighting. The heat retained within the building envelope is critical, in the sense that it reduces energy requirements during the nighttime. It is essential to develop design strategies and use materials that are able to retain this heat for an extended period of time. Active solar energy is trapped through the use of photo voltaic cells, which convert the direct heat gain from the sun into usable AC to run building systems within the home (Energy URL 2004b).

3.4.4 Fire protection

Fire protection systems begin with appropriate material selection and design decisions such as fire escapes. An important component of a fire protection system is the sprinkler layout and placement of fire extinguishers. The purpose of the combination of these approaches is to allow the users enough lead-time to safely evacuate the premises. Fire protection systems fall into four categories: wet systems, where water in the pipes is always under pressure and the reduction in pressure due to hot air causes the sprinkler heads to burst; dry systems where the pipes contain compressed air or nitrogen instead of water; pre-action systems, which are similar to dry systems, except that valves let water into the pipes before the sprinkler system turns on; and finally, deluge systems, where the sprinklers are always open and go off at once (Korman 2001). The fire protection system is not considered for the purpose of this thesis, although the author believes that it is important to mention the presence of the system.

3.4.5 Communication / Structured Wiring systems

All communication systems typically installed within a home will be discussed in this section. These include wiring for telephone, data and video communication. Structured wiring systems are used to integrate these communication uses. A structured wire is a low-voltage, high-performance wire that is capable of broadband distribution of telephone and data, it is composed of four twisted pairs of high capacity wires enclosed in an insulated cover (Centex 2004). The most commonly used variety is the Category 5 wiring for voice and data transfer and RG-6 cabling for video signals. Wires run from a central location directly to each wall plate or outlet location. Such a layout can result in substantial wiring for separate runs for each outlet. Therefore, the installation requires advance planning to provide locations that maximize user flexibility while minimizing the amount of wire runs (PATH URL 2004c). These also provide low voltage sensing and communications functions that can become the basis for more extensive automation systems. Initial costs and installation costs may be higher than traditional communication wiring.

3.4.6 Home Automation systems

Home automation as an idea came into existence around the mid 1980's and since then many manufacturers have been pursuing it. The intent is to automate building systems through the use of computer technology, such that every appliance and building system is controlled through a single personal computer. Home automation is no longer a vision of the future, it is becoming an expensive, although popular, reality (PATH URL 2004i).

There are three types of home automation controls: individual control devices, distributed-control systems, and centrally controlled systems.

- Individual control devices control a single appliance or function such as programmable thermostats, occupancy detectors, photosensitive lighting controls, as well as security sensors. These are commonly found in homes designed and built today.
- Distributed-control system uses standard power line wiring, telephone wire (4 pair), video wire (dual coaxial), radio frequency signals, and infrared signals. These systems allow appliances to communicate with each other over existing wiring after computer chips are added to their wiring systems. Structured wiring is used to enable such systems. These systems are outside the scope of this research and thus will be dealt with as future research areas.
- Centrally controlled systems route signals between a central computer and appliance controllers or environmental sensors. This allows the system to control the functioning of the entire building envelope. The idea of "smart homes" springs from this technology. For the purpose of this research we will not be discussing these in detail and will refer to them as future research areas.

These systems have built-in savings associated with them, such as automatic shut-off capabilities offsetting the wastage of energy. Occupancy sensors are an excellent addition to outdoor lighting for nighttime illumination. Although technology, installation and products costs are high and may increase the initial costs by a substantial amount, the cost of replacement of parts is lower, since these smart systems control surges and protect

the equipment. It is believed that individual control systems have a proven record for energy savings over the lifetime of the home.

3.5 Structural and architectural integration

This section will focus on tools and techniques, which integrate structural and architectural requirements. This includes hybrid design techniques and alternative framing materials. Hybrid design techniques, such as tilt up roofs for manufactured and modular home, which allow for ease in transportation will be discussed. The intent is to tabulate tools and techniques, which offer alternatives to traditional systems; these are hybrid systems, which use technology from both site-built housing as well as factory produced components.

3.5.1 Alternative framing materials

The use of lumber in the construction of homes in the United States has been extensive, and it is estimated that residential construction and remodeling accounts for two-thirds of the lumber purchased in the country today (HUD 1994). The cost of lumber has been steadily increasing, and it is becoming increasingly uneconomical to use this material. The environmental costs of the excessive use of lumber must also not be ignored. The U.S. uses twice as much wood as other industrial nations, according to the Wood Reduction Clearinghouse. It takes about one-and-a-half acres to grow the dimensional lumber for a typical American home not including another 10,000 sq. ft. of panel products, such as plywood and oriented strand board (OSB). Wood use is projected

to double over the next few decades. It is anticipated that the existing forests will not be able to meet the increasing demands (Energy URL 2004a).

This section demonstrates the practical and economic feasibility of using alternatives to traditional timber frame construction. The alternatives considered for the purpose of this study are as follows (HUD 1994):

- Foam-core structural sandwich panels - A foam-core structural sandwich panel, hereafter referred to as a foam-core panel, consists of a foam material sandwiched between two facings. The foam material is usually made from molded-bead expanded polystyrene (EPS), extruded polystyrene (XPS), urethane, or polyisocyanurate. The facing materials provide the panel's structural strength. Facing materials commonly include oriented strand board (OSB), wafer board, and plywood. The material has better thermal resistance in both wall and roof framing than timber framing. These are more durable, and the materials allows for custom forms to be built. Larger roof spans are possible, and since these are prefabricated there are lower labor requirements on site. The large size of the units does make it difficult to maneuver on site, heavy machinery such as cranes are required, and there is a higher initial cost associated with the material.
- Light-gauge steel framing - Steel framing has been used for many years as partition studs in both commercial and residential construction. With higher lumber prices, heavier-gauge members are becoming more attractive for use as bearing wall studs and floor and roof framing. Members are manufactured by a cold-forming process, in which various thicknesses of sheet steel are put through a series of roll forming dies that form the sheets into desired widths, lengths, thicknesses, and shapes. Steel can be

used as individual framing members in much the same way as wood. Since standardization becomes a prerequisite, the overall production costs may be reduced over a period of time. This material also requires no cutouts for running electrical wiring since the chases are prefabricated. Compared with timber framing, the unit cost of steel framing is not much higher (around 7% more than timber framing) therefore the material and equipment costs on site are reduced. A disadvantage is that additional insulation must be provided, since steel has lower thermal performance than timber. Also specialized labor may be required to erect the building since the material is relatively difficult to handle, which also reduces overall productivity on site.

- Welded-wire sandwich panels - Welded-wire sandwich panels are composed of a polystyrene or polyurethane insulation core surrounded by a welded-wire space frame. A layer of shotcrete is sprayed or trowel-applied over the wire mesh. The strength of the system and rigidity is provided by diagonal truss wires welded to the wire mesh on each side. The panels can be used as floors, load-bearing exterior or interior walls, partitions, or roofs. There is ease of running wiring since, no cutouts are required and the structural strength is much higher. The disadvantages are that accuracy may not be achieved which leads to double work on site. Both plumbing and electrical operations must be carried out in two stages, first to run the wiring and the piping through the wire mesh, and then to pull the wiring and make the connections after the shotcrete is completed. Welded-wire sandwich roof panels, while easy to erect, are difficult to support. The panels alone cannot support the wet weight of the shotcrete. Consequently, the required shoring is an extra step that takes a long time to

complete and delays the schedule. The roof requires a seven-day period for curing and the costs are substantially higher due to cost of material and additional shoring costs.

- Concrete systems – Fiber reinforced cellular concrete (FRCC) panels are suited for home energy conservation, since thermal performance is enhanced due to the cellular composition of the material. Insulated concrete forms (ICF) are used as floor systems largely because they have required strength with shallower depths and they have better thermal and acoustic performance (O'Brien et al 2005).

3.5.2 Tilt-up Roofs for Manufactured and Modular Homes

In conventional manufactured homes the roof pitches are much lower to facilitate transportation through overpasses and bridges, thus, a height restriction is imposed on these homes. Hinged roofs for modular homes allow the use of larger pitch heights so that attic spaces may be usable. These houses are transported with the roofs collapsed and then brought up to their original heights once placed on site. The upper half of the top chord member laps and bolts to the side of the lower half. At the ridge the vertical truss member is similarly bolted to the lapped top chord member. The bolts act as hinges and enable the upper part of the top chord and the vertical portions to fold and rest for shipment on the bottom chord and diagonal members (Fleet 2004).

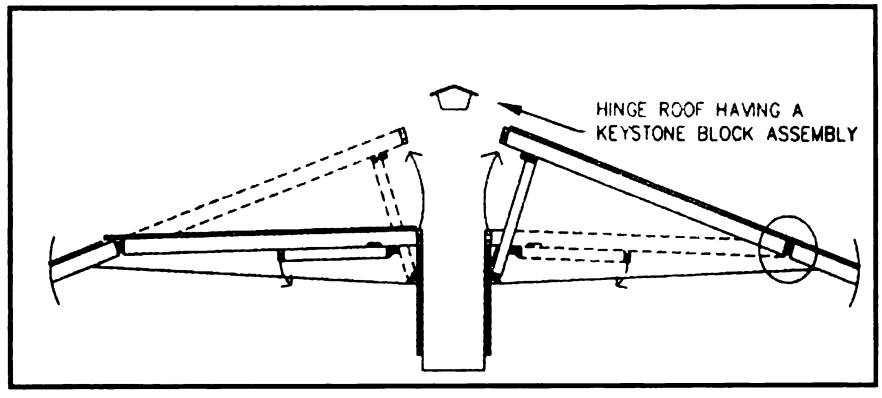

Figure 3.5: Hinged roof assembly (Fleet 2004)

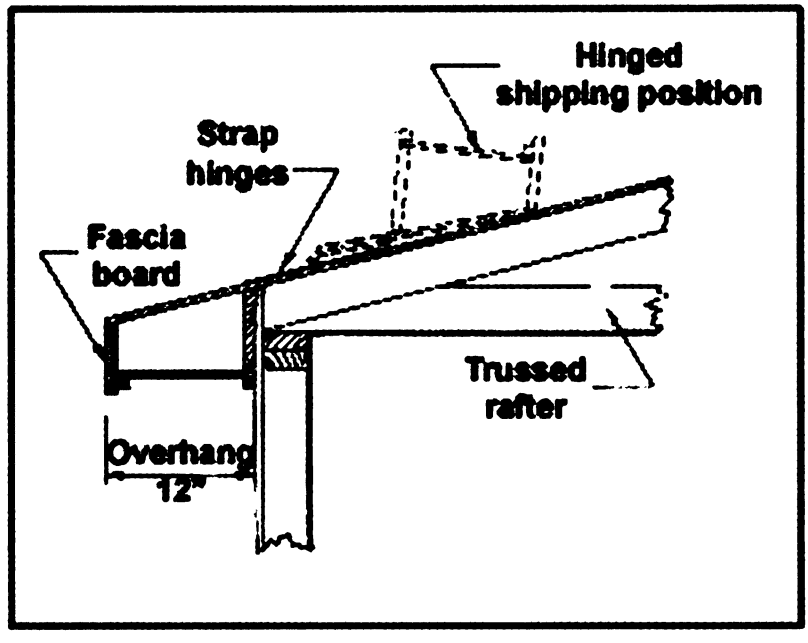

Figure 3.6: Eave overhang assembly (Reidelbach 1982)

The eave overhang is added in an effort to design housing closer to traditional stick built homes. The overhang is built as a component and attached to the eave of the roof during production. The typical overhang, which is 12 inches wide, is then folded back to rest on

the roof, where it is temporarily fastened for shipping. At the jobsite it is flipped down and nailed into position (Reidelbach 1982).

3.5.3 Hybrid modular/panelized housing

Factory panelization of some components offers a compromise between site building and full factory assembly. Garages are most economical to build as panels bolted together on site. For all but the largest modules, there is usually enough transporter area to fit framed panels either side-by-side or front-to back with the modular units. To prevent damaging vibrations, assemblers use various methods to temporarily affix the panels to the modular boxes. Often these are strapped on. Alternately, for large or oddly shaped pieces, temporary 2x12 joists and brackets are used to hold the units together.

In conventional modular, steep roofs are often designed to hinge up on site. However, these are often framed with 2x6's and 2x4's, limiting the amount of insulation between rafters. These roofs often require additional pieces and labor. Hybrid manufacturers sometimes find it more economical and energy efficient to truck roofs separately from the boxes, especially cathedral roofs or those framed with 2x12's for thicker insulation. Depending on the size and configuration, the roof is delivered in one or several units (PATH URL 2004b).

Hinging the floor to compress the shipping size of the unit addresses the issue of just "shipping air" in a box. In its folded position, the shell still has room for roof trusses and other components, reducing the number of transporters needed. Set by crane, the "roof" of the structure folds down to become a wall, the telescoping floor joists are expanded, and roof trusses are installed. The system can be detailed with standard infill

steel stud walls or to accommodate a SIP envelope. Since the units are delivered without installed roofs, they may be appropriate for multi-story housing, with a steel frame that can meet fire codes. The narrow shipping size is economical also for remote or hard-to-reach areas.

But the advantages of hybrid modular come more from scheduling than first cost. Because panels and boxes can be built while the site is prepared, the construction cycle can be half that of an entirely site-built house. Savings come in reduced construction loan interest, and land that generates income sooner. Availability of manufacturing facilities willing to carry out this process is lower today, and so cost saving may be offset by market dynamics.

3.6 Sustainable approaches to design

As consumers become more and more aware of the implications of energy costs over the lifetime of the structure and of the possible adverse environmental impacts of certain practices it is imperative that the industry address issues of sustainability as well. It is possible to reduce the liabilities of a built structure both to the owners as well as the society at large through conscientious design and streamlining of the process itself. This would reduce both one-time costs, as well as lifetime costs of the built structure; this is beneficial for the consumer, along with addressing environmental issues, which are fast becoming reasons for concern for all major societies in the world.

3.6.1 Passive solar design

The information for this section has been taken from Eicker (2003).

- Maximum use of daylight rather than artificial lighting is one of the primary strategies of passive solar design. This is achieved by providing openings for all spaces including the wet cores. Internal rooms without access to a peripheral wall can be lighted using regular skylights and solatube skylights.
- Sunlight also provides solar heat that can be captured within the home during the daytime to be slowly released during the night. This is achieved largely through the proper orientation of the design. Placing the larger portion of windows on the south side of the home increases comfort both in summer and winter along with reducing fuel consumption for heating and cooling the home.
- Use of overhangs on windows that are retraceable to maximize the use of sunlight in winters, and which can be put in place to protect the windows from direct sunlight during the summers while being able to light the space.

3.6.2 Active solar design

The information for this section has been taken from (Eicker 2003).

- Solar cell technology constitutes a thin film cell based on amorphous silicon, which are applied to both flexible metal substrates and coated glass. Encasing the photovoltaic cells usually 6 sqm in size forms standard modules. Along with glass panels a range of photovoltaic roof tiles are now available which are impermeable and easy to connect to the standard tiles. The solar cells covert direct current (DC) to usable alternating current (AC). The cells can be used to produce current for stand-alone appliances or can be connected to the local grid to provide power to the home and introduce any additional usable power into the local grid.

- Solar thermal water collectors follow the same concept of using photovoltaic cells to trap solar energy and convert it into usable power. These can be used to heat swimming pools or usable water supply for within the home.

3.6.3 Bio-Based materials / recycled content materials

Bio-based chemicals and materials are commercial or industrial products derived from biomass feedstock. Bio-based products include bio-chemicals, renewable plastics natural fibers, and natural structural material.

Products exist that contain recycled post-consumer paper by-product, gypsum, and recovered gypsum, wood waste, wood chips, and annually renewable agricultural fibers. These materials include hardboard made from waste wood, wallboard made from perlite, gypsum and recycled post consumer newsprint; 100% recycled newsprint fiberboard and fiberboard made from straw (Green 2004).

- Renewable plastics – plastics produced from biomass resources show great promise for replacing materials derived from petrochemicals. General categories include plant-based polymers, carbohydrate polymers (cellulose starch and chitin) and lignite.
- Natural fibers – New products based on natural fibers are being developed including insulation and geo-textiles for control applications. These fibers are being used to replace nonrenewable materials as fillers for many products.
- Natural Structural Materials – Many building products such as engineered lumber and structural panels made primarily from wood have been used traditionally. New composite structural materials are being made to incorporate biomass fibers as fillers with other organic material (e.g. Plastics).

- Fiber reinforced gypsum panels – Made from gypsum, perlite, and cellulose from recycled newsprint and telephone directories, for interior use on ceilings and walls. These can be nailed, screwed and stapled easily providing uniform strength and superior holding characteristics. The material also resists surface abrasion and impact damage. Taping is not required and the surface is fully scrubbable. It provides good sound and thermal insulation but is heaver than traditional wallboard and needs to be scored on both sides for cutting.
- Thermo-ply insulated sheathing – Made from several continuous piles of wood fiber, the material is rated for water resistance. It consists of white polyethylene coating on one side and aluminum radiant barrier on other. A thin roof and wall sheathing is installed for structural applications. The material is cheaper to install than plywood and is stronger than foam or fiberboard sheathing and is non-toxic.
- Pan TERRE panel – Made from equal amounts of mixed waste paper and agricultural fibers such as straw, rice hulls or peanut shells, the panel is finish coated with recycled Kraft board (or sent raw to manufacture cabinets and flooring). It has many applications including exterior sidewall sheathing, roof sheathing, false ceilings, and cabinetry. It is easy to handle, saw, glue and nail and can be finished with a variety of material such as wood veneers, paperboard or plastic laminates. It can also be manufactured using indigenous waste material.
- Meadowood wall and ceiling board – It is made from ryegrass straw which is an agricultural by-product. It can be used as an exposed decorative panel or faced with wood veneer for a desired interior finish. The material is also being made available as a core material for laminated trim and interior building panels.

- Wheat board - Wheat board is created from wheat chaff as a substitute for traditional wood fiberboard. Unlike wood fiberboard, it does not use formaldehyde.

3.6.4 Energy Star products

Energy Star appliances are certified for comparably lesser energy usage than traditional appliances over their lifetime, along with reduction of generated by products, which are detrimental to the environment. Some of the types of Energy Star appliances are discussed below (EPA URL 2004):

1. Clothes Washers - Compared to a model manufactured before 1994, an ENERGY STAR qualified clothes washers can save up to $110 per year on utility bills. Qualified clothes washers clean clothes using 50% less energy than standard washers and use 18-25 gallons of water per load, compared to the 40 gallons used by a standard machine. Qualified washers extract more water from clothes during the spin cycle; this reduces the drying time and saves energy and wear and tear on clothes.
2. Dishwashers - Qualified dishwashers can save more than $25 a year in energy costs. Qualified dishwashers use a minimum of 25% less energy than the federal minimum standard for energy consumption and an average of 44% less water than conventional models. Since they use less hot water compared to conventional models, an ENERGY STAR qualified dishwasher saves about $100 over its lifetime.
3. Refrigerators - Qualified models use high efficiency compressors, improved insulation, and more precise temperature and defrost mechanisms to improve energy efficiency. Qualified models use at least 15% less energy than required by current

federal standards, and 40% less energy than the conventional models sold in 2001. Many options are available for consumers to choose from.

4. Air-source Heat Pumps - Electric air-source heat pumps, often used in moderate climates, use the difference between outdoor air temperatures and indoor air temperatures to cool and heat the home. Qualified heat pumps have a higher seasonal efficiency rating (SEER) and heating seasonal performance factor (HSPF) than standard models, which makes them about 20% percent more efficient than standard new models and 20-50% more efficient than the products traditionally used.
5. Geothermal Heat Pumps - Geothermal heat pumps are similar to ordinary heat pumps, but use the ground instead of outside air to provide heating, air conditioning, and, in most cases, hot water. Because they use the earth's natural heat, they are among the most efficient and comfortable heating and cooling technologies currently available. Qualified geothermal heat pumps use about 40-60 % less energy than a standard heat pump and are quieter than conventional systems.
6. Televisions - If half of all the U.S. households replaced their regular TV with an ENERGY STAR model, the change would have the same effect as shutting down a power plant. Qualified models use about 25% less energy than standard units.
7. Compact Fluorescent Light Bulbs (CFLs) - If every household in the U.S. replaced one light bulb with an Energy Star qualified compact fluorescent light bulb (CFL), it would prevent enough pollution to equal removing one million cars from the roads. Qualified CFLs use 66% less energy than a standard incandescent bulb and last up to 10 times longer. Replacing a 100-watt incandescent with a 32-watt CFL can save you at least $30 in energy costs over the life of the bulb. Qualified CFLs operate at less

than 100F; they are also safer than typical halogen bulbs, which are frequently used in floor lamps or torchieres and burn at 1,000F. Due to their high heat output, halogens can cause burns and fires while CFLs are cool to the touch.

8. Residential Light Fixtures - By replacing the five most frequently used lights in the home with Energy Star qualified lighting, savings of about $60 each year can be achieved in energy costs. Energy Star fixtures last 10,000 - 20,000 hours which means, with regular use (i.e., 3.5 hours per day), the bulb will not need to be changed for at least seven years. Qualified fixtures distribute the light more efficiently and evenly than standard fixtures.
9. Computers - An Energy Star qualified computer uses 70% less electricity than computers without enabled power management features. If left inactive, ENERGY STAR qualified computers enter a low-power mode and use 15 watts or less. Spending a large portion of time in low-power mode not only saves energy, but helps equipment run cooler and last longer and can save enough electricity to light an entire home for more than 4 years.
10. Thermostat Type - Programmable thermostats that can be automatically set back to lower temperatures, based on ambient temperatures which are zoned such that individuals may determine their own comfort space without heating/cooling the entire home.
11. Heat Recovery Ventilator - A heat recovery ventilator (also called an air-to-air heat exchanger) is a ventilation system that consists of two separate air-handling systems—one collects and exhausts stale indoor air and the other draws in fresh outdoor air and distributes it throughout the home.

12. Windows, Doors, & Skylights

a. Improved frame materials - Window frames have the greatest impact on the insulating capacity of the window. In Regions with cold winters qualified windows use wood, wood composites, vinyl, and fiberglass for frames. In regions with a mild cold season or none at all, windows with aluminum frames can be energy efficient. Thermally broken aluminum frames are generally more efficient than their solid aluminum counterparts.

b. Multiple glazing (Multi-pane) - Multiple panes improve the energy efficiency of windows, but adding other advanced technologies is necessary to achieve the greatest efficiency.

c. Glass coatings - A low-emittance (or "Low-E") glass coating is a microscopically thin film applied to the glass. This coating keeps heat inside in winter and outside in summer and must be chosen based on the climate of the parent site. High solar gain Low-E coatings allow as much heat from the sun to enter the house as clear glass. Windows with high solar gain Low-E coatings generally have solar heat gain coefficients between 0.56 and 0.75. Moderate solar gain Low-E coatings screen a portion of the sun's heat, keeping the home cooler in summer but admitting a good amount of solar heat in winter. Windows with moderate solar gain Low-E generally have solar heat gain coefficients between 0.41 and 0.55. low solar gain Low-E coatings screen the most heat from the sun. By blocking ultraviolet radiation, these coatings also reduce fading of furniture, floor coverings, artwork, and window treatments. Windows with low solar gain Low-E generally have solar heat gain coefficients between 0.20 and 0.40.

d. Gas fill - Some energy efficient windows have Argon, Krypton, or other gases between the panes. These odorless, colorless, non-toxic gases provide better insulation and a lower U-Factor. Many windows qualify for ENERGY STAR using only air. Windows with spacing of at least 1/2 inch for air or Argon fill and at least 3/4 inch for Krypton perform best.

e. Warm edge spacers - A spacer keeps a window's glazing layers the right distance apart. In the past, spacers were made of aluminum. In cold climates, aluminum can cause significant heat loss, leading to condensation on the window. Today's warm edge spacers--made of steel, foam, fiberglass, or vinyl--lower the U-Factor and prevent condensation.

f. Improved weather stripping - Weather stripping has also improved over the last 20 years. More durable, better performing plastic weather stripping is used in most ENERGY STAR qualified windows.

Many more of such appliances are now easy to buy and install within existing homes and are reasonably popular for many larger commercial chains to stock them. It was the author's intent to tabulate some of the primary appliances but many more are now in existence.

3.7 Summary

This chapter begins with reviewing techniques that can be employed in order to determine the nature of and the extent of, the integration required between any two or more building systems. Next the products and tools specific to each building system present within a home have been discussed. This has been referred to as Mechanical

Electrical and Plumbing integration and as the name suggest the section also looks into tools and techniques, which offer such solutions. In determining the products to be considered the author has taken into account both integrative technique as well as those, which render the building more sustainable. The energy efficiency of the home has been considered as a supplementary performance criterion for the purpose of this thesis.

Structural and architectural integration techniques are discussed next. After the building systems such as the utilities are designed to ensure that they do not interfere with each other, it is important to consider their integration with the structural envelope of the home. Here we discuss alternative framing techniques, which reduce the use of lumber as well being bale, to integrate utilities without compromising the structural integrity of the envelope. Hybridization of factory built housing is a significant step towards integrative design. Sustainable approaches to design include products that are certified by Energy Star as being energy efficient or products that use alternative sources of energy. Bio-based materials of renewable content construction materials are also discussed.

Chapter 4 – Proposed "Whole House" Performance Criteria Framework

4.1 Overview

This chapter includes a detailed description of the "Whole House" performance criteria development process, based on the building systems integration. The integration techniques used are based on the book Building Systems Integration Handbook, by Richard D. Rush and endorsed by the American Institute of Architects (AIA) (Rush 1986).

As discussed in Chapter 3, the building system integration techniques begin with defining the four- function model, which refers to the four basic building components. This forms the basis for all modeling. It is the author's belief that for a complete understanding of the building systems interactions, it is important to expand the four-function model to include individual building systems. The next step is to define the performance parameters, which refer to the expectations from a "Whole House" design. The performance parameters will be based on research and will be restricted to issues relating to systems integration. Sustainability has also been included as a supplementary parameter, since it is one of the underlying expectations for a "Whole House" design. It is the author's opinion that sustainable design is intrinsic to the "Whole-House" approach and must be addressed.

In order to determine strategies for the design of a "Whole House" based on the performance parameters defined earlier, it is important to understand the levels of integration among building systems. The building systems referred to here have already

been defined. The levels of integration are defined next; these will assist the researcher in understanding the types of integration that exist among building systems. Further, it will assist the researcher in determining strategies for effectively using the synergies, which may exist among these building systems.

Next, it important to determine the combinations of building systems for which detailed modeling will be conducted. Since there are eight building systems in total, the systems combinations can start from 2-systems, all the way to 8-systems all together. Given the scope of the thesis, it is adequate to complete detailed modeling on 2-systems interactions, e.g. Structure and HVAC, and 3-systems interactions, e.g. Structure, HVAC and Electrical.

The BSIH models are developed for both the 2-system and 3-system interactions. In addition the systems decision models are developed for the 3-system interactions only, since it was determined that systems decision models for 2-systems interactions were redundant and repetitive, and did not provide sufficient evidence to determine relevant strategies. Detailed description of the modeling will be provided in the relevant sections of the chapter.

The conclusions generated through this modeling form the basis for the development of the sample "Whole House" criterion. The sample "Whole House" criterion will be discussed in the next chapter with a brief discussion of the developmental process that will focus on the information generated through the modeling conducted. It is the author's intent to put forth a framework for the development of a criterion. Efforts were made to assure that the proposed framework is flexible enough to

accommodate individual requirements, while providing theoretical substantiation for the contents of the criterion.

4.2 Levels of integration

The first step is to understand the four-function model. The home functions are divided into four primary parts: structure, envelope, mechanical and interior; together these are referred to as the "four-function" model. These four functions are tested for their level of integration. As described in Chapter 3 (section 3.2.1) there are five levels of integration; remote, touching, connected, meshed and unified.

4.3 Modeling techniques

The modeling was conducted as per the techniques provided in Chapter 3 (section 3.2.1 and 3.2.3). Although the testing for levels of integration can be carried out for any number of combinations, the focus was placed on the 2-system combinations, such as structural and mechanical or structural and envelope and 3-systems combinations, such as structural, mechanical and envelope. The purpose of the modeling was to formalize the information required for the generation of the sample "Whole House" performance criterion.

4.4 Identification of building systems

The first step to begin modeling for this thesis is to determine and define the building systems, which must be integrated in the design of a home. The following

building systems have been determined for the purpose of this thesis. Abbreviations have been indicated for each building system and these will be utilized during modeling:

- Structure (Str) - That part of the building elements that provides stability to the home and allow it to stand.
- Envelope (Env) - That part of the building elements that protects the occupants from climate and other natural forces.
- Heating Ventilation and Cooling (HVAC) - The building system that tempers the living environment for comfort.
- Plumbing (Plum) - The building system that provides water supply to all outlets.
- Electrical (Elec) - The building system that provides electrical supply to run all home appliances and support systems.
- Communication (Comm) - The building system that provides communication supply such a phone, cable and Internet.
- Interior type A (Int A) - Those interior systems that are visible from the inside of the home and are in some manner connected to the structure or the envelope. This includes partition walls that do not serve any structural purpose, exposed ducts, electrical raceways, heating and cooling vents, lighting fixtures etc.
- Interior type B (Int B) - Those interior systems that are visible from the inside of the home and are movable such as furniture, movable storage etc.

4.5 Determination of performance parameters

This section deals with determining and defining the performance parameters. As mentioned earlier, the performance parameters refer to the characteristics that the design

of a home must achieve in order for it to be deemed a "Whole House" design. The parameters determined for the purpose of this thesis are; spatial flexibility, thermal performance, structural integrity, ease of construction, ease of maintenance and includes a supplementary parameter which is sustainable design. These parameters are primarily based on past and ongoing research and researchers' understanding (PATH 2001, PATH 2003, PATH 2004, O'Brien et al 2005, Syal, Hastak 2004, Sabharwal 2004, Garcia 2005)

4.5.1 Spatial flexibility

This parameter deals with the issue of flexibility of usage of space and adaptability of the structure over time, based on consumer choice and requirements. These are some of the primary expectations from a "Whole House" design. This can be accomplished through open space planning and use of furniture or temporary storage to define spaces rather than partition walls. The floor plan can be designed on a grid such that sliding panels may be attached or removed as per the requirements. Utility services could be laid out under the sub floor or within roof paneling such that wall panels are not restricted by utility distribution. Finally utility distribution should be detachable such that it is possible to mount on a different panel as the requirements for space change.

4.5.2 Thermal performance

Thermal performance, deals primarily with the issue of human comfort. Secondly, it deals with addressing possibilities of using design techniques, products and tools that increase the thermal efficiency of the home. This can be achieved by using daylight to supplement the heating requirements of the home with window systems that trap daytime

heat to release it during the night. Also by using daylight rather than artificial lighting within the home during the daylight hours. It is also important to seal the envelope and all possible escape routes for heat and cold from the home especially attic spaces. The use of heat recovery systems to reuse the heat generated by the cooling systems is another strategy to accomplish thermal efficiency. Introduction of zoned controls to allow the user to change the temperature based on their level of comfort and usage will help reduce unnecessary heating and cooling.

4.5.3 Structural integrity

Structural integrity is the underlying requirement for any structure. In the present scenario, where different kinds of factory-produced components are available, integrating them together to form a hybrid design becomes a feasible option. The integration of factory produced components and alternative-framing techniques must be checked for structural integrity when brought together. This can be accomplished through designing on a grid so that it is easier to integrate all forms of factory built units. Also avoiding puncturing of the walls while setting up utility distribution systems improves the structural integrity of the design. The use of materials, which have better structural performance, may also be explored.

4.5.4 Ease of construction

Ease of construction refers to the ease of assembly where components are used. For both site-built and factory-built homes, this would mean ease of assembly on site. Ease of assembly will lead to reduction of punch list items through reduction of errors

during construction. This can be accomplished by simplifying design of utility systems, disentangling these and integrating them within one utility core such that components are easily put together. Modular design is an important strategy to simplify the construction process. Design can be based on "use modules" referring to (1) wet cores, which include bath and kitchen areas, (2) dry cores, which include the living areas, and, (3) utility cores that are concentrated cores that house the distribution for all building systems. Also, all distribution systems for building systems may be detachable and / or wireless.

4.5.5 Ease of maintenance

Ease of maintenance or replaceability and accessibility is one of the recognized expectations from a "Whole House" design. The disentangling and integration of building systems leads to an ease of handling these systems over the lifetime of the home, as well as an ease of maintenance through ease of access. Design of a utility core that can be accessed easily from a designated spot in the home, is one of the primary strategies. The utility core serves as a single vertical conduit for all building systems such that all building systems can be accessed at one point without difficulty or without having to compromise the structural integrity of the home. It is also important to design distribution and placement of building systems such that the failure of one system does not affect any other. An integration of building systems will lead to a reduction of material used such as for wireless systems. Home automation also allows for increased ease in monitoring and maintaining building systems.

4.5.6 Sustainable design

For the purpose of this thesis, the term "sustainable design" refers to environmentally responsive design and use of tools, techniques and, products, which increase the energy efficiency of a home over its lifetime, thereby reducing the need for consumption of non-renewable and natural resources. These strategies include active solar design, such as use of solar panels; passive solar design, which deals with daytime lighting and use of shading devices that reduce the need for artificial sources of light. Another important consideration is glazing design, which increases window insulation and therefore, the thermal efficacy within the home. Water also being a natural resource must be conserved; therefore strategies such as rainwater harvesting and grey-water reuse must be incorporated. Sealing of building junctions to decrease loss of energy improves the thermal efficacy and in turn allows for better performance of the HVAC system. Finally it is also important to pay attention to materials used for building; recycled content materials contain recycled content which makes them desirable from the point of view of being environmentally responsive.

4.6 Developed BSIH matrix

The BSIH matrix is, as indicated earlier, a tool that allows the researcher to assess the kind of integration between any two or more building system. In the following sections we will discuss the process of developing the BSIH matrixes for the 2-system and 3-system interactions. Since there are 8 building systems that have been considered for the purpose of this thesis, the system interaction combinations could be up till 8-system interactions. The BSIH matrixes were developed for 2-system and 3-system

interactions only, since it was determined that any further matrix development would only result in repetitions.

In a BSIH matrix the system combinations are placed on the vertical axis and the levels of integration on the horizontal axis. Each interaction is then matched with one or more level of integration. The BSIH matrixes are developed for each 2-system and 3-system interaction to depict their level of integration. The choices are based on certain reasons that are stated along with each strategy. The detailed matrices developed for this particular research along with the reasons for the choices are illustrated with an example in Figure 4.4. Finally the purpose of developing the matrices and the inferences gathered from the exercise, are discussed.

There are 28 possible combinations for the 2-systems interactions and 57 possible combinations for the 3-system interactions, which have been accessed. Each combination has been accessed for its level of integration with each other and then the reasoning for the choice has also been tabulated. Figure 4.1 is a part of the BSIH matrix developed for the 2-system interactions; the complete matrix is included in Appendix A. A complete BSIH matrix developed for the 3-system, interactions along with the reasoning, is also included in Appendix B1.

The BSIH matrix allows the researcher to understand as well as tabulate the extent of integration between any two or more building systems in a systematic format. This provides a preliminary understanding of systems integration applications, along with a formal framework on which to base the choice of integrative strategy as being suitable or not. The BSIH matrix serves as a valuable tool in conveying the need for integrative design, while also shedding some light on the manner in which to approach it for each

specific systems interaction. The understanding generated by going through this exercise is used to develop detailed integration models for each scenario. The detailed modeling will allow the researcher to substantiate the choice of strategies as well as materials and products.

	Remote	Touching	Connected	Meshed	Unified
Str + Env			Structural elements may be the studs and the envelope may be the drywall attached to the studs. In this case both are permanently attached.		In some cases both may be able to be told apart for e.g. alternative framing materials such as foam core panels where the structure and the envelope are unified.
Str + HVAC	The actual generator equipment might be placed within a basement space and be remote to the structural system.	AHU may be touching the structure where they are placed	Ducting, distribution system is connected to the structural system	Outlets may be meshed with the floor structure. Sometimes the idea of connected and meshed may have to be based on a value judgment.	
Str + Plum			Fixtures such as the water closet are connected to the structure.	Distribution systems may be meshed within a wall cavity as part of the overall structure.	
Str + Elec	Actual appliances may be remote from the structure.		Electrical outlasts are connected to the structure with screws or bolts. Distribution systems such as the electrical raceways are also connected to the wall structure.	Wiring may be meshed within the wall structure.	
Str + Comm	Actual appliances may be remote from the structure.		Outlets and raceways are connected to the wall or floor structure.	Wiring may be meshed within the wall structure.	

Figure 4.1: Part BSIH matrix for 2-systems interactions along with reasoning

4.7 Developed Systems Decision models

This section will focus on the next step in the modeling for systems integration in order to develop a "Whole House" performance criterion framework and subsequent sample "Whole House" criterion. The systems decision models allow the researcher to systematically tabulate all physical decisions, which must be taken in order to integrate two or more building systems. Systems decision models will be developed for 3-system interactions only, since it was deduced through research that 2-system interactions would afford insufficient variability to allow for integrative design. Also, all 3-system interactions have not been included in this research, since it was deduced that most parameters stated begin to be repetitive and therefore only the relevant scenarios have been incorporated. A total of twenty, 3-system interactions, have been found to be useful. One example is discussed in the body of the text, and the remaining models developed will be included in Appendix B2.

A systems decision model is comprised of two sections, the intents and the strategies. The intent section includes all the physical decisions that must be taken for each building system when integrated with two or more building systems based on the performance parameters of the "Whole House" design. Physical decisions are tabulated specific to each performance parameter under each building system.

The author refers the reader to appendix B2 for a complete list of 20 systems decision models. The model is composed of three units, each depicting one of the building systems, which in this case are structure, HVAC and electrical respectively. Within each unit decisions pertaining to each performance parameter are tabulated. Since all three units must interact with each other, physical decisions to be taken under each

head must also be coordinated. Once all the decisions have been tabulated, inferences are made specific to each performance parameter. The inferences will serve as strategies to be followed in order to successfully integrate the three building systems.

The systems decision models developed will serve to systematically tabulate all information required to make decisions regarding integration of two or more building systems. After the systems decisions models were developed for the chosen interactions, it was determined that certain inferences were common to all building systems interactions. This led the researcher to deduce that these inferences were vital to a "Whole House" design. These inferences also provided the basis for suggesting strategies for designing a "Whole House" taking into account total systems interactions.

The systems decision models serve as the backbone for the "Whole House" performance criterion framework and the subsequent sample "Whole House" criterion. The framework is divided into three main parts: intents, strategies, and finally requirements in terms of material, personnel or expertise. The intents as well as the strategies will be extracted from the systems decision models, and the requirements section will be completed through literature review of new materials and methods available.

4.8 "Whole House" performance criteria (WHPC) framework

The BSIH matrixes and the systems decision models developed in earlier sections form the basis for the formulation of the WHPC framework. In the following sections, the format and the contents of the criteria will be discussed in detail. Three optional formats were considered; the first based on the Environmental Impact Matrix (DFE 1999), second

on the Decision Selection Method (DSM 2005) and the third based on the LEED guidelines (LEED 2002). The formats were tested for their ability to allow the user to conduct what-if scenarios in order to determine the appropriateness of the design with respect to "Whole House", as well as being comprehensive in providing all the relevant information.

4.8.1 Performance criteria framework

The first framework option (Fig 4.2) is based on the EIM (DFE 1999) which allows the user to determine the types and extent of environmental impacts of a product design and to conduct "what if" scenarios to improve the environmental performance and to lower the total score. A detailed description of the process in provided in Chapter 2, section 2.6.3.

The second framework option is based in the Decision Selection method (DSM 2005). Many alternatives may appear when finalizing decisions regarding the use of strategies to fulfill certain intent. The final decision-making must take into account the requirements of the customer and the capability of the company. The best decision which is tabulated is that alternative which optimizes the total product value based on requirements which have been stated. The systematic process is refereed to as the Decision Selection Method (DSM). The following steps must be completed: first determination of performance requirements, which have been specified in the thesis as six performance parameters. The criteria tree or the criteria flowchart is formulated next, it is produced on a top down basis by asking the question "How will this be accomplished?" This has been accomplished in the thesis in the form of the systems

decision models. A datum is determined next, based on which the applicability of the results will be tested; here the datum is the ideal "Whole House" score. The existing concept is rated next, which is done with the help of the scoring system developed. The detailed scoring system will be discussed in Chapter 5. Finally, the results are compared to determine the appropriateness of a system with respect to the ideal "Whole House" score.

The third framework option is based on the LEED guidelines and the manner in which the information is laid out in their text. The LEED guidelines divide the information required into intents, strategies and requirements. The intents refer to what needs to be achieved, the strategy is the process that will be employed to achieve it, and the requirements are the physical needs to fulfill the strategy, such as the particular types of codes to be followed, or the expertise required, or the materials required, and so on. Each set of intents, strategies and requirements refers to a particular credit that must be achieved, in order to be certified as a LEED building. The same breakup was used to define the framework option. In lieu of the credits, the intents, strategies and requirements were defined for a set of design considerations under each building system.

It was determined that the third option was better suited to depict the 'Whole House" criterion. This option represents a more comprehensive manner of presenting the information required to design a "Whole House". The author concedes that since the thesis focuses on the framework development, rather than the actual criterion, the framework may undergo changes as one uses it to develop the criterion itself. A section of the actual framework developed has been included in Figure 4.3 and the complete framework is provided in Appendix C1.

The framework will be used to conduct "what-if" scenarios by scoring the strategies employed in the design and construction of a home. The rating and scoring system will be discussed in detail in the next chapter. The LEED guidelines are used to formulate the framework only and have no bearing on the scoring system.

4.9 Summary

This chapter includes the modeling techniques used to formulate the "Whole House" performance criteria framework. In order to understand building system interactions, these were modeled using established modeling techniques. It is the author's intent to use the framework to formulate a sample "Whole House" criterion that is provided in the next chapter. By systematically tabulating the information required to affect systems integration with the BSIH matrixes and the systems decision models, the researcher was able to sufficiently understand, as well as corroborate, the strategies stated within the WHPC framework. The author concedes that the content of the framework is subjective and so are the chosen intents and strategies; these will largely be based on the level of expertise of the user as well as individual preferences.

Building system interactions	Recommendation	Credit	Spatial flexibility	Thermal performance	Structural Integrity	Ease of construction	Ease of maintenance	Total	Total x credit
			Weightage						
Final Score									Final score

Credit: Will be based on the indvidual requirements from particular building interactions. This may be equal for all as well based on equal importance level for all.
Weightage: Each particular systems interaction and its associated inpact on the performance parameters will be rated as follows:
0 - most effective, 1 - reasonably effective to most effective, 2 - reasonably effective, 3 - ineffective to reasonably effective, 4 - ineffective, 5 - not conducive
Note: The smaller the score the more effective the "Whole House" design is.

Figure 4.2: WHPC framework based on the EIM

No		Building systems (Design considerations)	Intent						Example Strategies	Information resources
			Spatial flexibility	Thermal performance	Structural Integrity	Ease of const	Ease of maint	Sustainable design	Performance parameters	Performance parameters
A										
	1									
	2									
	3									

Figure 4.3: WHPC framework based on the LEED guidelines

Chapter 5 – Sample "Whole House" Criterion and Its Applications

5.1 Overview

The WHPC framework was developed and presented in the previous chapter. In this chapter, the framework will be used to develop a sample "Whole House" criterion, along with a scoring system that will be used for applying the sample criterion to three case studies; site-built home, factory-built home and hybrid home. The scores obtained for these will be compared as a percentage of the hypothetical ideal "Whole House" score, which is the sum of all the ideal scores. Based on the results achieved from the scoring of strategies employed in a design, it can be ascertained whether the design approaches an ideal "Whole House" design. The step is included to allow the user to conduct "what-if" scenarios with respect to the choice of strategies employed to design a home. It is anticipated that the hybrid home will achieve the highest "Whole House" score, based on the assumptions made earlier with regards to the sample "Whole House" criterion.

5.2 Sample "Whole House" criterion components

There are five components that constitute the complete criterion namely; building systems, design considerations, intent, example strategies and finally information resources / professional expertise. The sample "Whole House" criterion is provided in Appendix C2.

1. The building systems constitute the first column and are the same as discussed in the previous chapter. These are Structure / Envelope which have been incorporated together, since it was determined during the formulation of the criterion that the information included under these two heads were overlapping; HVAC, Plumbing, Electrical, Communication, Interior A, and Interior B.
2. Each building system is further defined with a set of three major *design considerations* that are presented as rows within the first column. These are architectural design specifics, such as space usage in terms of placement of units and arrangement of partitions. Engineering design encompasses all services design issues, and lastly special design considerations include active passive solar design, choice of fuel, alternative techniques, and any other special considerations.
3. Under each design consideration, a set of intents is specified pertaining to each performance parameter. This forms the next column in the criterion; the individual intents are specified in each row relating to the particular design consideration. For example, the intent stated under the spatial flexibility parameter pertaining to architectural design considerations is "Changeability of spaces". This can be interpreted as: in order to achieve spatial flexibility based on architectural design the user must design for changeability of spaces.
4. The intent specified under each design consideration for each building system is then associated with a strategy. The strategies are specific to the user and may be tabulated as per the individual expertise. This forms the next column in the criterion; the intent in a particular row is associated with a strategy. A set of example strategies has been

specified for the purpose of this thesis. For example the intent "Changeability of spaces" is achieved using the example strategy "Grid based design".

5. Once the strategies have been specified, the last section tabulates the information resources or professional expertise required to realize the strategy that has been specified earlier. This forms the last column in the criterion; the strategy in a particular row is associated with an information resource. For example "Grid based design" will require "Design expertise" in order to accomplish the strategy. Other information resources are included, as part of the text of the thesis and readers will be referred to the relevant sections.

5.3 Scoring system for the sample criterion

Once the framework was the developed based on the LEED guidelines, a scoring system was set up to score the strategies used within a design in order to conduct "what-if" scenarios to determine the most appropriate strategy. The scoring system is based on the "Whole House Calculator" whereas the framework is based on the LEED guidelines. Each building system 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 weight age/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. The choice of level of importance is based on the rating system used in the formulation of the "Whole House calculator" report (O'Brien et al 2005). The tool developed at Virginia Tech has been discussed in detail in Chapter 2

section 2.6.4.1. This is primarily a scoring system developed to test a existing design to determine to what extent it approaches a "Whole House". The report defines a set of ten building systems and assigns credits to these. These credits are used a basis for the credit system developed for this thesis. Although the individual systems defined for the Whole House calculator are different from the ones defined for the purpose of this research, certain assumption have been made.

Figure 5.1 illustrates the assumptions made, the first column refers to the systems defined within the "Whole House calculator" text, the second column tabulates the weights assigned for each system. The third column refers to the assumptions made by the author for the purpose of this thesis; for example process design weights will be divided evenly for all building systems other than structure and envelope. Foundation, structure and envelope defined separately for the calculator will be combined and associated with the Structure/Envelope section, and so on. Based on the assumptions made, certain weights have been determined as provided in Figure 5.2 for each building system.

Systems	Weights	Assumptions			
Process Design	5	Will be evenly divided except for structure			
Foundation	15	Structure / Envelope			
Superstructure	25				
Envelope	15				
Interior partitions	2	Interior B			
Millwork	3				
Utility distribution	7	Distribute evenly among utility systems			
Electrical	10	Electrical	Assuming elec here refers to elec dist, oulets and comm lines % of total divided as	Electrical	60%
Plumbing	5	Plumbing		Communication	25%
Thermal	13	HVAC		Interior A	15%
Total	**100**				

Figure 5.1: Assumptions made based on the "Whole House calculator"

No	Building system	%age	Weight
1+2	Structure / Envelope	55.00	4.4
3	HVAC	16.00	1.28
4	Plumbing	8.00	0.64
5	Electrical	8.00	0.64
6	Communication	4.00	0.32
7	Interior A	6.00	0.48
8	Interior B	3.00	0.24
		100	8

Figure 5.2: Weights for each building system

The next step is the scoring of each strategy based on it 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 (Eq 1). The sum of these weighted scores for all

building systems is the final score (Eq 2). Once each case study has been scored, it will be compared against the ideal "Whole House" score of 755 points. This will be referred to as the ideal score. The ideal score may be viewed as a hypothetical score only based on the sample criterion developed for this thesis. This number may change based on whoever is conducting the analysis and formulating the framework. The results of the scoring of the case studies will be expressed as a percentage of the ideal score.

$$\sum \textbf{Raw scores x Weight} = \textbf{Weighted score} \qquad \textbf{(Eq 1)}$$

$$\sum \textbf{Weighted score} = \textbf{Final score} \qquad \textbf{(Eq 2)}$$

The intent of the criterion is to be able to conduct "what-if" scenarios in order to determine which strategy may render the design closer to being a "Whole House" design. The total score, which is the sum of the weighted scores, is compared with the ideal "Whole House" score for this particular scenario. The ideal score is computed by assigning the "most effective" score to all the strategies, (which is 5) and then computing a total score. This ideal score is then compared to the score obtained for a particular case study in terms of percentage, which gives the user an idea of how close the case study design comes to being a ideal "Whole House" design. These comparisons will be made in the following sections where the criterion is applied to the three case studies.

5.4 Application of "Whole House" criterion

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 Site-built home

The design and drawings for the case study are the property of a major homebuilder and were shared with the research team for academic purposes only. 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 4198square 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 intents within the "Whole House" criteria are scored with respect to the information associated with the design. In instances where it is determined that the intent was not considered within the design, these have been stated and the strategy employed is considered ineffective since the intent is non-existent. The scoring for each intent is subjective and is based on the understanding of the user, in this case the author. The author concedes that the scores may be different, based on the individual conducting the analysis. The "Whole House' score for the site-built home was 310, with respect to the ideal score of 755 as stated before, this represents 41.06% of the ideal "Whole House" score. The completed criterion sheet for the site-built home has been included in Appendix C3.

5.4.2 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 "Whole House' score for the factory-built home was 391, this represents 51.8% of the ideal "Whole House" score. The completed criterion sheet for the factory-built home has been included in Appendix C4.

5.4.3 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 (Orient 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 "Whole House' score for the hybrid home was 506; this represents 67.02% of the ideal "Whole House" score. The completed criterion sheet for the hybrid home has been included in Appendix C5.

5.4.4 Comparison of the criterion application on three case studies

All three designs for site-built, factory-built and hybrid homes are similar, in order to maintain a certain consistency. The intent for the application was not to critique the architectural design or structural design of the home but to score the building systems and their performance. It is assumed that the specifications are standard and the quality of

construction is satisfactory for all three case studies. Since the specifications for all three designs are similar, a large part of the scoring was similar. The results have been presented both as points achieved, as well as percentages of the ideal "Whole House" score (Fig 5.3).

Home Type	Score	% age
Ideal Whole House	755	100
Site-built	310	41.06
Factory-built	391	51.8
Hybrid	506	67.02

Figure 5.3: Comparison of scores obtained

The decisions regarding the scoring of each strategy were partly based on an understanding of the specification and partly on whether the intent was considered at the time of the design. In cases where it was felt that the intent was not consciously included into the design process, the strategy was scored as being ineffective since it was non-existent. In instances where the intent was considered, the strategy was scored based on the author's understanding of the specifications and the details represented in the drawings supplied by the major homebuilder. The reasons stated for choosing a score for a particular strategy may be reviewed.

In all three cases the engineering drawing, design consideration for the building systems excluding structure/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. The differences in scoring for the three types of homes were noticed mostly in the materials used and in the construction process.

It was determined that the component design and assembly process used in the construction of the hybrid home provides it with enhanced structural performance owing to the specially manufactured OSB. 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. Both the factory-built home and the hybrid home take advantage of the ease of construction affected through components assembly whereas the site-built home received lower scores, since the intent was not considered as a separate entity. For site-built homes it is assumed that the management team placed on site by the General Contractor (GC) will manage the construction process and therefore designing for ease of construction is not considered. This particular design has received better scores for the ease of maintenance performance parameter, since the design incorporates a mechanical chase for the distribution of HVAC ducts over floors, rendering it easily accessible. The mechanical chase is included in the architectural design for all three types of homes and therefore the scores received are similar.

Another significant observation is that all three types of homes received ineffective scores for all intents stated for the Interior (Type B) building system. This is because the furniture placement for the interiors is an afterthought in most of the building designs today. It is author's intention to introduce the concept of using internal furniture placement as an effective means of increasing thermal efficiency within the home. Furniture placement could also assist in defining spaces such that no structural or partition walls are required; this would serve to improve the spatial flexibility within the home.

The results obtained for the three case studies were as anticipated, based on the performance parameters specified beforehand. The site-built home case study received the least score; this is largely because the production process does not take advantage of the inherent ease of assembly of factory-produced components. In addition, there were no attempts to use materials with enhanced thermal and structural performance. The factory-built case study home received relatively better scores with respect to ease of construction and therefore a better overall score. The hybrid home case study received the highest score compared to the other two types of homes. This is because, along with enjoying the advantages of factory built components that are assembled easily on site, this particular case study design also used specially designed materials and products, such as high performance OSB and insulating strip for opening.

5.5 Feedback on the WHPC framework, sample criterion, and application process

The effectiveness of the research outputs and the process of their application were reviewed with the help of feedback from selected academic/government researchers and industry professionals. A summary of the research outputs, their development process and case study applications were sent to the selected professionals and telephone interviews were conducted. During the 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. The survey set from the academia and governmental researchers was determined based on their past and ongoing research activities in the area of "Whole House". A total of three academic researchers were interviewed. The survey set from the industry professionals was based on the type of

work conducted by the organization and their interest in incorporating new materials and processes into their product. A total of three industry personnel were interviewed.

5.5.1 General observations

Overall it was argued that the research approach and the outputs are timely and will mark a well-needed contribution to the emerging field of "Whole House". It was noted that the academic/governmental researchers' community felt that the framework was simplistic in its approach; however the industry community felt that the approach was rather complicated and may be difficult to assimilate within the industry. This observation was to be expected and does not seem unusual. The intent of the research was to put forth a framework flexible enough to incorporate individual requirements as one of the initial contributions to this field. Although it was intended that the framework itself be easily understood and therefore easy to use, it is natural that the professional community prefers a more hands-on approach than academic research sometimes offers. The "Whole House" approach has only lately been recognized as a credible direction to take with the intent of revolutionizing the homebuilding industry, and therefore its introduction into the mainstream industry may take a few more years.

In general, it was stated that the framework was adequately substantiated, when relating to building systems interactions through the use of the modeling techniques. The author recognizes the presence of many other modeling techniques, which have been used by other researchers. It was also observed that as an initial academic exploration, the research provided a valuable starting point. To a large degree, specifics of the building systems chosen as well as the performance parameters were not questioned, since the

framework is intended to be flexible and the choice will be subjective to the specific user. Specific concerns have been acknowledged in the following section, which include suggestions for further research.

This research focuses on the modeling of systems interactions that leads to an understanding of the intents and further allows the user to associate with it the appropriate strategy. The underlying intent in the formulation of the framework is to allow the user to substitute design and construction strategies at the pre-construction stage. The WHPC framework is intended to serve as a design assist tool and not only as a scoring tool for an existing design.

5.5.2 Specific observations

Certain critical observations were made which include inclusion of Indoor Air Quality (IAQ) as one of the performance parameters owing to the attention this particular aspect is receiving through homebuilding claims today. It was noted that site and consumer related aspects must be addressed as part of the overall "Whole House" approach. Another observation was that financial analysis must be conducted in order to render the approach much more realistic. Certain additional performance parameters were suggested such as aesthetics and functionality, which have been addressed. Lastly it was noted that the building systems interactions had been considered for their physical proximity and placement and along with this non-physical levels of integration, must also be considered. These will be discussed in some detail in the relevant sections.

5.5.2.1 Indoor Air Quality (IAQ)

IAQ includes two significant parts; first adequate ventilation for the home and second, chemical / biological processes within the built structure with regards to materials used as well as adequate ventilation and access to outside air within the home. Adequate ventilation was included as a special design consideration for the HVAC building system. It was observed that in the present day a large part of homebuilding litigation is caused by harmful chemical residue and emissions within the home and therefore it is important to consider the effect of construction materials at the time of design. The chemical and biological processes are recognized as a future research direction to be included in detail within the next thesis produced by the research team.

5.5.2.2 Site and consumer related issues

It was also noted that design and production aspects such as specific site considerations and consumer specifics should also be included. The research team concedes that although we recognize the importance of including these aspects within the overall "Whole House" design approach, for the purpose of this thesis the focus has been on physical interactions among building systems. These aspects will be included as future research directions.

5.5.2.3 Financial analysis

It is important to consider cost implications when addressing new technology. It was pointed out that the user must be able to derive some advantage in terms of first costs and / or lifetime costs. According to a government researcher affordability is a real

possibility with the "Whole House" approach. It is the author's opinion that under the present circumstances, where the supply chain functions as a separate entity, this might not be possible to achieve. However, if the supply chain were personally monitored and designed for the specific purpose of a homebuilder, affordability could be built in due to achieved reduction in cost based on the streamlining of the design and construction process. The financial analysis will be addressed as a future research direction.

5.5.2.4 Other factors

It was observed that additional performance parameters such as affordability as discussed earlier, aesthetics and functionality could be explored. It is the author's opinion that although aesthetics can be included, the definition would be entirely subjective; the government researcher making this observation agreed with this contention. Owing to the diversity of preferences this parameter is at best quantifiable for a local user set for a specific site. Surveys would need to be conducted within the area that the residential community is to be placed. As for functionality, the author refers the reader to the definition of spatial flexibility as a performance parameter.

The levels of integration stated within the text for the purpose of the BSIH matrix were discussed and it was observed that these largely referred to the physical proximity and location of the building systems. Along with physical levels of integration, non-physical levels of integration referred to a "systemic interactions" must also be recognized. Systemic interactions may be defined as cause and effect interactions; for example, if a user owns pets this could affect the IAQ, if the ventilation system is not designed to take into account this factor.

5.6 Summary

The building systems integration models and the WHPC framework were discussed in the previous chapters. This chapter focused on the sample "Whole House" criterion and the scoring systems developed in order to conduct what-if scenarios to analyze the case study designs with respect to an ideal "Whole House" design. This analysis can assist designers, builders, and users in establishing the best strategy to follow.

The sample criterion was applied to three case study designs. The results obtained as scores for each design were based on the author's understanding of the design and specifications. The results are also subject to the choice of performance parameters and individual approach to the same. Based on the criterion application, the Hybrid home received the best "Whole House" score. The advantage was noticed with the ease of construction for a hybrid home, since it was designed as a component assembly, and the production process and the supply chain was monitored by the same homebuilder. Also, ease of construction exerts more influence in the scheme for this research, since it is one of six performance parameters; if the number of performance parameters were increased it would dilute the effect of this one factor.

Finally, the performance criteria framework and the resultant sample "Whole House" criterion were discussed with involved personnel from both academic and industry sectors. This served as the review process for the research approach and outputs. It was noted that the framework was adequately formulated and the sample criterion was adequate for the purpose of the thesis. The comprehensiveness and accuracy of the actual

criterion are not in question here, since the research intends to put forth a framework rather than a prescriptive and accurate "Whole House" criterion.

Chapter 6 – Summary and Conclusions

6.1 Overview

The "Whole House roadmap" (PATH 2003) defines the "Whole House" approach in terms of building systems integration. The intent is to be able to design in a manner that reduces the negative interactions that exist among building systems, since they are not designed to interact, and also to use the synergies that exist among building systems to better the performance of the home without increasing the cost.

The research conducted through this thesis was aimed as an initial foray into the emerging field of the "Whole House" approach. The research team intended that this be the beginning of a series of academic research projects related to the inclusion of the "Whole House" approach into mainstream home building. Therefore with this thesis the aim was to understand the "Whole House" approach through literature review and then attempt to put forth a preliminary "Whole House" performance criteria framework. This is intended to be a framework that equips the user with tools and techniques to effectively substantiate strategies that must be employed to achieve a "Whole House" design. During the review of the research methodology and outputs it was stated that this was valuable academic research with the object of developing a pool of knowledge upon the "Whole House" approach. This framework will be further developed and refined before it can be used as a prescriptive tool to determine how to design and build a "Whole House".

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 is referred to as stage one of the literature review, which focused on the evolution of the "Whole

House" approach. The review was divided into three parts: first the origins of the concept before the 1990's including the initiatives by the U.S. government to promote relevant research in housing, next recent developments which include other schools of thought which feed into the "Whole House" approach, such as lean construction and open building, and finally other attempts at developing a criterion were discussed such as the LEED guidelines, the Energy Star guidelines and more.

Chapter 3 deals with stage two of the literature review, focused on the tools and techniques, used to achieve a "Whole House" design. The review begins with determining the modeling tools needed to put forth a preliminary understanding of building systems integration. Mechanical electrical plumbing (MEP) integration techniques were discussed since it was important to mention the existence of such techniques. All building systems, which function within the home, were identified and the means and methods to improve the performance of these systems through change in design or type of fuel were discussed. This chapter forms the basis for the information resources needed for the sample "Whole House" criterion.

Chapter 4 deals with the "Whole House" performance criteria framework. The framework development process begins with a review of the building systems identified for this research followed by the performance parameters and their definitions. The framework options were discussed next, and the most appropriate framework based on the LEED guidelines was decided upon. The chapter also includes the modeling techniques, which assist the user to formulate an understanding of the building systems interactions. Two modeling techniques were used; the BSIH matrix were developed for 2-system and 3-system interactions and the systems decision models for 3-systems

interactions were completed. Both these modeling techniques have been endorsed by the AIA (Rush 1986). This formed the basis for the information included within the sample "Whole House" criterion.

Chapter 5 deals with the sample "Whole House" criterion and the scoring system developed in order to conduct "what-if" scenarios. The sample criterion was applied to three case studies, one each for site-built, factory-built and hybrid home. The application of the criterion is based on the understanding of the researcher and the results achieved are subjective to this research. It was determined that the hybrid home receives the highest "Whole House" score.

6.2 Summary

This section includes the steps carried out to achieve the goals and objectives set out for this research. The hypothesis set out for the purpose of this thesis has been proven correct based on the research conducted.

6.2.1 Objective 1

To map the evolution of the "Whole House" approach.

Step 1 – Conduct literature review.

This was accomplished through the literature review conducted in chapter 1 and 2, which included the evolution process and the tools and techniques present today to better the performance of the home. The intent here was to review relevant literature within the scope of the "Whole House" approach to building systems integration.

6.2.2 Objective 2

To develop "systems integration models" in order to demonstrate systems interactions and their impacts on each other.

Step 2 – Model the "Whole House" as an overall systems integration model.

The overall model for the home was accomplished using the BSIH matrixes for 2-system and 3-system interactions. Although the actual number of combinations can be much more when considering eight building systems, it was determined that these would be adequate to formulate an understanding of levels of interactions.

Step 3 – Determine performance parameters.

The performance parameters refer to the performance expectations from a "Whole House" design. For the purpose of this research six parameters are defined which are spatial flexibility, thermal performance, structural integrity, ease of construction, ease of maintenance, and a supplementary parameter; sustainable design. The selection was based on the researcher's understanding of the most critical performance requirements from a "Whole House" design.

Step 4 – Understand the impact of "systems interactions" among the selected building components.

This was accomplished by generating "systems decision models" for each set of building system interactions based on the predetermined performance parameters. The understanding of the systems interactions generated here forms the basis for the sample "Whole House" criterion. It was determined that the systems decision models developed

for 2-system interactions are redundant, and therefore the models will be completed for 58 possible 3-system interactions only.

6.2.3 Objective 3

To develop a "Whole House" performance criteria framework.

Step 5 – Review any existing attempts to define similar frameworks.

The following were reviewed in detail: LEED guidelines, Energy Star guidelines, Environmental Impact Matrix, Whole House Calculator, and other contributors such as the Cleaner Technology Substitute Assessment and Federal guidelines for green building.

Step 6 – Review and determine the appropriate option and formulate the framework.

Three options were considered; one based on the EIM (DFE 1999), another based on the DSM (DSM 2005), and the third based on the LEED guidelines (LEED 2002). It was determined that the LEED guidelines were the most appropriate format for the "Whole House" performance criterion framework. The format used is comprehensive in the sense that it provides adequate information in an organized outline.

6.2.4 Objective 4

To develop a sample "Whole House" criterion and apply it to site-built, factory-built and hybrid case study homes.

Step 7 – To develop a sample "Whole House" performance criterion.

A sample "Whole House" performance criterion was formulated based on the format inspired by the LEED guidelines and the understanding of building systems interactions generated through the modeling techniques. The format has three sections; the intents, the

strategies, and the information resources. Each building system was further defined, based on three major design considerations; architectural design, engineering design specifics, and special design considerations. The intents were tabulated based on the specific design considerations for each building system in order to fulfill each of the six performance parameters. A strategy and information resource corresponds to a specific intent and these are indicated in terms of the specific section within the thesis text.

Step 8 - To demonstrate the application of the sample criterion to site-built, factory-built and hybrid case study homes.

Three case studies were scored based on the sample "Whole House" criterion that was formulated through research. The drawings and specifications for the site-built and hybrid home case studies were obtained through a major homebuilder. The factory-built home case study was modified from the design of the same home. Basic design and specifications were considered similar for all three case studies to avoid being swayed by the quality of the architectural design.

6.2.5 Objective 5

To review the "Whole House" performance criteria framework based on feedback form researchers and industry personnel.

Step 9 - To compare the results obtained for the three case study homes.

The results of the application of the criterion to the three case studies were expressed in the form of points achieved. These points were compared to the ideal "Whole House" score, which is a hypothetical score, based on all strategies being most effective in achieving the set of performance parameters defined. These comparisons were then

presented in the form of percentage of the datum score giving the reader a measure of how close a design comes to being an ideal "Whole House". It was determined that based on the assumptions made during this research the hybrid home received the largest score.

Step 10 – Feedback on the "Whole House" performance criterion framework and its applications.

The "Whole House" performance criteria framework and the sample criterion were reviewed by a survey set including both academia/government researchers and industry personnel. It was determined that the framework provided adequate substantiation for the content of the sample "Whole House" criterion. It was also stated that since the framework was considered flexible enough to include individual choices in terms of defining building systems and performance parameters, it was considered robust. Several areas of research were pointed out as being important which will be included in the future research areas.

6.3 Limitations of the research

The major observation was that the "Whole House" approach has been viewed in terms of building systems integration. The overall "Whole House" approach, however, may include many other factors not included in the body of this research. The framework developed, is on the other hand flexible enough to include all the important aspects and therefore the author does not consider this a significant limitation.

The framework may be considered limited in its approach since it is subjective to whomever may be using it to formulate a "Whole House" criterion. The content of the sample criterion itself is intended to be an example rather than firm fact. The tool set

forth in this research is intended to be an initial step towards a prescriptive "Whole House" criterion, which may eventually become a set of firm guidelines.

The result obtained with regard to the hybrid home being the most effective when leading to a "Whole House" design is subjective to assumptions made during this research. This result could have been obtained due to the following reasons: the understanding of the researcher based on the specific construction methods employed by the homebuilder constructing the hybrid home, the observation that ease of construction was a major contributor to the higher score, and since this accounts for a large part of the performance parameters, it could have affected the result. Moreover the fact that external factors, such as specific site conditions, labor and supply chain particulars, and extraneous climatic conditions, have not been considered could vary the result under different circumstances.

6.4 Conclusions and inferences

This section focuses on the conclusions and inferences made based on the research conducted. After having conducting the modeling it was concluded that the 2 and 3 system interaction modeling was adequate for the understanding of building systems interactions. The framework developed is also considered adequately substantiated through the use of these modeling techniques and allows for refinement through future research. The ideal "Whole House" score obtained for the purpose of this thesis is a hypothetical score and may be different based on the formulation of the framework, chosen performance parameters, as well as individual requirements in terms of design. The modeling techniques used for the purpose of this thesis are required for the

purpose of substantiating the claims made within the sample criterion. It was concluded that it was indeed imperative to conduct the modeling in order to have an understanding of the systems interactions. This understanding allows the user to decide upon the intents and strategies to be included within the criterion.

It can also be concluded through the review of literature conducted for this process that sealing the home for optimal HVAC performance is an important factor to be considered at the time of design especially sealing of the attic spaces. Also integrative communication and electrical distribution is no longer a thing of the future and must be incorporated into mainstream building.

It was observed that a large part of the problem existing today is the ineffective interactions among different trades, which results in negative interactions among building systems. This led the author to infer that building systems interactions are the most important aspect to be considered in relation to the "Whole House" approach. It can be inferred from the literature review that most of the technology and products available today which enhance the performance of the home in one form or another are cost intensive in terms of one time initial costs. They do however reduce the lifetime costs of the home, and therefore in order to render the approach more acceptable, lifetime costs will have to be recognized as an important specification for a home. A large part of the challenge in assimilating "Whole House" strategies is to educate the user with regards to long-term advantages. It can also be inferred that interior furniture placement can be used for other than aesthetic purposes, which could include the partition of spaces such that the use of partition walls would be reduced thus giving the user much more flexibility in floor plan. This could also be used to channel the air movement within the home based on

the climatic requirements over the year as weather changes. Last but not the least it can be inferred that sustainable design is an intrinsic requirement of all "Whole House" strategies and approaches and must be reviewed in greater detail.

Finally it can also be concluded that the hybrid home is in fact the best "Whole House" solution for several reasons. To begin with the hybrid, component assembly approach along with the supply chain is personally monitored which provides increased efficiency and ease in functioning on site. This approach also gets past the stigma attached to factory built homes since consumers associate these with regular site-built homes. This approach also provides opportunities for innovation within a setting where one entity handles all trades involved in the design and production of the home, which renders it more effective.

Future research directions are discussed in this chapter. It is anticipated that these are not likely to be assimilated into mainstream construction in the near future. It is the author's understanding that substantial research is required in the areas chosen in order to make it possible for them to be accepted as realistic and viable options by a large part of the industry.

6.5 Areas of future research

This section deals with the list of future research directions that is not considered exhaustive, although it is the authors' understanding that at the present time these ideas are widely mentioned in the academic community and research is underway upon the subjects.

1. **Expansion of the framework**

The immediate research direction to take based on this research would be the expansion of the proposed framework by including all aspects of IAQ especially chemical and biological processes within the home. Site and consumer related issues must also be considered. Finally financial analysis and design for affordability are important aspects to consider in order to render the product more acceptable by the consumer.

2. **Development of a comprehensive "Whole House" criterion and prescriptive guidelines**

The next step that the author anticipates is the development of a comprehensive "Whole House" criterion using the enhanced framework. The comprehensive criterion could be put through review with a panel of experts in order to develop a set of prescriptive guidelines to design a "Whole House" similar to the manner in which the LEED guidelines are set out. This would help in assimilating the "Whole House" approach into the industry.

3. **Sustainability**

It is the author's belief that in order to take a comprehensive look at the "Whole House" approach it is important to consider aspects of sustainability. This is a vast subject and must be undertaken as a separate research attempt in order to do justice to it.

4. **Other contributors**

This section includes several other future research directions that are considered important. The idea of "self healing homes" comes from the technological advancement in the use of material technology. Structural polymers of all kinds are traditionally susceptible to cracks but there have been developments in the field of such structural

polymers that can automatically heal those cracks. This self-healing polymer incorporates a microencapsulated healing agent and a catalytic chemical trigger within an epoxy matrix. An approaching crack ruptures embedded microcapsules, releasing healing agent into the crack plane through capillary action. An additional unique feature of the healing concept is the utilization of living polymerization (that is, having un-terminated chain-ends) catalysts, thus enabling multiple healing events (Energy URL 2004c).

Net positive homes are extension to the idea of Zero energy homes. ZEH are homes that generate enough energy to supplement the usage needs of the individual home in question. A Net positive home on the other hand is intended to generate enough energy to be able to give back to the local grid. Sometimes these two terms are used interchangeably.

Smart homes or intelligent homes are a futuristic approach to home functioning and design. The overall concept is to automate the functioning of the residence using a control system to integrate the various automation systems. Integrating the home systems allows them to communicate with one another through the control system, thereby enabling single button and voice control of the various home systems simultaneously (Energy URL 2004d).

The construction processes today are plagued with issues such as low labor efficiency, high accident rates, lower work quality and lack of control on the worksite. These problems can be mitigated through the use of automation. A new technique of automation is layered fabrication also known as *Rapid prototyping* or *Solid free form fabrication*. As the name suggests the procedure involves the production of an object by forming it layer by layer. The key feature is the use of two trowels, which in effect act as

two solid planar surfaces, to create surfaces on the object being fabricated that are exceptionally smooth and accurate. This operation is controlled through computer programming such that the arms of the equipment are instructed as per input to software. It can be used for concrete and plaster surfaces. The proposal is to extend this application in the construction industry through the visionary use of a gantry carrying the robotic arms of the equipment (Khoshnevis 2004).

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Appendix A

No	Description	Credit	Intent	Strategies	Requirements
A	**Sustainable Sites**	**14**			
P1	Erosion and Sedimentation Control	Prerequisite (1)	Control erosion to reduce negative impacts on water and air quality.	Consider employing strategies such as temporary and permanent seeding, mulching, earth dikes, silt fencing, sediment traps and sediment basins.	Must follow EPA Document No. EPA 832/R-92-005 (September 1992), Storm Water Management for Construction Activities, Chapter 3, or local erosion and sedimentation control standards and codes, whichever is more stringent.
C1	Site Selection	1	Avoid development of inappropriate sites and reduce the environmental impact from the location of a building on a site.	Design of footprint to minimally impact the site, tuckunder parking, and sharing facilities with neighbors.	Must not develop on Prime farmland, wetland and parkland as defined by the US govt, land with elevation lower than 5ft from the 100-year flood as defined by FEMA, and that which is specific to a particular habitat
C2	Development Density	1	Channel development to urban areas with existing infrastructure, protect greenfields and preserve habitat and natural resources.	During the site selection process, give preference to urban sites.	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
C3	Brownfield Redevelopment	1	Rehabilitate damaged sites where development is complicated by real or perceived environmental contamination, reducing pressure on undeveloped land.	During the 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	Develop on a site documented as contaminated (by means of an ASTM E1903- 97 Phase II Environmental Site Assessment) OR on a site classified as a brownfield by a local, state or federal government agency.
C4.1	Alternative Transportation, Public Transportation Access	1	Reduce pollution and land development impacts from automobile use.	Perform a transportation survey of future building occupants to identify transportation needs. Site the building near mass transit.	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.
C4.2	Alternative Transportation: Bicycle Storage & Changing Rooms	1	Reduce pollution and land development impacts from automobile use.	Design the building with transportation amenities such as bicycle racks and showering/changing facilities.	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 5% or more of regular building occupants. For residential buildings, provide occupants

No	Description	Credit	Intent	Strategies	Requirements
C4.3	Alternative Transportation: Alternative Fuel Vehicles	1	Reduce pollution and land development impacts from automobile use.	Provide transportation amenities such as alternative fuel refueling stations and carpool/vanpool programs. Consider sharing the costs and benefits of refueling stations with neighbors.	Provide alternative fuel vehicles for 3% of building occupants and provide preferred parking for these vehicles, or install alternative-fuel refueling stations for 3% of the total vehicle parking capacity of the site. Liquid or gaseous fueling facilities must be separately ventilated or located outdoors.
C4.4	Alternative Transportation: Parking Capacity	1	Reduce pollution and land development impacts from single occupancy vehicle use.	Minimize parking lot/garage size. Consider sharing parking facilities with adjacent buildings.	Size parking capacity to meet, but not exceed, minimum local zoning requirements and provide preferred parking for carpools or vanpools capable of serving 5% of the building occupants; or add no new parking for rehabilitation projects and provide preferred parking for carpools or vanpools capable of serving 5% of the building occupants.
C5.1	Reduced Site Disturbance: Protect or Restore Open Space	1	Conserve existing natural areas and restore damaged areas to provide habitat and promote biodiversity.	Design of footprint to minimally impact the site, tuckunder 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.	Greenfield site limit site disturbance to 40ft 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 or, 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.
C5.2	Reduced Site Disturbance: Development Footprint	1	Conserve existing natural areas and restore damaged areas to provide habitat and promote biodiversity.	Design of footprint to minimally impact the site, tuckunder 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	Reduce the development footprint and increase open area prescribed by the local zoning 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 the development footprint.
C6.1	Stormwater Management: Rate and Quantity	1	Limit disruption and pollution of natural water flows by managing 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.	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 or 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.

No	Description	Credit	Intent	Strategies	Requirements
C6.2	Stormwater Management: Treatment	1	Limit disruption of natural water flows by eliminating stormwater runoff, increasing on-site infiltration and eliminating contaminants.	Design mechanical or natural treatment systems such as constructed wetlands, vegetated filter strips and bioswales to treat the site's stormwater.	Construct site stormwater treatment systems designed to remove 80% of the average annual post-development total suspended solids (TSS) and 40% of the average annual post-development total phosphorous (TP) based on the average annual loadings from all storms less than or equal to the 2-year/24- hour storm. Defined in EPA's Best Management Practices (BMP) or local govt.'s BMP whichever is more stringent.
C7.1	Heat Island Effect: Non-Roof	1	Reduce heat islands (thermal gradient differences between developed and undeveloped areas) to minimize impact on microclimate and human and wildlife habitat.	Shade constructed surfaces on the site with landscape features and minimize the overall building footprint. Consider replacing constructed surfaces (i.e. roof, roads, sidewalks, etc.) with vegetated surfaces such as garden roofs and open grid paving or specify high-albedo materials to reduce the heat absorption.	Provide shade (within 5 years) and/or use light-colored/high-albedo materials (reflectance of at least 0.3) and/or open grid pavement for at least 30% of the site's non-roof impervious surfaces, including parking lots, walkways, plazas, etc.; or place a minimum of 50% of parking spaces underground or covered by structured parking; or use an open-grid pavement system (less than 50% impervious) for a minimum of 50% of the parking lot area.
C7.2	Heat Island Effect: Roof	1	Reduce heat islands (thermal gradient differences between developed and undeveloped areas) to minimize impact on microclimate and human and wildlife habitat.	Visit the ENERGY STAR Web site, www.energystar.gov, to look for compliant products. Consider installing high-albedo and vegetated roofs to reduce heat absorption.	Use ENERGY STAR compliant (highly reflective) and high emissivity roofing (emissivity of at least 0.9 when tested in accordance with ASTM 408) for a minimum of 75% of the roof surface; or install a "green" (vegetated) 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.
C8	Light Pollution Reduction	1	Eliminate light trespass from the building and site, improve night sky access and reduce development impact on nocturnal environments.	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 lowangle spotlights.	The maximum candela value of all interior lighting shall fall within the building (not out through windows) and the maximum candela value of all exterior lighting shall fall within the property. Any luminaire within a distance of 2.5 times its mounting height from the property boundary shall have shielding such that no light from that luminaire crosses the property boundary.

No.	Recommendation	Goal	Intent	Milestone	Requirements
[illegible]	Water Efficiency Water Efficient Landscaping Irrigation Systems	[illegible]	Limit or eliminate the use of potable water for	Perform a soils lab analysis to determine	Use high efficiency irrigation technology OR use

No	Description	Credit	Intent	Strategies	Requirements
B	**Water Efficiency**	**5**			
C1.1	Water Efficient Landscaping: Reduce by 50%	1	Limit or eliminate the use of potable water for landscape irrigation.	Perform a soil/climate analysis to determine appropriate landscape types and design the landscape with indigenous plants to reduce or eliminate irrigation requirements. Use high-efficiency irrigation systems and consider using stormwater and/or greywater for irrigation.	Use high-efficiency irrigation technology OR use captured rain or recycled site water to reduce potable water consumption for irrigation by 50% over conventional means.
C1.2	Water Efficient Landscaping: No Potable Use or No Irrigation	1	Limit or eliminate the use of potable water for landscape irrigation.	Perform a soil/climate analysis to determine appropriate landscape types and design the landscape with indigenous plants to reduce or eliminate irrigation requirements. Consider using stormwater and/or greywater for	Use only captured rain or recycled site water to eliminate all potable water use for site irrigation (except for initial watering to establish plants), OR do not install permanent landscape irrigation systems.
C2	Innovative Wastewater Technologies	1	Reduce generation of wastewater and potable water demand, while increasing the local aquifer recharge.	Specify high-efficiency fixtures and dry fixtures such as composting toilets and waterless urinals to reduce wastewater volumes. Consider reusing stormwater or greywater for sewage conveyance or on-site wastewater treatment systems (mechanical and/or natural).	Reduce the use of municipally provided potable water for building sewage conveyance by a minimum of 50%, OR treat 100% of wastewater on site to tertiary standards.
C3.1	Water Use Reduction: 20% Reduction	1	Maximize water efficiency within buildings to reduce the burden on municipal water supply and wastewater systems.	Estimate the potable and non-potable water needs for the building. Use highefficiency fixtures, dry fixtures such as composting toilets and waterless urinals, and occupant sensors to reduce the potable water demand. Consider reuse of stormwater and greywater for non-potable applications such as toilet and urinal flushing, mechanical systems and custodial uses.	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.
C3.2	Water Use Reduction: 30% Reduction	1	Maximize water efficiency within buildings to reduce the burden on municipal water supply and wastewater systems.	Estimate the potable and non-potable water needs for the building. Use highefficiency fixtures, dry fixtures such as composting toilets and waterless urinals, and occupant sensors to reduce the potable water demand. Consider reuse of stormwater and greywater for non-potable applications such as toilet and urinal flushing, mechanical systems and custodial uses.	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.

No	Description	Credit	Intent	Strategies	Requirements
C	**Energy & Atmosphere**	17			
P1	Fundamental Building Systems Commissioning	Prerequisite (1)	Verify and ensure that fundamental building elements and systems are designed, installed and calibrated to operate as intended.	Engage a commissioning authority and adopt a commissioning plan. Include commissioning requirements in bid documents and task the commissioning agent to produce a commissioning report once commissioning activities are completed.	Engage a commisioning team, review the drawings and specifications and develop a plan and complete a commisioning report
P2	Minimum Energy Performance	Prerequisite (1)	Establish the minimum level of energy efficiency for the base building and systems.	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	Design the building to comply with ASHRAE/IESNA Standard 90.1-1999 (without amendments) or the local energy code, whichever is more stringent.
P3	CFC Reduction in HVAC&R Equipment	Prerequisite (1)	Reduce ozone depletion.	When reusing existing HVAC systems, conduct an inventory to identify equipment that uses CFC refrigerants and adopt a replacement schedule for these refrigerants. For new buildings, specify new HVAC equipment that uses no CFC refrigerants.	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.
C1	Optimize Energy Performance	1 to 10	Achieve increasing levels of energy performance above the prerequisite standard to reduce environmental impacts associated with excessive energy use.	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	Reduce design energy cost compared to the energy cost budget for energy systems regulated by ASHRAE/IESNA

New Bldgs	Existing Bldgs	Points
15%	5%	1
20%	10%	2
25%	15%	3
30%	20%	4
35%	25%	5
40%	30%	6
45%	35%	7
50%	40%	8
55%	45%	9
60%	50%	10

No	Description	Credit	Intent	Strategies	Requirements
C2.1	Renewable Energy: 5%	1	Encourage and recognize increasing levels of on-site renewable energy selfsupply in order to reduce environmental impacts associated with fossil fuel energy use.	Supply at least 5% 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. When applying these strategies, take advantage of net metering with the local utility.
C2.2	Renewable Energy: 10%	1	Encourage and recognize increasing levels of on-site renewable energy selfsupply in order to reduce environmental impacts associated with fossil fuel energy use.	Supply at least 10% 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. When applying these strategies, take advantage of net metering with the local utility.
C2.3	Renewable Energy: 20%	1	Encourage and recognize increasing levels of on-site renewable energy selfsupply in order to reduce environmental impacts associated with fossil fuel energy use.	Supply at least 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. When applying these strategies, take advantage of net metering with the local utility.
C3	Additional Commissioning	1	Verify and ensure that the entire building is designed, constructed and calibrated to operate as intended.	Engage the commissioning authority early in the design phases.	An independent commissioning authority shall review the contractor submittals relative to systems being commissioned. Have a contract in place to review building operation with O&M staff, including a plan for resolution of outstanding commissioning-related issues within one year after construction completion date.
C4	Ozone Protection	1	Reduce ozone depletion and support early compliance with the Montreal Protocol.	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.	Install base building level HVAC and refrigeration equipment and fire suppression systems that do not contain HCFCs or Halons.

No	Description	Credit	Intent	Strategies	Requirements
C5	Measurement and Verification	1	Provide for the ongoing accountability and optimization of building energy and water consumption performance over time.	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.	Install continuous metering devices for appliances and such.
C6	Green Power	1	Encourage the development and use of grid-source, renewable energy technologies on a net zero pollution basis.	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.Visit www.green-e.org for details about the Green-e program.	Provide at least 50% of the building's electricity from renewable sources by engaging in at least a two-year renewable energy contract. Renewable sources are as defined by the Center for Resource Solutions (CRS) Green-e products certification requirements.
D	**Materials & Resources**	**13**			
P1	Storage & Collection of Recyclables	1	Facilitate the reduction of waste generated by building occupants that is hauled to and disposed of in landfills.	Provide an easily accessible area that serves the entire building and is dedicated to the separation, collection and storage of materials for recycling including (at a minimum) 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. Instruct occupants of the procedures and benefits of recycling.
C1.1	Building Reuse: Maintain 75% of Existing Walls, Floors and Roof	1	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.	Consider 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.	Maintain at least 75% of existing building structure and shell (exterior skin and framing, excluding window assemblies and non-structural roofing material).

No	Description	Credit	Intent	Strategies	Requirements
C1.2	Building Reuse: Maintain 100% of Existing Walls, Floors and Roof	1	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.	Consider 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.	Maintain at least 100% of existing building structure and shell (exterior skin and framing, excluding window assemblies and non-structural roofing material).
C1.3	Building Reuse: Maintain 100% of Shell/Structure and 50% of Non-Shell/Non-Structure	1	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.	Consider 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.	Maintain at least 100% of existing building structure and shell (exterior skin and framing, excluding window assemblies and non-structural roofing material) and at least 505 of the non shell areas (interior walls, doors, floor coverings and ceiling systems)
C2.1	Construction Waste Management: Divert 50% From Landfill	1	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.	Consider recycling 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.	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.
C2.2	Construction Waste Management: Divert 75% From Landfill	1	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.	Consider recycling 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.	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.
C3.1	Resource Reuse: 5%	1	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.	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.	Use salvaged, refurbished or reused materials, products and furnishings for at least 5% of building materials.

No	Description	Credit	Intent	Strategies	Requirements
C3.2	Resource Reuse: 10%	1	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.	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.	Use salvaged, refurbished or reused materials, products and furnishings for at least 10% of building materials.
C4.1	Recycled Content: 5% (post-consumer + 1/2 post-industrial)	1	Increase demand for building products that incorporate recycled content materials, therefore reducing impacts resulting from extraction and processing of new virgin materials.	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.	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.
C4.2	Recycled Content: 10% (post-consumer + 1/2 post-industrial)	1	Increase demand for building products that incorporate recycled content materials, therefore reducing impacts resulting from extraction and processing of new virgin materials.	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	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.
C5.1	Regional Materials: 20% manufactured regionally	1	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.	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.	Use a minimum of 20% of building materials and products that are manufactured regionally within a radius of 500 miles.
C5.2	Regional Materials: 50% manufactured regionally	1	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.	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.	Use a minimum of 50% of building materials and products that are extracted and manufactured regionally within a radius of 500 miles.

No	Description	Credit	Intent	Strategies	Requirements
C6	Rapidly Renewable Materials	1	Reduce the use and depletion of finite raw materials and long-cycle renewable materials by replacing them with rapidly renewable materials.	Establish a project goal for rapidly renewable materials and identify materials and suppliers that can achieve this goal. Consider materials such 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.	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 all building materials and products used in the project.
C7	Certified Wood	1	Encourage environmentally responsible forest management.	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 FSCcertified wood products installed.	Use a minimum of 50% of wood-based materials and products, certified in accordance with the Forest Stewardship Council's Principles and Criteria
E	**Indoor Environmental Quality**	**15**			
P1	Minimum IAQ Performance	Prerequisite (1)	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.	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.	Meet the minimum requirements of voluntary consensus standard ASHRAE 62-1999, Ventilation for Acceptable Indoor Air Quality, and approved Addenda (see ASHRAE 62-2001, Appendix H, for a complete compilation of Addenda) using the Ventilation Rate
P2	Environmental Tobacco Smoke (ETS) Control	Prerequisite (1)	Prevent exposure of building occupants and systems to Environmental Tobacco Smoke (ETS).	Prohibit smoking in the building or provide separate smoking rooms with isolated ventilation systems.	Prohibit smoking in the building or provide separate smoking rooms with isolated ventilation systems.
C1	Carbon Dioxide (CO2) Monitoring	1	Provide capacity for indoor air quality (IAQ) monitoring to help sustain longterm occupant comfort and well-being.	Design the HVAC system with carbon dioxide monitoring sensors and integrate these sensors with the building automation system (BAS).	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.

[illegible]	Combination Fire Incinerator	Provide for the effective delivery and mixing of fresh air to support the safety, comfort and well being of building occupants.	Design that HVAC system and building envelope for optimum air change effectiveness. Air change effectiveness can be optimized	For naturally ventilated buildings, design ventilation systems that result in an air change effectiveness (Ea) greater than or equal to 0.9 as determined by ASHRAE

No	Description	Credit	Intent	Strategies	Requirements
C2	Ventilation Effectiveness	1	Provide for the effective delivery and mixing of fresh air to support the safety, comfort and well-being of building occupants.	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, plug-flow ventilation such as under floor or near floor delivery, and operable windows. Test the air change effectiveness of the building after construction.	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 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.
C3.1	Construction IAQ Management Plan: During Construction	1	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.	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 wall board.	Meet or exceed the recommended SMACNA IAQ Guideline for Occupied Buildings under Construction, 1995, Chapter 3. Protect stored on-site or installed absorptive materials from moisture damage. 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.
C3.2	Construction IAQ Management Plan: Before Occupancy	1	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.	Prior to occupancy, perform a two week building flush-out or test the contaminant levels in the building.	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.
C4.1	Low-Emitting Materials: Adhesives & Sealants	1	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.	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,	Specify Low-VOC materials in construction documents. Ensure that VOC limits are clearly stated in each section where adhesives and sealants are addressed.
C4.2	Low-Emitting Materials: Paints and Coatings	1	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.	Specify Low-VOC paints and coatings in construction documents. Ensure that VOC limits are clearly stated in each section where paints are addressed.	VOC emissions from paints and coatings must not exceed the VOC and chemical component limits of Green Seal's Standard GS-11 requirements.

No	Description	Credit	Intent	Strategies	Requirements
C4.3	Low-Emitting Materials: Carpet	1	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.	Specify Low-VOC carpet products and systems in construction documents. Ensure that VOC limits are clearly stated where carpet systems are addressed.	Carpet systems must meet or exceed the requirements of the Carpet and Rug Institute's Green Label Indoor Air Quality Test Program.
C4.4	Low-Emitting Materials: Composite Wood	1	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.	Specify wood and agrifiber products that contain no added urea-formaldehyde resins.	Composite wood and agrifiber products must contain no added urea-formaldehyde resins.
C5	Indoor Chemical & Pollutant Source Control	1	Avoid exposure of building occupants to potentially hazardous chemicals that adversely impact air quality.	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 occupantborne contaminants from entering the building.	Employ permanent entryway systems (grills, grates, etc.) to capture dirt, particulates, etc. Where chemical use occurs (including housekeeping areas and copying/printing rooms), provide segregated areas with deck to deck partitions with separate outside exhaust.
C6.1	Controllability of Systems: Perimeter Spaces	1	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 wellbeing of building occupants.	Design the building with occupant controls for airflow, temperature and lighting. Strategies to consider include lighting controls, task lighting and operable windows.	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.
C6.2	Controllability of Systems: Non-Perimeter Spaces	1	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 wellbeing of building occupants.	Design the building with occupant controls for airflow, temperature and lighting. Strategies to consider include lighting controls, task lighting and operable windows.	Provide controls for each individual for airflow, temperature and lighting for at least 50% of the occupants in non-perimeter, regularly occupied areas.
C7.1	Thermal Comfort: Compliance with ASHRAE 55-1992	1	Provide a thermally comfortable environment that supports the productivity and well-being of building occupants.	Establish temperature and humidity comfort ranges and design the building envelope and HVAC system to maintain these comfort ranges.	Comply with ASHRAE Standard 55-1992, Addenda 1995, for thermal comfort standards including humidity control within established ranges per climate zone.

No	Description	Credit	Intent	Strategies	Requirements
C7.2	Thermal Comfort: Permanent Monitoring System	1	Provide a thermally comfortable environment that supports the productivity and well-being of building occupants.	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.	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.
C8.1	Daylight and Views. Daylight 75% of Spaces	1	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.	Design the building to maximize interior daylighting. 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 daylighting via calculations or model daylighting strategies with a physical or computer model to assess footcandle levels and daylight factors achieved.	Achieve a minimum Daylight Factor of 2% (excluding all direct sunlight penetration) in 75% of all space occupied for critical visual tasks. Certain spaces are exempted
F	**Innovation & Design Process**	**5**			
C1	Innovation in Design	1to4	To provide design teams and projects the opportunity to be awarded points for exceptional performance above the requirements set by the LEED Green Building Rating System and/or innovative performance in Green Building categories not specifically addressed by the LEED Green Building Rating System.	Substantially exceed a LEED performance credit such as energy performance or water efficiency. Apply strategies or measures that are not covered by LEED such as acoustic performance, education of occupants, community development or lifecycle analysis of material choices.	In writing, identify the intent of the proposed innovation credit, the proposed requirement for compliance, the proposed submittals to demonstrate compliance, and the design approach (strategies) that might be used to meet the requirements. 1.2 same as above 1.3 same as above 1.4 same as above
C2.1	LEED Accredited Professional	1	To support and encourage the design integration required by a LEED Green Building project and to streamline the application and certification process.	Attending a LEED Accredited Professional Training Workshop is recommended but not required. Study the LEED Reference Guide. Successfully pass the LEED accreditation exam.	At least one principal participant of the project team that has successfully completed the LEED Accredited Professional exam

Appendix B1

a. BSIH matrix for 2 system interactions

	Remote	Touching	Connected	Meshed	Unified
Str + Env			Structural elements may be the studs and the envelope may be the drywall attached to the studs. In this case both are permanently attached.		In some cases both may be able to be told apart for e.g. alternative framing materials such as foam core panels where the structure and the envelope are unified.
Str + HVAC	The actual generator equipment might be placed within a basement space and be remote to the structural system.	AHU may be touching the structure where they are placed	Ducting, distribution system is connected to the structural system	Outlets may be meshed with the floor structure. Sometimes the idea of connected and meshed may have to be based on a value judgment.	
Str + Plum			Fixtures such as the water closet are connected to the structure.	Distribution systems may be meshed within a wall cavity as part of the overall structure.	
Str + Elec	Actual appliances may be remote from the structure.		Electrical outlasts are connected to the structure with screws or bolts. Distribution systems such as the electrical raceways are also connected to the wall structure.	Wiring may be meshed within the wall structure.	

Sr-C

Sr-I

Sr-I

Zn-
HNAC

Zn-

Zn-

	Remote	Touching	Connected	Meshed	Unified
Str + Comm	Actual appliances may be remote from the structure.		Outlets and raceways are connected to the wall or floor structure.	Wiring may be meshed within the wall structure.	
Str + Int A			All mentioned parts of the Int A system are connected to the structure.		
Str + Int B	All interior elements are remote from the structure since they are movable and replaceable.				
Env + HVAC	The actual generator equipment might be placed within a basement space and be remote from the envelope.	AHU may be touching the envelope where they are placed	Ducting system may be connected to the envelope through the structure.		
Env + Plum			Fixtures such as the water closet are connected to the envelope via the structure.		
Env + Elec			Electrical outlets as well as the distribution systems are connected to the envelope via the structure with screws or bolts.		

Env -
Comm

Env - Int

Env - In

HVAC -
Plum

HVAC -
Elec

HVAC -
Comm

HVAC -
A

HVAC -
B

Plum - E

	Remote	Touching	Connected	Meshed	Unified
Env + Comm			Outlets and raceways are connected to the envelope via the structure.		
Env + Int A			All mentioned parts of the Int A system are connected to the envelope via the structure.		
Env + Int B	All interior elements are remote from the envelope since they are movable and replaceable.	In some instances interior elements may be touching the envelope.			
HVAC + Plum	Systems are remote from each other.				
HVAC + Elec	Systems are remote from each other.				
HVAC + Comm	Systems are remote from each other.				
HVAC + Int A	Systems are remote from each other.				HVAC outlets may be considered Int A
HVAC + Int B	Systems are remote from each other.				
Plum + Elec	Systems are remote from each other.				

	Remote	Touching	Connected	Meshed	Unified
Plum + Comm	Systems are remote from each other.				
Plum + Int A	Systems are remote from each other.				
Plum + Int B	Systems are remote from each other.				Outlets may be considered Int A
Elec + Comm				Wiring distribution may be from the same cavity.	Adapters which can transfer data on existing electrical wiring.
Elec + Int A					Outlets may be considered Int A
Elec + Int B	Systems are remote from each other in cases where the objects are moveable and replaceable.				
Comm + Int A					Outlets may be considered Int A
Comm + Int B	Systems are remote from each other.				
Int A + Int B	Systems are remote from each other in cases where the objects are moveable and replaceable.	In many instances sytems may be touching such as a partition wall and a piece of furniture.			In instances a piece of furniture may serve as a partition wall.

Str - Env -
HVAC

Str - Env -

Str - Env

Str - Env
Comm

Str - Env

Str - Env

Str - HV
Plum

Str - HV
Elec

b. BSIH matrix for 3 system interactions

	Remote	Touching	Connected	Meshed	Unified
Str + Env + HVAC			HVAC distribution systems are connected to the structure via the envelope		In many cases the envelope and structure might not be different
Str + Env + Plum			Plumbing distribution systems are connected to the structure via the envelope		In many cases the envelope and structure might not be different
Str + Env + Elec			Electrical distribution systems are connected to the structure via the envelope		In many cases the envelope and structure might not be different
Str + Env + Comm			Communication distribution systems are connected to the structure via the envelope		In many cases the envelope and structure might not be different
Str + Env + Int A			Partition walls and fixtures are connected to the structure via the envelope		In many cases the envelope and structure might not be different
Str + Env + Int B	Moveable furniture may be remote from the structure and the envelope	In many cases the movable units may be touching			
Str + HVAC + Plum	In most cases the two builing systems would be remote from each other		The outlets are connected to the structure in both cases HVAC and plumbing		
Str + HVAC + Elec	In most cases the two building systems would be remote from each other		The outlets are connected to the structure in both cases HVAC and electrical		

Str - HVA
Comm

Str - HVA
Int B

Str - Plu
Elec

Str - Plu
Comm

Str - Plu
A

Str - Plu
B

Str - Ele
Comm

Str - Elec
A

	Remote	Touching	Connected	Meshed	Unified
Str + HVAC + Comm	In most cases the two building systems would be remote from each other		The outlets are connected to the structure in both cases HVAC and communication systems		
Str + HVAC + Int B	Int B elements will remote from structure and HVAC systems in most cases		Structure and HVAC systems will be connected		
Str + Plum + Elec	Plumbing and electrical systems will be remote		Distribution systems for both plumbing and electrical systems will be connected to the structure		In many cases electrical distribution will be unified with the structural wall
Str + Plum + Comm	Plumbing and communication systems will be remote		Distribution systems for both plumbing and communication systems will be connected to the structure		In many cases communication distribution will be unified with the structural wall
Str + Plum + Int A			Plumbing distribution and oulets will be connected to the structure		The outlets for plumbing are part of both Plumbing systems as well as Int A systems
Str + Plum + Int B	Int B elements will remote from structure and plumbing systems in most cases	Structure and Int B systems may be touching	Plumbing distribution will be connected to the structure		
Str + Elec + Comm			Structure and electrical and communication systems will be connected		In some cases electrical and communication systems are unified
Str + Elec + Int A			Structure and electrical will be connected		The outlets for electrical are part of both electrical systems as well as Int A systems

	Remote	Touching	Connected	Meshed	Unified
Str + Elec + Int B	Int B elements will remote from structure and electrical systems in most cases	Structure and Int B systems may be touching			In many cases electrical distribution will be unified with the structural wall
Str + Comm + Int A			Structure and communcation systems will be connected		The outlets for communication are part of both Communication systems as well as Int A systems
Str + Comm + Int B	Int B elements will remote from structure and communication systems in most cases	Structure and Int B systems may be touching	Communication distribution will be connected to the structure		
Str + Int A + Int B	Int B elements will be remote	Int B systems may be toucing structure and Int A systems	Int A systems may be connected to the structure		
Env + HVAC + Plum	HVAC and Plumbing systems are remote		Envelope will be connected to both systems via the structure		
Env + HVAC + Elec	HVAC and Electrical systems are remote		Envelope will be connected to both systems via the structure		
Env + HVAC + Comm	HVAC and Communication systems are remote		Envelope will be connected to both systems via the structure		
Env + HVAC + Int A			Envelope will be connected to both systems via the structure		
Env + HVAC + Int B	Int B systems may be remote	Int B systems may be touching the envelope	Envelope will be connected to HVAC systems via the structure		

Env - E
Ele

Env - E
Comm

Env - E
A

Env - E
B

Env - E
Comm

Env -
A

Env -
B

Env -
Ins: A

	Remote	Touching	Connected	Meshed	Unified
Env + Plum + Elec	Plumbing and electrical systems will be remote		Envelope will be connected to both systems via the structure		
Env + Plum + Comm	Plumbing and communication systems will be remote		Envelope will be connected to both systems via the structure		
Env + Plum + Int A			All systems will be connected		Outlets are part of both plumbing systems and Int A
Env + Plum + Int B	Int B elements will remote from envelope and plumbing systems in most cases	Envelope and Int B systems may be touching	Plumbing distribution will be connected to the structure		
Env + Elec + Comm			Envelope and electrical and communication systems will be connected		In some cases electrical and communication systems are unified
Env + Elec + Int A			Envelope and electrical will be connected		The outlets for electrical are part of both electrical systems as well as Int A systems
Env + Elec + Int B	Int B elements will remote from envelope and electrical systems in most cases	Envelope and Int B systems may be touching			In many cases electrical distribution will be unified with the structural wall as well as
Env + Comm + Int A			Envelope and communcation systems will be connected		The outlets for communication are part of both Communication systems as well as Int A systems

Env - C
Int B

Env - I
B

HVAC -
Elec

HVAC -
Comm

HVAC -
Int A

HVAC -
Int B

HVAC
Comm

	Remote	Touching	Connected	Meshed	Unified
Env + Comm + Int B	Int B elements will remote from envelope and communication systems in most cases	Envelope and Int B systems may be touching	Communication distribution will be connected to the structure via the envelope		
Env + Int A + Int B	Int B elements will be remote	Int B systems may be touching envelope and Int A systems	Int A systems may be connected to the structure via the envelope		
HVAC + Plum + Elec	HVAC and Plumbing and electrical systems are remote				
HVAC + Plum + Comm	HVAC and Plumbing and communication systems are remote				
HVAC + Plum + Int A	HVAC and Plumbing systems are remote		HVAC and plumbing systems are connected to the Int A systems		The outlets for both building systems are part of Int A systems as well
HVAC + Plum + Int B	Int B systems may be remote as well as HVAC and plumbing systems				
HVAC + Elec + Comm	All systems are remote				In some cases electrical and communication systems are unified

HVAC
Int A

HVAC
Int B

HVAC
- Int A

HVAC -
- Int B

HVAC -
Int B

Plum -
Comm

Plum -
A

Plum -
B

	Remote	Touching	Connected	Meshed	Unified
HVAC + Elec + Int A	HVAC and Electrical systems are remote		HVAC and electrical systems are connected to the Int A systems		The outlets for both building systems are part of Int A systems as well
HVAC + Elec + Int B	All systems are remote				
HVAC + Comm + Int A	HVAC and Communication systems are remote		HVAC and communication systems are connected to the Int A systems		The outlets for both building systems are part of Int A systems as well
HVAC + Comm + Int B	All systems are remote				
HVAC + Int A + Int B	Int B elements will be remote				The outlets for building systems are part of Int A systems as well
Plum + Elec + Comm	Plumbing systems are remote from electrical and communicaiton				In some cases electrical and communication systems are unified
Plum + Elec + Int A	Plumbing and electrical systems will be remote				The outlets for building systems are part of Int A systems as well
Plum + Elec + Int B	All systems are remote				

Plum
Int A

Plum
Int B

Plum
Int B

Elec -
Int A

Elec -
Int B

Elec -
B

Comm
Int B

	Remote	Touching	Connected	Meshed	Unified
Plum + Comm + Int A	Plumbing and communication systems will be remote				The outlets for building systems are part of Int A systems as well. In some cases electrical and communication systems are unified
Plum + Comm + Int B	All systems are remote				
Plum + Int A + Int B	Int B elements will be remote				The outlets for building systems are part of Int A systems as well
Elec + Comm + Int A		Electrical and communication systems may be touching			The outlets for building systems are part of Int A systems as well. In some cases electrical and communication systems are unified
Elec + Comm + Int B	Int B systems are remote	Electrical and communication systems may be touching			In some cases electrical and communication systems are unified
Elec + Int A + Int B	Int B systems are remote				The outlets for building systems are part of Int A systems as well
Comm + Int A + Int B	Int B systems are remote				The outlets for building systems are part of Int A systems as well

Appendix B2

Intent

Physical decisions for HVAC systems

Spatial flexibility
- Selection of appropriate HVAC system
  - Building type
  - Sizing
  - Aesthetics
  - Noise and vibrations
  - Space requirements
- Passive Solar heating
- Active solar heating

Thermal performance
- Human confort zone (db) 68-78F, RH 20-70%
- Sun control to reduce solar heat gain / shading (refer Bobenhausen 1994)
- Heat loss due to building envelope (refer Bobenhausen 1994)
- Integrating Heating and ventilating requirements (HRV)
- Selection of appropriate HVAC system
  - Building type
  - Climate
  - Heating requirements
  - Response time
  - Reliability and maintainability
- Passive solar heating
- Active solar heating
- Fuel requirements

Physical decisions for HVAC systems

Structural Integrity
- Selection of appropriate HVAC system
  - Building type
  - Aesthetics
  - Space requirements
  - Fire safety
- Placement of equipment such as rooftops
- Active Solar design

Ease of construction
- Placement of equipment
  - Ease of handling
  - Space requirements
  - Access
- Placement of distribution system
  - Ease of handling
  - Oulets
  - Distribution core
- Clarity of installation instructions

Ease of maintanence
- Accessibility
- Compactness of distribution
- Inteferences from other utility systems

Physical decisions for Plum systems

Spatial flexibility
- Placement of distribution system
  - Wall distribution
  - Floor distribution
- Design for vertical stacking of wet cores
- Water less outlets

Thermal performance
- Loss of heat from heated water during distribution
- Insulation of wiring
- Crawl space design
- Grey water resue
- Waterless outlets
- Reduction of water consumption
- Rainwater harvesting

Physical decisions for Plum systems

Structural Integrity
- Placement of distribution system
  - Utility core

Ease of construction
- Placement of equipment
  - Ease of handling
  - Space requirements
  - Access
- Placement of distribution system
  - Ease of handling
  - Oulets
  - Distribution core
- Clarity of installation instructions

Ease of maintanence
- Accessibility
- Compactness of distribution
- Inteferences from other utility systems
- Fixtures reliability
- Equipment reliability

Physical decisions for Str systems

Spatial flexibility
- Selection of appropriate Str system
  - Building type
  - Sizing of memebers
  - Aesthetics
- Standardization of members
- Movability of partitions
- Handelability of members
  - Size
  - Weight
- Rainwater harvesting design
- Grey water reuse

Thermal performance
- Sealing wall cavity
- Material thermal performance
- Junctions energy loss
  - Wall and roof
  - Wall and floor
  - Subfloor energy loss
- Reduction of loss of heat from distribution of heated water
- Use of solar water heaters
- Use of solar panels to generate electricity for water heaters

Physical decisions for Str systems

Structural Integrity
- Not applicable

Ease of construction
- Ease of handling
- Space requirements
- Access
- Handelability of members
  - Size
  - Weight
- Clarity of installation instructions

Ease of maintanence
- Accessibility
- Compactness of distribution
- Distribution of utility systems
  - Utility core / structural core
  - Embedded utility runs

Strategies

Inferences for integration between Str, HVAC and Plum systems

Spatial flexibility
- Movable walls and partitions for flexibility of usage
- Design for "Use modules" (Wet cores / Dry cores / Utility cores) serve as structural cores
- Design on a grid for flexibility
- Snap on / sliding walls
- Rainwater harvesting through design
- Grey water reuse design to be incorporated

Thermal Performance
- Passive energy design / shading
- Active energy design / use solar panels
- Wall material thermal performance
- Glass composition for the windows to better the thermal performance
- Sealing junctions
- Better thermal performance through improved OSB design for framing walls
- Grey water reuse

Structural integrity
- Utility core serves as a structural core
- Design on a grid for integrity
- Use of alternative framing vs regular wooden stud walls
- OSB strength redesign to increase structural strength in both directions

Ease of construction
- Grid design to facilitate usage of prefabricated components
- "Use modules" which are dry cores, wet cores, utility cores
- OSB strength redesign for ease during construction with respect to placement of windows

Ease of maintanence
- Utility cores intergarte all utlities in one space such that they are easy to maintain
- Easy access of all utlities
- HVAC distribution to be placed in the subfloor to faciltate ease of access
- Detacheable panels on the subfloor to facilitate access
- Plumbing through vertical stack avoiding horizontal distribution

Sustainable design
- Active / Passive solar design
- Shading devices
- Daylighting techniques
- Window glazing design
- Greywater reuse
- Waterless outlets
- Rainwater harvesting
- Junction sealent / gaskets

Intent

Physical decisions for HVAC systems

Spatial flexibility
- Selection of appropriate HVAC system
  - Building type
  - Sizing
  - Aesthetics
  - Noise and vibrations
  - Space requirements
- Passive Solar heating
- Active solar heating

Thermal performance
- Human confort zone (db) 68-78F, RH 20-70%
- Sun control to reduce solar heat gain / shading (refer Bobenhausen 1994)
- Heat loss due to building envelope (refer Bobenhausen 1994)
- Integrating Heating and ventilating requirements (HRV)
- Selection of appropriate HVAC system
  - Building type
  - Climate
  - Heating requirements
  - Response time
  - Reliability and maintainability
- Passive solar heating
- Active solar heating
- Fuel requirements

Physical decisions for HVAC systems

Structural Integrity
- Selection of appropriate HVAC system
  - Building type
  - Aesthetics
  - Space requirements
  - Fire safety
- Placement of equipment such as rooftops
- Active Solar design

Ease of construction
- Placement of equipment
  - Ease of handling
  - Space requirements
  - Access
- Placement of distribution system
  - Ease of handling
  - Oulets
  - Distribution core
- Clarity of installation instructions

Ease of maintanence
- Accessibility
- Compactness of distribution
- Inteferences from other utility systems

Physical decisions for Elec systems

Spatial flexibility
- Selection of appropriate Elec service system
  - Building type
  - Sizing
  - Aesthetics
  - Overhead / Underground
  - Clearence required
- Placement of distribution system
  - Raceways
  - Wall embedded
  - Utility core
  - Ducting system
- Flexibility of usage
- Placement of outlets
- Capacity
- Fire safety
- Natural light as an alternative

Thermal performance
- Distance run for distribution system to determine energy lost
- Sealing building structure to avoid energy loss
- Type of wiring
- Utility core to avoid dispersion of energy
- Effectiveness of lighting fixtures
- Natural light as an alternative
- Lighting fixtures

Physical decisions for Elec systems

Structural Integrity
- Placement of equipment
- Placement of distribution system
  - Raceways
  - Utility core

Ease of construction
- Placement of equipment
  - Ease of handling
  - Space requirements
  - Access
- Placement of distribution system
  - Ease of handling
  - Oulets
  - Distribution core
- Clarity of installation instructions

Ease of maintanence
- Accessibility
- Compactness of distribution
- Inteferences from other utility systems
- Lighting fixtures reliability
- Equipment reliability

Physical decisions for Str systems

Spatial flexibility
- Selection of appropriate Str system
  - Building type
  - Sizing of memebers
  - Aesthetics
- Standardization of members
- Movability of partitions
- Handelability of members
  - Size
  - Weight

Thermal performance
- Sealing wall cavity
- Material thermal performance
- Junctions energy loss
  - Wall and roof
  - Wall and floor
  - Subfloor energy loss

Physical decisions for Str systems

Structural Integrity
- Not applicable

Ease of construction
- Ease of handling
- Space requirements
- Access
- Handelability of members
  - Size
  - Weight
- Clarity of installation instructions

Ease of maintanence
- Accessibility
- Compactness of distribution
- Distribution of utility systems
  - Utility core / structural core
  - Embedded utility runs

Strategies

Inferences for integration between Str, HVAC and Elec systems

Spatial flexibility
- Movable walls and partitions for flexibility of usage
- Design for "Use modules" (Wet cores / Dry cores / Utility cores) serve as structural cores
- Alternative framing materials for ease of handling
- Use of movable storage units to define space
- Design on a grid for flexibility
- Snap on / sliding walls
- Utility runs to be under the floor structure to increase manouverability

Thermal Performance
- Passive energy design / shading
- Active energy design / use solar panels
- Wall material thermal performance
- Glass composition for the windows to better the thermal performance
- Sealing junctions
- Better thermal performance through improved OSB design for framing walls

Structural integrity
- Utility core serves as a structural core
- Design on a grid for integrity
- Use of alternative framing vs regular wooden stud walls
- OSB strength redesign to increase structural strength in both directions

Ease of construction
- Grid design to facilitate usage of prefabricated components
- "Use modules" which are dry cores, wet cores, utility cores
- OSB strength redesign for ease during construction with respect to placement of windows

Ease of maintanence
- Utility cores intergarte all utilities in one space such that they are easy to maintain
- Easy access of all utilities
- Electrical distribution through raceways
- Flexibility of placement of distribution systems through the use of detacheable raceways
- HVAC distribution to be placed in the subfloor to facilitate ease of access
- Detacheable panels in the subfloor for easy access

Sustainable design
- Energy Star appliances
- Active / Passive solar design
- Shading devices
- Daylighting techniques
- Window glazing design
- Junction sealent / gaskets

Intent

Physical decisions for HVAC systems

Spatial flexibility
- Selection of appropriate HVAC system
  - Building type
  - Sizing
  - Aesthetics
  - Noise and vibrations
  - Space requirements
- Passive Solar heating
- Active solar heating

Thermal performance
- Human confort zone (db) 68-78F, RH 20-70%
- Sun control to reduce solar heat gain / shading (refer Bobenhausen 1994)
- Heat loss due to building envelope (refer Bobenhausen 1994)
- Integrating Heating and ventilating requirements (HRV)
- Selection of appropriate HVAC system
  - Building type
  - Climate
  - Heating requirements
  - Response time
  - Reliability and maintainability
- Passive solar heating
- Active solar heating
- Fuel requirements

Physical decisions for HVAC systems

Structural Integrity
- Selection of appropriate HVAC system
  - Building type
  - Aesthetics
  - Space requirements
  - Fire safety
- Placement of equipment such as rooftops
- Active Solar design

Ease of construction
- Placement of equipment
  - Ease of handling
  - Space requirements
  - Access
- Placement of distribution system
  - Ease of handling
  - Oulets
  - Distribution core
- Clarity of installation instructions

Ease of maintanence
- Accessibility
- Compactness of distribution
- Inteferences from other utility systems

Physical decisions for Comm systems

Spatial flexibility
- Placement of distribution system
  - Wall distribution
  - Floor distribution
- Flexible distribution systems such as raceways which may be unclipped and placed as required
- Distribution over existing electrical wiring
- Wireless systems
- Integrated wiring systems for phone cable and internet/structured wiring

Thermal performance
- Not applicable

Physical decisions for Comm systems

Structural Integrity
- Placement / flexibilityof distribution system

Ease of construction
- Placement of equipment
  - Ease of handling
  - Space requirements
  - Access
- Placement of distribution system
  - Ease of handling
  - Oulets
  - Distribution core
- Clarity of installation instructions

Ease of maintanence
- Accessibility
- Compactness of distribution
- Integration of communication wiring
- Integration with electrical systems
- Fixtures reliability
- Equipment reliability

Physical decisions for Str systems

Spatial flexibility
- Selection of appropriate Str system
  - Building type
  - Sizing of memebers
  - Aesthetics
- Standardization of members
- Movability of partitions
- Handelability of members
  - Size
  - Weight
- Rainwater harvesting design
- Grey water reuse

Thermal performance
- Sealing wall cavity
- Material thermal performance
- Junctions energy loss
  - Wall and roof
  - Wall and floor
  - Subfloor energy loss

Physical decisions for Str systems

Structural Integrity
- Not applicable

Ease of construction
- Ease of handling
- Space requirements
- Access
- Handelability of members
  - Size
  - Weight
- Clarity of installation instructions

Ease of maintanence
- Accessibility
- Compactness of distribution
- Distribution of utility systems
  - Utility core / structural core
  - Embedded utility runs

Strategies

Inferences for integration between Str, HVAC and Comm systems

Spatial flexibility
- Movable walls and partitions for flexibility of usage
- Design for "Use modules" (Wet cores / Dry cores / Utility cores) serve as structural cores
- Design on a grid for flexibility
- Snap on / sliding walls
- Integrative wiring / structured wiring for phone cable and internet
- Data transfer over existing electrical wiring
- Flexible placement of raceways so that they can be moved around as per chages in spatial arrangement

Thermal Performance
- Passive energy design / shading. Active energy design / use solar panels
- Glass composition for the windows to better the thermal performance
- Sealing junctions
- Better thermal performance through improved OSB design for framing walls

Structural integrity
- Utility core serves as a structural core
- Design on a grid for integrity
- Use of alternative framing vs regular wooden stud walls
- OSB strength redesign to increase structural strength in both directions

Ease of construction
- Grid design to facilitate usage of prefabricated components
- "Use modules" which are dry cores, wet cores, utility cores
- OSB strength redesign for ease during construction with respect to placement of windows

Ease of maintanence
- Utility cores intergarte all utlities in one space such that they are easy to maintain
- Easy access of all utilities
- Use of structured wiring
- Integration of electrical and communication systems
- Flexibility of placement of distribution systems through the use of detacheable raceways
- HVAC distribution to be placed in the subfloor to faciltate ease of access
- Detacheable panels on the subfloor for easy access

Sustainable design
- Active / Passive solar design
- Shading devices
- Daylighting techniques
- Window glazing design
- Junction sealent / gaskets

Intent

Physical decisions for HVAC systems

Spatial flexibility
- Selection of appropriate HVAC system
  - Building type
  - Sizing
  - Aesthetics
  - Noise and vibrations
  - Space requirements
- Passive Solar heating
- Active solar heating

Thermal performance
- Human confort zone (db) 68-78F, RH 20-70%
- Sun control to reduce solar heat gain / shading (refer Bobenhausen 1994)
- Heat loss due to building envelope (refer Bobenhausen 1994)
- Integrating Heating and ventilating requirements (HRV)
- Selection of appropriate HVAC system
  - Building type
  - Climate
  - Heating requirements
  - Response time
  - Reliability and maintainability
- Passive solar heating
- Active solar heating
- Fuel requirements

Physical decisions for HVAC systems

Structural Integrity
- Selection of appropriate HVAC system
  - Building type
  - Aesthetics
  - Space requirements
  - Fire safety
- Placement of equipment such as rooftops
- Active Solar design

Ease of construction
- Placement of equipment
  - Ease of handling
  - Space requirements
  - Access
- Placement of distribution system
  - Ease of handling
  - Oulets
  - Distribution core
- Clarity of installation instructions

Ease of maintanence
- Accessibility
- Compactness of distribution
- Inteferences from other utility systems

Physical decisions for Int A systems

Spatial flexibility
- Placement of distribution for HVAC system
  - Wall distribution
  - Floor distribution
- Flexible distribution systems such as raceways which may be unclipped and placed as required
- Wireless systems
- Clip on outlets
- Partition walls to be moveable
- Raceways to serve as skirting for walls

Thermal performance
- Sealing loss from distribution systems
- Placement of distribution systems in the crawl space to be insulated
- Zoned heating and cooling to allow for flexibility

Physical decisions for Int A systems

Structural Integrity
- Design of partition wall layout
- Design on a grid
- Material / improved strength OSB

Ease of construction
- Placement of equipment
  - Ease of handling
  - Space requirements
  - Access
- Placement of distribution system
  - Ease of handling
  - Oulets
  - Distribution core
- Clarity of installation instructions

Ease of maintanence
- Accessibility
- Compactness of distribution
- Integration of communication wiring
- Integration with electrical systems
- Fixtures reliability
- Equipment reliability

Physical decisions for Str systems

Spatial flexibility
- Selection of appropriate Str system
  - Building type
  - Sizing of memebers
  - Aesthetics
- Standardization of members
- Movability of partitions
- Handelability of members
  - Size
  - Weight
- Rainwater harvesting design
- Grey water reuse

Thermal performance
- Sealing wall cavity
- Material thermal performance
- Junctions energy loss
  - Wall and roof
  - Wall and floor
  - Subfloor energy loss

Physical decisions for Str systems

Structural Integrity
- Not applicable

Ease of construction
- Ease of handling
- Space requirements
- Access
- Handelability of members
  - Size
  - Weight
- Clarity of installation instructions

Ease of maintanence
- Accessibility
- Compactness of distribution
- Distribution of utility systems
  - Utility core / structural core
  - Embedded utility runs

Strategies

Inferences for integration between Str, HVAC and Int A systems

Spatial flexibility
- Movable walls and partitions for flexibility of usage
- Design for "Use modules" (Wet cores / Dry cores / Utility cores) serve as structural cores
- Design on a grid for flexibility
- Snap on / sliding walls
- Flexible placement of raceways so that they can be moved around as per chages in spatial arrangement
- Wireless systems
- Zoned heating and cooling to allow for flexibility

Thermal Performance
- Passive energy design / shading. Active energy design / use solar panels
- Glass composition for the windows to better the thermal performance
- Sealing junctions
- Better thermal performance through improved OSB design for framing walls

Structural integrity
- Utility core serves as a structural core
- Design on a grid for integrity
- Use alternative framing vs. regular wooden stud walls
- OSB strength redesign to increase structural strength in both directions

Ease of construction
- Grid design to facilitate usage of prefabricated components
- "Use modules" which are dry cores, wet cores, utility cores
- OSB strength redesign for ease during construction with respect to placement of windows

Ease of maintanence
- Utility cores intergarte all utlities in one space such that they are easy to maintain
- Easy access of all utilities
- Flexibility of placement of distribution systems through the use of detacheable raceways
- HVAC distribution to be placed in the subfloor to faciltate ease of access
- Detacheable panels on the subfloor for easy access

Sustainable design
- Energy Star appliances
- Active / Passive solar design
- Shading devices
- Daylighting techniques
- Window glazing design
- Junction sealent / gaskets

Intent

Physical decisions for HVAC systems

Spatial flexibility
- Selection of appropriate HVAC system
  - Building type
  - Sizing
  - Aesthetics
  - Noise and vibrations
  - Space requirements
- Passive Solar heating
- Active solar heating

Thermal performance
- Human confort zone (db) 68-78F, RH 20-70%
- Sun control to reduce solar heat gain / shading (refer Bobenhausen 1994)
- Heat loss due to building envelope (refer Bobenhausen 1994)
- Integrating Heating and ventilating requirements (HRV)
- Selection of appropriate HVAC system
  - Building type
  - Climate
  - Heating requirements
  - Response time
  - Reliability and maintainability
- Passive solar heating
- Active solar heating
- Fuel requirements

Physical decisions for HVAC systems

Structural Integrity
- Selection of appropriate HVAC system
  - Building type
  - Aesthetics
  - Space requirements
  - Fire safety
- Placement of equipment such as rooftops
- Active Solar design

Ease of construction
- Placement of equipment
  - Ease of handling
  - Space requirements
  - Access
- Placement of distribution system
  - Ease of handling
  - Oulets
  - Distribution core
- Clarity of installation instructions

Ease of maintanence
- Accessibility
- Compactness of distribution
- Inteferences from other utility systems

Physical decisions for Int B systems

Spatial flexibility
- Use of moveable storage units as partitions
- Primary utility systems to be attached to structural walls
- Roof mounted utilities to facilitate flexibility

Thermal performance
- Flexible design for height of partitions so that they can be lowered during summer time to facilitte movement of air

Physical decisions for Int B systems

Structural Integrity
- Not applicable

Ease of construction
- Open plans to facilitate ease in design and construciton

Ease of maintanence
- Seperate furniture units which are replaceable and moveable

Physical decisions for Str systems

Spatial flexibility
- Selection of appropriate Str system
  - Building type
  - Sizing of memebers
  - Aesthetics
- Standardization of members
- Movability of partitions
- Handelability of members
  - Size
  - Weight
- Rainwater harvesting design
- Grey water reuse

Thermal performance
- Sealing wall cavity
- Material thermal performance
- Junctions energy loss
  - Wall and roof
  - Wall and floor
  - Subfloor energy loss

Physical decisions for Str systems

Structural Integrity
- Not applicable

Ease of construction
- Ease of handling
- Space requirements
- Access
- Handelability of members
  - Size
  - Weight
- Clarity of installation instructions

Ease of maintanence
- Accessibility
- Compactness of distribution
- Distribution of utility systems
  - Utility core / structural core
  - Embedded utility runs

Strategies

Inferences for integration between Str, HVAC and Int B systems

Spatial flexibility
- Movable walls and partitions for flexibility of usage
- Design for "Use modules" (Wet cores / Dry cores / Utility cores) serve as structural cores
- Design on a grid for flexibility
- Wireless systems
- Zoned heating and cooling to allow for flexibility
- Moveable storage units

Thermal Performance
- Passive energy design / shading. Active energy design / use solar panels
- Glass composition for the windows to better the thermal performance
- Sealing junctions
- Better thermal performance through improved OSB design for framing walls
- Changeable height of storage units for internal air movement

Structural integrity
- Utility core serves as a structural core
- Design on a grid for integrity
- Use alternative framing vs. regular wooden stud walls aterials may prove effective
- OSB strength redesign to increase structural strength in both directions

Ease of construction
- Grid design to facilitate usage of prefabricated components
- "Use modules" which are dry cores, wet cores, utility cores
- OSB strength redesign for ease during construction with respect to placement of windows

Ease of maintanence
- Utility cores intergarte all utilities in one space such that they are easy to maintain
- Easy access of all utilities
- Flexibility of placement of distribution systems through the use of detacheable raceways
- HVAC distribution to be placed in the subfloor to facilitate ease of access
- Moveable, changeable storage units built in modules

Sustainable design
- Active / Passive solar design
- Shading devices
- Daylighting techniques
- Window glazing design
- Junction sealent / gaskets

Physical decisions for

Physical decisions for

Intent

Physical decisions for Plum systems

Spatial flexibility
- Placement of distribution system
  - Wall distribution
  - Floor distribution
- Design for vertical stacking of wet cores
- Water less outlets

Thermal performance
- Loss of heat from heated water during distribution
- Insulation of equipment and piping
- Crawl space design
- Grey water resue
- Waterless outlets
- Reduction of water consumption
- Rainwater harvesting

Physical decisions for Plum systems

Structural Integrity
- Placement of distribution system
  - Utility core

Ease of construction
- Placement of equipment
  - Ease of handling
  - Space requirements
  - Access
- Placement of distribution system
  - Ease of handling
  - Oulets
  - Distribution core
- Clarity of installation instructions

Ease of maintanence
- Accessibility
- Compactness of distribution
- Inteferences from other utility systems
- Fixtures reliability
- Equipment reliability

Physical decisions for Elec systems

Spatial flexibility
- Selection of appropriate Elec service system
  - Building type
  - Sizing
  - Aesthetics
  - Overhead / Underground
  - Clearence required
- Placement of distribution system
  - Raceways
  - Wall embedded
  - Utility core
  - Ducting system
- Flexibility of usage
- Placement of outlets
- Capacity
- Fire safety
- Natural light as an alternative

Thermal performance
- Distance run for distribution system to determine energy lost
- Sealing building structure to avoid energy loss
- Type of wiring
- Utility core to avoid dispersion of energy
- Effectiveness of lighting fixtures
- Natural light as an alternative
- Lighting fixtures

Physical decisions for Elec systems

Structural Integrity
- Placement of equipment
- Placement of distribution system
  - Raceways
  - Utility core

Ease of construction
- Placement of equipment
  - Ease of handling
  - Space requirements
  - Access
- Placement of distribution system
  - Ease of handling
  - Oulets
  - Distribution core
- Clarity of installation instructions

Ease of maintanence
- Accessibility
- Compactness of distribution
- Inteferences from other utility systems
- Lighting fixtures reliability
- Equipment reliability

Physical decisions for Str systems

Spatial flexibility
- Selection of appropriate Str system
  - Building type
  - Sizing of memebers
  - Aesthetics
- Standardization of members
- Movability of partitions
- Handelability of members
  - Size
  - Weight

Thermal performance
- Sealing wall cavity
- Material thermal performance
- Junctions energy loss
  - Wall and roof
  - Wall and floor
  - Subfloor energy loss

Physical decisions for Str systems

Structural Integrity
- Not applicable

Ease of construction
- Ease of handling
- Space requirements
- Access
- Handelability of members
  - Size
  - Weight
- Clarity of installation instructions

Ease of maintanence
- Accessibility
- Compactness of distribution
- Distribution of utility systems
  - Utility core / structural core
  - Embedded utility runs

Strategies

Inferences for integration between Str, Plum and Elec systems

Spatial flexibility
- Movable walls and partitions for flexibility of usage
- Design for "Use modules" (Wet cores / Dry cores / Utility cores) serve as structural cores
- Alternative framing materials for ease of handling
- Use of movable storage units to define space
- Design on a grid for flexibility
- Snap on / sliding walls
- Utility runs to be under the floor structure to increase manouverability
- Raceways

Thermal Performance
- Passive energy design / shading
- Active energy design / use solar panels
- Sealing junctions
- Better thermal performance through improved OSB design for framing walls
- Insulation for plumbing equipment and piping
- Utility stack to be insulated

Structural integrity
- Utility core serves as a structural core
- Design on a grid for integrity
- Use alternative framing vs. regular wooden stud walls
- OSB strength redesign to increase structural strength in both directions

Ease of construction
- Grid design to facilitate usage of prefabricated components
- "Use modules" which are dry cores, wet cores, utility cores
- OSB strength redesign for ease during construction with respect to placement of windows

Ease of maintanence
- Utility cores intergarte all utilities in one space such that they are easy to maintain
- Easy access of all utilities
- Integration of electrical and communication systems
- Flexibility of placement of distribution systems through the use of detacheable raceways
- HVAC distribution to be placed in the subfloor to faciltate ease of access
- Plumbing through vertical stack and avoid horizontal distribution

Sustainable design
- Energy Star appliances
- Active / Passive solar design
- Shading devices
- Daylighting techniques
- Window glazing design
- Greywater reuse
- Waterless outlets
- Rainwater harvesting
- Junction sealent / gaskets

Intent

Physical decisions for Plum systems

Spatial flexibility
- Placement of distribution system
  - Wall distribution
  - Floor distribution
- Design for vertical stacking of wet cores
- Water less outlets

Thermal performance
- Loss of heat from heated water during distribution
- Insulation of wiring
- Crawl space design
- Grey water resue
- Waterless outlets
- Reduction of water consumption
- Rainwater harvesting

Physical decisions for Plum systems

Structural Integrity
- Placement of distribution system
  - Utility core

Ease of construction
- Placement of equipment
  - Ease of handling
  - Space requirements
  - Access
- Placement of distribution system
  - Ease of handling
  - Oulets
  - Distribution core
- Clarity of installation instructions

Ease of maintanence
- Accessibility
- Compactness of distribution
- Inteferences from other utility systems
- Fixtures reliability
- Equipment reliability

Physical decisions for Comm systems

Spatial flexibility
- Placement of distribution system
  - Wall distribution
  - Floor distribution
- Flexible distribution systems such as raceways which may be unclipped and placed as required
- Distribution over existing electrical wiring
- Wireless systems
- Integrated wiring systems for phone cable and internet / structured wiring

Thermal performance
- Not applicable

Physical decisions for Comm systems

Structural Integrity
- Placement / flexibilityof distribution system

Ease of construction
- Placement of equipment
  - Ease of handling
  - Space requirements
  - Access
- Placement of distribution system
  - Ease of handling
  - Oulets
  - Distribution core
- Clarity of installation instructions

Ease of maintanence
- Accessibility
- Compactness of distribution
- Integration of communication wiring
- Integration with electrical systems
- Fixtures reliability
- Equipment reliability

Physical decisions for Str systems

Spatial flexibility
- Selection of appropriate Str system
  - Building type
  - Sizing of memebers
  - Aesthetics
- Standardization of members
- Movability of partitions
- Handelability of members
  - Size
  - Weight
-

Thermal performance
- Sealing wall cavity
- Material thermal performance
- Junctions energy loss
  - Wall and roof
  - Wall and floor
  - Subfloor energy loss

Physical decisions for Str systems

Structural Integrity
- Not applicable

Ease of construction
- Ease of handling
- Space requirements
- Access
- Handelability of members
  - Size
  - Weight
- Clarity of installation instructions

Ease of maintanence
- Accessibility
- Compactness of distribution
- Distribution of utility systems
  - Utility core / structural core
  - Embedded utility runs

Strategies

Inferences for integration between Str, Plum and Comm systems

Spatial flexibility
- Movable walls and partitions for flexibility of usage
- Design for "Use modules" (Wet cores / Dry cores / Utility cores) serve as structural cores
- Alternative framing materials for ease of handling
- Use of movable storage units to define space
- Design on a grid for flexibility
- Snap on / sliding walls
- Utility runs to be under the floor structure to increase manouverability
- Structured wiring

Thermal Performance
- Passive energy design / shading
- Active energy design / use solar panels
- Wall material thermal performance
- Glass composition for the windows to better the thermal performance
- Sealing junctions
- Better thermal performance through improved OSB design for framing walls

Structural integrity
- Utility core serves as a structural core
- Design on a grid for integrity
- Use alternative framing vs. regular wooden stud walls
- OSB strength redesign to increase structural strength in both directions

Ease of construction
- Grid design to facilitate usage of prefabricated components
- "Use modules" which are dry cores, wet cores, utility cores
- OSB strength redesign for ease during construction with respect to placement of windows

Ease of maintanence
- Utility cores intergarte all utlities in one space such that they are easy to maintain
- Easy access of all utlities
- Structured wiring
- Integration of electrical and communication systems
- Flexibility of placement of distribution systems through the use of detacheable raceways
- HVAC distribution to be placed in the subfloor to faciltate ease of access

Sustainable design
- Active / Passive solar design
- Shading devices
- Daylighting techniques
- Window glazing design
- Greywater reuse
- Waterless outlets
- Rainwater harvesting
- Junction sealent / gaskets

Intent

Physical decisions for Plum systems

Spatial flexibility
- Placement of distribution system
  - Wall distribution
  - Floor distribution
- Design for vertical stacking of wet cores
- Water less outlets

Thermal performance
- Loss of heat from heated water during distribution
- Insulation of wiring
- Crawl space design
- Grey water resue
- Waterless outlets
- Reduction of water consumption
- Rainwater harvesting

Physical decisions for Plum systems

Structural Integrity
- Placement of distribution system
  - Utility core

Ease of construction
- Placement of equipment
  - Ease of handling
  - Space requirements
  - Access
- Placement of distribution system
  - Ease of handling
  - Oulets
  - Distribution core
- Clarity of installation instructions

Ease of maintanence
- Accessibility
- Compactness of distribution
- Inteferences from other utility systems
- Fixtures reliability
- Equipment reliability

Physical decisions for Int A systems

Spatial flexibility
- Placement of distribution for HVAC system
  - Wall distribution
  - Floor distribution
- Flexible distribution systems such as raceways which may be unclipped and placed as required
- Wireless systems
- Clip on outlets
- Partition walls to be moveable
- Raceways to serve as skirting for walls

Thermal performance
- Sealing loss from distribution systems
- Placement of distribution systems in the crawl space to be insulated
- Zoned heating and cooling to allow for flexibility

Physical decisions for Int A systems

Structural Integrity
- Design of partition wall layout
- Design on a grid
- Material / improved strength OSB

Ease of construction
- Placement of equipment
  - Ease of handling
  - Space requirements
  - Access
- Placement of distribution system
  - Ease of handling
  - Oulets
  - Distribution core
- Clarity of installation instructions

Ease of maintanence
- Accessibility
- Compactness of distribution
- Integration of communication wiring
- Integration with electrical systems
- Fixtures reliability
- Equipment reliability

Physical decisions for Str systems

Spatial flexibility
- Selection of appropriate Str system
  - Building type
  - Sizing of memebers
  - Aesthetics
- Standardization of members
- Movability of partitions
- Handelability of members
  - Size
  - Weight

Thermal performance
- Sealing wall cavity
- Material thermal performance
- Junctions energy loss
  - Wall and roof
  - Wall and floor
  - Subfloor energy loss

Physical decisions for Str systems

Structural Integrity
- Not applicable

Ease of construction
- Ease of handling
- Space requirements
- Access
- Handelability of members
  - Size
  - Weight
- Clarity of installation instructions

Ease of maintanence
- Accessibility
- Compactness of distribution
- Distribution of utility systems
  - Utility core / structural core
  - Embedded utility runs

Strategies

Inferences for integration between Str, Plum and Int A systems

Spatial flexibility
- Movable walls and partitions for flexibility of usage
- Design for "Use modules" (Wet cores / Dry cores / Utility cores) serve as structural cores
- Alternative framing materials for ease of handling
- Use of movable storage units to define space
- Design on a grid for flexibility
- Snap on / sliding walls
- Utility runs to be under the floor structure to increase manouverability

Thermal Performance
- Passive energy design / shading
- Active energy design / use solar panels
- Wall material thermal performance
- Glass composition for the windows to better the thermal performance
- Sealing junctions
- Better thermal performance through improved OSB design for framing walls

Structural integrity
- Utility core serves as a structural core
- Design on a grid for integrity
- Use alternative framing vs. regular wooden stud walls
- OSB strength redesign to increase structural strength in both directions

Ease of construction
- Grid design to facilitate usage of prefabricated components
- "Use modules" which are dry cores, wet cores, utility cores
- OSB strength redesign for ease during construction with respect to placement of windows

Ease of maintanence
- Utility cores intergarte all utilities in one space such that they are easy to maintain
- Easy access of all utilities
- Flexibility of placement of distribution systems through the use of detacheable raceways
- Plumbing through vertical stacks and avoid horizontal distribution

Sustainable design
- Energy Star appliances
- Active / Passive solar design
- Shading devices
- Daylighting techniques
- Window glazing design
- Greywater reuse
- Waterless outlets
- Rainwater harvesting
- Junction sealent / gaskets

Intent

Physical decisions for Plum systems

Spatial flexibility
- Placement of distribution system
  - Wall distribution
  - Floor distribution
- Design for vertical stacking of wet cores
- Water less outlets

Thermal performance
- Loss of heat from heated water during distribution
- Insulation of wiring
- Crawl space design
- Grey water resue
- Waterless outlets
- Reduction of water consumption
- Rainwater harvesting

Physical decisions for Plum systems

Structural Integrity
- Placement of distribution system
  - Utility core

Ease of construction
- Placement of equipment
  - Ease of handling
  - Space requirements
  - Access
- Placement of distribution system
  - Ease of handling
  - Oulets
  - Distribution core
- Clarity of installation instructions

Ease of maintanence
- Accessibility
- Compactness of distribution
- Inteferences from other utility systems
- Fixtures reliability
- Equipment reliability

Physical decisions for Int B systems

Spatial flexibility
- Use of moveable storage units as partitions
- Primary utility systems to be attached to structural walls
- Roof mounted utilities to facilitate flexibility

Thermal performance
- Flexible design for height of partitions so that they can be lowered during summer time to faciliitte movement of air

Physical decisions for Int B systems

Structural Integrity
- Not applicable

Ease of construction
- Open plans to facilitate ease in design and construciton

Ease of maintanence
- Seperate furniture units which are replaceable and moveable

Physical decisions for Str systems

Spatial flexibility
- Selection of appropriate Str system
  - Building type
  - Sizing of memebers
  - Aesthetics
- Standardization of members
- Movability of partitions
- Handelability of members
  - Size
  - Weight

Thermal performance
- Sealing wall cavity
- Material thermal performance
- Junctions energy loss
  - Wall and roof
  - Wall and floor
  - Subfloor energy loss

Physical decisions for Str systems

Structural Integrity
- Not applicable

Ease of construction
- Ease of handling
- Space requirements
- Access
- Handelability of members
  - Size
  - Weight
- Clarity of installation instructions

Ease of maintanence
- Accessibility
- Compactness of distribution
- Distribution of utility systems
  - Utility core / structural core
  - Embedded utility runs
- Replaceability of outlets

Strategies

Inferences for integration between Str, Plum and Int B systems

Spatial flexibility
- Movable walls and partitions for flexibility of usage
- Design for "Use modules" (Wet cores / Dry cores / Utility cores) serve as structural cores
- Alternative framing materials for ease of handling
- Use of movable storage units to define space
- Design on a grid for flexibility
- Snap on / sliding walls
- Utility runs to be under the floor structure to increase manouverability

Thermal Performance
- Passive energy design / shading
- Active energy design / use solar panels
- Wall material thermal performance
- Glass composition for the windows to better the thermal performance
- Sealing junctions
- Better thermal performance through improved OSB design for framing walls
- Changeable heights for storage units to facilitate air movement

Structural integrity
- Utility core serves as a structural core
- Design on a grid for integrity
- Use alternative framing vs. regular wooden stud walls
- OSB strength redesign to increase structural strength in both directions

Ease of construction
- Grid design to facilitate usage of prefabricated components
- "Use modules" which are dry cores, wet cores, utility cores
- OSB strength redesign for ease during construction with respect to placement of windows

Ease of maintanence
- Utility cores intergarte all utlities in one space such that they are easy to maintain
- Easy access of all utlities
- Integration of electrical and communication systems
- Flexibility of placement of distribution systems through the use of detacheable raceways
- HVAC distribution to be placed in the subfloor to faciltate ease of access
- Plumbing through vertical stacks and avoid horizontal distribution

Sustainable design
- Energy Star appliances
- Active / Passive solar design
- Shading devices
- Daylighting techniques
- Window glazing design
- Greywater reuse
- Waterless outlets
- Rainwater harvesting
- Junction sealent / gaskets

Intent

Physical decisions for Elec systems

Spatial flexibility
- Selection of appropriate Elec service system
  - Building type
  - Sizing
  - Aesthetics
  - Overhead / Underground
  - Clearence required
- Placement of distribution system
  - Raceways
  - Wall embedded
  - Utility core
  - Ducting system
- Flexibility of usage
- Placement of outlets
- Capacity
- Fire safety
- Natural light as an alternative

Thermal performance
- Distance run for distribution system to determine energy lost
- Sealing building structure to avoid energy loss
- Type of wiring
- Utility core to avoid dispersion of energy
- Effectiveness of lighting fixtures
- Natural light as an alternative
- Lighting fixtures

Physical decisions for Elec systems

Structural Integrity
- Placement of equipment
- Placement of distribution system
  - Raceways
  - Utility core

Ease of construction
- Placement of equipment
  - Ease of handling
  - Space requirements
  - Access
- Placement of distribution system
  - Ease of handling
  - Oulets
  - Distribution core
- Clarity of installation instructions

Ease of maintanence
- Accessibility
- Compactness of distribution
- Inteferences from other utility systems
- Lighting fixtures reliability
- Equipment reliability

Physical decisions for Comm systems

Spatial flexibility
- Placement of distribution system
  - Wall distribution
  - Floor distribution
- Flexible distribution systems such as raceways which may be unclipped and placed as required
- Distribution over existing electrical wiring
- Wireless systems
- Integrated wiring systems for phone cable and internet

Thermal performance
- Not applicable

Physical decisions for Comm systems

Structural Integrity
- Placement / flexibilityof distribution system

Ease of construction
- Placement of equipment
  - Ease of handling
  - Space requirements
  - Access
- Placement of distribution system
  - Ease of handling
  - Oulets
  - Distribution core
- Clarity of installation instructions

Ease of maintanence
- Accessibility
- Compactness of distribution
- Integration of communication wiring
- Integration with electrical systems
- Fixtures reliability
- Equipment reliability

Physical decisions for Str systems

Spatial flexibility
- Selection of appropriate Str system
  - Building type
  - Sizing of memebers
  - Aesthetics
- Standardization of members
- Movability of partitions
- Handelability of members
  - Size
  - Weight

Thermal performance
- Sealing wall cavity
- Material thermal performance
- Junctions energy loss
  - Wall and roof
  - Wall and floor
  - Subfloor energy loss

Physical decisions for Str systems

Structural Integrity
- Not applicable

Ease of construction
- Ease of handling
- Space requirements
- Access
- Handelability of members
  - Size
  - Weight
- Clarity of installation instructions

Ease of maintanence
- Accessibility
- Compactness of distribution
- Distribution of utility systems
  - Utility core / structural core
  - Embedded utility runs

Strategies

Inferences for integration between Str, Elec and Comm systems

Spatial flexibility
- Movable walls and partitions for flexibility of usage
- Design for "Use modules" (Wet cores / Dry cores / Utility cores) serve as structural cores
- Alternative framing materials for ease of handling
- Use of movable storage units to define space
- Design on a grid for flexibility
- Snap on / sliding walls
- Utility runs to be under the floor structure to increase manouverability

Thermal Performance
- Passive energy design / shading
- Active energy design / use solar panels
- Sealing junctions
- Better thermal performance through improved OSB design for framing walls

Structural integrity
- Utility core serves as a structural core
- Design on a grid for integrity
- Use alternative framing vs. regular wooden stud walls
- OSB strength redesign to increase structural strength in both directions

Ease of construction
- Grid design to facilitate usage of prefabricated components
- "Use modules" which are dry cores, wet cores, utility cores
- OSB strength redesign for ease during construction with respect to placement of windows

Ease of maintanence
- Utility cores intergarte all utilities in one space such that they are easy to maintain
- Easy access of all utilities
- Integration of electrical and communication systems
- Flexibility of placement of distribution systems through the use of detacheable raceways
- HVAC distribution to be placed in the subfloor to facilitate ease of access

Sustainable design
- Energy Star appliances
- Active / Passive solar design
- Shading devices
- Daylighting techniques
- Window glazing design
- Junction sealent / gaskets

Intent

Physical decisions for Elec systems

Spatial flexibility
- Selection of appropriate Elec service system
  - Building type
  - Sizing
  - Aesthetics
  - Overhead / Underground
  - Clearence required
- Placement of distribution system
  - Raceways
  - Wall embedded
  - Utility core
  - Ducting system
- Flexibility of usage
- Placement of outlets
- Capacity
- Fire safety
- Natural light as an alternative

Thermal performance
- Distance run for distribution system to determine energy lost
- Sealing building structure to avoid energy loss
- Type of wiring
- Utility core to avoid dispersion of energy
- Effectiveness of lighting fixtures
- Natural light as an alternative
- Lighting fixtures

Physical decisions for Elec systems

Structural Integrity
- Placement of equipment
- Placement of distribution system
  - Raceways
  - Utility core

Ease of construction
- Placement of equipment
  - Ease of handling
  - Space requirements
  - Access
- Placement of distribution system
  - Ease of handling
  - Oulets
  - Distribution core
- Clarity of installation instructions

Ease of maintanence
- Accessibility
- Compactness of distribution
- Inteferences from other utility systems
- Lighting fixtures reliability
- Equipment reliability

Physical decisions for Int A systems

Spatial flexibility
- Placement of distribution for HVAC system
  - Wall distribution
  - Floor distribution
- Flexible distribution systems such as raceways which may be unclipped and placed as required
- Wireless systems
- Clip on outlets
- Partition walls to be moveable
- Raceways to serve as skirting for walls

Thermal performance
- Sealing loss from distribution systems
- Placement of distribution systems in the crawl space to be insulated
- Zoned heating and cooling to allow for flexibility

Physical decisions for Int A systems

Structural Integrity
- Design of partition wall layout
- Design on a grid
- Material / improved strength OSB

Ease of construction
- Placement of equipment
  - Ease of handling
  - Space requirements
  - Access
- Placement of distribution system
  - Ease of handling
  - Oulets
  - Distribution core
- Clarity of installation instructions

Ease of maintanence
- Accessibility
- Compactness of distribution
- Integration of communication wiring
- Integration with electrical systems
- Fixtures reliability
- Equipment reliability

Physical decisions for Str systems

Spatial flexibility
- Selection of appropriate Str system
  - Building type
  - Sizing of memebers
  - Aesthetics
- Standardization of members
- Movability of partitions
- Handelability of members
  - Size
  - Weight
-

Thermal performance
- Sealing wall cavity
- Material thermal performance
- Junctions energy loss
  - Wall and roof
  - Wall and floor
  - Subfloor energy loss

Physical decisions for Str systems

Structural Integrity
- Not applicable

Ease of construction
- Ease of handling
- Space requirements
- Access
- Handelability of members
  - Size
  - Weight
- Clarity of installation instructions

Ease of maintanence
- Accessibility
- Compactness of distribution
- Distribution of utility systems
  - Utility core / structural core
  - Embedded utility runs
- Replaceability of outlets

Strategies

Inferences for integration between Str, Elec and Int A systems

Spatial flexibility
- Movable walls and partitions for flexibility of usage
- Design for "Use modules" (Wet cores / Dry cores / Utility cores) serve as structural cores
- Alternative framing materials for ease of handling
- Use of movable storage units to define space
- Design on a grid for flexibility
- Snap on / sliding walls
- Utility runs to be under the floor structure to increase manouverability

Thermal Performance
- Passive energy design / shading
- Active energy design / use solar panels
- Sealing junctions
- Better thermal performance through improved OSB design for framing walls
- Insulation for wiring
- Utilty core to be insulated

Structural integrity
- Utility core serves as a structural core
- Design on a grid for integrity
- Use alternative framing vs. regular wooden stud walls
- OSB strength redesign to increase structural strength in both directions

Ease of construction
- Grid design to facilitate usage of prefabricated components
- "Use modules" which are dry cores, wet cores, utility cores
- OSB strength redesign for ease during construction with respect to placement of windows

Ease of maintanence
- Utility cores intergarte all utlities in one space such that they are easy to maintain
- Easy access of all utlities
- Integration of electrical and communication systems
- Flexibility of placement of distribution systems through the use of detacheable raceways
- HVAC distribution to be placed in the subfloor to faciltate ease of access

Sustainable design
- Energy Star appliances
- Active / Passive solar design
- Shading devices
- Daylighting techniques
- Window glazing design
- Junction sealent / gaskets

Intent

Physical decisions for Elec systems

Spatial flexibility
- Selection of appropriate Elec service system
  - Building type
  - Sizing
  - Aesthetics
  - Overhead / Underground
  - Clearence required
- Placement of distribution system
  - Raceways
  - Wall embedded
  - Utility core
  - Ducting system
- Flexibility of usage
- Placement of outlets
- Capacity
- Fire safety
- Natural light as an alternative

Thermal performance
- Distance run for distribution system to determine energy lost
- Sealing building structure to avoid energy loss
- Type of wiring
- Utility core to avoid dispersion of energy
- Effectiveness of lighting fixtures
- Natural light as an alternative
- Lighting fixtures

Physical decisions for Elec systems

Structural Integrity
- Placement of equipment
- Placement of distribution system
  - Raceways
  - Utility core

Ease of construction
- Placement of equipment
  - Ease of handling
  - Space requirements
  - Access
- Placement of distribution system
  - Ease of handling
  - Oulets
  - Distribution core
- Clarity of installation instructions

Ease of maintanence
- Accessibility
- Compactness of distribution
- Inteferences from other utility systems
- Lighting fixtures reliability
- Equipment reliability

Physical decisions for Int B systems

Spatial flexibility
- Use of moveable storage units as partitions
- Primary utility systems to be attached to structural walls
- Roof mounted utilities to facilitate flexibility

Thermal performance
- Flexible design for height of partitions so that they can be lowered during summer time to facilitte movement of air

Physical decisions for Int B systems

Structural Integrity
- Not applicable

Ease of construction
- Open plans to facilitate ease in design and construciton

Ease of maintanence
- Seperate furniture units which are replaceable and moveable

Physical decisions for Str systems

Spatial flexibility
- Selection of appropriate Str system
  - Building type
  - Sizing of memebers
  - Aesthetics
- Standardization of members
- Movability of partitions
- Handelability of members
  - Size
  - Weight

Thermal performance
- Sealing wall cavity
- Material thermal performance
- Junctions energy loss
  - Wall and roof
  - Wall and floor
  - Subfloor energy loss

Physical decisions for Str systems

Structural Integrity
- Not applicable

Ease of construction
- Ease of handling
- Space requirements
- Access
- Handelability of members
  - Size
  - Weight
- Clarity of installation instructions

Ease of maintanence
- Accessibility
- Compactness of distribution
- Distribution of utility systems
  - Utility core / structural core
  - Embedded utility runs

Strategies

Inferences for integration between Str, Elec and Int B systems

Spatial flexibility
- Movable walls and partitions for flexibility of usage
- Design for "Use modules" (Wet cores / Dry cores / Utility cores) serve as structural cores
- Alternative framing materials for ease of handling
- Use of movable storage units to define space
- Design on a grid for flexibility
- Snap on / sliding walls
- Utility runs to be under the floor structure to increase manouverability

Thermal Performance
- Passive energy design / shading
- Active energy design / use solar panels
- Sealing junctions
- Better thermal performance through improved OSB design for framing walls
- Changeable heights of storage units to facilitate air movement

Structural integrity
- Utility core serves as a structural core
- Design on a grid for integrity
- Use alternative framing vs. regular wooden stud walls
- OSB strength redesign to increase structural strength in both directions

Ease of construction
- Grid design to facilitate usage of prefabricated components
- "Use modules" which are dry cores, wet cores, utility cores
- OSB strength redesign for ease during construction with respect to placement of windows

Ease of maintanence
- Utility cores intergarte all utilities in one space such that they are easy to maintain
- Easy access of all utilities
- Integration of electrical and communication systems
- Flexibility of placement of distribution systems through the use of detacheable raceways
- HVAC distribution to be placed in the subfloor to facilitate ease of access

Sustainable design
- Energy Star appliances
- Active / Passive solar design
- Shading devices
- Daylighting techniques
- Window glazing design
- Junction sealent / gaskets

Intent

Physical decisions for Comm systems

Spatial flexibility
- Placement of distribution system
  - Wall distribution
  - Floor distribution
- Flexible distribution systems such as raceways which may be unclipped and placed as required
- Distribution over existing electrical wiring
- Wireless systems
- Integrated wiring systems for phone cable and internet / structured wiring

Thermal performance
- Not applicable

Physical decisions for Comm systems

Structural Integrity
- Placement / flexibilityof distribution system

Ease of construction
- Placement of equipment
  - Ease of handling
  - Space requirements
  - Access
- Placement of distribution system
  - Ease of handling
  - Oulets
  - Distribution core
- Clarity of installation instructions

Ease of maintanence
- Accessibility
- Compactness of distribution
- Integration of communication wiring
- Integration with electrical systems
- Fixtures reliability
- Equipment reliability

Physical decisions for Int A systems

Spatial flexibility
- Placement of distribution for HVAC system
  - Wall distribution
  - Floor distribution
- Flexible distribution systems such as raceways which may be unclipped and placed as required
- Wireless systems
- Clip on outlets
- Partition walls to be moveable
- Raceways to serve as skirting for walls

Thermal performance
- Sealing loss from distribution systems
- Placement of distribution systems in the crawl space to be insulated
- Zoned heating and cooling to allow for flexibility

Physical decisions for Int A systems

Structural Integrity
- Design of partition wall layout
- Design on a grid
- Material / improved strength OSB

Ease of construction
- Placement of equipment
  - Ease of handling
  - Space requirements
  - Access
- Placement of distribution system
  - Ease of handling
  - Oulets
  - Distribution core
- Clarity of installation instructions

Ease of maintanence
- Accessibility
- Compactness of distribution
- Integration of communication wiring
- Integration with electrical systems
- Fixtures reliability
- Equipment reliability

Physical decisions for Str systems

Spatial flexibility
- Selection of appropriate Str system
  - Building type
  - Sizing of memebers
  - Aesthetics
- Standardization of members
- Movability of partitions
- Handelability of members
  - Size
  - Weight

Thermal performance
- Sealing wall cavity
- Material thermal performance
- Junctions energy loss
  - Wall and roof
  - Wall and floor
  - Subfloor energy loss

Physical decisions for Str systems

Structural Integrity
- Not applicable

Ease of construction
- Ease of handling
- Space requirements
- Access
- Handelability of members
  - Size
  - Weight
- Clarity of installation instructions

Ease of maintanence
- Accessibility
- Compactness of distribution
- Distribution of utility systems
  - Utility core / structural core
  - Embedded utility runs

Strategies

Inferences for integration between Str, Comm and Int A systems

Spatial flexibility
- Movable walls and partitions for flexibility of usage
- Design for "Use modules" (Wet cores / Dry cores / Utility cores) serve as structural cores
- Alternative framing materials for ease of handling
- Use of movable storage units to define space
- Design on a grid for flexibility
- Snap on / sliding walls
- Utility runs to be under the floor structure to increase manouverability
- Raceways

Thermal Performance
- Passive energy design / shading
- Active energy design / use solar panels
- Sealing junctions
- Better thermal performance through improved OSB design for framing walls

Structural integrity
- Utility core serves as a structural core
- Design on a grid for integrity
- Use of alternative framing vs. regular wooden stud walls
- OSB strength redesign to increase structural strength in both directions

Ease of construction
- Grid design to facilitate usage of prefabricated components
- "Use modules" which are dry cores, wet cores, utility cores
- OSB strength redesign for ease during construction with respect to placement of windows

Ease of maintanence
- Utility cores intergarte all utlities in one space such that they are easy to maintain
- Easy access of all utilities
- Integration of electrical and communication systems
- Flexibility of placement of distribution systems through the use of detacheable raceways

Sustainable design
- Energy Star appliances
- Active / Passive solar design
- Shading devices
- Daylighting techniques
- Window glazing design
- Junction sealent / gaskets

Intent

Physical decisions for Comm systems

Spatial flexibility
- Placement of distribution system
  - Wall distribution
  - Floor distribution
- Flexible distribution systems such as raceways which may be unclipped and placed as required
- Distribution over existing electrical wiring
- Wireless systems
- Integrated wiring systems for phone cable and internet

Thermal performance
- Not applicable

Physical decisions for Comm systems

Structural Integrity
- Placement / flexibilityof distribution system

Ease of construction
- Placement of equipment
  - Ease of handling
  - Space requirements
  - Access
- Placement of distribution system
  - Ease of handling
  - Oulets
  - Distribution core
- Clarity of installation instructions

Ease of maintanence
- Accessibility
- Compactness of distribution
- Integration of communication wiring
- Integration with electrical systems
- Fixtures reliability
- Equipment reliability

Physical decisions for Int B systems

Spatial flexibility
- Use of moveable storage units as partitions
- Primary utility systems to be attached to structural walls
- Roof mounted utilities to facilitate flexibility

Thermal performance
- Flexible design for height of partitions so that they can be lowered during summer time to facilitte movement of air

Physical decisions for Int B systems

Structural Integrity
- Not applicable

Ease of construction
- Open plans to facilitate ease in design and construciton

Ease of maintanence
- Seperate furniture units which are replaceable and moveable

Physical decisions for Str systems

Spatial flexibility
- Selection of appropriate Str system
  - Building type
  - Sizing of memebers
  - Aesthetics
- Standardization of members
- Movability of partitions
- Handelability of members
  - Size
  - Weight

Thermal performance
- Sealing wall cavity
- Material thermal performance
- Junctions energy loss
  - Wall and roof
  - Wall and floor
  - Subfloor energy loss

Physical decisions for Str systems

Structural Integrity
- Not applicable

Ease of construction
- Ease of handling
- Space requirements
- Access
- Handelability of members
  - Size
  - Weight
- Clarity of installation instructions

Ease of maintanence
- Accessibility
- Compactness of distribution
- Distribution of utility systems
  - Utility core / structural core
  - Embedded utility runs
- Changeable outlets

Strategies

Inferences for integration between Str, Comm and Int B systems

Spatial flexibility
- Movable walls and partitions for flexibility of usage
- Design for "Use modules" (Wet cores / Dry cores / Utility cores) serve as structural cores
- Alternative framing materials for ease of handling
- Use of movable storage units to define space
- Design on a grid for flexibility
- Snap on / sliding walls
- Utility runs to be under the floor structure to increase manouverability
- Raceways

Thermal Performance
- Passive energy design / shading
- Active energy design / use solar panels
- Sealing junctions
- Better thermal performance through improved OSB design for framing walls

Structural integrity
- Utility core serves as a structural core
- Design on a grid for integrity
- Use alternative framing vs. regular wooden stud walls
- OSB strength redesign to increase structural strength in both directions

Ease of construction
- Grid design to facilitate usage of prefabricated components
- "Use modules" which are dry cores, wet cores, utility cores
- OSB strength redesign for ease during construction with respect to placement of windows

Ease of maintanence
- Utility cores intergarte all utlities in one space such that they are easy to maintain
- Easy access of all utlities
- Integration of electrical and communication systems
- Flexibility of placement of distribution systems through the use of detacheable raceways
- HVAC distribution to be placed in the subfloor to faciltate ease of access

Sustainable design
- Energy Star appliances
- Active / Passive solar design
- Shading devices
- Daylighting techniques
- Window glazing design
- Junction sealent / gaskets

Intent

Physical decisions for Int B systems

Spatial flexibility
- Use of moveable storage units as partitions
- Primary utility systems to be attached to structural walls
- Roof mounted utilities to facilitate flexibility

Thermal performance
- Flexible design for height of partitions so that they can be lowered during summer time to facilitte movement of air

Physical decisions for Int B systems

Structural Integrity
- Not applicable

Ease of construction
- Open plans to facilitate ease in design and construciton

Ease of maintanence
- Seperate furniture units which are replaceable and moveable

Physical decisions for Int A systems

Spatial flexibility
- Placement of distribution for HVAC system
  - Wall distribution
  - Floor distribution
- Flexible distribution systems such as raceways which may be unclipped and placed as required
- Wireless systems
- Clip on outlets
- Partition walls to be moveable
- Raceways to serve as skirting for walls

Thermal performance
- Sealing loss from distribution systems
- Placement of distribution systems in the crawl space to be insulated
- Zoned heating and cooling to allow for flexibility

Physical decisions for Int A systems

Structural Integrity
- Design of partition wall layout
- Design on a grid
- Material / improved strength OSB

Ease of construction
- Placement of equipment
  - Ease of handling
  - Space requirements
  - Access
- Placement of distribution system
  - Ease of handling
  - Oulets
  - Distribution core
- Clarity of installation instructions

Ease of maintanence
- Accessibility
- Compactness of distribution
- Integration of communication wiring
- Integration with electrical systems
- Fixtures reliability
- Equipment reliability

Physical decisions for Str systems

Spatial flexibility
- Selection of appropriate Str system
  - Building type
  - Sizing of memebers
  - Aesthetics
- Standardization of members
- Movability of partitions
- Handelability of members
  - Size
  - Weight

Thermal performance
- Sealing wall cavity
- Material thermal performance
- Junctions energy loss
  - Wall and roof
  - Wall and floor
  - Subfloor energy loss

Physical decisions for Str systems

Structural Integrity
- Not applicable

Ease of construction
- Ease of handling
- Space requirements
- Access
- Handelability of members
  - Size
  - Weight
- Clarity of installation instructions

Ease of maintanence
- Accessibility
- Compactness of distribution
- Distribution of utility systems
  - Utility core / structural core
  - Embedded utility runs

Strategies

Inferences for integration between Str, Int A and Int B systems

Spatial flexibility
- Movable walls and partitions for flexibility of usage
- Design for "Use modules" (Wet cores / Dry cores / Utility cores) serve as structural cores
- Alternative framing materials for ease of handling
- Use of movable storage units to define space
- Design on a grid for flexibility
- Snap on / sliding walls
- Utility runs to be under the floor structure to increase manouverability

Thermal Performance
- Passive energy design / shading
- Active energy design / use solar panels
- Wall material thermal performance
- Glass composition for the windows to better the thermal performance
- Sealing junctions
- Better thermal performance through improved OSB design for framing walls

Structural integrity
- Utility core serves as a structural core
- Design on a grid for integrity
- Use alternative framing vs. regular wooden stud walls
- OSB strength redesign to increase structural strength in both directions

Ease of construction
- Grid design to facilitate usage of prefabricated components
- "Use modules" which are dry cores, wet cores, utility cores
- OSB strength redesign for ease during construction with respect to placement of windows

Ease of maintanence
- Utility cores intergarte all utlities in one space such that they are easy to maintain
- Easy access of all utilities
- Integration of electrical and communication systems
- Flexibility of placement of distribution systems through the use of detacheable raceways
- HVAC distribution to be placed in the subfloor to faciltate ease of access

Sustainable design
- Energy Star appliances
- Active / Passive solar design
- Shading devices
- Daylighting techniques
- Window glazing design
- Junction sealent / gaskets

Intent

Physical decisions for Elec systems

Spatial flexibility
- Selection of appropriate Elec service system
  - Building type
  - Sizing
  - Aesthetics
  - Overhead / Underground
  - Clearence required
- Placement of distribution system
  - Raceways
  - Wall embedded
  - Utility core
  - Ducting system
- Flexibility of usage
- Placement of outlets
- Capacity
- Fire safety
- Natural light as an alternative

Thermal performance
- Distance run for distribution system to determine energy lost
- Sealing building structure to avoid energy loss
- Type of wiring
- Utility core to avoid dispersion of energy
- Effectiveness of lighting fixtures
- Natural light as an alternative
- Lighting fixtures

Physical decisions for Elec systems

Structural Integrity
- Placement of equipment
- Placement of distribution system
  - Raceways
  - Utility core

Ease of construction
- Placement of equipment
  - Ease of handling
  - Space requirements
  - Access
- Placement of distribution system
  - Ease of handling
  - Oulets
  - Distribution core
- Clarity of installation instructions

Ease of maintanence
- Accessibility
- Compactness of distribution
- Inteferences from other utility systems
- Lighting fixtures reliability
- Equipment reliability

Physical decisions for Plum systems

Spatial flexibility
- Placement of distribution system
  - Wall distribution
  - Floor distribution
- Design for vertical stacking of wet cores
- Water less outlets

Thermal performance
- Loss of heat from heated water during distribution
- Insulation of wiring
- Crawl space design
- Grey water resue
- Waterless outlets
- Reduction of water consumption
- Rainwater harvesting

Physical decisions for Plum systems

Structural Integrity
- Placement of distribution system
  - Utility core

Ease of construction
- Placement of equipment
  - Ease of handling
  - Space requirements
  - Access
- Placement of distribution system
  - Ease of handling
  - Oulets
  - Distribution core
- Clarity of installation instructions

Ease of maintanence
- Accessibility
- Compactness of distribution
- Inteferences from other utility systems
- Fixtures reliability
- Equipment reliability

Physical decisions for HVAC systems

Spatial flexibility
- Selection of appropriate HVAC system
  - Building type
  - Sizing
  - Aesthetics
  - Noise and vibrations
  - Space requirements
- Passive Solar heating
- Active solar heating

Thermal performance
- Human confort zone (db) 68-78F, RH 20-70%
- Sun control to reduce solar heat gain / shading (refer Bobenhausen 1994)
- Heat loss due to building envelope (refer Bobenhausen 1994)
- Integrating Heating and ventilating requirements (HRV)
- Selection of appropriate HVAC system
  - Building type
  - Climate
  - Heating requirements
  - Response time
  - Reliability and maintainability
- Passive solar heating
- Active solar heating
- Fuel requirements

Physical decisions for HVAC systems

Structural Integrity
- Selection of appropriate HVAC system
  - Building type
  - Aesthetics
  - Space requirements
  - Fire safety
- Placement of equipment such as rooftops
- Active Solar design

Ease of construction
- Placement of equipment
  - Ease of handling
  - Space requirements
  - Access
- Placement of distribution system
  - Ease of handling
  - Oulets
  - Distribution core
- Clarity of installation instructions

Ease of maintanence
- Accessibility
- Compactness of distribution
- Inteferences from other utility systems

Strategies

Inferences for integration between HVAC, Plum and Elec systems

Spatial flexibility
- Movable walls and partitions for flexibility of usage
- Design for "Use modules" (Wet cores / Dry cores / Utility cores) serve as structural cores
- Design on a grid for flexibility
- Snap on / sliding walls
- Rainwater harvesting through design
- Grey water reuse design to be incorporated

Thermal Performance
- Passive energy design / shading
- Active energy design / use solar panels
- Wall material thermal performance
- Glass composition for the windows to better the thermal performance
- Sealing junctions
- Better thermal performance through improved OSB design for framing walls
- Grey water reuse

Structural integrity
- Utility core serves as a structural core
- Design on a grid for integrity
- Use alternative framing vs. regular wooden stud walls
- OSB strength redesign to increase structural strength in both directions

Ease of construction
- Grid design to facilitate usage of prefabricated components
- "Use modules" which are dry cores, wet cores, utility cores
- OSB strength redesign for ease during construction with respect to placement of windows

Ease of maintanence
- Utility cores intergarte all utilities in one space such that they are easy to maintain
- Easy access of all utilities
- Integration of electrical and communication systems
- Flexibility of placement of distribution systems through the use of detacheable raceways
- HVAC distribution to be placed in the subfloor to facilitate ease of access
- Detacheable panels in the subfloor to facilitate access

Sustainable design
- Energy Star appliances
- Active / Passive solar design
- Shading devices
- Daylighting techniques
- Window glazing design
- Greywater reuse
- Waterless outlets
- Rainwater harvesting
- Junction sealent / gaskets

Physical decisions for Comm systems	Physical decisions for Comm systems
Spatial flexibility	Structural Integrity

Physical decisions for Plum systems	Physical decisions for Plum systems

Intent

Physical decisions for Comm systems

Spatial flexibility
- Placement of distribution system
  - Wall distribution
  - Floor distribution
- Flexible distribution systems such as raceways which may be unclipped and placed as required
- Distribution over existing electrical wiring
- Wireless systems
- Integrated wiring systems for phone cable and internet

Thermal performance
- Not applicable

Physical decisions for Comm systems

Structural Integrity
- Placement / flexibilityof distribution system

Ease of construction
- Placement of equipment
  - Ease of handling
  - Space requirements
  - Access
- Placement of distribution system
  - Ease of handling
  - Oulets
  - Distribution core
- Clarity of installation instructions

Ease of maintanence
- Accessibility
- Compactness of distribution
- Integration of communication wiring
- Integration with electrical systems
- Fixtures reliability
- Equipment reliability

Physical decisions for Plum systems

Spatial flexibility
- Placement of distribution system
  - Wall distribution
  - Floor distribution
- Design for vertical stacking of wet cores
- Water less outlets

Thermal performance
- Loss of heat from heated water during distribution
- Insulation of wiring
- Crawl space design
- Grey water resue
- Waterless outlets
- Reduction of water consumption
- Rainwater harvesting

Physical decisions for Plum systems

Structural Integrity
- Placement of distribution system
  - Utility core

Ease of construction
- Placement of equipment
  - Ease of handling
  - Space requirements
  - Access
- Placement of distribution system
  - Ease of handling
  - Oulets
  - Distribution core
- Clarity of installation instructions

Ease of maintanence
- Accessibility
- Compactness of distribution
- Inteferences from other utility systems
- Fixtures reliability
- Equipment reliability

Physical decisions for HVAC systems

Spatial flexibility
- Selection of appropriate HVAC system
  - Building type
  - Sizing
  - Aesthetics
  - Noise and vibrations
  - Space requirements
- Passive Solar heating
- Active solar heating

Thermal performance
- Human confort zone (db) 68-78F, RH 20-70%
- Sun control to reduce solar heat gain / shading (refer Bobenhausen 1994)
- Heat loss due to building envelope (refer Bobenhausen 1994)
- Integrating Heating and ventilating requirements (HRV)
- Selection of appropriate HVAC system
  - Building type
  - Climate
  - Heating requirements
  - Response time
  - Reliability and maintainability
- Passive solar heating
- Active solar heating
- Fuel requirements

Physical decisions for HVAC systems

Structural Integrity
- Selection of appropriate HVAC system
  - Building type
  - Aesthetics
  - Space requirements
  - Fire safety
- Placement of equipment such as rooftops
- Active Solar design

Ease of construction
- Placement of equipment
  - Ease of handling
  - Space requirements
  - Access
- Placement of distribution system
  - Ease of handling
  - Oulets
  - Distribution core
- Clarity of installation instructions

Ease of maintanence
- Accessibility
- Compactness of distribution
- Inteferences from other utility systems

Strategies

Inferences for integration between HVAC, Plum and Comm systems

Spatial flexibility
- Movable walls and partitions for flexibility of usage
- Design for "Use modules" (Wet cores / Dry cores / Utility cores) serve as structural cores
- Design on a grid for flexibility
- Snap on / sliding walls
- Rainwater harvesting through design
- Grey water reuse design to be incorporated
- Structured wiring and Raceways

Thermal Performance
- Passive energy design / shading
- Active energy design / use solar panels
- Wall material thermal performance
- Glass composition for the windows to better the thermal performance
- Sealing junctions
- Better thermal performance through improved OSB design for framing walls
- Grey water reuse

Structural integrity
- Utility core serves as a structural core
- Design on a grid for integrity
- Use alternative framing vs. regular wooden stud walls
- OSB strength redesign to increase structural strength in both directions

Ease of construction
- Grid design to facilitate usage of prefabricated components
- "Use modules" which are dry cores, wet cores, utility cores
- OSB strength redesign for ease during construction with respect to placement of windows

Ease of maintanence
- Utility cores intergarte all utilities in one space such that they are easy to maintain
  - Easy access of all utlities
  - Structured wiring
  - Integration of electrical and communication systems
  - Flexibility of placement of distribution systems through the use of detacheable raceways
  - HVAC distribution to be placed in the subfloor to faciltate ease of access
  - Detacheable panels in the subfloor for ease of access

Sustainable design
- Energy Star appliances
- Active / Passive solar design
- Shading devices
- Daylighting techniques
- Window glazing design
- Greywater reuse
- Waterless outlets
- Rainwater harvesting
- Junction sealent / gaskets

Physical decisions for

Physical decisions for

Physical decisions for

Intent

Physical decisions for Comm systems

Spatial flexibility
- Placement of distribution system
  - Wall distribution
  - Floor distribution
- Flexible distribution systems such as raceways which may be unclipped and placed as required
- Distribution over existing electrical wiring
- Wireless systems
- Integrated wiring systems for phone cable and internet

Thermal performance
- Not applicable

Physical decisions for Comm systems

Structural Integrity
- Placement / flexibilityof distribution system

Ease of construction
- Placement of equipment
  - Ease of handling
  - Space requirements
  - Access
- Placement of distribution system
  - Ease of handling
  - Oulets
  - Distribution core
- Clarity of installation instructions

Ease of maintanence
- Accessibility
- Compactness of distribution
- Integration of communication wiring
- Integration with electrical systems
- Fixtures reliability
- Equipment reliability

Physical decisions for Elec systems

Structural Integrity
- Placement of equipment
- Placement of distribution system
  - Raceways
  - Utility core

Ease of construction
- Placement of equipment
  - Ease of handling
  - Space requirements
  - Access
- Placement of distribution system
  - Ease of handling
  - Oulets
  - Distribution core
- Clarity of installation instructions

Ease of maintanence
- Accessibility
- Compactness of distribution
- Inteferences from other utility systems
- Lighting fixtures reliability
- Equipment reliability

Physical decisions for Elec systems

Spatial flexibility
- Selection of appropriate Elec service system
  - Building type
  - Sizing
  - Aesthetics
  - Overhead / Underground
  - Clearence required
- Placement of distribution system
  - Raceways
  - Wall embedded
  - Utility core
  - Ducting system
- Flexibility of usage
- Placement of outlets
- Capacity
- Fire safety
- Natural light as an alternative

Thermal performance
- Distance run for distribution system to determine energy lost
- Sealing building structure to avoid energy loss
- Type of wiring
- Utility core to avoid dispersion of energy
- Effectiveness of lighting fixtures
- Natural light as an alternative
- Lighting fixtures

Physical decisions for HVAC systems

Spatial flexibility
- Selection of appropriate HVAC system
  - Building type
  - Sizing
  - Aesthetics
  - Noise and vibrations
  - Space requirements
- Passive Solar heating
- Active solar heating

Thermal performance
- Human confort zone (db) 68-78F, RH 20-70%
- Sun control to reduce solar heat gain / shading (refer Bobenhausen 1994)
- Heat loss due to building envelope (refer Bobenhausen 1994)
- Integrating Heating and ventilating requirements (HRV)
- Selection of appropriate HVAC system
  - Building type
  - Climate
  - Heating requirements
  - Response time
  - Reliability and maintainability
- Passive solar heating
- Active solar heating
- Fuel requirements

Physical decisions for HVAC systems

Structural Integrity
- Selection of appropriate HVAC system
  - Building type
  - Aesthetics
  - Space requirements
  - Fire safety
- Placement of equipment such as rooftops
- Active Solar design

Ease of construction
- Placement of equipment
  - Ease of handling
  - Space requirements
  - Access
- Placement of distribution system
  - Ease of handling
  - Oulets
  - Distribution core
- Clarity of installation instructions

Ease of maintanence
- Accessibility
- Compactness of distribution
- Inteferences from other utility systems

Strategies

Inferences for integration between HVAC, Elec and Comm systems

Spatial flexibility
- Movable walls and partitions for flexibility of usage
- Design for "Use modules" (Wet cores / Dry cores / Utility cores) serve as structural cores
- Design on a grid for flexibility
- Snap on / sliding walls
- Rainwater harvesting through design
- Grey water reuse design to be incorporated
- Structured wiring and Raceways

Thermal Performance
- Passive energy design / shading
- Active energy design / use solar panels
- Wall material thermal performance
- Glass composition for the windows to better the thermal performance
- Sealing junctions
- Better thermal performance through improved OSB design for framing walls
- Grey water reuse
- Insulation of utility stack

Structural integrity
- Utility core serves as a structural core
- Design on a grid for integrity
- Use of alternative framing vs. regular wooden stud walls
- OSB strength redesign to increase structural strength in both directions

Ease of construction
- Grid design to facilitate usage of prefabricated components
- "Use modules" which are dry cores, wet cores, utility cores
- OSB strength redesign for ease during construction with respect to placement of windows

Ease of maintanence
- Utility cores intergarte all utlities in one space such that they are easy to maintain
- Easy access of all utlities
- Structured wiring
- Integration of electrical and communication systems
- Flexibility of placement of distribution systems through the use of detacheable raceways
- HVAC distribution to be placed in the subfloor to facilitate ease of access

Sustainable design
- Energy Star appliances
- Active / Passive solar design
- Shading devices
- Daylighting techniques
- Window glazing design
- Junction sealent / gaskets

Physical decisions for Int A systems

Physical decisions for Int A systems

Physical decisions for Int B systems

Physical decisions for Int B systems

Intent

Physical decisions for Int A systems

Spatial flexibility
- Placement of distribution for HVAC system
  - Wall distribution
  - Floor distribution
- Flexible distribution systems such as raceways which may be unclipped and placed as required
- Wireless systems
- Clip on outlets
- Partition walls to be moveable
- Raceways to serve as skirting for walls

Thermal performance
- Sealing loss from distribution systems
- Placement of distribution systems in the crawl space to be insulated
- Zoned heating and cooling to allow for flexibility

Physical decisions for Int A systems

Structural Integrity
- Design of partition wall layout
- Design on a grid
- Material / improved strength OSB

Ease of construction
- Placement of equipment
  - Ease of handling
  - Space requirements
  - Access
- Placement of distribution system
  - Ease of handling
  - Oulets
  - Distribution core
- Clarity of installation instructions

Ease of maintanence
- Accessibility
- Compactness of distribution
- Integration of communication wiring
- Integration with electrical systems
- Fixtures reliability
- Equipment reliability

Physical decisions for Int B systems

Spatial flexibility
- Use of moveable storage units as partitions
- Primary utility systems to be attached to structural walls
- Roof mounted utilities to facilitate flexibility

Thermal performance
- Flexible design for height of partitions so that they can be lowered during summer time to facilitte movement of air

Physical decisions for Int B systems

Structural Integrity
- Not applicable

Ease of construction
- Open plans to facilitate ease in design and construciton

Ease of maintanence
- Seperate furniture units which are replaceable and moveable

Physical decisions for HVAC systems

Spatial flexibility
- Selection of appropriate HVAC system
  - Building type
  - Sizing
  - Aesthetics
  - Noise and vibrations
  - Space requirements
- Passive Solar heating
- Active solar heating

Thermal performance
- Human confort zone (db) 68-78F, RH 20-70%
- Sun control to reduce solar heat gain / shading (refer Bobenhausen 1994)
- Heat loss due to building envelope (refer Bobenhausen 1994)
- Integrating Heating and ventilating requirements (HRV)
- Selection of appropriate HVAC system
  - Building type
  - Climate
  - Heating requirements
  - Response time
  - Reliability and maintainability
- Passive solar heating
- Active solar heating
- Fuel requirements

Physical decisions for HVAC systems

Structural Integrity
- Selection of appropriate HVAC system
  - Building type
  - Aesthetics
  - Space requirements
  - Fire safety
- Placement of equipment such as rooftops
- Active Solar design

Ease of construction
- Placement of equipment
  - Ease of handling
  - Space requirements
  - Access
- Placement of distribution system
  - Ease of handling
  - Oulets
  - Distribution core
- Clarity of installation instructions

Ease of maintanence
- Accessibility
- Compactness of distribution
- Inteferences from other utility systems

Strategies

Inferences for integration between HVAC, Int A and Int B systems

Spatial flexibility
- Movable walls and partitions for flexibility of usage
- Design for "Use modules" (Wet cores / Dry cores / Utility cores) serve as structural cores
- Design on a grid for flexibility
- Snap on / sliding walls
- Rainwater harvesting through design

Thermal Performance
- Passive energy design / shading
- Active energy design / use solar panels
- Wall material thermal performance
- Glass composition for the windows to better the thermal performance
- Sealing junctions
- Better thermal performance through improved OSB design for framing walls

Structural integrity
- Utility core serves as a structural core
- Design on a grid for integrity
- Use alternative framing vs. regular wooden stud walls
- OSB strength redesign to increase structural strength in both directions

Ease of construction
- Grid design to facilitate usage of prefabricated components
- "Use modules" which are dry cores, wet cores, utility cores
- OSB strength redesign for ease during construction with respect to placement of windows

Ease of maintanence
- Utility cores intergarte all utilities in one space such that they are easy to maintain
- Easy access of all utilities
- Integration of electrical and communication systems
- Flexibility of placement of distribution systems through the use of detacheable raceways
- HVAC distribution to be placed in the subfloor to facilitate ease of access

Sustainable design
- Energy Star appliances
- Active / Passive solar design
- Shading devices
- Daylighting techniques
- Window glazing design
- Junction sealent / gaskets

Intent

Physical decisions for Plum systems

Spatial flexibility
- Placement of distribution system
  - Wall distribution
  - Floor distribution
- Design for vertical stacking of wet cores
- Water less outlets

Thermal performance
- Loss of heat from heated water during distribution
- Insulation of wiring
- Crawl space design
- Grey water resue
- Waterless outlets
- Reduction of water consumption
- Rainwater harvesting

Physical decisions for Plum systems

Structural Integrity
- Placement of distribution system
  - Utility core

Ease of construction
- Placement of equipment
  - Ease of handling
  - Space requirements
  - Access
- Placement of distribution system
  - Ease of handling
  - Oulets
  - Distribution core
- Clarity of installation instructions

Ease of maintanence
- Accessibility
- Compactness of distribution
- Inteferences from other utility systems
- Fixtures reliability
- Equipment reliability

Physical decisions for Elec systems

Spatial flexibility
- Selection of appropriate Elec service system
  - Building type
  - Sizing
  - Aesthetics
  - Overhead / Underground
  - Clearence required
- Placement of distribution system
  - Raceways
  - Wall embedded
  - Utility core
  - Ducting system
- Flexibility of usage
- Placement of outlets
- Capacity
- Fire safety
- Natural light as an alternative

Thermal performance
- Distance run for distribution system to determine energy lost
- Sealing building structure to avoid energy loss
- Type of wiring
- Utility core to avoid dispersion of energy
- Effectiveness of lighting fixtures
- Natural light as an alternative
- Lighting fixtures

Physical decisions for Elec systems

Structural Integrity
- Placement of equipment
- Placement of distribution system
  - Raceways
  - Utility core

Ease of construction
- Placement of equipment
  - Ease of handling
  - Space requirements
  - Access
- Placement of distribution system
  - Ease of handling
  - Oulets
  - Distribution core
- Clarity of installation instructions

Ease of maintanence
- Accessibility
- Compactness of distribution
- Inteferences from other utility systems
- Lighting fixtures reliability
- Equipment reliability

Physical decisions for Comm systems

Spatial flexibility
- Placement of distribution system
  - Wall distribution
  - Floor distribution
- Flexible distribution systems such as raceways which may be unclipped and placed as required
- Distribution over existing electrical wiring
- Wireless systems
- Integrated wiring systems for phone cable and internet

Thermal performance
- Not applicable

Physical decisions for Comm systems

Structural Integrity
- Placement / flexibilityof distribution system

Ease of construction
- Placement of equipment
  - Ease of handling
  - Space requirements
  - Access
- Placement of distribution system
  - Ease of handling
  - Oulets
  - Distribution core
- Clarity of installation instructions

Ease of maintanence
- Accessibility
- Compactness of distribution
- Integration of communication wiring
- Integration with electrical systems
- Fixtures reliability
- Equipment reliability

Strategies

Inferences for integration between Plum, Elec and Comm systems

Spatial flexibility
- Movable walls and partitions for flexibility of usage
- Design for "Use modules" (Wet cores / Dry cores / Utility cores) serve as structural cores
- Alternative framing materials for ease of handling
- Use of movable storage units to define space
- Design on a grid for flexibility
- Snap on / sliding walls
- Utility runs to be under the floor structure to increase manouverability

Thermal Performance
- Better thermal performance through improved OSB design for framing walls
- Grey water reuse
- Insulation of utility stack

Structural integrity
- Utility core serves as a structural core
- Design on a grid for integrity
- Use alternative framing vs. regular wooden stud walls
- OSB strength redesign to increase structural strength in both directions

Ease of construction
- Grid design to facilitate usage of prefabricated components
- "Use modules" which are dry cores, wet cores, utility cores
- OSB strength redesign for ease during construction with respect to placement of windows

Ease of maintanence
- Utility cores intergarte all utlities in one space such that they are easy to maintain
- Easy access of all utlities
- Integration of electrical and communication systems
- Flexibility of placement of distribution systems through the use of detacheable raceways
- HVAC distribution to be placed in the subfloor to faciltate ease of access

Sustainable design
- Energy Star appliances
- Active / Passive solar design
- Shading devices
- Daylighting techniques
- Window glazing design
- Greywater reuse
- Waterless outlets
- Rainwater harvesting
- Junction sealent / gaskets

Appendix C1

(View as joined at A-B-C-D)

No.		Building systems (Design considerations)	Credit	Intent																A
				Spatial flexibility	Sc.	Thermal performance	Sc.	Structural Integrity	Sc.	Ease of const.	Sc.	Ease of maint.	Sc.	Sustainable design	Sc.	Total score	Sc. x credit			
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																		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.	Sustainable design

B

No.		Building systems (Design considerations)	Credit	Intent														C
				Spatial flexibility	Sc.	Thermal performance	Sc.	Structural Integrity	Sc.	Ease of const.	Sc.	Ease of maint.	Sc.	Sustainable design	Sc.	Total score	Sc. x credit	
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.	Sustainable design

D

Appendix C2

(View as joined at E-F-G-H-I-J-K-L)

No.		Building systems (Design considerations)	Cr.	Intent															E
				Spatial flexibility	Sc.	Thermal performance	Sc.	Structural Integrity	Sc.	Ease of const.	Sc.	Ease of maint.	Sc.	Sustainable design	Sc.	Total sc.	Sc. x Cr.		
A		**Structure / Env**	4.4																
1		Architectural design		Changeability of spaces	5	Material thermal performance	5	Moveable / changeable elements	5	Ease of assembly	5	Ease of handling / changeability	5	Material choice	5				
2		Engineering design		Modular design	5	Reduction of loss of heat and cold from building envelope	5	Flexibility of assembling units	5	Ease of assembly	5	Ease of handling / changeability	5						
						Decreased use of artificial lighting	5			Clarity of instructions	5								
						Air movement within the home	5												
3		Special design consideration																	
	a	Active solar design				Use of alternative energy sources	5	Integrative energy structure	5			Low maint. requirements over lifetime	5	Reduction in use of traditional energy sources	5				
	b	Passive solar design				Sunlight in wet areas	5							Reduction in use of traditional energy sources	5				
						Use of sunlight as per seasonal requirements	5												
		Cumulative score			10		35		15		15		15		15	105.00	462.00		E

E	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.**	**Sustainable design**
	Grid based design	Foam core panels. High strength OSB	Snap on panels	Clarity in instructions	Utility core integrating all utilities in an organized manner	Recycled content material	Design expertise	Alternative framing materials (refer sec 3.5.1)	Pre manufactured systems (refer sec 2.4)	Hybrid systems (refer sec 3.5.3)	Premanufactured systems (refer sec 2.4)	Recycled content material (refer sec 3.6.3)
	Use modules - Dry core, Wet core and Utility core	Sealing building junctions	Grid based design with collapsible panels	Standard snap on panels	Utility core integrating all utilities in an organized		Design expertise	Rubber gasket / insulating strip	Design expertise	Premanufactured systems (refer sec 2.4)	Design expertise	
		Day lighting design						Day lighting design (refer sec 3.6.1and 3.6.4)				
		Storage modules serving as partitions with changeable heights for internal air movement						Pre manufactured systems (refer sec 2.4)				
		Solar panels	Solar roof			Daylight design for interior and basement spaces		Solar design (refer sec 3.6.1 and 3.6.2 and 3.6.4)	Solar design (refer sec 3.6.1 and 3.6.2 and 3.6.4)			Light wells in interior spaces (refer sec 3.6.1)
		Day lighting design						Bio-based material (refer sec 3.6.3)				
		Collapsible shading devices						Hybrid systems (refer sec 3.5.3)				
E												

No.		Building systems (Design considerations)	Cr.	Intent														F
				Spatial flexibility	Sc.	Thermal performance	Sc.	Structural Integrity	Sc.	Ease of const.	Sc.	Ease of maint.	Sc.	Sustainable design	Sc.	Total sc.	Sc. x Cr.	
B		HVAC	1.28															
1		Architectural design																
	a	Comfort requirements	P		na		na		na		na		na		na			
2		Engineering design		Space requirements for placement of units and distribution systems	5	Type of HVAC systems to be used and its inherent efficiency	5	Placement of units and distribution system	5	Ease of assembly	5	Ease of handling / changeability	5	Reduction in loss of energy	5			
				Reorganization of spaces to be possible	5	Reuse of heat generated within the home	5			Clarity of instructions	5	Ease of access of distribution systems	5					
				Heating and cooling as per requirements	5					Lesser no of parts	5			Elimination of unnecessary heating or cooling	5			
3		Special design consideration																
	a	Choice of Fuel				Use of alternative fuels	5					Renewable fuel	5	Reduction in use of traditional energy sources	5			
	b	Passive design techniques		Placement of distribution system	5	Use of sunlight for daytime heating	5			Distribution material	5							F

	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.**	**Sustainable design**
							For prerequisites refer systems decision model. Human comfort zone (db) 68-78F, RH 20-70%					
	Utility core design - wet core, dry core, utility core	Water based systems most appropriate	Consider load requirements	Clarity in instructions	Flexible ducting	Sealing junctions	Design expertise	Appropriate HVAC type (refer sec 3.4.1)	Design expertise	Design expertise	Flexi duct	Rubber gasket / insulating strip
	Distribution system through roof or floor to allow for reorganizing	Heat recovery system to be used		Flexible ducting	Utility core integrating all utilities in an organized manner		Design expertise	Heat recovery ventilator (refer sec 3.4.1.1)		Flexi duct	Design expertise	
	Zoned heating and cooling					Zoned heating and cooling	Zoned HVAC design (refer sec 3.4.1.3)					Zoned HVAC design (refer sec 3.4.1.3)
		Solar energy			Solar energy	Solar energy		Solar design (refer sec 3.6.1 and 3.6.2 and 3.6.4)			Solar design (refer sec 3.6.1 and 3.6.2 and 3.6.4)	Solar design (refer sec 3.6.1 and 3.6.2 and 3.6.4)
H	Distribution system to be placed within subfloor and utility core	Large openings with retraceable shading devices		Use of flexible ducting			Design expertise	Design expertise				

No.		Building systems (Design considerations)	Cr.	Intent															G
				Spatial flexibility	Sc.	Thermal performance	Sc.	Structural Integrity	Sc.	Ease of const.	Sc.	Ease of maint.	Sc.	Sustainable design	Sc.	Total sc.	Sc. x Cr.		
				Flexibility of distribution system	5	Reuse of heat generated within the home	5												
						Reduction of loss of heat and cold from building envelope	5												
						Reduction of loss of heat and cold from distribution system	5												
	c	Indoor Air Quality (ventilation)				Adequate natural and /or artificial ventilation provided	5												
		Cumulative score			25		40		5		20		15		15	120.00	153.60		G

G	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.**	**Sustainable design**
	Use of flexible ducting	Heat recovery system to be used						Heat recovery ventilator (refer sec 3.4.1.1)				
		Sealing building junctions						Rubber gasket / insulating strip				
		Adequate insulation of distribution systems						Duct tape for edges, batt insulation for attic spaces				
		Vented attics and adequately design return air plenums						Design expertise				
G												

No.		Building systems (Design considerations)	Cr.	Intent															H
				Spatial flexibility	Sc.	Thermal performance	Sc.	Structural Integrity	Sc.	Ease of const.	Sc.	Ease of maint.	Sc.	Sustainable design	Sc.	Total sc.	Sc. x Cr.		
C		**Plumbing**	**0.64**																
1		Architectural design																	
2		Engineering design		Wet cores to be consolidated	5	Reduction in loss of heat	5			Ease of assembly	5	Ease of handling / changeability	5						
				Restrict distribution lines	5	Reuse of heat generated within the home	5					Ease of access	5						
				Reduced horizontal distribution	5														
3		Special design consideration																	
	a	Water conservation				Grey water reuse	5							Grey water reuse	5				
	b	Fuel requirements												Reduction in use of traditional energy sources	5				
		Cumulative score			15		15		0		5		10		10	55.00	35.20		H

H	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.**	**Sustainable design**
	Utility core design wet core	Insulation of distribution system		Clarity in instructions	Utility core design wet core		Design expertise	Storage tank system (refer sec 3.4.2.3)		Design expertise	Design expertise	
	Vertical chase distribution	Heat recovery system to be used					Design expertise	Heat recovery ventilator (refer sec 3.4.1.1)				
		Grey water reuse systems				Grey water reuse systems		Systems(refer sec 3.4.2.4)				Systems(refer sec 3.4.2.4)
						Solar heatng systems						Solar design (refer sec 3.6.1 and 3.6.2 and 3.6.4)
H												

No.		Building systems (Design considerations)	Cr.	Intent														
				Spatial flexibility	Sc.	Thermal performance	Sc.	Structural Integrity	Sc.	Ease of const.	Sc.	Ease of maint.	Sc.	Sustainable design	Sc.	Total sc.	Sc. x Cr.
D		**Electrical**	0.64														
1		Architectural design															
2		Engineering design		Distribution to be flexible	5	Avoid compromising structural integrity to place wiring	5	Adequate insulation	5	Ease of assembly	5	Ease of handling / changeability	5				
				Placement of distribution system	5	Reduction of use of artificial lighting in the daytime	5			Integration with other uses	5	Ease of access	5				
														Use efficient wiring	5		
						Use of efficient outlets	5										
3		Special design consideration															
	a	Energy requirements												Use of efficient outlets	5		
														Use of alternative sources of energy	5		
		Cumulative score			10		15		5		10		10		15	65.00	41.60

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.**	**Sustainable design**
Use of raceways	Wall mounted distribution rather than wall embedded	Insulated wiring and raceway	Clarity in instructions	Energy star outlets		Raceways (refer sec 3.4.3.3)	Raceways (refer sec 3.4.3.3)	No insulation required by code	Design expertise	Energy star appliances (refer sec 3.6.4)	
Use of standardized electrical chase heights	Day lighting design		Data and electrical wiring integration	Use of standardized electrical chase heights		Panelized building design (refer sec 3.4.3)	Day lighting design (refer sec 3.6.1and 3.6.4)		Power line networking (refer sec 3.4.3.3)	Raceways (refer sec 3.4.3.3)	
				Utility core design - wet core, dry core, utility core	Integrative use for wiring					Design expertise	Power line networking (refer sec 3.4.3.3)
	Energy star outlets						Energy star appliances (refer sec 3.6.4)				
					Energy star outlets						Energy star appliances (refer sec
					Solar energy						Solar design (refer sec 3.6.1 and 3.6.2 and 3.6.4)

No.		Building systems (Design considerations)	Cr.	Intent														J
				Spatial flexibility	Sc.	Thermal performance	Sc.	Structural Integrity	Sc.	Ease of const.	Sc.	Ease of maint.	Sc.	Sustainable design	Sc.	Total sc.	Sc. x Cr.	
E		Communication	0.32															
1		Architectural design																
2		Engineering design		Distribution to be flexible	5	Avoid compromising structural integrity to place wiring	5			Ease of assembly	5	Ease of handling / changeability	5	Use efficient wiring	5			
				Placement of distribution system	5							Ease of access	5					
3		Special design consideration																
	a	Integrative design								Integration with other uses	5	Elimination of wiring	5					
		Cumulative score			10		5		0		10		15		5	45.00	14.40	J

J	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.**	**Sustainable design**
	Use of raceways	Wall mounted distribution rather than wall embedded		Clarity in instructions	Wireless systems	Structured wiring	Raceways (refer sec 3.4.3.3)	Raceways (refer sec 3.4.3.3)		Design expertise	Wireless systems (refer 3.6.4)	Structured wiring (refer sec 3.4.5)
	Integration of electrical and communication wiring through raceways				Use of standardized chase heights		Power line networking (refer sec 3.4.3.3)				Raceways (refer sec 3.4.3.3)	
				Data and electrical wiring integration	Wireless systems					Power line networking (refer sec 3.4.3.3)		
J												

No.		Building systems (Design considerations)	Cr.	Intent															K
				Spatial flexibility	Sc.	Thermal performance	Sc.	Structural Integrity	Sc.	Ease of const.	Sc.	Ease of maint.	Sc.	Sustainable design	Sc.	Total sc.	Sc. x Cr.		
F		Interior (Type A)	0.48																
1		Architectural design																	
2		Engineering design		Detachable outlets	5	Adequate insulation	5	Moveable / changeable elements	5	Ease of assembly	5	Ease of handling / changeability	5						
				Eliminate wiring	5			Flexibility of assembling units	5										
				Elimination of partition walls	5									Efficient outlets	5				
3		Special design consideration																	
	a	Energy requirements				Use of efficient outlets	5							Use of alternative sources of	5				
						Use of efficient wiring	5							Efficient appliances	5				
		Cumulative score			15		15		10		5		5		15	65.00	31.20		K

K	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.**	**Sustainable design**
	Use of raceways as wall skirting	Exposed wiring and raceways use insulating	Modular design	Clarity in instructions	Modular design		Raceways (refer sec 3.4.3.3)	Raceways (refer sec 3.4.3.3)	Design expertise	Design expertise	Design expertise	
	Wireless systems		Modular design				Wireless systems (refer 3.6.4)		Design expertise			
	Non structural moveable partition walls					Energy star outlets	Design expertise					Energy star appliances (refer sec
		Energy star outlets				Active / Passive solar design		Energy star appliances (refer sec 3.6.4)				Solar design (refer sec 3.6.1 and 3.6.2 and
		Data and electrical wiring integration				Energy star appliances		Power line networking (refer sec				Energy star appliances (refer sec
K												

No.		Building systems (Design considerations)	Cr.	Intent																
				Spatial flexibility	Sc.	Thermal performance	Sc.	Structural Integrity	Sc.	Ease of const.	Sc.	Ease of maint.	Sc.	Sustainable design	Sc.	Total sc.	Sc. x Cr.	L
G		**Interior (Type B)**	**0.24**															
1		Architectural design		Changeability of spaces as requirements	5	Material thermal performance	5	Moveable / changeable elements	5	Ease of assembly	5	Ease of handling / changeability	5	Material choice	5			
2		Engineering design		Modular furniture design	5	Summer and winter partition design	5			Ease of assembly	5	Ease of handling / changeability	5	Alternative material use rather than lumber	5			
														Reusable materials	5			
3		Special design consideration																
	a	Flexible space design		Access floor	5													
				Movable walls	5													
		Cumulative score	8		20		10		5		10		10		15	70.00	16.80	
		Final score														525.00	**755**	L

L

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.**	**Sustainable design**
Grid based design	Foam core panels. High strength OSB	Snap on panels	Clarity in instructions	Utility core integrating all utilities in an organized	Recycled content material	Design expertise	Alternative framing materials (refer sec 3.5.1)	Pre manufactured systems (refer sec 2.4)	Hybrid systems (refer sec 3.5.3)	Pre manufactured systems (refer sec	Recycled content material (refer sec 3.6.3)
Modular design	Modular furniture elements which can be arranged according to air		Clarity in instructions	Modular design	Alternative material use rather than lumber						
	Alternative materials				Reusable materials						Bio based material (refer

L

Appendix C3

(View as joined at 1-2-3-4-5)

No.	Building systems (Design considerations)	Cr.	Intent								
			Spatial flexibility	Sc.	Reasons	Thermal performance	Sc.	Reasons	Structural Integrity	Sc.	Reasons
A	**Structure / Env.**	**4.4**									
1	Architectural design		Changeability of spaces	2	Since open planning is used to some degree in the first floor design the strategy is not completely ineffective but since the intent was not central to the design it cannot be considered effective.	Material thermal performance	4	The minimum code requirements have been enforced with gypsum board on 2 x 4 16 inch OC. It is assumed that this specification is effective but not as effective as using alternative materials	Moveable / changeable elements	1	Since no structural elements are changeable or moveable the strategy is non existent therefore it is considered ineffective
2	Engineering design		Modular design	1	The design has not been envisaged as a modular design and therefore there are no components.	Reduction of loss of heat and cold from building enveiope	1	Since no specific steps have been taken the strategy will be considered ineffective.	Flexibility of assembling units	1	Since no flexible units are defined the strategy is non existent therefore it is considered ineffective
						Decreased use of artificial lighting	2	The strategy has not been considered although minimum requirements are fulfilled.			
						Air movement within the home	1	Air movement is restricted due to plan therefore must be achieved through artificial means which involves expending energy therefore the strategy is considered ineffective			
3	Special design consideration										
a	Active solar design					Use of alternative energy sources	1	The strategy is non existent therefore it is considered ineffective	Integrative energy structure	1	The strategy is non existent therefore it is considered ineffective.
b	Passive solar design					Sunlight in wet areas	4	Bathroom at the 2nd floor is ventilated artificially. All the other bathrooms have appropriate access to sunlight.			
						Use of sunlight as per seasonal requirements	1	The strategy is non existent therefore it is considered ineffective			
	Cumulative score			3			14			3	

1	Intent										
	Ease of const.	Sc.	Reasons	Ease of maint.	Sc.	Reasons	Sustainable design	Sc.	Reasons	Total sc.	Sc. x Cr.
	Ease of assembly	1	The strategy is non existent therefore it is considered ineffective	Ease of handling / changeability	1	The strategy is non existent therefore it is considered ineffective	Material choice	1	The strategy is non existent therefore it is considered ineffective		
	Ease of assembly	1	The strategy is non existent therefore it is considered ineffective	Ease of handling / changeability	1	The strategy is non existent therefore it is considered ineffective.					
	Clarity of instructions	5	Assumed that the specifications are clearly defined all through the construction process and therefore the strategy is considered effective.								
				Low maintaianence requirements over lifetime	3	Assumed that the specifications are clearly defined all through the construction process and therefore the strategy is considered effective.	Reduction in use of traditional energy sources	1	The strategy is non existent therefore it is considered ineffective.		
							Reduction in use of traditional energy sources	1	The strategy is non existent therefore it is considered ineffective.		
1		7			5			3		37.00	162.80

No.		Building systems (Design considerations)	Cr.	Intent								
				Spatial flexibility	Sc.	Reasons	Thermal performance	Sc.	Reasons	Structural Integrity	Sc.	Reasons
B		HVAC	1.28									
1		Architectural design										
	a	Comfort requirements	P		na			na			na	
2		Engineering design		Space requirements for placement of units and distribution systems	5	A mechanical chase is used and most distribution is through the floor.	Type of HVAC systems to be used and its inherent efficiency	5	Determined that Water based systems are most effective. Gas fired HVAC system is used here.	Placement of units and distribution system	5	Structural integrity has been considered since most distribution is through floor.
				Reorganization of spaces to be possible	1	The strategy is non existent therefore it is considered ineffective.	Reuse of heat generated within the home	5	No heat recovery system is used therefore the strategy is considered ineffective.			
				Heating and cooling as per requirements	5	Option for zoned HVAC systems within the design the strategy is considered effective.						
3		Special design consideration										
	a	Choice of Fuel					Use of alternative fuels	5	The strategy is non existent therefore it is considered ineffective.			
	b	Passive design techniques		Placement of distribution system	5	Distribution system organized thru subfloor and mech chase with supply registers located within the partition walls.	Use of sunlight for daytime heating	5	Low "E" glass is used therefore strategy is considered effective			
				Flexibility of distribution system	5	Use of flex ducts for manageability	Reuse of heat generated within the home	5	No heat recovery system therefore strategy is considered ineffective.			
							Reduction of loss of heat and cold from building envelope	5	Insulated windows and doors are used but no additional insulation is used, the strategy is considered reasonably effective.			
							Reduction of loss of heat and cold from distribution system	5	The distribution system is insulated with duct tape and all ducting in the attic space is insulated with 2" batt insulation.			
	c	Indoor Air Quality (ventilation)					Adequate natural and /or artificial ventilation provided	4	Design of the HVAC system provides adequate vent. The attic is not specified as vented.			
		Cumulative score			21			39			5	

2

2

2	Intent										
	Ease of const.	Sc.	Reasons	Ease of maint.	Sc.	Reasons	Sustainable design	Sc.	Reasons	Total sc.	Sc. x Cr.
		na			na			na			
	Ease of assembly	1	The strategy is non existent therefore it is considered ineffective	Ease of handling / changeability	1	The strategy is non existent therefore it is considered ineffective	Reduction in loss of energy	3	Some measures have been taken such as Low "E" glass for skylights.		
	Clarity of instructions	5	Assumed that the specifications are clearly defined therefore the strategy is considered effective.	Ease of access of distribution systems	3	Access for within the mechanical chase is easy but regular distribution through the wall as in traditional construction.					
	Lesser no of parts	1	The strategy is non existent therefore it is considered ineffective				Elimination of unnecessary heating or cooling	5	Zoned systems are optional		
				Renewable fuel	1	The strategy is non existent therefore it is considered ineffective.	Reduction in use of traditional energy sources	1	The strategy is non existent therefore it is considered ineffective		
	Distribution material	5	Use of flex ducts for manageability								
2		12			5			9		95.00	121.60

No.		Building systems (Design considerations)	Cr.	Intent								
				Spatial flexibility	Sc.	Reasons	Thermal performance	Sc.	Reasons	Structural Integrity	Sc.	Reasons
C		**Plumbing**	0.64									
1		Architectural design										
2		Engineering design		Wet cores to be consolidated	3	Wet cores have been consolidated to a certain extend especially at the first floor.	Reduction in loss of heat	1	Copper piping is used but no special insualtion to be provided therefore the strategy is considered ineffective.			
				Restrict distribution lines	3	No special systems are used other than a mechanical chase therefore reasonably effective.	Reuse of heat generated within the home	1	No heat recovery system is used therefore the strategy is considered ineffective.			
				Reduced horizontal distribution	1	The strategy is non existent therefore it is considered ineffective.						
3		Special design consideration										
	a	Water conservation					Grey water reuse	1	The strategy is non existent therefore it is considered ineffective.			
	b	Fuel requirements										
		Cumulative score			7			3			0	
D		**Electrical**	0.64									
1		Architectural design										
2		Engineering design		Distribution to be flexible	1	The strategy is non existent therefore it is considered ineffective.	Avoid compromising structural integrity to place wiring	1	Distribution system is through the wall, the strategy is considered ineffective.	Adequate insulation	1	No special insulation is specified for electrical wiring.
				Placement of distribution system	1	Distribution through wall compromises flexibility of space layout in the interior of the house the strategy is considered ineffective.	Reduction of use of artificial lighting in the daytime	4	Orientation for openings mostly East/West is not as satisfactory as South. Minimum glazed opening required provided.			
							Use of efficient outlets	1	Strategy non existent therefore ineffective.			
3		Special design consideration										
	a	Energy requirements										
		Cumulative score			2			6			1	

3	Intent										
	Ease of const.	Sc.	Reasons	Ease of maint.	Sc.	Reasons	Sustainable design	Sc.	Reasons	Total sc.	Sc. x Cr.
	Ease of assembly	1	The strategy is non existent therefore it is considered ineffective	Ease of handling / changeability	1	The strategy is non existent therefore it is considered ineffective					
				Ease of access	3	Access for within the mechanical chase is easy but regular distribution through the wall as in traditional construction.					
							Grey water reuse	1	The strategy is non existent therefore it is considered ineffective.		
							Reduction in use of traditional energy sources	1	The strategy is non existent therefore it is considered ineffective.		
		1			4			2		17.00	10.88
	Ease of assembly	1	The strategy is non existent therefore it is considered ineffective	Ease of handling / changeability	1	The strategy is non existent therefore it is considered ineffective					
	Integration with other uses	1	The strategy is non existent therefore it is considered ineffective	Ease of access	3	Access for within the mechanical chase is easy but regular distribution through the wall has inbuilt difficulties as in traditional construction.					
							Use efficient wiring	3	Regular copper wiring in PVC casing is used therefore the strategy will be considered reasonably effective.		
							Use of efficient outlets	1	Strategy non existent therefore ineffective.		
							Use of alt. sources of energy	1	Strategy non existent therefore ineffective.		
3		2			4			5		26.00	16.64

No.		Building systems (Design considerations)	Cr.	Intent								
				Spatial flexibility	Sc.	Reasons	Thermal performance	Sc.	Reasons	Structural Integrity	Sc.	Reasons
E		**Comm.**	**0.32**									
1		Architectural design										
2		Engineering design		Distribution to be flexible	1	The strategy is non existent therefore it is considered ineffective.	Avoid compromising structural integrity to place wiring	1	Distribution through wall compromises flexibility of space layout in the interior of the house the strategy is considered ineffective.			
				Placement of distribution system	1	Distribution through wall compromises flexibility of space layout in the interior of the house the strategy is considered ineffective.						
3		Special design consideration										
	a	Integrative design										
		Cumulative score			2			1			0	
F		**Interior (Type A)**	**0.48**									
1		Architectural design										
2		Engineering design		Detachable outlets	1	Strategy non existent therefore ineffective.	Adequate insulation	5	Adequate insulation is inbuilt into products	Moveable / changeable elements	1	Strategy non existent therefore ineffective.
				Eliminate wiring	1	Strategy non existent therefore ineffective.				Flexibility of assembling units	1	Strategy non existent therefore ineffective.
				Elimination of partition walls	1	Strategy non existent therefore ineffective.						
3		Special design consideration										
	a	Energy requirements					Use of efficient outlets	1	Strategy non existent therefore ineffective.			
							Use of efficient wiring	1	Strategy non existent therefore ineffective.			
		Cumulative score			3			7			2	

4	Intent										
	Ease of const.	Sc.	Reasons	Ease of maint.	Sc.	Reasons	Sustainable design	Sc.	Reasons	Total sc.	Sc. x Cr.
	Ease of assembly	1	The strategy is non existent therefore it is considered ineffective	Ease of handling / changeability	1	The strategy is non existent therefore it is considered ineffective	Use efficient wiring	3	Regular copper wiring in PVC casing is used therefore the strategy will be considered reasonably effective.		
				Ease of access	3	Access for within the mechanical chase is easy but regular distribution through the wall has inbuilt difficulties as in traditional construction.					
	Int with other uses	1	Strategy non existent therefore ineffective.	Elimination of wiring	1	Strategy non existent therefore ineffective.					
		2			5			3		13.00	4.16
	Ease of assembly	1	Strategy non existent therefore ineffective.	Ease of handling / changeability	1	Strategy non existent therefore ineffective.					
							Efficient outlets	1	Strategy non existent therefore ineffective.		
							Use of alternative sources of energy	1	Strategy non existent therefore ineffective.		
							Efficient appliances	1	Strategy non existent therefore ineffective.		
4		1			1			3		25.00	12.00

No.		Building systems (Design considerations)	Cr.	Intent								
				Spatial flexibility	Sc.	Reasons	Thermal performance	Sc.	Reasons	Structural Integrity	Sc.	Reasons
G		**Interior (Type B)**	**0.24**									
1		Architectural design		Changeability of spaces as requirements	1	Strategy non existent therefore ineffective.	Material thermal performance	1	Strategy non existent therefore ineffective.	Moveable / changeable elements	1	Strategy non existent therefore ineffective.
2		Engineering design		Modular furniture design	1	Strategy non existent therefore ineffective.	Summer and winter partition design	1	Strategy non existent therefore ineffective.			
							Material choice	1	Strategy non existent therefore ineffective.			
3		Special design consideration										
	a	Flexible space design		Access floor	1	Strategy non existent therefore ineffective.						
				Movable walls	1	Strategy non existent therefore ineffective.						
		Cumulative score	8		4			3			1	
		Final score										

5

5

	Intent										
5	Ease of const.	Sc.	Reasons	Ease of maint.	Sc.	Reasons	Sustainable design	Sc.	Reasons	Total sc.	Sc. x Cr.
	Ease of assembly	1	Strategy non existent therefore ineffective.	Ease of handling / changeability	1	Strategy non existent therefore ineffective.	Material choice	1	Strategy non existent therefore ineffective.		
	Ease of assembly	1	Strategy non existent therefore ineffective.	Ease of handling / changeability	1	Strategy non existent therefore ineffective.	Alternative material use rather than lumber	1	Strategy non existent therefore ineffective.		
							Reusable materials	1	Strategy non existent therefore ineffective.		
		2			2			3		15.00	3.60
5										228.00	332

Appendix C4

(View as joined at 6-7-8-9-10)

No.		Building systems (Design considerations)	Cr.	Intent									6
				Spatial flex	Sc.	Reasons	Thermal perform	Sc.	Reasons	Str. Integrity	Sc.	Reasons	
A		**Structure / Envelope**	**4.4**										
1		Architectural design		Changeability of spaces	1	Changeability is very minimal due to minimal required structural design.	Material thermal performance	3	The minimum code requirements have been enforced with gypsum board on 2 x 4 16 inch OC. It is assumed that this specification is effective but not as effective as using alternative materials	Moveable / changeable elements	1	Changeability is very minimal due to minimal required structural design.	
2		Engineering design		Modular design	5	The entire home is largely designed using components such as foundation walls, wall panels, floor truss systems and roof trusses.	Reduction of loss of heat and cold from building envelope	1	Since no specific steps have been taken to complete this intent such as special insulation the strategy will be considered ineffective.	Flexibility of assembling units	1	Changeability is very minimal due to minimal required structural design.	
							Decreased use of artificial lighting	2	The strategy has not been considered although minimum requirements are fulfilled.				
							Air movement within the home	1	Air movement is restricted due to the plan and therefore must be achieved through artificial means which involves expending energy therefore the strategy is considered ineffective				
3		Special design consideration											
	a	Active solar design					Use of alternative energy sources	1	The strategy is non existent therefore it is considered ineffective	Integrative energy structure	1	The strategy is non existent therefore it is considered ineffective	
	b	Passive solar design					Sunlight in wet areas	4	One bathroom at the second floor is ventilated artificially with no natural light. All the other bathrooms have appropriate access to sunlight.				
							Use of sunlight as per seasonal requirements	1	The strategy is non existent therefore it is considered ineffective				
		Cumulative score			6			13			3		6

6	Intent										
	Ease of const.	Sc.	Reasons	Ease of maint.	Sc.	Reasons	Sustainable design	Sc.	Reasons	Total sc.	Sc. x Cr.
	Ease of assembly	4	Ease of assembly is reasonably enhanced	Ease of handling / changeability	4	Changeability is very minimal due to minimal required structural design. Handling is greatly enhanced due to a factory produced product	Material choice	1	The strategy is non existent therefore it is considered ineffective		
	Ease of assembly	4	Ease of assembly is reasonably enhanced	Ease of handling / changeability	4	Changeability is very minimal due to minimal required structural design. Handling is greatly enhanced due to a factory produced product					
	Clarity of inst.	5	The industry has set up a system of clear and precise instructions for assembly								
				Low maintaianence requirements over lifetime	5	The strategy is non existent therefore it is considered ineffective	Reduction in use of traditional energy sources	1	The strategy is non existent therefore it is considered ineffective		
							Reduction in use of traditional energy sources	4	Although there is no direct usage of alternative energy sources, the mass production of components constitutes some reduction of energy usage overall.		
6		13			13			6		66.00	290.40

No.		Building systems (Design considerations)	Cr.	Intent									
				Spatial flex	Sc.	Reasons	Thermal perform	Sc.	Reasons	Str. Integrity	Sc.	Reasons	
B		HVAC	1.28										
1		Architectural design											
	a	Comfort requirements	P		na			na			na		
2		Engineering design		Space requirements for placement of units and distribution systems	5	Most distribution is through subfloor, since this a single storey unit mechanical chase is not required.	Type of HVAC systems to be used and its inherent efficiency	4	It has been determined that Water based systems are the most effective. A gas fired HVAC system is used here.	Placement of units and distribution system	5	Structural integrity has been considered since most distribution is through floor, the system is considered effective.	
				Reorganization of spaces to be possible	3	Reorganization of spaces is possible to a certain extent owing to component assembly design.	Reuse of heat generated within the home	1	No heat recovery system is used therefore the strategy is considered ineffective.				
				Heating and cooling as per requirements	1	Zoned HVAC options may not be available							
3		Special design consideration											
	a	Choice of Fuel					Use of alternative fuels	1	The strategy is non existent therefore it is considered ineffective.				
	b	Passive design techniques		Placement of distribution system	5	Distribution system organized thru subfloor and mech chase with supply registers located within the partition walls.	Use of sunlight for daytime heating	5	Low "E" glass is used therefore strategy is considered effective				
				Flexibility of distribution system	5	Use of flex ducts for manageability	Reuse of heat generated within the home	1	No heat recovery system is used therefore the strategy is considered ineffective.				
							Reduction of loss of heat and cold from building envelope	1	A manufactured home may not come with standard with any special energy design due to the small margin of profit.				

7

7

7	Intent										
	Ease of const.	Sc.	Reasons	Ease of maint.	Sc.	Reasons	Sustainable design	Sc.	Reasons	Total sc.	Sc. x Cr.
		na			na			na			
	Ease of assembly	5	Ease of assembly is immensely enhanced	Ease of handling / changeability	5	Componentized construciton, reduction of punch list	Reduction in loss of energy	1	A manufactured home may not come with standard with any special energy design due to the small margin of profit.		
	Clarity of instructions	5	The industry has set up a system of clear and precise instructions for assembly	Ease of access of distribution systems	4	Distribution systems are mostly accessed through the crawl space which may not be considered as the best possible option.					
	Lesser no of parts	5	Since the Manufactured home is built as a unit and transferred to site the no of parts on site are virtually non existent.				Elimination of unnecessary heating or cooling	1	Zoned systems are not optional		
				Renewable fuel	1	The strategy is non existent therefore it is considered ineffective.	Reduction in use of traditional energy sources	1	The strategy is non existent therefore it is considered ineffective		
	Distribution material	5	Use of flex ducts for manageability								
7											

No.		Building systems (Design considerations)	Cr.	Intent									
				Spatial flex	Sc.	Reasons	Thermal perform	Sc.	Reasons	Str. Integrity	Sc.	Reasons	
							Reduction of loss of heat and cold from distribution system	5	All distribution systems in the crawl space is insulated and ideally lifted from the ground.				
	c	Indoor Air Quality (ventilation)					Adequate natural and /or artificial ventilation provided	4	It is assumed that the design of the HVAC system provides for adequate ventilation of indoor air. The attic is not specified as vented.				
		Cumulative score			19			22			5		8
C		**Plumbing**	0.64										
1		Architectural design											
2		Engineering design		Wet cores to be consolidated	5	The wet cores are consolidated	Reduction in loss of heat	1	Copper piping is used but there is no mention of any special insulation to be provided. Hence the strategy is considered ineffective.				
				Restrict distribution lines	1	The strategy is non existent therefore it is considered ineffective.	Reuse of heat generated within the home	1	No heat recovery system is used therefore the strategy is considered ineffective.				
				Reduced horizontal distribution	1	The strategy is non existent therefore it is considered ineffective.							
3		Special design consideration											
	a	Water conservation					Grey water reuse	1	The strategy is non existent therefore it is considered ineffective.				
	b	Fuel requirements											
		Cumulative score			7			3			0		8

	Intent										
8	Ease of const.	Sc.	Reasons	Ease of maint.	Sc.	Reasons	Sustainable design	Sc.	Reasons	Total sc.	Sc. x Cr.
		20			10			3		79.00	101.12
	Ease of assembly	4	Ease of assembly is reasonably enhanced	Ease of handling / changeability	5	The components are transported on specially designed trailers to facilitate access at the jobsite and placement is conducted using a crane. The punch list items are reduced largely by using this construction process.					
				Ease of access	4	Distribution systems are mostly accessed through the crawl space which may not be considered as the best possible option.					
							Grey water reuse	1	The strategy is non existent therefore it is considered ineffective.		
							Reduction in use of traditional energy sources	1	The strategy is non existent therefore it is considered ineffective.		
8		4			9			2		41.00	26.24

No.		Building systems (Design considerations)	Cr.	Intent									
				Spatial flex	Sc.	Reasons	Thermal perform	Sc.	Reasons	Str. Integrity	Sc.	Reasons	
D		**Electrical**	**0.64**										
1		Architectural design											
2		Engineering design		Distribution to be flexible	1	The strategy is non existent therefore it is considered ineffective.	Avoid compromising structural integrity to place wiring	1	Distribution system is through the wall, the strategy is considered ineffective.	Adequate insulation	1	No special insulation is specified for electrical wiring.	
				Placement of distribution system	1	Distribution system is through the wall, since this compromises flexibility of space layout in the interior of the house the strategy is considered ineffective.	Reduction of use of artificial lighting in the daytime	4	Orientation for openings is specified as most East/West which is not as satisfactory as South. Minimum of 4% glazed opening required which has been provided. One bathroom on the second floor has not window access.				
							Use of efficient outlets	1	The strategy is non existent therefore it is considered ineffective.				
3		Special design consideration											
	a	Energy requirements											
		Cumulative score			2			6			1		
E		**Communication**	**0.32**										
1		Architectural design											
2		Engineering design		Distribution to be flexible	1	The strategy is non existent therefore it is considered ineffective.	Avoid compromising structural integrity to place wiring	1	Distribution system is through the wall, the strategy is considered ineffective.				

	Intent										
9	Ease of const.	Sc.	Reasons	Ease of maint.	Sc.	Reasons	Sustainable design	Sc.	Reasons	Total sc.	Sc. x Cr.
	Ease of assembly	4	Ease of assembly is reasonably enhanced	Ease of handling / changeability	5	The components are transported on specially designed trailers to facilitate access at the jobsite and placement is conducted using a crane. The punch list items are reduced largely by using this construction process.					
	Integration with other uses	1	The strategy is non existent therefore it is considered ineffective	Ease of access	4	Distribution systems are mostly accessed through the crawl space which may not be considered as the best possible option.					
							Use efficient wiring	3	Regular copper wiring in PVC casing is used therefore the strategy will be considered reasonably effective.		
							Use of efficient outlets	1	The strategy is non existent therefore it is considered ineffective.		
							Use of alternative sources of energy	1	The strategy is non existent therefore it is considered ineffective.		
		5			9			5		28.00	17.92
9	Ease of assembly	4	Ease of assembly is reasonably enhanced	Ease of handling / changeability	5	The components are transported on specially designed trailers to facilitate access at the jobsite and placement is conducted using a crane. The punch list items are reduced largely by using this construction process.	Use efficient wiring	3	Regular copper wiring in PVC casing is used therefore the strategy will be considered reasonably effective.		

No.		Building systems (Design considerations)	Cr.	Intent								
				Spatial flex	Sc.	Reasons	Thermal perform	Sc.	Reasons	Str. Integrity	Sc.	Reasons
				Placement of distribution system	1	Distribution compromises flexibility of space layout in the interior of the house the strategy is considered ineffective.						
3		Special design consideration										
	a	Integrative design										
		Cumulative score			2			1			0	
F		**Interior (Type A)**	**0.48**									
1		Architectural design										
2		Engineering design		Detachable outlets	1	Strategy non existent therefore ineffective.	Adequate insulation	5	Adequate insulation is inbuilt into products	Moveable / changeable elements	1	Strategy non existent therefore ineffective.
				Eliminate wiring	1	Strategy non existent therefore ineffective.				Flexibility of assembling units	1	Strategy non existent therefore ineffective.
				Elimination of partition walls	1	Strategy non existent therefore ineffective.						
3		Special design consideration										
	a	Energy requirements					Use of efficient outlets	1	Strategy non existent therefore ineffective.			
							Use of efficient wiring	1	Strategy non existent therefore ineffective.			
		Cumulative score			3			7			2	
G		**Interior (Type B)**	**0.24**									
1		Architectural design		Changeability of spaces as requirements	1	Strategy non existent therefore ineffective.	Material thermal performance	1	Strategy non existent therefore ineffective.	Moveable / changeable elements	1	Strategy non existent therefore ineffective.
2		Engineering design		Modular furniture design	1	Strategy non existent therefore ineffective.	Summer and winter partition design	1	Strategy non existent therefore ineffective.			
3		Special design consideration										
	a	Flexible space design		Access floor	1	Strategy non existent therefore ineffective.						
				Movable walls	1	Strategy non existent therefore ineffective.						
		Cumulative score	8		4			2			1	
		Final score										

Intent										
Ease of const.	Sc.	Reasons	Ease of maint.	Sc.	Reasons	Sustainable design	Sc.	Reasons	Total sc.	Sc. x Cr.
			Ease of access	4	Distribution systems are mostly accessed through the crawl space which may not be considered as the best possible option.					
Integration with other uses	1	The strategy is non existent therefore it is considered ineffective	Elimination of wiring	1	The strategy is non existent therefore it is considered ineffective					
	5			10			3		21.00	6.72
Ease of assembly	1	Strategy non existent therefore ineffective.	Ease of handling / changeability	1	Strategy non existent therefore ineffective.					
						Efficient outlets	1	Strategy non existent therefore ineffective.		
						Use of alternative sources of energy	1	Strategy non existent therefore ineffective.		
						Efficient appliances	1	Strategy non existent therefore ineffective.		
	1			1			3		17.00	8.16
Ease of assembly	1	Strategy non existent therefore ineffective.	Ease of handling / changeability	1	Strategy non existent therefore ineffective.	Material choice	1	Strategy non existent therefore ineffective.		
Ease of assembly	1	Strategy non existent therefore ineffective.	Ease of handling / changeability	1	Strategy non existent therefore ineffective.	Alternative material use rather than lumber	1	Strategy non existent therefore ineffective.		
						Reusable materials	1	Strategy non existent therefore ineffective.		
	2			2			3		14.00	3.36
									266.00	454

Appendix C5

(View as joined at 11-12-13-14-15-16)

No.		Building systems (Design considerations)	Cr.	Intent									11
				Spatial flex	Sc.	Reasons	Thermal perform	Sc.	Reasons	Str Integrity	Sc.	Reasons	
A		**Structure / Env.**	**4.4**										
1		Architectural design		Changeability of spaces	4	Possible to add internal partitions with ease although it is not possible to modify the existing form of the home without compromising the structural integrity.	Material thermal performance	5	Through discussion with the factory personnel it was determined that a special strength OSB is being manufactured by their suppliers which affords the similar strength in both axes.	Moveable / changeable elements	3	Since components are built within a factory and the design is composed of component assembly it will be relatively easier to change and move components.	
2		Engineering design		Modular design	5	The entire home is largely designed using components such as foundation walls, wall panels, floor truss systems and roof trusses.	Reduction of loss of heat and cold from building envelope	5	A special insulating strip is being used to insulate the door and window openings. Also due to the composition of the OSB it is possible to place windows within a precut SIP without adding headers further increasing the integrity of the wall panel.	Flexibility of assembling units	3	Since components are built within a factory and the design is composed of component assembly it will be relatively easier to change and move components.	
							Decreased use of artificial lighting	2	The strategy has not been considered although minimum requirements are fulfilled.				
							Air movement within the home	1	Air movement is restricted therefore involves expending energy therefore the strategy is considered ineffective				
3		Special design consideration											
	a	Active solar design					Use of alternative energy sources	1	The strategy is non existent therefore it is considered ineffective	Integrative energy structure	1	The strategy is non existent therefore it is considered ineffective	
	b	Passive solar design					Sunlight in wet areas	4	One bathroom at the second floor is ventilated artificially with no natural light. All the other bathrooms have appropriate access to sunlight.				
							Use of sunlight as per seasonal requirements	1	The strategy is non existent therefore it is considered ineffective				
		Cumulative score			9			19			7		11

11	Intent										
	Ease of const.	Sc.	Reasons	Ease of maint.	Sc.	Reasons	Sustainable design	Sc.	Reasons	Total sc.	Sc.x Cr.
	Ease of assembly	5	Ease of assembly is immensely enhanced	Ease of handling / changeabilit y	5	The components are transported on specially designed trailers to facilitate access at the jobsite and placement is conducted using a crane. The punch list items are reduced largely by using this construction process.	Material choice	5	Steel, concrete are usable materials and OSB is a recycled content material. There is minimal lumber used in the home construction mostly in the roof.		
	Ease of assembly	5	Ease of assembly is immensely enhanced	Ease of handling / changeabilit y	5	The components are transported on specially designed trailers to facilitate access at the jobsite and placement is conducted using a crane. The punch list items are reduced largely by using this construction process.					
	Clarity of instructions	5	The concerned party has expended reasonable efforts in training the involved personnel and instructions for assembly are clear.								
				Low maint. requirement s over lifetime	5	The materials used are steel studs and high strength OSB, SIP's. These will require relatively lower maintainence over time.	Reduction in use of traditional energy sources	1	The strategy is non existent therefore it is considered ineffective		
							Reduction in use of traditional energy sources	4	Although there is no direct usage of alternative energy sources, the mass production of components constitutes some reduction of energy usage overall.		
11		15			15			10		97.00	426.80

No.		Building systems (Design considerations)	Cr.	Intent								
				Spatial flex	Sc.	Reasons	Thermal perform	Sc.	Reasons	Str Integrity	Sc.	Reasons
B		HVAC	1.3									
1		Architectural design										
	a	Comfort requirements	P		na			na			na	
2		Engineering design		Space requirements for placement of units and distribution systems	5	A mechanical chase is used and most distribution is through the floor.	Type of HVAC systems to be used and its inherent efficiency	4	It has been determined that Water based systems are the most effective. A gas fired HVAC system is used here.	Placement of units and distribution system	5	Structural integrity has been considered since most distribution is through floor, the system is considered effective.
				Reorganization of spaces to be possible	3	Reorganization of spaces is possible to a certain extent owing to component assembly design.	Reuse of heat generated within the home	1	No heat recovery system is used therefore the strategy is considered ineffective.			
				Heating and cooling as per requirements	5	Since there is an option for zoned HVAC systems within the design the strategy is considered effective.						
3		Special design consideration										
	a	Choice of Fuel					Use of alternative fuels	1	The strategy is non existent therefore it is considered ineffective.			
	b	Passive design techniques		Placement of distribution system	5	Distribution system is largely restricted to subfloor and mech chase with supply registers located within the partition walls. Since the distribution is organized the strategy is considered effective.	Use of sunlight for daytime heating	5	Low "E" glass is used therefore strategy is considered effective			
				Flexibility of distribution system	5	Use of flex ducts for manageability	Reuse of heat generated within the home	1	No heat recovery system is used therefore the strategy is considered ineffective.			

12	Intent										
	Ease of const.	Sc.	Reasons	Ease of maint.	Sc.	Reasons	Sustainable design	Sc.	Reasons	Total sc.	Sc.x Cr.
		na			na			na			
	Ease of assembly	5	Ease of assembly is immensely enhanced	Ease of handling / changeability	5	The components are transported on specially designed trailers to facilitate access at the jobsite and placement is conducted using a crane. The punch list items are reduced largely by using this construction process.	Reduction in loss of energy	5	A special insulating strip is being used to insulate the door and window openings. Also due to the composition of the OSB it is possible to place windows within a precut SIP without adding headers further increasing the integrity of the wall panel. Some measures have been taken such as Low "E" glass for skylights.		
	Clarity of instructions	5	The concerned party has expended reasonable efforts in training the involved personnel and instructions for assembly are clear.	Ease of access of distribution systems	3	Access for within the mechanical chase is easy but regular distribution through the wall has inbuilt difficulties as in traditional construction.					
	Lesser no of parts	5	Due to component design within the factory including wall panels the no of parts to be handled on site is immensely reduced. This also includes JIT delivery.				Elimination of unnecessary heating or cooling	5	Zoned systems are optional		
				Renewable fuel	1	The strategy is non existent therefore it is considered ineffective.	Reduction in use of traditional energy sources	1	The strategy is non existent therefore it is considered ineffective		
	Distribution material	5	Use of flex ducts for manageability								
12											

No.		Building systems (Design considerations)	Cr.	Intent								
				Spatial flex	Sc.	Reasons	Thermal perform	Sc.	Reasons	Str Integrity	Sc.	Reasons
							Reduction of loss of heat and cold from building envelope	5	A special insulating strip is being used to insulate the door and window openings. Also due to the composition of the OSB it is possible to place windows within a precut SIP without adding headers further increasing the integrity of the wall panel.			
							Reduction of loss of heat and cold from distribution system	5	The distribution system is insulated with duct tape and all ducting in the attic space is insulated with 2" batt insulation.			
	c	Indoor Air Quality (ventilation)					Adequate natural and /or artificial ventilation provided	4	It is assumed that the design of the HVAC system provides for adequate ventilation of indoor air. The attic is not specified as vented.			
		Cumulative score			23			26			5	
C		**Plumbing**	**0.6**									
1		Architectural design										
2		Engineering design		Wet cores to be consolidated	3	Wet cores have been consolidated to a certain extend especially at the first floor.	Reduction in loss of heat	1	Copper piping is used but there is no mention of any special insualtion to be provided therefore the strategy is considered ineffective.			
				Restrict distribution lines	3	No special systems are used other than a mechanical chase therefore the system is considered reasonably effective.	Reuse of heat generated within the home	1	No heat recovery system is used therefore the strategy is considered ineffective.			
				Reduced horizontal distribution	1	The strategy is non existent therefore it is considered ineffective.						
3		Special design consideration										
	a	Water conservation					Grey water reuse	1	The strategy is non existent therefore it is considered ineffective.			
	b	Fuel requirements										
		Cumulative score			7			3			0	

13	Intent										
	Ease of const.	Sc.	Reasons	Ease of maint.	Sc.	Reasons	Sustainable design	Sc.	Reasons	Total sc.	Sc.x Cr.
		20			9			11		94.00	120.32
	Ease of assembly	5	Ease of assembly is immensely enhanced	Ease of handling / changeability	5	The components are transported on specially designed trailers to facilitate access at the jobsite and placement is conducted using a crane. The punch list items are reduced largely by using this construction process.					
				Ease of access	3	Access for within the mechanical chase is easy but regular distribution through the wall has inbuilt difficulties as in traditional construction.					
							Grey water reuse	1	The strategy is non existent therefore it is considered ineffective.		
							Reduction in use of traditional energy sources	1	The strategy is non existent therefore it is considered ineffective.		
13		5			8			2		51.00	32.64

No.		Building systems (Design considerations)	Cr.	Intent									
				Spatial flex	Sc.	Reasons	Thermal perform	Sc.	Reasons	Str Integrity	Sc.	Reasons	14
D		**Electrical**	**0.6**										
1		Architectural design											
2		Engineering design		Distribution to be flexible	1	The strategy is non existent therefore it is considered ineffective.	Avoid compromising structural integrity to place wiring	5	Distribution system is through the wall, since the wall is a SIP this does not compromise the thermal performance therefore the strategy is considered effective.	Adequate insulation	1	No special insulation is specified for electrical wiring.	
				Placement of distribution system	1	Distribution system is through the wall, since this compromises flexibility of space layout in the interior of the house the strategy is considered ineffective.	Reduction of use of artificial lighting in the daytime	4	Orientation for openings is specified as most East/West which is not as satisfactory as South. Minimum of *% glazed opening required which has been provided. One bathroom on the second floor has not window access.				
							Use of efficient outlets	1	The strategy is non existent therefore it is considered ineffective.				
3		Special design consideration											
	a	Energy requirements											
		Cumulative score			2			10			1		
E		**Communication**	**0.3**										
1		Architectural design											
2		Engineering design		Distribution to be flexible	1	The strategy is non existent therefore it is considered ineffective.	Avoid compromising structural integrity to place wiring	5	Distribution system is through the wall, since the wall is a SIP this does not compromise the thermal performance therefore the strategy is considered effective.				14

	Intent										
14	Ease of const.	Sc.	Reasons	Ease of maint.	Sc.	Reasons	Sustainable design	Sc.	Reasons	Total sc.	Sc.x Cr.
	Ease of assembly	5	Ease of assembly is immensely enhanced	Ease of handling / changeability	5	The components are transported on specially designed trailers to facilitate access at the jobsite and placement is conducted using a crane. The punch list items are reduced largely by using this construction process.					
	Integration with other uses	1	The strategy is non existent therefore it is considered ineffective	Ease of access	3	Access for within the mechanical chase is easy but regular distribution through the wall has inbuilt difficulties as in traditional construction.					
							Use efficient wiring	3	Regular copper wiring in PVC casing is used therefore the strategy will be considered reasonably effective.		
							Use of efficient outlets	1	The strategy is non existent therefore it is considered ineffective.		
							Use of alternative sources of energy	1	The strategy is non existent therefore it is considered ineffective.		
		6			8			5		32.00	20.48
14	Ease of assembly	5	Ease of assembly is immensely enhanced	Ease of handling / changeability	5	The components are transported on specially designed trailers to facilitate access at the jobsite and placement is conducted using a crane. The punch list items are reduced largely by using this construction process.	Use efficient wiring	3	Regular copper wiring in PVC casing is used therefore the strategy will be considered reasonably effective.		

No.		Building systems (Design considerations)	Cr.	Intent									
				Spatial flex	Sc.	Reasons	Thermal perform	Sc.	Reasons	Str Integrity	Sc.	Reasons	15
				Placement of distribution system	1	Distribution system is through the wall, since this compromises flexibility of space layout in the interior of the house the strategy is considered ineffective.							
3		Special design consideration											
	a	Integrative design											
		Cumulative score			2			5			0		
F		**Interior (Type A)**	**0.5**										
1		Architectural design											
2		Engineering design		Detachable outlets	1	The strategy is non existent therefore it is considered ineffective.	Adequate insulation	5	Adequate insulation is inbuilt into products	Moveable / changeable elements	1	The strategy is non existent therefore it is considered ineffective.	
				Eliminate wiring	1	The strategy is non existent therefore it is considered ineffective.				Flexibility of assembling units	1	The strategy is non existent therefore it is considered ineffective.	
				Elimination of partition walls	1	The strategy is non existent therefore it is considered ineffective.							
3		Special design consideration											
	a	Energy requirements					Use of efficient outlets	1	The strategy is non existent therefore it is considered ineffective.				
							Use of efficient wiring	1	The strategy is non existent therefore it is considered ineffective.				
		Cumulative score			3			7			2		15

15	Intent										
	Ease of const.	Sc.	Reasons	Ease of maint.	Sc.	Reasons	Sustainable design	Sc.	Reasons	Total sc.	Sc.x Cr.
				Ease of access	3	Access for within the mechanical chase is easy but regular distribution through the wall has inbuilt difficulties as in traditional construction.					
	Integration with other uses	1	The strategy is non existent therefore it is considered ineffective.	Elimination of wiring	1	The strategy is non existent therefore it is considered ineffective.					
		6			9			3		25.00	8.00
	Ease of assembly	1	The strategy is non existent therefore it is considered ineffective.	Ease of handling / changeability	1	The strategy is non existent therefore it is considered ineffective.					
							Efficient outlets	1	The strategy is non existent therefore it is considered ineffective.		
							Use of alternative sources of energy	1	The strategy is non existent therefore it is considered ineffective.		
							Efficient appliances	1	The strategy is non existent therefore it is considered ineffective.		
15		1			1			3		47.00	22.56

No.		Building systems (Design considerations)	Cr.	Intent									16
				Spatial flex	Sc.	Reasons	Thermal perform	Sc.	Reasons	Str Integrity	Sc.	Reasons	
G		**Interior (Type B)**	**0.2**										
1		Architectural design		Changeability of spaces as requirements	1	The strategy is non existent therefore it is considered ineffective.	Material thermal performance	1	The strategy is non existent therefore it is considered ineffective.	Moveable / changeable elements	1	The strategy is non existent therefore it is considered ineffective.	
2		Engineering design		Modular furniture design	1	The strategy is non existent therefore it is considered ineffective.	Summer and winter partition design	1	The strategy is non existent therefore it is considered ineffective.				
3		Special design consideration											
	a	Flexible space design		Access floor	1	The strategy is non existent therefore it is considered ineffective.							
				Movable walls	1	The strategy is non existent therefore it is considered ineffective.							
		Cumulative score	8		4			2			1		
		Final score											16

16	Intent										
	Ease of const.	Sc.	Reasons	Ease of maint.	Sc.	Reasons	Sustainable design	Sc.	Reasons	Total sc.	Sc.x Cr.
	Ease of assembly	1	The strategy is non existent therefore it is considered ineffective.	Ease of handling / changeability	1	The strategy is non existent therefore it is considered ineffective.	Material choice	1	The strategy is non existent therefore it is considered ineffective.		
	Ease of assembly	1	The strategy is non existent therefore it is considered ineffective.	Ease of handling / changeability	1	The strategy is non existent therefore it is considered ineffective.	Alternative material use rather than lumber	1	The strategy is non existent therefore it is considered ineffective.		
							Reusable materials	1	The strategy is non existent therefore it is considered ineffective.		
		2			2			3		14.00	3.36
16										360.00	634

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