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Prefabricated Housing and LEED

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PREFABRICATED HOUSING AND LEED

By

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Abstract

Prefabricated house could be a sustainable way to provide residences for Canadians. This research project is intended to assess prefabrication in terms of its compliances and potential links to LEED for Home by a commentary approach on each selected components of LEED. To achieve this goal, an in-depth analysis of the current situation of the prefabricated housing industry in Canada was carried out to come up with the appropriate results for this paper. Also a relevancy assessment has been carried out to identify potential LEED credits that can be directly or indirectly relevant to prefabricated homes. Furthermore, LEED credits have been examined to show to which degree prefabricated homes can facilitate achieving LEED points. EcoTerra house has been selected to be LEED rated to assess the role of prefabrication in achieving LEED points. As results some recommendations are given to be considered followed by limitations and suggestions for future researchers.

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CIR	Credit Interpretation Request	**NFRC**	National Fenestration Rating Council
IDR	Innovation Design Request	**HRAI**	Heating, Refrigeration and Air Conditioning Institution of Canada
PH	Prefabricated Homes	**HVAC**	Heating, Ventilating and Air Conditioning
ID	Innovation and Design Process	**FSC**	Forest Stewardship Council
PV	Photovoltaic	**EPP**	Environmentally Preferable Products
CMHC	Canadian Mortgage and Housing Corporation	**AE**	Awareness and Education
EA	Energy and Atmosphere	**NT**	Not Relevant
IECC	International Energy Conservation Code	**SR**	Somewhat Relevant
ACH	Air Changes per Hour	**R**	Relevant
SHGC	Solar Heat Gain Coefficient		

1- Introduction

Over time, benefits and advantages of prefabricated homes have been highlighted in many publications. This has been a sustainable approach to build homes which is the preferable practice in many regions specifically in Scandinavian countries. In Canada, according to the Canadian Housing Observer (2010), 11% of new homes starts (2009 statistic) are prefabricated; nonetheless, this is less than in some countries. The increasing importance of prefabricated housing sector makes researchers and students put more efforts and pay more attention to prefabricated homes.

The prefabricated housing industry is very dependent on the public acceptance, innovative approaches, material selection, methods, techniques and other factors which are discussed in this research. In addition, novel architectural designs, innovation in building science, environmental concerns and challenges triggered by climate change as well as social aspects have introduced new issues to be investigated further in this segment of industry.

The Canadian prefabricated housing sector is diversified in terms of techniques of build, materials and compliance with the latest energy-efficient standards. Also it has faced fluctuations in terms of economy and public acceptance. On the other hand, LEED for Home, which is providing invaluable criteria for assessment and rating homes based on their compliance with the energy-saving and other environmentally beneficial measures, does not yet address prefabricated homes properly based on the changing dynamic of this industry.

The objective of this research is to study the prefabricated housing industry in Canada in depth to find more links between prefabricated homes and LEED for Homes in terms of recommendations for further improvements for prefabrication industry in accordance to the findings and areas of improvements in the LEED for Homes' documents.

2- Research questions and goals

The goals of this research project are:

1- To identify relevant credits in LEED for Homes in regards to prefabricated homes (tabular approach).The Relevant (R) credits and Somewhat Relevant will be further considered.

2- To find out how prefabricated housing can directly help us achieve LEED rating. (For Relevant credits)

3- To identify how prefabricated housing can facilitate LEED rating. (For Somewhat Relevant credits)

4- To find out if LEED recognize the benefits of prefabricated homes and to what extent?

5- To evaluate as a case study one prefabricated house (EcoTerra) against LEED credits to assess the rating of the house according to the LEED Project Checklist (Preliminary Assessment)

3- Methodology

Since there are no sufficient directions and information in LEED for Home in regards to prefabricated homes it is intended to review categories of LEED for Homes to identify and tabulate relevant areas that can potentially contribute to implementation of prefabrication techniques. To achieve goals of this research project, many related sources have been considered to accumulate information for literature review and for results and conclusions. Books, articles and newspapers are considered as the major sources of information as well as online information gathered from government agencies, manufacturer websites and related organizations. Also, LEED Canada for Home 2009 – Reference Guide.

The steps taken towards completion of the research project are:

1- Review of prefabricated housing industry in Canada
2- Review of LEED for Homes
3- Identifying the relevant LEED credits that directly help prefabricated housing to achieve LEED rating, based on the literature review, LEED reference guide and available knowledge.
4- Identified relevant credits will be further studied to discover the ways that prefab industry can help us to achieve those credits.
5- Credits that are potentially identified as Somewhat Relevant (i.e. applicable to both prefabricated and site built houses will also be addressed in order to identify if and how they can be adjusted to better assess prefabrication.
6- Based on the findings on this research project it will be further discussed if and to what extent LEED recognize the benefits of prefabricated housing.
7- Similar to the LEED Project Checklist, all credits will be tabulated and the degree of their relevancy will be reflected on the relevancy table. After thorough consideration, comparison, applicability, identifying the potential areas and assessment of the documents, some suggestions will be given specifically for prefabricated homes.
8- Last but not least, EcoTerra project will be taken as an example to evaluate against LEED criteria to determine the LEED rating for this specific house.

4- Literature Review

4.1 Introduction

Back in early 19th century, the idea of prefabricated homes was conceived (Michaels, S. T., Gauthier A. & Azarian J. (Eds.), 2009). Since then this industry has evolved based on the needs and demand of the time. After World War II all soldiers returning from war wanted to start a family and the boost in demand of the housing was beyond the market capabilities thus the prefabricated homes was one solution in the 1950's to respond to an increasing demand. (http://www.modulartoday.com/modular-history.html) Also, in a natural disaster like hurricane Katrina, $3.5 billion in Emergency Housing vouchers approved by Senate to assist people build new shelters for themselves. (Illinois Housing Development Authority, 2010). Another example is provision of home in remote areas in the northern territories in Canada with an extreme climate.

On the other hand, prefabricated homes have broken their boundaries of practicality and have innovatively progressed in terms of architectural aspects. Nowadays, there are ample prefab manufacturers offering luxurious homes with reasonable and competitive prices. And even beyond luxury and practicality it is the realm of creativity and innovation that have captured lots of attentions from market (Herbers, 2004).

In North America with the emergence of mail-order house kits which were introduced by Sears, Roebuck and Co. in the early 20th century, the market had been faced with a limited interest in those types of homes. But modular homes with more to offer and higher level of innovation were able to establish a market and sold around 150,000 units before it stopped selling the homes through their catalogue.

In Canada, more than 100 companies are delivering prefabricated homes to their clients; however, the main hindrance is lack of new designs and innovation. For instance, Royal Homes has been serving the market for over 30 years. The Wingham, Ontario-based company has sold prefabricated homes throughout the province but the architect Lloyd Alter who is working with the company explain the situation as "The prefab look has typically derived from an engineering standpoint, not design," which implies a steadily traditional point of view in the market. (Donnelly, 2006)

4.2- Prefabrication in Housing Industry

Prefabrication in housing is defined as the provision of housing components in a factory. There are different levels of prefabrication in regards to housing. It can range from prefabricated components to be attached to the existing part of a house to a fully built house to be shipped to a site. (Forintek Canada Corp, 2001)

It is claimed that prefabrication in housing market has offered efficiency within the process of manufacturing, as well as cost effectiveness and reduction in eco-footprint due to material use and labour in addition to transportation of bulk material and so on.

4.3- Prefab Systems

Generally, prefabrication may fall into one of these categories:

4.3.1- Pre-engineered homes

Also known as Kit Homes in which all components of the home come in pre-cut packages in accordance with the drawings and specifications. This is the lowest level of prefabrication, (Forintek Canada Corp., 2001). This is a method that can be employed and considered both as prefabricated homes and on-site built homes, therefore; this option isn't covered in this research project.

4.3.2- Panellized homes

All the manufactured panels such as walls, roofs or roof elements are manufactured and shipped to the site as two-dimensional panels. This is the most common practices in Canadian prefabrication industry. Generally, panels can be wood-frame or steel frame, both structural elements and infill panels. Light panels may fall into one of these categories: wood, steel framed or sandwiched panels (expanded polyurethane or polystyrene) between two skins than can be plywood, aluminium sheets, concrete, steel or structural installed panes so called SIPs. (Forintek Canada Corp., 2001).

Most prefabricated residential homes in Canada have wood-framed panels (Clayton Research Associates, 2008). There are two main categories of panelized systems:

Closed panels: in this practice more elements are included into the panels such as insulation and drywall and in some cases even doors and windows are installed in the plant. This is a great practice to add efficient approaches to projects such as measures that increase air tightness. Also, this practice decreases errors from poor workmanship.

Open panels: in this method which is more prevalent in the Canadian prefabrication industry, exterior sheathing and framing are installed in the factory and the rest of the works such as interior gypsum boards, and exterior cladding are attached on site. (Forintek Canada Corp. 2001)

4.3.3- Modular Housing

This technique could help accelerate the process of construction by having *pre-manufac*tured housing modules transported to the location and erected by local workforces. This is the highest level of prefabrication that provides three-dimensional units which are built and finished in the plant. Almost 90% of the work is completed in the plant. There are different approaches within the industry: some manufacturers prefer to install drywall, and others choose to install exterior cladding on site to avoid damages that may occur during shipping. In this method almost all plumbing electrical works, kitchen facilities, windows and doors are installed in the factory and minor works are left to be done onsite such as final touches and connecting water, electricity and sewage systems to the city's facility.

Transportation plays a huge role in this method. Since the structure should sustain the vibrations and other loads imposed during transportation, it should be stronger than the conventional homes. Research conducted by Forintek Canada Corp, 2001, it argues that modular homes are 30% stronger in structure in comparison to conventional which can be considered as an disadvantage for unnecessary use of construction materials and in terms of sustainability issues.

4.3.4- Manufactured Housing

It the highest level of prefabrication in housing. The entire house is built in a factory and transported to the site that that has already been prepared. It is important to separate this method of prefabrication from the others that are being covered in this research due to the fact that these types of house do not have a permanent foundation and they are built with a lower quality in material and less insulation. These houses fall into mobile houses and therefore they don't comply with conventional building codes. Instead, they are built under HUD codes regulated by U.S. Department of Housing and Urban Development . Even here in Canada and in some municipalities builders cannot get the permit for them as a real home. This category will not be covered in this report.

4.4- Advantages and Benefits of Prefabricated Homes

Higher quality of a building that can be achieved within a controlled-environment (factory) is the main focus of this method. It is generally believed that prefabrication in housing sector can cut costs: Canada Mortgage and Housing Corporation suggests that labour saving and efficiencies in the production process of prefabricated houses results in 18 % cut in the costs.

The reasons why prefab house can be beneficial:

4.4.1- The Workforce

Using prefab houses significantly limits the dependency on plumber, carpenter, electricians, roofers and other trades on site. Since most of the work is done in a plant, the work force and delays associated with human components and workforce factors are considerably restricted. (Gianino, 2005)

4.4.2- Tools and Inventory

Working in a factory that has been equipped for producing for long periods and for many projects, is considerably better in comparison with working on site where worker may have some obstacles to have all equipment in hand. In other words, production in the factory is being done more organized with better flow and higher level of quality control (Gianino, 2005). Also it is claimed that the inventory is better controlled and materials are better kept in the storage and the weather-related damages decrease noticeably; the same report also shows that large-scale use of pneumatic tools linked to the central compressor is a time, fuel, and electricity saving measure. (Clayton Research Associates, 2008)

4.4.3- Controlled Climate

Working and building in climate-controlled conditions have many advantages including protection from severe weather-related defects including rain, freeze and thaw, strong winds and snow. Another issue in this regards is workmanship; in a climate controlled environment all poor workmanship considerably decreases in a well-organized and managed plant. These two factors enable manufacturers to provide homes to customers without significant delays and can provide services throughout a year. (Gianino, 2005) In addition to that, some process and performance of materials can be improved in an environmentally controlled situation. For instance the use of gas-fired heater to cure the asphalt on roofing shingles. (Clayton Research Associates, 2008)

4.4.4- Material and Processes

Prefab homes and more specifically modular housing are built stronger than on-site built homes in order to be transported to the site (Profile and prospects, 2006). Another issue is the quality of building materials and their conformance to the respective standards when materials are procured in large volume with comparatively lower prices. In that regards, many site builders may consider the minimum requirements for material standards, if not lower, to increase marginal benefits. But it is almost unlikely for well-known and reputable manufacturer to downgrade the building specification. (Gianino, 2005)

Another crucial factor to consider is reuse and recycling of building materials. (Jaillon & Poon, 2008). Reusing and recycling materials are easier to achieve as material can be stored in a controlled environment. Also, the lean production techniques can be implemented better in an environmentally controlled setting resulting in reduction in material use achieved by efficient use of material. (Roaf, S. 2007).

In addition, it is claimed that prefabricated housing has the ability to incorporate material and processes that either is not available or it has particular advantages when it is applied in a factory setting. For example, the use of structural insulated panels (SIPs) while it is available to conventional home builder it is more beneficial to apply in within factory settings. (Clayton Research Associates, 2008)

4.4.5- Energy Efficiency

One of the most substantial requirements which is expected to be met within housing industry is energy efficiency. Air leakage has been recognized as the main culprit for heat loss. Gianino A. (2005) claims that 25 to 40 percentage of energy used during cooling and heating seasons are lost due to air leakage in a typical home. Building a home in a factory is deemed to result in reduction of air leakage because, in general, manufactured homes have better sealed gaps. For instance, caulking along the exterior sheathing, windows flanges and electrical fixtures reduces leakage. Manufacturers can accomplish this task more efficiently because they build from inside out, while site builders usually and most often build from outside in. In a factory, drywall is installed before the exterior sheathings; in contrast, in an on-site built house, the installation of drywalls usually comes after exterior sheathings. The reason behind this method is to prevent damages to the drywall in case of rain. Installing exterior sheathing before the drywall makes it more difficult to reach behind the drywalls to seal electrical fixtures, pipes and other areas exposed to the exterior environment and can potentially allow air leakage.

The air tightness of a home is measured by the blower-door test. A report carried out for the U.S Department of Energy suggests that a typical modular home finished in a climate-controlled environment has a significantly better result (30 percent) for the blower-door test in comparison to a typical in-site built home (Gianino, 2005).

4.4.6- Quality Control

When it comes to modular homes, the quality of build is better controlled because the level and the accuracy of inspection is better than on-site built homes due to the environmentally controlled situation. This level of inspection is applied to every aspect of construction from wiring and plumbing to electrical fixtures (Gianino, 2005).

4.4.7- Warranty

Most modular homes have a minimum warranty of at least one year which includes all features. Gianino A. (2005).

4.4.8- Time Advantages

Manufactured homes usually take less time to build compared with the conventional on-site built homes. Gianino (2005) suggests that a modular home can be built and be ready to move in about eight weeks while in conventional way it takes at least 13 weeks to build a small uncomplicated home.

4.4.9- Cost Benefits

Because of all savings and efficiency in material consumption and the methods of construction which is being carried out in a plant and also because of the expertise of the various trades involved with a project in an environmentally controlled situation prefabricated homes tends to be more cost-effective than a regularly built house. According to Statistics Canada data, in 2004, a (modular) prefabricated house would cost approximately \$560/m^2; by adding the retail margins including transportation, installation of the prefabricated house on site, foundation and garages the total cost would rise to \$985/m^2. At the same time an average conventionally built residential house would cost \$1200/m^2.Therefore, 18 % cut in costs of material and labor can be expected from a prefabricated house. (Profile and prospects, 2006)

4.4.10- Material procurement

Purchasing building material also procurements of finishes and appliances are made in bulk which can significantly save money. (Gianino, 2005; Profile and prospects of the factory-built housing industry in Canada, 2006)

4.4.11- Better Compliance with Green Building Criteria

Prefabricated housing sector is aware of environmental benefits that can be gained through the prefab procedures from more energy efficient choices. For instance, Royal Homes and Guildcrest Homes are using the standards and programs set by government agencies such as R-2000 to comply with Energy Star specifications. R-2000 and Energy Star are standards administered by Natural Resource Canada to promote energy efficiency measures (Clayton Research Associates, 2008). To meet the requirements, homes should be 30 % more energy efficient than the base local codes (Model National Energy Code). That can be achieved by higher level of air tightness, using the heat recovery ventilator (HRV).

4.4.12- Effectiveness in Assembly Line

Organizing and coordinating of an assembly line is more efficient that on-site construction. (Gianino, 2005)

4.4.13- Less Waste

Reduced waste is a huge benefit that can be gained from prefab homes that in many occasions is considered as the primary goal of prefabricated homes. (Jaillon & Poon, 2008) Normally, all cut and scrap materials are saved to be reused as much as possible. Therefore, modular homes provide a better way to recycle in comparison to the conventional practices. Also, because all construction process occurs in a climate-controlled environment the weather and the problems and difficulties associated with the weather specifically in colder provinces of Canada such as Alberta can have the minimal effects. Therefore, the material loss is decreased significantly by prefabricating homes.

4.4.14- Labor Costs

The labor force is well trained; as a result, the quality and the speed of the final work will justify costs associated for training. Also, because all the process is happening in a climate controlled environment, the workmanship and productivity is significantly better. On the other hand it decreases further costs that may incur because of problems that may occur down the line which are associated with poor workmanship. It is important to mention that workers in a plant are offered less pay in comparison with the site-built home works. Because they work in a comfortable environment and as the precision and accuracy of the productions increase, job security for workers and tradesmen escalates as well, that results in a decrease in the labor costs in long-run and for each individual project due to the fact that an expert team has been tailored to work on a project most efficiently. (Gianino, 2005)

4.5- Issues and Concerns over Prefabricated Housing

Aside from many benefits that can be gained from factory built homes, there are some limitations and shortcomings in this method of building homes which are listed below:

4.5.1- Minimized flexibility

The design and models of the factory built homes get limited as the level of prefabrication increases. For instance, there are more options and designs when it comes to pre-cut option and less options of design for panellized and modular homes since most of the work are being done in the plant, thus the flexibility is minimized unless the client is willing to pay more for a real custom made home. In contrast, the flexibility in design is maximized for on-site built homes.

4.5.2- Design limitation

Since the efficiency, minimal waste and cost reduction are the main focuses of the prefabricated homes and due to mass production of homes which are, in some noticeable degrees, standardized the design in many cases is compromised (Ghandehari, 2000). Public perception and acceptance of prefab homes in Canada is lower that other leading countries.

4.5.3- Cost and pricing of prefabricated homes

Cost is the next shortcoming when it comes to have a custom made home with all desired components and options. As a general rule, the cost of prefab homes is less than traditionally built homes when a simple design with the basic options has been selected. However, for more options and design prefab industry should compete with the conventional built homes.

4.5.4- Real market value.

In Canada due to public perception about prefabricated homes and with respect to the fact that prefab industry are not as popular as it could be, the future market value of factory built homes is an issue for many prospective home owners who want to make sure that money which will be invested in their property will maintain the same value or even increase by passing time and in comparison with the conventional homes. This issue is magnified when the value of land is high and the site is located in a comparatively high-profile neighbourhood.

4.6- Prefabricated Housing Industry in Canada

Prevailing of prefabricated homes in different countries greatly depends on many factors such as the culture and customs, the economical profile of the society, common practices for housing industry, demographic and population density, public perception and acceptance, and environmental and climatic issues. Research carried out by the Canada Mortgage and Housing Corporation (Clayton Research Associates, 2008) suggests that the prospective demand for prefabricated housing sector is dependent on population growth, household formation, affordability, the potential growth area as well as moving of generation (those born in baby-boom). For instance In Japan, the public perception of the prefabricated home differs from those in Canada. In such an environment prefabricated homes are expected to offer higher quality with approximately 10% higher in pricing compared with the conventional homes. (Forintek Canada Corp. 2001)

Compared with some leading countries in prefab market, Canada has only 11% of the whole home's stock that indicates relatively a slow market for this industry. Another sign is the number of prefab companies that has decreased from 190 in 2003 to 100 in 2010 which is implying a slower market in Canada, resulting to decrease in number of active prefabricating manufacturers. (Tsang, 2006)

4.7- Historical Developments of Prefab Sector in Canada

According to a research by Clayton Research Associates, 2008, prefabricated homes started in 1890's on Nova Scotia to serve the domestic demand in remote areas as well as to export to the Caribbean.

In 1932, the Halliday Company was providing panelized houses to rural areas and after that it served the post-war (World War II) needs for shelter called Wartime Housing due to shortage of labor and sources of construction material.

In the 1960's and 1970's the post-war trend changed and the main focus turned to efficiencies, quality, look, saving in labor material and time, and advancement in method and technology of production.

To meet the demand of the time many companies emerged in 1970's across Canada such as: Canada Comstock (Montreal), West Coat Trailer (Vancouver), Engineered Building (Calgary) and North American Building (Winnipeg). By then the market share of residential sector rose significantly from 7 percent in 1940's to the peak 15 %.

This report shows that the 1960's and 70's were very prosperous for prefab industry and the number of companies were dabbled and even some of them excelled in their services and production in terms of productivity compared to conventional homebuilders. Companies such as Minto in Ottawa and Bramalea Rocket Lumber in Toronto emerged in that period in which companies were supported by government's new initiatives; for instance the Department of

Reginal Economic Expansion (DREE), established in 1969, was financially supporting the prefab sector. Companies like Atlantic Canada and part of Western Canada which are still existing were among those companies that received grants from (DREE).

During 1980’s and 1990’s this trend changed and the peak declined partly due to the shift in demand for product best suit for a “greater lifestyle” with more open concepts and better architectural features that the prefabricated housing sector couldn’t be able or unwilling to satisfy its clients taste. However, in the second half of 1980s this trend rocketed to 11.4 % of total housing starts. (Ghandehari, 2000) Also, new initiatives introduced by Federal government such as the Assisted Home Owner Program (AHOP), 1973 to 1979, slowed the prefab sector and demand for prefabricated homes. By that time conventional home builders began to implement new techniques to elevate efficiencies and quality of their works which was another reason for slowing prefab market.

In terms of provincial contribution to the prefabricated homes, the province of Ontario and Quebec had the most shares, about 210 and 220 million dollars respectively, followed by the Alberta and British Colombia with 170 and 75 million dollars in shipment of prefabricated homes. (Forintek Canada Corp, 2001).

Since then, only about 100 of certified prefabricated home’s manufacturers have survived in Canada and thirteen of them have their main facilities in the United States. (Canadian Housing Observer, 2010)

In terms of economic aspects of prefabricated houses, overall residential sector contribute about $80 billion to the economy each year and prefabricated housing has a relatively small portion of that which is $1.2 billion (Clayton Research Associates, 2008).

2.7.1- Industry Profile

As mentioned in previous sections, in Canada there are two major segments for residential prefabricated housing, manufactured homes (generally, components are built in the plant and shipped to the site for assembly) and modular homes (modules are mainly finished in the plant and shipped to the permanent foundation),

Prefabricated homes (panelized) in Canada account for 23 % of single-family factory-built residential homes while modular homes have more shares to contribute to the housing industry which is about 40%. (Tsang, 2006)

Table 1 - Factory-built housing production 1993-2004 (Eric Tsang, 2006)

	2004	Market Share	1993	Market Share
Total Units	24,440		17,330	
Non-residential[1]	7,550		2,343	
Multi-Family units [2]	2,090		1,289	
Single- Family units	14,890		13,698	
Panelized homes	3,420	23%	3,033	22%
Modular homes	6,160	42%	4,679	34%
Other (mobile homes and etc.)	5,220	35%	5,986	44%
Percentage of total single-family unit production				
Non-residential uses such as work camps and community centers				

Having compared the trends for 2004 and 1993, it can be deduced that since 1993, prefabricated housing has grown 1.4 times which is more related to non-residential and multi-family units. As the table also shows the modular homes are increasingly getting more popular compared with other types of the prefabrication. And also according to the same source between 1994 and 2004, the price of prefabricated homes increased by 37% (or 3.1 % annually) while the price for site-built homes rose by 28%. Also it is reported that 47 percent of the prefabricated home manufacturers are located in Western Canada. In terms of export and import in 2004, exports of factory-built residential units were $157 million, while the imports were $9 million. (Tsang 2006)

4.7.2- Variety in Practices

There are various methods of build implemented by manufacturers. Clayton Research Associates has found these methods and techniques more prevalent in Canadian prefab sector implemented mainly for the modular houses:

Floor Framing: it is a common practice to hang the floor upside down to frame and sheet while installing the mechanicals such as plumbing, duct work and wiring. Then the floor is flipped to complete the rest of works. However, in some production line floor frame is up-right and by using hydraulic jacks workers can access to the under the floor. Another practice is use of a pit below the production line.

Drywall: almost each manufacturer has its own way to install drywalls. Some may install drywall to walls in the jigs and then whole drywall (and clad wall) is placed on the frame. Another way is to frame panels and then install drywalls and ceilings within each room of the house. Other technique is to install drywalls after the house is assembled on site.

Production Line: usually the floor frame moves from the first station to the last station for the completion of tasks in the production line which is most often tracks

Inventory Management: LEAN manufacturing adapted from Toyota is now more common in the prefab sector in which all necessary inventories are eliminated by using the computerized tracking of the tools and materials.

Insulation: generally there are two types of insulations for the wall and ceiling, fiberglass and cellulose which can be either blown or placed in.

4.7.3- Material Usage

Timber is predominantly used in the Canadian prefab industry. Use of value-added wood product such as oriented strand board (OSB), for paneling, roof sheeting and exterior walls sheeting has become more common because of quality and its strength which is a crucial factor during transpiration.

Engineered roof trusses are widely used in almost all production lines; hinged truss is an innovative method which gives a better flexibility during the shipment.

4.7.4- Contributing Factors for factory built homes in Canada

Prospect of manufactured homes heavily depends on three main factors: Eric Tsang (2006)

5- Demands for conventionally built homes: For this part many elements should be taken into consideration such as population growth, composition of households and demands for single-family units.

6- The innovation in the prefab industry to maintain the level of public interest in factory built homes. This part deals with the affordability, energy efficiency, level of customization and etc.

7- Demographic characteristic of the population: Eric Tsang (2006) suggests that a decline in population growth and household’s formation is expected in 2010 leading to less starts in single-family units as population ages and tendency to apartment life-style increases. And also on this report it is claimed that immigration is a crucial contributor to the housing market as the existing population is aging.

On the other side, according to the Clayton Research Associates (2006) there are many signs of improvement that indicate a thriving future for the prefab sector including:

- Mounting in consumer acceptance: aesthetic and quality are standard in the process and prefab homes are not perceived as a ‘’house in a box’’
- Cost effectiveness: with saving of time, labor and material due to nature of the production
- Multi Section homes: which allows more than one span for a larger space.
- Non wood-base prefab housing alternative
- Architectural design: which add more features to the end product in terms of interior design ad well as overall look of the house

4.7.5- Prediction of trend for prefab sector

In terms of modular homes, merely in 2004, 6200 units were produced in Canada which shows 30 % growth compared with the1993 figure. This indicates popularity of modular homes (that accounts 42 percent of single-family homes starts) among Canadians that has caused prefab sector to be in transition toward modular house. According to this report and from a production standpoint factory-built procedures can easily shift from one to another for instance from panelized to modular since most of techniques are similar(Clayton Research Associates, 2008).

On the other side, panelized homes have remained popular in Canada and even it is pioneering in the market with a better flexibility in architectural design more specifically when it comes to steep roofs. The majority of panelized homes are produced by Viceroy Homes which is an public company which has facilities in Port Hope, Ontario and lower mainland in B.C. Also there is another Vancouver based public company based with 6,500 m^2 facility called International Hi-Tech Industries (IHI) which is planning the same establishment in Ontario.

4.7.6- Challenges on the Way of Prefab Sector in Canada

In 2006 Canadian Manufactured Housing Institute (CMHI) conducted a report on factory-built home specifications in Canada, criteria are as below: (Clayton Research Associates, 2008)

- RSI 3.53 (R-20) or better for exterior walls
- RSI- 7.05 (R-40) or Higher for roof and attic
- Low-E or argon-filled energy efficient windows
- Insulated door systems
- Tight envelope construction
- Heat recovery ventilation (HRV)
- Efficient heating equipment

According to the report these are the base requirements, however; many manufacturers are considering them as “secondary” rather than “primary” goal and they pay more attention to the features such as design, layout amenities and price which are the main focus of potential buyers. CMHI study also notes that these are challenges in the way of provision of higher energy efficient homes by prefab sector; challenges are as below:

- Homebuyer’s decisions are not derived from energy efficiency measures
- Inadequate mechanism to relate higher up-front cost form energy efficiency with on-going maintenance and energy savings down the road

- Potential buyers are only interested in features which are energy efficient during the period in which energy costs are higher.
- Buyers are able to equate energy and cost saving with the up-front costs usually consider short ‘’payback period’’ between 3 to 5 years.
- The growing expectation among buyer that energy efficiency measures should be included and priced as standard not at a premium price.

4.9- Architectural aspects

There are many books that have been published in regards to illustrate quality of architectural design in prefab homes including: Home Delivery by Bergdoll B., Christensen P., (2008), prefab modern written by Herbers, J. (2004). Modular Mansion by Koones, S. (2005). PREFAB Houses (Michaels, Gauthier & Azarian (Eds.).2009). and PreFabNow (Trulove, J. G. & Cha R. (Ed), 2007). These books are providing a wealth of knowledge which is based on demonstrating detailed case studies. These sources are giving some distinguished case studies in prefab homes in which innovation, sustainable features and outstanding architectural features are incorporated.

4.9- Eco-Principles and Prefabricated Housing

In addition to already described characteristics, prefabrication can offer additional potential in achieving sustainable housing, as will be described below.4.11.1- Smart Design

Sustainability begins with smart and thoughtful design. A smart design can sustain lower environmental impacts within the lifecycle of a home. Here are some criteria which are reflected in a book entitled Prefab Green by Kaufmann & Remick, 2009.

- Design to use less: The first step for a smart design is to minimize material use while maintaining the purpose of design.
- Design big instead of building big: proper and smart sizing of rooms and other spaces and use of spaces to reduce the waste area and to use even small spaces efficiently are the key. Double or multifunction design: a smart design can make a space serve for two or more purposes. For instance use of roof decks and covered outdoor spaces to enlarge the home's usable area or even with some creative furnishing ideas like sofa-bed or versatile partition wall a space can have various spatial uses. Another example is a proper design for roof's windows to illuminate the space through skylight as well as to ventilate it naturally.
- Natural cooling, heating and ventilation: this is a significant contributing factor to sustainable design. Make use of breezes and every single possibility that may help you reduce energy consumption. Smart design is not expensive, but thoughtful.
- Longevity and flexibility: design to last longer to serve generations with a low maintenance and low impact to the environment while it is flexible to adopt changing needs of inhabitants or design to be ''future proof'' (Kaufmann& Remick 2009)

4.11.2- Using Eco-Materials

Use sustainably sourced and sipped to reduce eco-footprint. Some measures are included into the table below:

Renewable Materials	Sustainably harvested materials	recycled materials
reuse of materials	waste reduction	long lasting and low-maintenance materials

4.11.3- Energy Efficiency

To address sustainability to fit in LEED, energy efficient features, substantially can add more credits to the prefab homes. These are some of the criteria for consideration:

- *Efficient Envelope:* This is air tight for all exterior parts including foundation, roof, walls doors, and windows. Kaufmann& Remick (2009) claims that a 12.9 cm^2 hole can reduce heating and cooling costs by up to 15%. And also high-quality insulation plays an important role in heat and cool exchange between indoor and outdoor.
- *Efficient Cooling and Heating Systems:* This is an important stage for a green prefab project. As it has mentioned many before in this research, energy saving measures and smart design necessarily isn't more expensive way in comparison with traditional and conventional methods. Just by incorporating some intelligent features such as mini duct serving as cooling tower, radiant heating system, cool roofs (with roofs), shading devices, siding wood sunshades, use of vegetation and many more, a green prefab home can be resulted.
- *Renewable sources:* such as Photovoltaic Panels (PV), wind power, solar and thermal water heating, geothermal power. It seems essential to mention that choosing the right method requires expertise and knowledge.
- *Monitoring systems:* That helps occupants to learn how much energy they have consumed and also to compare it with the best practice. Another benefit is raising awareness among people to be energy-conscious.

5- LEED

5.1-Introduction

Leadership in Energy and Environmental Design is a green rating system that promotes whole-building sustainable and green approaches through accepted and organized tools and performance criteria. The Canadian version of LEED is an adaptation of the US LEED developed by USGBC (US Green Building Council) which is tailored to suit Canadian climate, construction codes of practices and regulations. The main emphases of LEED are predominantly in five key areas which deal with human and environmental issues as follows:

- sustainable site development
- water efficiency
- energy efficiency
- materials selection
- indoor environmental quality

In addition, Innovation and Design Process addresses design measures and expertise. For each category there are certain Credits and Prerequisites.

LEED Canada rating systems cover seven major areas including new construction, commercial interiors, core and shells, existing buildings, homes and neighborhood developments and homes. (CaGBC , 2010) For the purpose of this research it is intended to look at the LEED for Homes in which there are two more categories addressing Awareness & Education and Location and Linkages.

5.2- LEED Canada for Homes

LEED Canada for Homes is voluntary certification systems that promotes the design and construction of high-performance green homes and encourage the adaptation of sustainable approaches. The LEED Canada for Homes is a part of LEED Green Building Rating System which is regulated by the CaGBC. According to LEED for homes it targets the top 25 % of home building in terms of environmental design and responsibility. LEED Canada for Homes addresses these types of residential construction: (LEED Canada for Homes, Reference Guide 2009)

- Single Family homes
- Low-rise multi-family
- Production homes
- Affordable Homes
- Manufactured and modular homes
- Existing homes
- Mid-size Multifamily

To be a LEED certified as a nominated project should be awarded certain credits as tabulated below: (CaGBC , 2010)

Table 2- LEED for Homes certification thresholds

	Certified	**45—59**
Silver		60—74
Gold		75—89
Platinum		90—136

5.3- LEED and Prefabricated Homes

Looking at different categories of LEED for Homes there are potentials improvements in regards to the prefabricated homes. For instance, in Energy and Atmosphere (EA) category, the credits that can be awarded to reduction of air filtration don't include credits that can be potentially gained by using prefab techniques in a climate-controlled environment. Construction procedures of exterior walls being built in a plant allow reaching to the behind of drywalls to seal all electrical fixtures, piping, windows joints and etc. so the prefab homes will have a better energy rating therefore, they can achieve more LEED points. While, all this measures to control air filtration can be met with more efforts in on-site built home. And also another good example in regards to the category of Material and Resource (MR) is when it is attempted to award credit on grounds of Environmentally Preferable Materials: there are no considerations over prefabricated homes that can substantially control waste and recycled contents and minimize emission by different measures such as locally and bulk purchased materials. Obviously in a large scale it is much more possible and easier to control all those factors.

5.4- Credit Categories

LEED for Homes has 19 prerequisite and 67 credits. The Prerequisites are basic performance standards which are mandatory for all projects and they cannot achieve any points. On the other hand to achieve certification, builders should obtain credit points by exceeding the minimum criteria of the prerequisites. In total there are 136 credit points available to achieve.

There are 8 categories for LEED Canada for Homes:

1- Innovation & Design (ID): This category deals with the special design methods, regional credits and exemplary performance level.

2- Location & Linkages (LL): It covers the placement of the home in socially and environmentally responsible way in regard to larger community

3- Sustainable Site (SS): It is to minimize the project's impact on the site

4- Water Efficiency (WE): This category is about the indoor and outdoor water conservation practices

5- Energy & Atmosphere (EA): Energy efficiency specifically in the building envelope and heating and cooling design

6- Material & Resources (MR): This credit is to utilize construction material efficiently, to select environmental preferable materials and to minimize the construction waste.

7- Indoor Environmental Quality (EQ): This category is intended to improve the indoor air quality by reducing exposure to pollutant

8- Awareness & Education : The education of home owners, tenants or building managers about the operation and maintenance of the green features of a LEED home

6-LEED Categories, Credits and Relevancy Assessment

In this part of the research project, it is intended to give an overview of categories, sub-categories and credits and points that can be attained from LEED for Homes. Based on the defined research question each credit will be assessed and those which are relevant will be selected for future discussion.

Note: NR refers to Not Relevant, SR refers to Somewhat Relevant and R refers to Relevant

Innovation and Design (ID)					
1-Integrated Project Planning		Points	NR	SR	R
1.1	Preliminary Rating	P		×	

1.2	Integrated Project Team	1		×	
1.3	Professional Credentialed (LEED)	1		×	
1.4	Design Charrette	1		×	
1.5	Building Orientation(Solar Design)	1		×	
	2-Durability Management	Points	NR	SR	R
2.1	Durability Planning	P		×	
2.2	Durability Management	P		×	
2.3	3rd -Party Durability Verification	3		×	
	3-Innovative or Regional Design	Points	NR	SR	R
3.1	Innovation # 1 to #4	Max 4			

Location and Linkages (LL)					
	1-LEED ND	Points	NR	SR	R
1	LEED for Neighborhood Development	10	×		
	2-Site Selection	Points	NR	SR	R
2	Site Selection	2	×		
	3-Prefered Locations	Points	NR	SR	R
3.1	Edge Development	1	×		
3.2	Infill	2	×		
3.3	Previously Developed	1	×		
	4- Infrastructure	Points	NR	SR	R
4	Existing Infrastructure	1	×		
	5- Community Resources/Transit	Points	NR	SR	R
5.1	Basic Community Resources/Transit	1	×		
5.2	Extensive Community Resources/Transit	2	×		
5.3	Outstanding Community Resources/Transit	3	×		
	6-Access to Open Space	Points	NR	SR	R
6	Access to Open Space	1	×		

Sustainable Sites (SS)				
1-Site Stewardship	Points	NR	SR	R

1.1	Erosion Controls During Construction	P			×
1.2	Minimize Disturbed Area of Site	1			×
2-Landscaping		Points	NR	SR	R
2.1	No Invasive Plants	P	×		
2.2	Basic landscape Design	2	×		
2.3	Limit Conventional Turf	3	×		
2.4	Drought Tolerant Plants	2	×		
2.5	Reduce Overall Irrigation Demand by at least 20%	6	×		
3-Local Heat Island Effect		Points	NR	SR	R
3	Reduce Local Heat Island Effect	1	×		
4- Surface Water Management		Points	NR	SR	R
4.1	Permeable Lot	4	×		
4.2	Permanent Erosion Controls	1	×		
4.3	Management of Runoff from the Roof	2	×		
5- Nontoxic Pest Control		Points	NR	SR	R
5	Pest Control Alternative	2			
6-Compact Development		Points	NR	SR	R
6.1	Moderate Density	2	×		
6.2	High Density	3	×		
6.3	Very High Density	4	×		

Water Efficiency (WE)					
1-Water Reuse		Points	NR	SR	R
1.1	Rainwater Harvesting System	4	×		
1.2	Graywater Reuse System	4	×		
1.3	Use of Municipal Recycled Water System	3	×		
2-Irrigation System		Points	NR	SR	R
2.1	High Efficiency Irrigation System	3	×		
2.2	Third Party Inspection	1	×		
2.3	Reduce Overall Irrigation Demand by at Least 45%	4	×		
2.4	Non-Potable Water Irrigation System	4	×		
3-Indoor Water Use		Points	NR	SR	R

3.1	Fixture Efficiencies	P	×		
3.2	High Efficiency Fixtures and Fittings	3	×		
3.3	Very High Efficiency Fixtures and Fittings	6	×		

Energy and Atmosphere (EA)					
1- Optimize Energy Performance		Points	NR	SR	R
1.1	Minimum Energy Performance	P		×	
1.2	Exceptional Energy Performance	34		×	
2-Insulation		Points	NR	SR	R
2.1	Basic Insulation	P		×	
2.2	Enhanced Insulation	2		×	
3-Air Infiltration		Points	NR	SR	R
3.1	Reduced Envelope Leakage	P			×
3.2	Greatly Reduced Envelope Leakage	2			×
3.3	Minimal Envelope Leakage	3			×
4-Windows		Points	NR	SR	R
4.1	Good Windows	P		×	
4.2	Enhanced Windows	2		×	
4.3	Exceptional Windows	3		×	
5-Heating and Cooling Distribution System		Points	NR	SR	R
5.1	Reduced Distribution Losses	P			×
5.2	Greatly Reduced Distribution Losses	2			×
5.3	Minimal Distribution Losses	3			×
6-Space Heating And Cooling		Points	NR	SR	R
6.1	Good HVAC Design and Installation	P	×		
6.2	High-Efficiency HVAC	2	×		
6.3	Very High Efficiency HVAC	4	×		

7-Water Heating		Points	NR	SR	R
7.1	Efficient Hot Water Distribution	2	×		
7.2	Pipe Insulation	1	×		
7.3	Efficient Domestic Hot Water Equipment	3	×		
8-Lighting		Points	NR	SR	R
8.1	ENERGY STAR Lights	P	×		
8.2	Improved Lighting	1.5	×		
8.3	Advanced Lighting Package	3	×		
9-High Efficiency Appliances		Points	NR	SR	R
9.1	High-Efficiency Appliances	2	×		
9.2	Water-Efficient Clothes Washer	1	×		
9.3	High-Efficiency Appliances	2	×		
10-Renwable Energy		Points	NR	SR	R
10	Renewable Energy System	10	×		
11-Residential Refrigerant Management		Points	NR	SR	R
11.1	Refrigerant Charge Test	P	×		
11.2	Appropriate HVAC Refrigerants	2	×		

Material and Resources (MR)					
1-Material Efficient Framing		Points	NR	SR	R
1.1	Framing Order Waste Factor Limit	P			×
1.2	Detailed Framing Documents	1			×
1.3	Detailed Cut List and Lumber Order	1			×
1.4	Framing Efficiencies	3			×
1.5	Off-site Fabrication	4			×
2-Environmentlly Preferable Materials		Points	NR	SR	R
2.1	FSC Certified Tropical Wood	P		×	
2.2	Environmentally Preferable Products	8		×	
3-Wast Management		Points	NR	SR	R
3.1	Construction Waste Management Planning	P			×
3.2	Construction Waste Reduction	3			×

Indoor Environmental Quality (EQ)					
1- ENERGY STAR with IAP		Points	NR	SR	R
1	ENERGY STAR with Indoor Air Package	13	×		
2-Combustion Venting		Points	NR	SR	R
2.1	Basic Combustion Venting Measures	P	×		
2.2	Enhanced Combustion Venting Measures	2	×		
3-Moisture Control		Points	NR	SR	R
3	Moisture Load Control	1	×		
4-Outdoor Air Ventilation		Points	NR	SR	R
4.1	Basic Outdoor Air Ventilation	P	×		
4.2	Enhanced Outdoor Air Ventilation	2	×		
4.3	Third-Party Performance Testing	1	×		
5-Local Exhaust		Points	NR	SR	R
5.1	Basic local Exhaust	P	×		
5.2	Enhanced Local Exhaust	1	×		
5.3	Third-Party Performance Testing	1	×		
6-Distrebution of Space Heating and Cooling		Points	NR	SR	R
6.1	Room-by-Room Load Calculation	P	×		
6.2	Return Air Flow/Room by Room Controls	1	×		
6.3	Third-Party Performance Test/Multiple Zone	2	×		
7-Air Filtering		Points	NR	SR	R
7.1	Good Filters	P	×		
7.2	Better Filters	1	×		
7.3	Best Filters	2	×		
8-Contaminant Control		Points	NR	SR	R
8.1	Indoor Contaminant Control during Construction	1			×
8.2	Indoor Contaminant Control	2	×		
8.3	Preoccupancy Flush	1	×		
9-Radon Protection		Points	NR	SR	R
9.1	Radon-Resistant Construction: Passive Ventilation	P	×		
9.2	Radon Resistant Construction	1	×		
9.3	High-Efficiency Appliances	2	×		
10-Garage Pollutant Protection		Points	NR	SR	R

10.1	No HVAC in Garage	P	×		
10.2	Minimize Pollutant from Garage	P	×		
10.3	Exhaust Fan in Garage	2	×		
10.4	Detached Garage or No Garage	3	×		

Awareness and Education (AE)					
1- Education of the Homeowners or Tenant		Points	NR	SR	R
1.1	Basic Operations Training	P		×	
1.2	Enhanced Training	1		×	
1.3	Public Awareness	1		×	
2-Education of Building Manager		Points	NR	SR	R
2	Education of Building Manager	1	×		

6.2-Assessment of Relevancy Chart

In this section it is intended to explore how credits which are Somewhat Relevant (SR) and Relevant can help us achieve more LEED rating. As mentioned before for SR credits they may not be directly relevant but somehow prefabricated housing can be potentially a preferred option. For each credit a brief introduction will be given followed by further discussion.

Fifteen credits have been identified as Relevant credits as follow:

Category	**Points**
Sustainable Site (SS)	1
Energy and Atmosphere (EA)	6
Material and Resources (MR)	7
Indoor Environment Quality (EQ)	1

Also eighteen credits have been selected as Somewhat Relevant which is listed below:

Category	Points
Innovation and Design	8
Material land Resources (MR)	2
Energy and Atmosphere (EA)	7
Awareness and Education (AE)	1

6.3- Relevant Credits

In this section all relevant (R) credits will be further assessed, also it will be discussed in detail that how these credits can help us achieve more credits.

6.3.1- Sustainable Sites (SS)

For this category two credits have been identified to be relevant.

1-Site Stewardship		Points	NR	SR	R
1.1	Erosion Controls During Construction	P			×
1.2	Minimize Disturbed Area of Site	1			×

Erosion Controls During Construction:

Each year 175,000 to 225,000 kilograms of soil per hectare are lost because of construction in Canada (LEED for Homes 2009). On the other hand the runoff from the construction sites can carry debris and pollutants to the lakes and water streams in surrounding areas. The most important impact of erosion is loss of topsoil that leads to in a great reduce in soil ability to support plants and regulate the water flow. LEED for Home requires a design a plan for the site under construction to control erosion, no-disturbance zone for trees and plants and placement of material that implements five measures including: controlling the path and velocity of runoff with site fencing and stockpile and protect the topsoil from erosion for reuse. By using off-site construction this credits can be achieved more easily.

Minimize Disturbed Area of Site:

Construction can destroy habitat, kill vegetation and trees and displace wildlife. Storing material onsite, construction vehicles can compact the topsoil which makes it difficult to recover the damages caused. To achieve one point for this credit LEED for Homes requires at least 40% undisturbed area of the buildable lot area, not including area under the roof. Prefabricated houses can potentially achieve this credit because much of the work is done in the plant and there is minimal material storing and presence of construction vehicles on site.

6.3.2- Energy and Atmosphere (EA)

In this category there are two sub-categories and in total there are six credits which are identified as relevant.

3-Air Infiltration		Points	NR	SR	R
3.1	Reduced Envelope Leakage	P			×
3.2	Greatly Reduced Envelope Leakage	2			×
3.3	Minimal Envelope Leakage	3			×
5-Heating and Cooling Distribution System		Points	NR	SR	R
5.1	Reduced Distribution Losses	P			×
5.2	Greatly Reduced Distribution Losses	2			×
5.3	Minimal Distribution Losses	3			×

Air Infiltration:

Gianino A. (2005) claims that 25 to 40 percentage of energy used during cooling and heating seasons are lost due to air leakage in a typical home. LEED for Homes emphasizes that homes with tighter envelope use much less energy; in these houses comfort is substantially improved for instance fewer drafts. Also durability is improved due to reduced flow of moisture through the envelope and less condensation.

Prefabricated houses are deemed to better respond in reduction of air leakage due to the fact that prefab homes have better sealed gaps. For instance, caulking along the exterior sheathing, windows flanges and electrical fixtures reduces leakage. In fact prefabricated houses can more efficiently achieve reduction in air leakage because they build from inside out but site builders usually and most often build from outside in. Manufacturers install drywall before the exterior sheathings; in contrast, in a traditionally built house, the installation of drywalls usually comes after exterior sheathings. The reason behind this method is to prevent damages to the drywall in case of rain. Installing exterior sheathing before the drywall makes it more difficult to reach behind the drywalls to seal electrical fixtures, pipes and other areas exposed to the exterior environment and can potentially allow air leakage which is not the case in prefabricated houses. To achieve this credit the acceptable method by LEED for Homes is Air Change per Hour (ACH) by conducting blower door test.

To achieve more points (maximum of 3 for Minimal Envelope Leakage) the house should be air tighter. LEED for Homes has defined four different zones in which the minimum requirement to achieve points varies. For instance for zone A to obtain 3 points for Minimal Envelope Leakage ACH@50PA should be 2.5 or less. There are some considerations in this regard:

- The minimum requirement for different regions varies slightly for instance, Ontario and British Colombia are different in minimum requirements.
- The home located in Ontario should has the air leakage less than 2.5 ACH@50PA

- Design for natural ventilation for homes is a contributing measure that assures the house is not under-ventilated also to improve indoor air quality.
- A certified energy rater will verify the air leakage of the home after all works finish by using Blower Door Test which works based on the pressure differential of indoor and outdoor. In the meantime and during the test a Smoke Test will show the exact locations of the air leakages.
- Minimal air leakage results in smaller size of HVAC system to respond to the required heating and cooling loads of the home. It should mention that according to LEED for Homes, one-quarter of the heat losses are due to air leakage.
- To calculate the ACH @50 Pa: (L/s@50 Pa)×(3.6 Sec/hr)÷volume (in metric system)

As mentioned earlier, a report carried out for the U.S Department of Energy suggests that a typical modular home finished in a climate-controlled environment has a significantly better result (30 percent) for the blower-door test in comparison to a typical in-site built home (Gianino, 2005).

To conclude prefabricated homes are very likely to achieve maximum points for this credit because of the process of build in the factory that decrease the chances of air leakage through plumbing and electrical fixtures.

6.3.3- Material and Resources (MR)

For this category three sub-categories and credits have been found relevant. A detailed explanation as well as further consideration will be given in this part.

Material and Resources (MR)				
1-Material Efficient Framing	Points	NR	SR	R

1.1	Framing Order Waste Factor Limit	P			×
1.2	Detailed Framing Documents	1			×
1.3	Detailed Cut List and Lumber Order	1			×
1.4	Framing Efficiencies	3			×
1.5	Off-site Fabrication	4			×
	3-Waste Management	Points	NR	SR	R
3.1	Construction Waste Management Planning	P			×
3.2	Construction Waste Reduction	3			×

Material Efficient Framing:

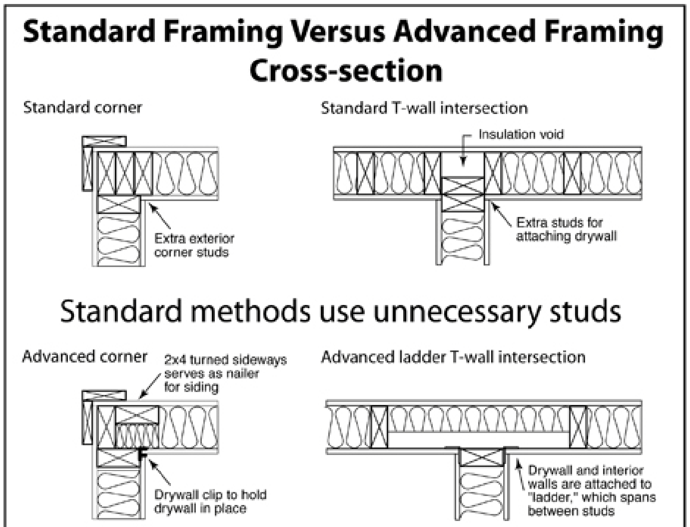
According to LEED for Homes credit 1.5- Off-Site Fabrication maximum of four points can be achieved. LEED for Homes recognizes these two systems:

1- Panelized construction. Wall, roof, and floor components are delivered to the job site.

2- Modular, prefabricated construction. All principle building sections are delivered to the job site as the prefabricated modules.

These are some considerations as follows:

Advanced framing technique which is called Optimum Value Engineering (OVE) can result minimizing use of material and labor costs and improved energy performance for the building. This system can be applied as a whole package, however; many of its components can be used independently, depending on the specific needs of the project. Figure below illustrate the standard framing versus advance framing.



Comparison	Standard	Advanced
Insulation Voids	3%	0%
Framing factor	15-25%	10-15%
Batt R-value	R-13	R-13
Sheathing R-value	R-0.5 to 2.0	R-2.5
Effective Average R-value	R-11.1	R-14.6 (30% higher)

Figure 3 - Advance Framing – Source: www.energysavers.gov

Use of structural insulated panels (SIPs) is encouraged; it can give more strength to the structure and longer spans; in addition it can add value for more uniform insulation.

Waste Management

The National Association of Home Builder estimates that a typical 186 m^2 house generates about 3629 kilograms of waste that should be dumped in 39 cubic meters of landfill which translate 1.8 kilograms of waste per square meter. On the other hand, reduce, reuse and recycle construction waste can substantially save money, a better cleaner and safer job site, and less use of landfill. This is a way to reduce the eco-footprint and the environmental by using less virgin materials. There are two credits in LEED for Homes that address this issue. One is prerequisite and the other one can awards three points.

According to LEED for Homes, Construction Waste Management planning (Prerequisite) can be achieved by fulfilling two requirements as follows:

1- Document local options for recycling and reuse of major project waste
2- Document diversion rate for construction waste

Also Construction Waste Reduction can give three points by meeting these requirements:

- Reduced construction waste
- Increased waste diversion

LEED for Homes recognizes the use of prefabricated components as one of the approaches and implementations. As it was noted before one of the primary goal of prefabricated homes is reduced waste (Jaillon & Poon, 2008). In a climate-controlled environment all weather-related problems and deficiencies that generates construction waste is minimized. Also all cuts and scarp materials are reused in other projects or other parts of the same project. Therefore, prefabricated houses can help us achieve these points by minimizing the waste and waste management strategies in the plants.

6.3.4- Indoor Environmental Quality

8-Contaminant Control		Points	NR	SR	R
8.1	Indoor Contaminant Control during Construction	1			×

During construction (conventional) open ductwork can get clogged with debris paint and other constructions material that may affect the operation of the system as well as imposing health-related issues to the future occupants. LEED for Homes notes that control of pollutants during construction as well as keeping the construction crews comfortable so they do not need space conditioning during construction can award this point. Prefabricated houses can more easily achieve this point because of environmentally – controlled situation in the plant.

6.4- Summary of Relevant Credits

According to the findings of this research project prefabricated houses can help us achieve 15 points more easily that conventional methods. 15 points count for almost 15 percents of the whole LEED credits which means, in terms of LEED rating, it can be 15 percents more efficient.

6.5- Somewhat Relevant Credits

As mentioned before somewhat relevant (SR) credits can be generalized for both conventional and prefab methods; however, it has been found that for these credits prefab techniques can be preferable. In assessment of EcoTerra more efforts will be given to realize to what extent SR credits can be preferable and can facilitate LEED process.

6.5.1- Innovation and Design (ID)

Eight credits have been identified to be SR in this category.

Innovation and Design (ID)						
1-Integrated Project Planning		Points	NR	SR	R
1.1	Preliminary Rating	P		×	
1.2	Integrated Project Team	1		×	
1.3	Professional Credentialed (LEED)	1		×	
1.4	Design Charrette	1		×	
1.5	Building Orientation(Solar Design)	1		×	
2-Durability Management		Points	NR	SR	R
2.1	Durability Planning	P		×	
2.2	Durability Management	P		×	

2.3	3rd -Party Durability Verification	3		×	
3-Innovative or Regional Design		Points	NR	SR	R
3.1	Innovation # 1 to #4	Max 4			

Many manufacturers have pre-priced plans for their customers to choose between them with small changes and to do in this way, the need to have a team consisting of Building Science professionals, Civil Engineering and Green Building and Sustainability expert increases. In general, by a small investment in the integrated design and planning team in-house, or by hiring a project planning firm this goal can be achieved. The growing trend of LEED is another issue; a housing project may not file for LEED certification now but in the future time it might. This is a great opportunity for the prefab companies to promote the sustainable way of construction and have this opportunity to get their projects LEED certified even with higher possibility compared with the conventional housing due to the compliance with sustainability principles reflected in the LEED. In addition to that as the prefab industry has a close relation with the potential home buyer, they can be the most influential tool to promote Green Movement.

In this research project it was found that although this category can be generalized for both conventionally built and prefabricated houses but due to some reasons listed below prefabricated houses can be a preferable was of construction.

- Most prefab manufactures have a limited number of plans for their potential customers compared with the custom-made houses with the conventional methods; this allows prefab manufacturer to be able to manage LEED process more easily and financially more viable.

- It should mention that getting a project LEED certified is substantially dependant on the location, orientation of the plot, public amenities of the neighborhood, regional climate and other important issues but on the other side there are many elements that don’t change for a prefab manufacturer and have been set as standards (this is more meaningful for well-established and organized companies) such as house plans, standard insulation, procurement of material in bulk (environmentally preferable material), use of certain types of window that can achieve the most points for LEED.
- These prefab companies can more benefit from items listed under Design and Innovation such as Integrated Project Team and, Durability Management and Design Charrette.

These are some consideration in this regard:

Hiring LEED Residential Accredited Professional can be another valuable feature; some prefab manufacturers don’t enjoy from long-term benefits of such a professional. By employing LEED Professional the company can potentially achieve the continuous improvement to keep updated with the latest changes. As this may incur extra expenses on the company, and it is not defined in many companies’ policy; collaborating with LEED Accredited Professionals can be done per case and for each project professional consultation can be received from an external LEED consultant firm.

Design Charette gives the opportunity of incorporating the green elements to a project, a full-day workshop can meet the requirement of LEED for this credit but apart from that this is an opportunity for the all participants of the project to use synergy and share their ideas to come up with the best design in regards to material and system selection, incorporation of passive and solar design, building orientation and any innovative design and much more. The team for design charrette can be an in-house team or even can be hired per project.

Planning for long-term durability assures that the prefab house has the minimal risk for moisture related damages. This is an integrated approach that can be achieved by training of on-site crew as well as collaboration of third-party durability management team.

The areas of consideration on this part are :

- The exterior wall assembly and how it perform against the moisture penetration and drying off the entrapped moisture including condensation
- The moisture loads that potentially exist inside
- Heat loss and air leakage through the envelope
- How the prefab home reacts in the natural disaster such as hurricane winds
- Many manufacturers follow a similar wall assembly and more generally a building envelope regardless the location of the prefab homes, the orientation, number of occupants, the regional climate and many other contributing factors that may change the envelope accordingly. So as a part of durability management, all those factors that play a significant role from the design stage should be taken into account.
- Having the Third-Party Durability Management Verification (a certified individual or company whose job is durability management) assures that all durability measures have been implemented properly. They also inspect the house to make sure that all moisture control measures are met such as use of water-resistance flooring instead of carpet, or installation of drain or drain pan for cloth washer in lining spaces.

- Quality Management Plan can be done through an in-house team or someone outside the company (except from provider and green rater whose job is to rate the house for LEED credits)

Innovation or Regional Design:

Innovation and Regional Design enables all prefab manufactures to introduce new measures that contribute to the sustainability such as new glazing and paints, wall assembly, insulation, waste management, and new materials. This is an area of innovation and creativity that allows prefab industry to introduce new techniques and system to enhance the quality of homes.

The relation between industry and universities are magnified in this area; it is recommended that prefab manufacturers collaborate closely with a university or a research institution to innovate new technologies, systems and materials.

There could be more encouragement and incentives over the innovation and regional design by LEED. Currently there are maximum 4 points to be awarded; one point for each innovation. It is understandable that the long-term benefits and results of each innovative approach can be further implemented by other manufacturers and can contribute to the body of knowledge. Therefore; more points can be awarded to this credit.

6.5.2- Material and Resources (MR)

2-Environmentlly Preferable Materials		Points	NR	SR	R
2.1	FSC Certified Tropical Wood	P		×	
2.2	Environmentally Preferable Products	8		×	

In LEED for Homes maximum of eight points can be awarded to the projects that comply with these criteria. According to LEED for Homes credits can be awarded in different areas including exterior wall, floor, foundation, interior wall and ceilings and etc. There are three requirements that have been mentioned in LEED for Homes to achieve these points as follow:

- FSC-certified wood products or recycled and reclaimed contents
- Low or no emissions for volatile organic components (VOCs)
- Local productions

This sub-category has been chosen as somewhat relevant (SR) because of the following reasons:

- Prefab manufacturers purchase their material in bulk
- Purchasing the FSC-certified material is systematically more possible and preferable for prefab industry
- In long-term, prefabricated housing industry can more easily and more conveniently accept and implement the requirements of the environmentally preferable material because of its organized nature.

For these credits there are some considerations as follow:

- FSC-Certified Wood should be used to meet this prerequisite. In early stage of design all components can be listed and ordered from suppliers that provide FSC-Certified Tropical Wood.
- In some cases that FSC-Certified Wood is not available or financially viable, with some changes in design, alternative materials might be used.

- Locally available material and product can significantly reduce environment impacts imposed by transportation. The locally available material should be extracted, processed and or manufactured within 800 km from the prefab plant.
- A list of suppliers which are located in a reasonably close distance with the prefab plant that distribute locally available material and FSC- Certified Wood is recommended.
- Providing information to and educating supplier in respect to green product and how they can provide green product to manufacturers and builders. It can encourage them to expand their offering to meet the principle of sustainable materials.
- Use of recycled material: at least 25% postconsumer or 50% postindustrial recycled material. (LEED for Homes, Reference Guide)
- Reclaimed materials (recovered from demolition) which is locally (within 800 km) available. It should note that only postconsumer material can fall into the reclaimed material category.
- Selecting low-emission materials is recommended for sealants, adhesives, painting, coating, carpet, flooring system and insulation with lower in Volatile Organic Components (VOCs).
- Meeting the Green Label Plus program or FloorScore program (that developed protocols to test all products for emission) can offer more LEED points.

6.5.3- Energy and Atmosphere (EA)

There are seven credits that have been identified as somewhat relevant (SR) in this category.

Energy and Atmosphere (EA)						
1- Optimize Energy Performance		Points	NR	SR	R
1.1	Minimum Energy Performance	P		×	
1.2	Exceptional Energy Performance	34		×	
2-Insulation		Points	NR	SR	R
2.1	Basic Insulation	P		×	
2.2	Enhanced Insulation	2		×	
4-Windows		Points	NR	SR	R
4.1	Good Windows	P		×	
4.2	Enhanced Windows	2		×	
4.3	Exceptional Windows	3		×	

Information collected from building industry indicates that the average size of houses have been doubled compared to 50 years ago. According to Worldwatch Institute ‘’Making Better Energy Choices’’ Canadians consume 5 times more energy that the average global rate. On the other hand, fossil-based energy releases carbon dioxide (CO_2) that is the main cause of climate change. CMHC indicates that buildings consume 38 percent of energy in Canada that counts for 15 percent of total CO_2 emission produced in Canada. Building Green Homes is one of the best ways to combat climate change and other environmental impact that may occur.

LEED for Homes indicates that the average LEED home 30 to 40 percent less electricity that saves approximately 100 metric tons of CO_2 over the life-span of a home (50 to 100 years). This emphasizes the importance of environmental design in terms of energy use in homes. As mentioned in previous chapters 13 to 17 % of homes in Canada are prefabricated houses which can potentially be LEED certified. There are some reasons that prefabricated houses can be preferred in terms of energy rating and use of material.

- This is a more systematic and organized way of building homes compared to the traditional methods because all processes are done in the plants and under almost same procedures that have been defined for the production line.
- Typical plans facilitate the energy rating in terms of modeling of the houses.
- Procurement of material in bulk and according to the defined standards can facilitate the better selection of construction material including windows and insulation
- Improved workmanship in the climate-controlled environment can facilitate the installation of insulation materials, windows and etc.

Exceptional Energy Performance credit can achieve maximum of 34 points which is roughly one third of the whole LEED points. Assessment of this credit is based on three paths that can be followed. In two approaches energy analysis software plays the main role to achieve 34 points out of 38 available points. Third approach is based on the assessment of each element that contributes to the overall energy reduction. Based on the reasoning mentioned above prefabricated houses can be potentially be a preferred way of construction when it comes to energy rating for LEED, although no researches have been carried out to prove it so far and it requires further investigations.

Below some comments will be given for each some selected subcategories.

Optimize Energy Performance

Energy analysis software: Either HERS or EnerGuide can be followed. EnerGuide (By Natural Resource Canada). Benefits that can be gained from implementing such an energy analysis are not just limited to some areas but it is a valuable guide that shows measures of the home's energy performance. This tool shows to which extend the house which is under design and build will be energy-efficient.

- HOT 2000 is the software which is used to compare the house with the benchmark house energy use. All information about building components including wall and roof assembly, foundation, areas, the energy use, and air infiltration, insulation level, air sealing, window sizes and specifications, HVAC system and renewable energy are plugged into the software and the result would be a number between 0 to 100. (Natural Resource Canada: http://oee.nrcan.gc.ca)
- The prerequisite set for LEED is 76; and above that points can be claimed based on an index developed by LEED for Homes.

Table 4 - Typical Energy Efficiency Rating Source: http://oee.nrcan.gc.ca

Typical Energy Efficiency Ratings	
Type of House	Rating
New House build to building code standards	65-72
New house with some energy-efficiency improvements	73-79
Energy-efficient new house	80-90
House requiring little or no purchased energy	91-100

The final result gives the amount of electricity, natural gas or oil which is consumed yearly. This is just an estimate and should be verified by a certified third-party. The procedures are:

- Get a certified energy advisor, (it can be an in-house team) to energy model the house which is in the stage of design. It helps the design team and energy modeling team to collaborate for any changes that may contribute to better the anticipated energy use.
- Finalize the energy modeling and build the house
- A certified third-party will be inspecting:
    - Thermal bypass (such as insulation) inspection before the drywalls are installed;
    - All energy efficiency measures that have been incorporated into the software will be visually inspected;
    - After finishing, a performance test including air-tightness performance of the envelope will be carried out

All these steps are intended to assure that the information that had been plugged into the energy analysis software and the final result after inspection corresponds. Continuous implementation and use of an energy analysis software leads to gradual improvement in many areas from design to the process of build by integration of new systems, materials and measures.

Overall Considerations:

Continuous improvement: this is a managerial method to be implemented at the very beginning stage of a project and more specifically during the design stage to be the most effective, so the prefab industry can maximize benefiting from that because of their flexibility in changing design and material in an controlled environment and also each changes can be a foundation for future project on the way.

Integration of sustainable Design: this is a great area of improvement for prefab manufactures. Many companies who are active in this field just follow very traditional ways of build, very common materials and similar plans that hamper innovation and creativity of designing for more sustainable homes. To clarify more, many energy efficiency and sustainable measures are not usually incorporated into the final design for example, using a thermal mass, or passive and/or active solar design, ,shading control devices, natural ventilation techniques, and many more.

Having considered the differences between prefab homes and stick built home builders, the public perception of the flexibility in design is a contributing factor in acceptance of stick-build homes. In that respect, if the prefab industry takes new initiatives in design that systematically incorporate more sustainable measures with more flexibility in design that would be a better move towards boosting the prefab market.

Insulation:

- The minimum level of insulation varies in accordance to the regional or provincial codes.
- It is substantially important that thermal bridging, thermal bypass and gaps and voids be considered within the design stage. An Energy Rater or Green Rater will assess the efficiency of the insulation system, after a house is built onsite.
- Using environmentally preferred insulation material is recommended such as material that contains recycled cellulose
- Using a insulation that has a higher R-value may seems more expensive; but the reduction in energy use by the HVAC system to provide cooling and heating loads may offset some extra costs (investments).

Windows:

- Certified ENERGY STAR windows should be installed in the house to meet the prerequisite for this credit.
- There are two approaches for Energy Rating (ER). One is developed by the National Fenestration Rating Council (NFRC) and considers the U-factor and solar heat gain coefficient (SHGC). Another approach depends on the zone that the house will be situated and the criteria to achieve points for LEED differ.
- During the design stage these issue should be taken into consideration:
    - Wall to window ratio
    - Glass to framing ratio
    - Number of glass layers (single, double or triple glazing)
    - Frame material
    - Low-E coating and the right placement of that on glass layers
    - Thermal bridging

    - Gas filing between the glass layers
    - Location of the windows

- Proper installation of windows will assure the prevention of water and air leakage around the perimeter of the window.
- Use of electro-chromic glass (with a coating that changes from clear to tinted powered by a small electric current) can create a buffer zone that enhance the performance of the window by minimizing the heat transfer from outside to inside. Potentially, it can reduce the cooling and heating load that leads to minimize the energy use in the house.
- An integral shading layer can notably affect the overall performance of the window; the integral shading devise can be operated manually or automatically and in accordance to the sun path, time, season of year, orientation of house and the temperature differences between inside and outside.
- Sun and shadow study is a sustainable approach to take to learn further about the angle of sun rays, number of days for sun exposure, shadow path, impact of microclimate and vegetation around the house and more. This should be carried out during the design stage and information derived from that may change the window's type and size, the location of the windows and even it may change the house design to maximize the benefits which can be potentially gained by solar design.
- One approach for Energy Rating (ER) for windows can be done by meeting the requirements for each zone. (determined by CSA Standard A440.2)

  Table below shows the minimum requirement for ENERGY STAR certified windows for each zone: (from LEED for Homes)

Table 5 - Climate Zones

EA Credit	Zone			
	A	B	C	D
Prerequisite	A	B	C	D
2 points	B	C	D	By calculation
3 points	C	D	By calculation	By calculation

The location of the house indicates the type of windows that should be installed in accordance to the criteria set for that specific zone to achieve a targeted point.

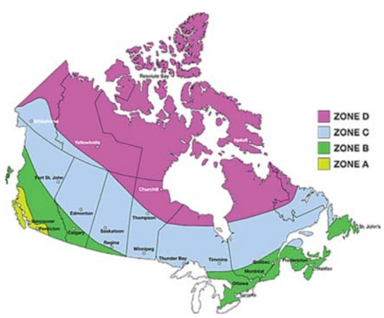


Figure 4- zones for window specification, from http://www.energuardwindows.com/energy_star.php

For example if a house is located in Toronto which is Zone B, the window specifications for Zone C and Zone D are required to achieve 2 or 3 points accordingly.

- Another approach for Energy Rating (ER) of windows is by calculation, more information can be found in LEED for Homes.

6.5.4- Awareness and Education (AE)

Three credits are somewhat relevant in this category as follow:

Awareness and Education (AE)				
1- Education of the Homeowners or Tenant	Points	NR	SR	R

1.1	Basic Operations Training	P		×	
1.2	Enhanced Training	1		×	
1.3	Public Awareness	1		×	

Aside from design and construction of new homes, environmental impact of new homes continue throughout of their life-span (which is expected to be 50 to 100 years) by consumption of energy, water and other resources by occupants. Therefore, occupants play an important role in use of resources during the life-span of the homes. Without enough training occupants are not able to learn about green features of the home and how to use and maintain them. This is the one of the goals of LEED to raise public awareness among homebuyers or tenants about the green features promoted and valued by LEED homes.

There are three credits in this category; Basic Operation Training is prerequisite and Enhanced Training and Public Awareness have one point (each one). The main purpose of these credits is to introduce, promote and advertise the green features gained by following LEED instructions. As prefabricated housing industry provides a more systematic way to provide homes for Canadians it can be a preferred in achieving these two credits. These are the criteria and requirement that should be fulfilled.

According to LEED for Homes, Enhanced Training credit that has maximum of one point can be achieved by eligible trainings including:

- An additional walkthrough or training in another home similar green measures and equipment;
- Sponsored meeting by builder.

Also requirements of Public Awareness credit can be fulfilled by conducting of any three items listed below:

- Hold and advertise public open house and guided tour about LEED green features
- Publish a website that has information in regard to LEED homes
- Newspaper article on LEED for Homes
- Display LEED Canada for Homes signage

Also, these are some comments and consideration about this LEED category:

- Many prefab companies' websites just provide the technical information about their products and services. It can be improved by providing more information about the new initiatives, sustainable techniques and design as well as explain about LEED and other green rating systems.
- On the other hand, more credits could have been awarded to this category. Long term benefits of sustainable approaches in housing industry and its benefits to the environment can be reflected more elaborately by raising public awareness and education. It also can contribute to the economy of prefab industry

7-Case Study : EcoTerra

This is a Net-Zero project that produces almost as much energy as it consumes. By using the prefabricated system (modular) and many energy-saving techniques this house won the CMHC's Equilibrium House in 2007.

EcoTerra house is located in the Province of Quebec in Eastman with area footage of 240 m^2 and in a vast land about 1.1 hectare. The energy system designed is led by Concordia University and Dr. Andreas Athienitis. (Solar Building Research Network)

Alouette Homes, a well-known and reputable company which is based in Quebec and provides prefabricated homes both modular and panelized, undertook the manufacturing of this project..

In terms of architectural design, the house has one living room, dining area, one kitchen and one bathroom (with the laundry facilities) at the first floor and two bedrooms, one office and one bathroom situated at the second floor. (CHMC, 2010)

Figure 1- EcoTerra project- from: http://www.cmhc-schl.gc.ca/en/inpr/su/eqho/eqhofo/eqhofo_002.cfm

The main focus of the project is on the energy reduction by using these measures:

- active and passive solar space and water heating
- a geothermal heat pump
- photovoltaic panels (on the rooftop)

A thermal mass system is integrated into the basement and main floor. The basement slab is approximately 100 mm thick and 75 mm thick in the rest of the basement. A 250 mm thick concrete dividing wall divides the basement in two and extends 900 mm upwards into the main floor living space.

BASF Walltote, Neopor is used for exterior wall insulation for a total of approximately RSI 6.4 (R 36.3). The roof is insulated to approximately RSI 9.2 (R 52.2) for the vaulted ceiling portions and RSI 10.9 (R 61.8) for the flat portion. The insulation under the basement slab is approximately RSI 1.3 (R 7.4). The basement walls are insulated to approximately RSI 2.5 (R 14.2) for the above grade portions and RSI 5.7 (R 32.3) below grade. (Doiron, 2011). The airthightness of the house was assesses by blower door test and it was 0.85 air change at 50 Pascal.

As mentioned before, ÉcoTerra was prefabricated in the Alouette Homes factory in 2007. There were six modules for this house; the roof itself was one module, the main and second floors had two modules each, and the basement mechanical systems module was the sixth. This house consumes 80% less energy compared with average Canadian houses. (http://www.maisonalouette.com/english/ecoterra2/)

7.1- Sustainable features:

- Triple-paned, double low-E, double argon filled windows
- Use of natural lighting by orientation and design
- Heat recovery from solar panels (that warm the concrete slabs and pre-heat domestic hot water)
- Fresh air in all rooms
- Passive solar heating and use of thermal mass
- Heat recovery from waste water (to pre-heat domestic hot water)
- Heat Recovery Ventilation (HRV) to prevent heat lose through ventilation

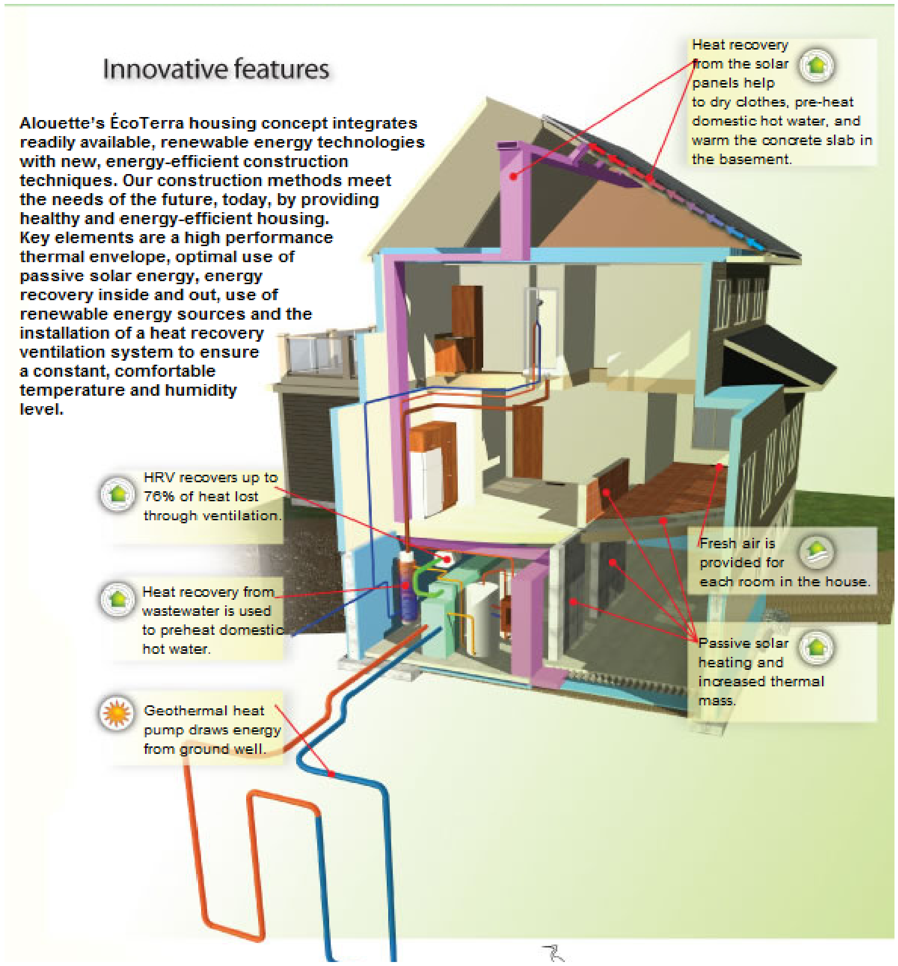


Figure 2 - - Schematic design to reduce energy consumption within the Eco Terra Project http://www.maisonalouette.com/

7.2-Comparison Table

Table below compares various features of the EcoTerra House with a green ordinary sustainable house and with a conventionally built house:

Table 3 – Comparison between different features of the EccoTerra house with other houses in the market Source: http://www.maisonalouette.com/english/ecoterra2/

Factors	EccoTerra House	Sustainable house	Conventional house
Insulation on Exterior Walls R value (RSI)	**6.60**	**3.98**	**3.34 (min)**
Ceiling insulation R-value (RSI)	**9.51**	**7.39**	**5.46**
Thermal bridge from exterior walls	**No**	**No**	**Yes**
Triple-paned, double low-E, double argon filled windows	**Yes**	**No**	**No**
Air leakage	**0.85 ACH**	**3.5 ACH**	**> 3.5 ACH**
Fresh air supply	**Yes**	**Yes**	**No**
Thermal mass	**Yes**	**No**	**No**
Waste water heat recovery	**Yes**	**No**	**No**
Optimum use of natural light	**Yes**	**No**	**No**
Geothermal heating/Solar panels	**Yes**	**No**	**No**

7.3- Other issues and consideration

Despite higher costs for EcoTerra Projects, there are some other benefits that are offered:

- Flexibility in design
- Verification of all components in the plant (such as plumping and electrical system)
- Precision in Installation of solar panels in the plant
- Considerable saving on energy bills
- Receiving incentives and grants from government

7.4- Equilibrium Competition

ÉcoTerra was constructed as part of CMHC's EQuilibrium™ competition. From the CMHC website (CMHC, 2010):

"EQuilibrium™ is a national Sustainable Housing Demonstration initiative, led by CMHC, that brings the private and public sectors together to develop homes that combine resource and energy efficient technologies with renewable energy technologies in order to reduce their environmental impact. Project teams have been selected to build EQuilibrium™ demonstration projects across Canada."

The EQuilibrium™ competition was announced in May of 2006. Approximately 80 teams submitted applications and 15 were selected to receive funding, technical support and public exposure for their projects (CMHC, 2009).

7.5- Design Process

During the design process many parties were involved in the funding, design, support and construction of ÉcoTerra. The goals of the design team were to design a home that reached or approached net zero energy while maintaining economic feasibility. Integration design can lead to reductions in the materials and labour required for construction (Chen et al., 2010a).

The very first steps in the design of ÉcoTerra was the design Charrette which is an intense brainstorming and design meeting that brings together all of the parties involved in the project so that they can create the basic design. Three main groups were present at the charrette for ÉcoTerra: the engineering team, the architectural team and the builder team. The engineering team, from Concordia University in Montreal, Canada., was headed by Dr. Andreas Athienitis and included several of his graduate students. They provided engineering, research, design and support. The architect for the project was Masa Noguchi, and the builder was Alouette Homes. The Alouette Homes group was made up of Bradley Berneche and his technicians and trades.

Other stakeholders that were involved with the design process include HydroQuébec (monitoring), a distributor of ground source heat pumps, a photovoltaic expert (Yves Poissant of NRCan) and a representative from the municipality. Nicole Laberge (project manager), Jean Ardouin (construction manager) and representatives from CMHC were also involved. (Doiron, 2011)

7.6- EcoTerra and Net-zero

On type of classification for ÉcoTerra, is the EnerGuide for Homes (EGH) rating system (NRCan, 2010a). This system was developed by NRCan and rates homes on a scale from 0 to 100. A home rated 0 would have a poor building envelope (minimal insulation and high air leakage) and high energy use. The average Canadian homes built to codes and standards will receive an EGH rating of between 65 to 72. A highly energy efficiency home would rate between 80 to 90. A home rated 100 is a net-zero home. (NRCan, 2010a). HOT2000 is the software used for energy rating homes which is developed by NRCan (NRCan, 2010b). HOT2000 models the house and compares it to a reference building with similar characteristics. Also there are other classification systems such as R2000. (Doiron, 2011)

7.7- Ecco Terra; final thoughts and comparisons

EcoTerra housing can be nominated as a one of the best practices to emulate in the future projects as well as to find potential areas of improvements to be introduced with regards to LEED for Homes. This is a project that involves a wide range of expertise to build homes in the most sustainable ways that have been discovered so far. However, having a EcoTerra house is costly compared with the conventionally built homes and regular prefabricated alternatives. For manufacturing and build process of such a house many specialists will be involved in the project. Experts such as an architect specializing in passive solar heating, an engineer who specializes in ventilation, an engineer specializing in PV solar panels, an engineer specializing in energy consumption calculations and a specialist for the HOT-2000 energy consumption simulation may be involved. It should be further studied that how each single sustainable element of such a project can be interpreted and incorporated into LEED for Homes.

Eco-Terra is a prefabricated house; however, it is not LEED certified. This house has exceeded most of criteria set by LEED in many categories. Eco- Terra potentially could have been LEED certified which made it a proper example for this project.

8- EcoTerra and LEED

For the purpose of this research project it is intended to rate EcoTerra house to determine how many points it can achieve based on LEED credits. This part will be achieved based on the information available from the EcoTerra house and LEED for Homes reference guild. First the house will be assessed by using the Simplified Project Checklist and then more explanation will be given in the subsequent section.

8.1- Limitations

There are some limitations in the way of conducting this part as follow:

1- Since the house was constructed for research purposes the location of it was outside of the town and therefore, for some it cannot achieve some credits such as Location and

Linkages and etc., which count about 14 percent of the whole points. In the more practical way, EcoTerra houses can be situated in an urban area and consequently they can achieve these points.

2- Some information were not available at the time of the completion of this report, for instance, the type of plants and irrigation system.

8.2- EcoTerra LEED Rating

In this section it is intended to rate the EcoTerra house based on the LEED Canada for Homes Simplified Project Checklist.

Innovation and Design (ID)					
1-Integrated Project Planning		Points	Yes	Maybe	N/A
1.1	Preliminary Rating	P	×		
1.2	Integrated Project Team	1	×		
1.3	Professional Credentialed (LEED)	1		×	
1.4	Design Charrette	1	×		
1.5	Building Orientation(Solar Design)	1	×		
2-Durability Management		Points	Yes	Maybe	N/A
2.1	Durability Planning	P	×		
2.2	Durability Management	P	×		
2.3	3rd -Party Durability Verification	3		×	
3-Innovative or Regional Design		Points	Yes	Maybe	N/A
3.1	Innovation # 1	1	×		
3.2	Innovation # 2	1	×		
3.3	Innovation # 3	1	×		
3.4	Innovation # 4	1	×		
Maximum points for this category: 11 LEED Points achieved : 7 Potential available points:11					

Note: Maximum Points for this category refers to the maximum points that this category can give a project. Potential available points also refers to the maximum points that this specific project can achieve for this credit based on its potentials. In the same way LEED Points achieved refers to the minimum points that this project can gain through this category. Please also note that Yes refers to the case that the point is achieved, Maybe refers to situations that there is not enough information available for this assessment and need further information and varies from case to case, and N/A means this point cannot be gained.

1.2 - According to LEED for Homes, Integrated Project Team should meet three criteria:

1- Include team members: Actively involve team members in at least three of the followings: Schematic design, Preliminarily design, Energy or envelope system design, Design development, Final design and Construction
2- Monthly meetings with the project members: As it was designed through Integrated Design Process in the Charrettes, the EcoTerra meets these criteria and can achieve this point.

1.3- In terms of LEED Residential Accredited we have no specific information to indicate about this issue yet so it has been decided to give it maybe. As soon as new information have been received we can modify this points.

1.4 Design Charrette: apparently and based on the information received there have been many design Charrette for this project.

1.5 Building Orientation: in many articles written for this specific project it has been indicated that this house has been designed based on the orientation for the solar design so this point can be awarded to this project.

2.1 For the Durability Management Process there have been any evidences that this project can achieve three points for the Third Party Durability Management Verification. So this part has been undecided. In terms on rating it has been assumed that this credit may achieve these points.

3.1- Innovation and Regional Design: LEED requires that there are at least four measures that can meet these criteria:

- Active and passive solar space and water heating (Yes);
- A geothermal heat pump (Yes);
- Photovoltaic panels (Yes);
- Use of natural lighting by orientation and design (Yes);
- Heat recovery from solar panels (that warm the concrete slabs and pre-heat domestic hot water) (Yes);
- Passive solar heating and use of thermal mass (Yes);
- Heat recovery from waste water (to pre-heat domestic hot water) (Yes);
- Heat Recovery Ventilation (HRV) to prevent heat lose through ventilation (Yes).

So for the Innovation and Regional Design the EcoTerra can achieve four points as it fulfills all requirements.

According to this assessment the minimum points is 7 and the maximum points can be 11. This discrepancy has occurred because of lack of information about the project.

Location and Linkages (LL)					
1-LEED ND		Points	Yes	Maybe	N/A
1	LEED for Neighborhood Development	10			×
2-Site Selection		Points	Yes	Maybe	N/A
2	Site Selection	2			×

3-Prefered Locations		Points	Yes	Maybe	N/A
3.1	Edge Development	1			×
3.2	Infill	2			×
3.3	Previously Developed	1			×
4- Infrastructure		Points	Yes	Maybe	N/A
4	Existing Infrastructure	1			×
5- Community Resources/Transit		Points	Yes	Maybe	N/A
5.1	Basic Community Resources/Transit	1			×
5.2	Extensive Community Resources/Transit	2			×
5.3	Outstanding Community Resources/Transit	3			×
6-Access to Open Space		Points	Yes	Maybe	N/A
6	Access to Open Space	1	×		
Maximum points for this category: 10 LEED Points achieved :1 Potential available points:1					

According to LEED for Home, these credits have been designed for those projects which are designed to certify communities that emphasize environmentally responsible planning in terms of sustainable neighborhood.

There are some criteria this category as follow:

- More efficient use of land
- Reduced need for infrastructure extension
- More sustainable transportation options including walking, biking and access to public transit

Based on the available information the EcoTerra project may not achieve these points (except for the Access to Open Space LL6) due to its location and linkage which is located in a rural area. It should mention that this is a research project and because of that this house is located in a location that lacks public resources and transit; however, it can get 1 point for the Access to the Open Space.

There are maximum of 10 points available for this category that can be potentially awarded for the EcoTerra house located in an urban area with the criteria stated in LEED for Home; which is a significant percentage of the total available points almost 11 percent. Therefore, if this specific project had been located in an urban area this 10 points could be easily achieved.

Sustainable Sites (SS)					
1-Site Stewardship		Points	Yes	Maybe	N/A
1.1	Erosion Controls During Construction	P	×		
1.2	Minimize Disturbed Area of Site	1	×		
2-Landscaping		Points	Yes	Maybe	N/A
2.1	No Invasive Plants	P		×	
2.2	Basic landscape Design	2		×	
2.3	Limit Conventional Turf	3		×	
2.4	Drought Tolerant Plants	2		×	
2.5	Reduce Overall Irrigation Demand by at least 20%	6		×	
3-Local Heat Island Effect		Points	Yes	Maybe	N/A
3	Reduce Local Heat Island Effect	1			×
4- Surface Water Management		Points	Yes	Maybe	N/A
4.1	Permeable Lot	4		×	
4.2	Permanent Erosion Controls	1		×	
4.3	Management of Runoff from the Roof	2		×	
5- Nontoxic Pest Control		Points	Yes	Maybe	N/A
5	Pest Control Alternative	2	×		
6-Compact Development		Points	Yes	Maybe	N/A
6.1	Moderate Density	2			×
6.2	High Density	3			×
6.3	Very High Density	4			×

Maximum points for this category: 22 LEED Points achieved : 3 Potential available points:18

For this category EcoTerra can potentially achieve maximum points; however, there is limited information about some credits such as the type of plants, landscaping and pest control.

For the first sub-category, Site Stewardship, EcoTerra can gain 1 point. According to LEED for Homes there are two main criteria to be met to achieve the point for Minimized Disturbed Area of Site:

a) Develop a tree or plant preservation plan
b) Leave undisturbed at least 40 % of the buildable lot area

As EcoTerra is a prefabricated house, criteria for erosion control during construction and minimize disturbed area of site can be met. In terms of landscaping, local heat island effect and surface water management there is no specific information in hand to decide about these credits including irrigation system and type of plants. But it can be assumed that these points are readily available for this project since every aspect of this house has been specifically designed.

For the Non-Toxic Pest Control, based on the available information from drawings and articles about this specific house these two points can be achieved. According to LEED for Home the types of local pests should be identified (unknown) and one of these strategies should be selected:

- Use of solid concrete foundation wall
- Keep all woods at least 12 inches above soil
- No wood to concrete connection

For the Compact Development, EcoTerra cannot obtain any points as this project is not located in a high density area; however, these points (max 4) can be achieved for similar EcoTerra projects located in a dense neighborhood.

Water Efficiency (WE)					
1-Water Reuse		Points	Yes	Maybe	N/A
1.1	Rainwater Harvesting System	4		×	
1.2	Graywater Reuse System	4		×	
1.3	Use of Municipal Recycled Water System	3		×	
2-Irrigation System		Points	Yes	Maybe	N/A
2.1	High Efficiency Irrigation System	3		×	
2.2	Third Party Inspection	1		×	
2.3	Reduce Overall Irrigation Demand by at Least 45%	4		×	
2.4	Non-Potable Water Irrigation System	4		×	
3-Indoor Water Use		Points	Yes	Maybe	N/A
3.1	Fixture Efficiencies	P	×		
3.2	High Efficiency Fixtures and Fittings	3		×	
3.3	Very High Efficiency Fixtures and Fittings	6		×	
Maximum points for this category: 15 LEED Points achieved : 3 Potential available points:15					

For this category is intended to make projects to use municipal recycled water or offset central water supply through the capture and controlled reuse of rainwater and/or greywater.

Since there has been little information about irrigation system, rainwater harvesting and types of fixtures used for this house, no points can be awarded at this point.

Energy and Atmosphere (EA)					
1- Optimize Energy Performance		Points	Yes	Maybe	N/A
1.1	Minimum Energy Performance	P		×	

1.2	Exceptional Energy Performance	34	X		
2-Insulation		Points	Yes	Maybe	N/A
2.1	Basic Insulation	P	×		
2.2	Enhanced Insulation	2	×		
3-Air Infiltration		Points	Yes	Maybe	N/A
3.1	Reduced Envelope Leakage	P	×		
3.2	Greatly Reduced Envelope Leakage	2			
3.3	Minimal Envelope Leakage	3	×		
4-Windows		Points	Yes	Maybe	N/A
4.1	Good Windows	P	×		
4.2	Enhanced Windows	2			
4.3	Exceptional Windows	3	×		
5-Heating and Cooling Distribution System		Points	Yes	Maybe	N/A
5.1	Reduced Distribution Losses	P	×		
5.2	Greatly Reduced Distribution Losses	2			
5.3	Minimal Distribution Losses	3	×		
6-Space Heating And Cooling		Points	Yes	Maybe	No
6.1	Good HVAC Design and Installation	P	×		
6.2	High-Efficiency HVAC	2			
6.3	Very High Efficiency HVAC	4	×		
7-Water Heating		Points	Yes	Maybe	No
7.1	Efficient Hot Water Distribution	2	×		
7.2	Pipe Insulation	1	×		
7.3	Efficient Domestic Hot Water Equipment	3	×		
8-Lighting		Points	Yes	Maybe	No
8.1	ENERGY STAR Lights	P	×		
8.2	Improved Lighting	1.5		×	
8.3	Advanced Lighting Package	3	X	×	
9-High Efficiency Appliances		Points	Yes	Maybe	No
9.1	High-Efficiency Appliances	2	×		
9.2	Water-Efficient Clothes Washer	1	×		
10-Renewable Energy		Points	Yes	Maybe	No
10	Renewable Energy System	10	×		

11-Residential Refrigerant Management		Points	Yes	Maybe	No
11.1	Refrigerant Charge Test	P	×		
11.2	Appropriate HVAC Refrigerants	2		×	
Maximum points for this category: 38 LEED Points achieved : 33 Potential available points:38					

According to LEED for Homes there are three possible way for rating system for this category in which two of them are based on energy modeling and third one which is a prescriptive pathway that enable a project to achieve LEED points without the need for energy modeling.

As shown on the table above and based on the available information about this specific house, it can achieve 33 points out of 38 available points; however for this category EcoTerra could achieve the maximum points and due to lack of information the rest of points cannot be claimed at this point which are as follow:

8.3 – Advanced lighting package (3 points)

11.2 – Appropriate HVAC Refrigerant

None the less, it is very likely for EcoTerra to achieve these points. As mentioned before the main focus of this project is on its energy efficiency and it is the strength point of this project.

Material and Resources (MR)					
1-Material Efficient Framing		Points	Yes	Maybe	N/A
1.1	Framing Order Waste Factor Limit	P	×		
1.2	Detailed Framing Documents	1	×		
1.3	Detailed Cut List and Lumber Order	1	×		
1.4	Framing Efficiencies	3	×		
1.5	Off-site Fabrication	4	×		
2-Environmentally Preferable Materials		Points	Yes	Maybe	N/A
2.1	FSC Certified Wood	P	×		

2.2	Environmentally Preferable Products	8	×		
3-Waste Management		Points	Yes	Maybe	N/A
3.1	Construction Waste Management Planning	P	×		
3.2	Construction Waste Reduction	3	×		
Maximum points for this category: 16 LEED Points achieved : 16 Potential available points:16					

Material Efficient Framing:

1.5- Off-site Fabrication: LEED for Homes awards 4 points for this credit if the house is prefabricated and based on the two criteria stated below:

- Panelized Construction, wall, roof, and floor components are delivered to the job site
- Modular prefabricated construction, that includes all principle building sections

Environmentally Preferable Materials

2.2 - Environmentally Preferable Products: there are three criteria that should be met (at least one) to achieve the maximum of 8 points.

- Based on the table provided in LEED for Homes Reference Guide (P297) there are 10 elements such as exterior wall, floor, foundation, interior wall and ceiling for which environmentally preferable products can be used. For each elements maximum of 0.5 point can be awarded.
- Low emission products stated in the same table (0.5 point for each component)
- Local production: use products that were extracted, processed and manufactured within 800 km of the home (if moved by truck) and 2400 km if moved by rail. (0.5 point for each component)

Waste Management

3.2 - Construction Waste Reduction: EcoTerra can achieve maximum of 3 points for this credits based on these criteria stated in LEED for Homes Reference Guide.

Reduced construction waste (calculation based: the weight or volume of the waste generated divided by building floor area and by using the table provided on LEED for Homes Reference Guide, p 315)

Increased waste diversion: divert 25 percents or more of the total materials taken off the construction site, landfills and incinerators.

It should mention that according to LEED for Homes, industry average is 20 kg or 0.02 cubic meters of waste per square meter.

One of the main advantages of prefabricated homes is less wastes compared to traditional methods. In this method all construction material will be used to its fullest and the waste materials and scraps are used in other projects or in other parts of the same project.

Indoor Environmental Quality (EQ)					
2- ENERGY STAR with IAP		Points	Yes	Maybe	N/A
1	ENERGY STAR with Indoor Air Package	13	×		
2-Combustion Venting		Points	Yes	Maybe	N/A
2.1	Basic Combustion Venting Measures	P	×		
2.2	Enhanced Combustion Venting Measures	2	×		
3-Moisture Control		Points	Yes	Maybe	N/A
3	Moisture Load Control	1	×		
4-Outdoor Air Ventilation		Points	Yes	Maybe	N/A
4.1	Basic Outdoor Air Ventilation	P	×		
4.2	Enhanced Outdoor Air Ventilation	2	×		

4.3	Third-Party Performance Testing	1		×	
5-Local Exhaust		Points	Yes	Maybe	N/A
5.1	Basic local Exhaust	P	×		
5.2	Enhanced Local Exhaust	1		×	
5.3	Third-Party Performance Testing	1		×	
6-Distribution of Space Heating and Cooling		Points	Yes	Maybe	N/A
6.1	Room-by-Room Load Calculation	P	×		
6.2	Return Air Flow/Room by Room Controls	1		×	
6.3	Third-Party Performance Test/Multiple Zone	2		×	
7-Air Filtering		Points	Yes	Maybe	N/A
7.1	Good Filters	P	×		
7.2	Better Filters	1		×	
7.3	Best Filters	2		×	
8-Contaminant Control		Points	Yes	Maybe	N/A
8.1	Indoor Contaminant Control during Construction	1		×	
8.2	Indoor Contaminant Control	2		×	
8.3	Preoccupancy Flush	1		×	
9-Radon Protection		Points	Yes	Maybe	N/A
9.1	Radon-Resistant Construction: Passive Ventilation	P	×		
9.2	Radon Resistant Construction	1		×	
9.3	High-Efficiency Appliances	2	X		
10-Garage Pollutant Protection		Points	Yes	Maybe	N/A
10.1	No HVAC in Garage	P	×		
10.2	Minimize Pollutant from Garage	P	×		
10.3	Exhaust Fan in Garage	2		×	
10.4	Detached Garage or No Garage	3			×
Maximum points for this category: 21 LEED Points achieved : 18 Potential available points:20					

1- ENERGY STAR with Indoor Air Package

The intent of this category is to improve the overall quality indoor environment of the home. LEED Canada for Homes Reference Guide has mentioned that this credit is not available in Canada at this time but NRCan is working to bring this credit to Canada as a future path option.

2.2 - Enhanced Combustion Venting Measures

This credit is to ensure that the leakage of combustion gases into the occupied space of the home is minimized by installing no fireplace or woodstove or design them according to the criteria stated in LEED for Homes. For this specific project this points can be achieved.

3. Moisture Load Control: the intent of this credit is to control indoor moisture level. This credit requires installing dehumidification equipment to maintain humidity at or lower 60 percents through one of the following methods:

a) Additional dehumidification system
b) A central HVAC system with additional control to operate in dehumidification mode
c) A passive ventilation design

4.2 - Enhanced Outdoor Air Ventilation: this credits requires a system that transfers heat between the incoming outdoor air stream and the exhaust air stream, such as heat recovery ventilator (HRV). Based on the features of EcoTerra, 2 points can be achieved.

4.3 – Third Party Performance Testing: there is no information available about this credit in regard to EcoTerra project.

About these five sub-categories, Local Exhaust, Distribution of Space Heating and Cooling, Contaminant Control, Garage Pollutant Protection and Radon Protection, there is no specific information to sate the house based on it. However it is deemed that the house can achieve these points so the Maybe has been chosen for these credits.

Awareness and Education (AE)					
2- Education of the Homeowners or Tenant		Points	Yes	Maybe	N/A
1.1	Basic Operations Training	P	×		
1.2	Enhanced Training	1	×		
1.3	Public Awareness	1			×
2-Education of Building Manager		Points	Yes	Maybe	N/A
2	Education of Building Manager	1			×
Maximum points for this category: 3 LEED Points achieved : 1 Potential available points:2					

Education of the Homeowners or Tenant

1.2 Enhanced Training: there are some criteria defined by LEED for Homes to achieve this point as below:

- Walkthrough or training about green measures and equipment
- A group homebuyer training
- A builder or developer sponsored meeting

Since EcoTerra Project has been open to public for many months and this specific house has won the Equilibrium Competition, EcoTerra can achieve 1 point for the Enhanced Training.

1.3 Public Awareness: Unfortunately, there is no information in regard to EcoTerra and LEED for Homes either in its manufacturer website or as an article to meet one of the criteria stated in LEED for Homes for this credit as below:

- Hold and advertised, attended public open house at least four hours a day talking about LEED Canada for Homes features.
- Publish a website (at least two pages) about the benefits and features of LEED Homes.
- Newspaper article on the LEED Canada for Homes projects.
- Display LEED Canada for homes signage.

2.1 Education of Building Manager: this credit doesn't apply to this specific EcoTerra; however, for other EcoTerra Projects with commercial purposes it can apply and 1 point can be achieved.

8.3- Conclusion

The minimum available points that EcoTerra can achieve is 84 which translates to Gold LEED. However the maximum potential points that can be achieved are 115.

This noticeable difference is chiefly due to lack of information from EcoTerra for its rating. Also it should mention that there are two consideration in this regard on is about the prefabrication and LEED ponit in case of EcoTerra and another one is limitations of prefabrication methods which are discussed below:

8.4- Prefabrication in EcoTerra and LEED Points

This section deals with the assessment of LEED points for EcoTerra to find out how many points are achieved because of EcoTerra is a prefabricated homes (Modular).

EcoTerra has been built to be a net-zero home with high standards in method of build and energy efficiency. Therefore, it is expected to achieve high LEED points. The question to discover is how many of these points are because of the prefabrication method.

To answer this question it is intended to go through Relevant credits to evaluate which of them can be related to EcoTerra project. Tables below show the credits that help EcoTerra achieve 15 points because of the use of prefabrication method:

Sustainable Site

1-Site Stewardship		Points
1.1	Erosion Controls During Construction	P
1.2	Minimize Disturbed Area of Site	3

Energy and Atmosphere

3-Air Infiltration		Points
3.1	Reduced Envelope Leakage	P
3.3	Minimal Envelope Leakage	3
5-Heating and Cooling Distribution System		Points
5.1	Reduced Distribution Losses	P
5.3	Minimal Distribution Losses	3

Material and Resources

1-Material Efficient Framing		Points
1.5	Off-site Fabrication	4
3-Waste Management		Points
3.1	Construction Waste Management Planning	P
3.2	Construction Waste Reduction	3

Indoor Environmental Quality

8-Contaminant Control		Points
8.1	Indoor Contaminant Control during Construction	1

As a result the maximum available points for EcoTerra just because of prefabrication are only 15 points and the rest of the points (69) are not related to this issue.

On the other hand, EcoTerra could achieve up to 115 points; it has been determined that just 18 credits could facilitate getting LEED points due to prefabrication method and all of the remaining points could be awarded due to other factors discussed before such as lack of information and location of the project.

8.5- Prefabricated Homes Limitations

On the other hand, and in regard to prefabricated homes and LEED there are some issues that should be considered otherwise those can turn to the negative aspects of prefabrication. One issue is limitation with the shipping distance. If the prefab plant is located far from the final destination (for instance 800 km) it can potentially create an environmental concern. However this issue hasn't been reflected on LEED for Homes (as a negative point in term of prefabricated homes)

Another limitation that prefabricated homes may face in regards to getting LEED points is in the category of Location and Linkages (LL).

For instance community resources and transit or previously developed location, as the new prefabricated home buyers may prefer to move to a new area with lower land prices with fewer amenities therefore, less point can be awarded in this situation due to prefabrication method of built.

Also there can be other issues and concerns that can be generalized to all homes which are not discussed in this research.

9- Conclusion

Two hundred years ago nobody would ever think about some issues and concerns that the world should deal with them today. Global warming, water scarcity, ozone depletion, CO_2 emission, energy crisis, and etc, are everyday headline of news that have occupied governments, agencies and even individuals. And these trends will be increasing in the future time with higher speed as population growth doesn't follow a linear rule. In this global challenge, construction industry plays a substantial role and has huge responsibility as it links many related industries to make the final product.

On the other hand, having considered the waste of material, efficiency of processes and etc, it makes it an important issue to think about better, more efficient and sustainable way of homebuilding. It is deemed that prefabricated housing is among the most sustainable ways for provision of houses. There are many benefits that can be gained such as waste reduction and better compliance with the green building criteria. However, prefabricated housing sector is facing many challenges such as public acceptance and design limitation.

Compared with leading countries, Canada has a less share in percentage of prefabricated houses in the nation with higher number in modular (40 percent of prefabricated house's starts) in comparison with panelized system (23 percent of prefabricated house's starts). Prefabricated housing sector, in Canada, has many contributing factors such as innovation and growing population; also it has to deal with some hindrances such as design and acceptability aspects; nonetheless, integration between prefabricated housing industry and conventional homebuilder has always been beneficial for both parties.

As mentioned and followed in preview sections, this research project has some goals. In this part it is intended to look at each individual research goal and determine to which degree our goals has been achieved.

There are five research goals as follow:

1- To identify relevant credits in LEED for Homes in regards to prefabricated homes (tabular approach).The Relevant (R) credits and Somewhat Relevant (SR) have been further considered.

This goal was achieved by responding to that all credits for LEED for Homes that have been considered and the Relevant and Somewhat Relevant credits.

Within this research project all eight categories of LEED are selected and based on the knowledge and information gained through the literature review some comments and recommendations are made on fifteen Relevant and eighteen Somewhat Relevant credits. These credits were selected and further discuses based on the literature review and LEED for Home Reference Guide.

2- To find out how prefabricated housing can directly help us achieve LEED rating. (For Relevant credits)

To answer to this question, the Relevant credits (fifteen) were deeply discussed to find the roots to see how prefabricated homes can help us achieve more points in some categories.

To conclude, fifteen credits were considered and discussed further to determine the relevancy of prefabricated homes and LEED in term of getting LEED points. It was discovered that

Sustainable Site (SS) category can help the project achieve 1 point followed by Energy and Atmosphere (EA) with 6 points, Material and Resources (MR) 7 points and Indoor Environmental Quality (EQ) 1 point.

3- To identify how prefabricated housing can facilitate LEED rating. (For Somewhat Relevant credits)

Also as mentioned before there are some credits (eighteen) that indirectly can facilitate to gain more LEED points, all these credits were considered and the relation between them as a benefit of prefabrication and LEED were found out. Innovation and Design (ID) can facilitate to gain 8 points followed by Material and Resources (MR) 2 points, Energy and Atmosphere (EA) 7 points and Awareness and Education (AE) 1 point.

4- To find out if LEED recognize the benefits of prefabricated homes and to what extent?

According to the findings of this research project LEED for Homes doesn't directly recognize the benefits of prefabricated homes except in one category (Material and Resources – off-site fabrication)

In the mean time, 15 points can be achieved by having a prefab home that can potentially be gained by a traditional home with higher degree of attention to the requirements of LEED credits.

5- To evaluate as a case study one prefabricated house (EcoTerra) against LEED credits to assess the rating of the house according to the LEED Project Checklist (Preliminary Assessment)

EcoTerra has been LEED rated in compliance with the LEED Canada for Homes Simplified Project Checklist. Based on the available information from this specific home, this project could achieve minimum of 84 points which is equivalent to Gold LEED.

EcoTerra could achieve up to 115 points (out of total 138 points) that translates to Platinum LEED, but due to lack of information and the location of the project these points cannot be achieved at this time. To summarize the findings Energy and Atmosphere could achieve 33 points out of 38 points and in Material and Resources all 16 LEED points were achieved. These two categories have the highest achieved points in all categories followed by Indoor Environmental Quality with 18 points out of 21. On the other hand Location and Linkages just could achieve 1 LEED point out of 10 which is the lowest percentage among all categories followed by Sustainable Site, Water Efficiency and Awareness and Education

Also in terms of prefabrication and LEED points it was found out that just 15 points can be achieved as the privilege of prefabrication over the traditional method.

To sum up, this research gave an overview of prefabricated housing industry particularly in Canada and assessed it with the wide range spectrum of LEED to detect the potential areas that can be further developed and improved for both; nevertheless, due to lack of information in regards to the links and connections between prefab homes and LEED, this research can be taken as an preliminary assessment and base for the future in-depth investigations in this field.

10- Research Limitations

Before getting into the details it seems essential to talk about some limitations and barriers for carrying out this research:

- Novelty of the issue: the link between LEED and prefab industry could have been researched more in depth; there are very little information and article about this which makes it a valid topic for future researchers.
- Prefab manufacturers: it is very important to talk with and get information from manufacturers. Visit to a prefab home's manufacturers couldn't be arranged due to unwillingness of prefabricated manufacturers to cooperate.

11- Recommendation for future works

Improvement can happen gradually; the body of knowledge evolves based on the existing information and researches. The prefabricated homes have a huge potential for improvement to comply with the latest changes and more importantly with LEED for homes which dominates all areas of the related industry.

For the future researcher, it can be a great opportunity to look at this more profoundly to find the roots of improvements; to do so it is recommended to take that as a Thesis not as a MRP. The very substantial element of future work would be working in collaboration with a prefab manufacturer to examine the whole process. And also it is recommended to take an prefab home as a case study from very beginning to the very end of the project (in collaboration with a prefab company) and get involved with the whole process of build.

Using energy modelling for the selected project can add value for the final result to determine the areas of improvements in energy in regards to material and system selection.

Integration of sustainable design into the design of prefab homes is a tremendous area of improvement for the prefab industry. It is not very common to implement sustainable measures such as passive and active solar design, thermal mass, natural ventilation and solar heating and cooling for the prefab homes. It is recommended to carry out this research in a close relation with innovative and pioneer prefab manufactures who are open to changes and to offer new systems in the future. This can contribute to the popularity of prefab homes in the long-term.

12- Suggestions and recommendations

All changes start from above

If we consider society as a hierarchical power, all changes which are offering from higher authority would be more effective and influential. This hierarchical example suggests that cultural shift is the job of governmental organization and relevant industries who deals with provision of homes for people.

Incentives and motivations for prefab manufacturers

Incentivize and motivate manufacturers to implement green and sustainable measures such as compliance with LEED for Homes and promote its benefits effectively among their customers.

Incentives and motivations for people

Having considered all long-term and short-term benefits that may be gained from prefabricated homes in terms of energy efficiency, ecological and environmental issues financial incentives can motivate people who are willing to build a new home for their family. Both customers and government can enjoy from short-term and long-run advantages of such a decision.

Customized design and material selection

This part requires a huge effort of cultural influence on the design and material selection for a specific region. Public perception is substantially important factor affecting the prefabrication choice. So it can be a social research which is in realm of architectural science to see the contributing factors which increase the chance of prefabrication's selection among people. This research for itself can be a PhD project. All stakeholders will benefit from such a cultural change.

Awareness and Education

As it said it is the responsibility of higher authorities to promote prefab homes, for instance in LEED for Homes and in category of Awareness and Education, one or more credits could have been given to promotion of prefab homes.

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