DESIGN OF NET ZERO ENERGY HOUSING


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Summary

This paper reviews recent initiatives in energy efficient and healthy housing in Canada and compares them with the current housing statistics. The focus is on the most recent Canadian initiative focusing on the development of prototypes for net zero energy housing in distinct climatic zones. Design issues related to net zero energy housing are presented generically as well as more specifically as they relate to two projects which are being undertaken in Toronto.

Keywords: Housing, energy efficiency, net zero, healthy, R-2000, EnergyStar, EnerGuide

1 Introduction

Residential construction forms 38.5 % of gross construction output in 2005 in Canada. Its contribution to national GDP was almost 6 % in 2005 [1]. It has been growing at 9 % per annum between 2000 and 2004, with a slightly slower pace in 2005. In 2004 about 17 % of the energy consumed in Canada was used to run our homes. This results in about 15 % of Canadian greenhouse gas (GHG) emissions that contribute to climate change [2]. In Ontario, the energy consumption of recently built homes is about 0.9 GJ/m^2, which is a considerable improvement over older homes. On average pre-war homes use 40% more energy, post-war homes up to 1969 use 36.5 % more, and homes built between 1970 and 1980 use 27 % more energy than recently built homes. The energy consumption of homes built after 1990 decreased only by 6 % in comparison with the previous decade. Despite the fact that the size of a typical dwelling is increasing in Canada, efficiency gains over recent years have reduced energy use per square meter by 14.8 %, and energy use per household by 11.9 % since 1990 [3]. Thus currently average energy use in dwellings is about 114.8 GJ/annum (31,890 kWh/yr), or 0.92 GJ/square meter of floor area/annum (253 kWh/m^2/yr) [2]. This has limited the increase in GHG emissions from housing to about 15 % since 1990.

A survey of the Canadian residential sector in 2004 [3] identified that space heating accounts for 57.1 % of the total energy used in housing, with hot water accounting for 24.5 %, appliances 13.1 %, lighting a further 4.5 %, and space cooling 0.9 %. Houses built more recently have better levels of insulation reducing heating loads by up to 50 % compared to houses built 50 years ago.

To address global warming, energy supply issues, and air pollution concerns there is now a recognised and urgent need to reduce energy use and GHG emissions from housing, particularly in the light of the predicted demand for new homes in Canada. The Greater Toronto Area is expected to grow by over 3 million people needing up to a million new dwellings in the next 30 years, consuming up to 1,000 sq km of non-urban land. There is therefore an urgent need to develop urban infill and densification solutions that demonstrate low energy, sustainable design solutions which avoid the use of non-urban land.

Homes that utilise renewable energy technologies (usually solar thermal, solar photovoltaic and wind) to generate as much energy as their yearly load are referred to as net-Zero Energy Homes. Over the last 20 years, there have been many one-of-a-kind projects and international initiatives that have demonstrated and promoted the development of low and net-zero energy homes. More recently there has been more interest from various levels of governments to develop coordinated programs that have wider market impact. In Canada the recent Equilibrium Housing competition (initially Net Zero Energy Healthy Housing) [5] has focussed interest on the design challenges of net zero energy housing.

2 Overview of sustainable housing in Canada

Below is a brief review of the main initiatives that have occurred in Canada in recent years to address energy use and other sustainability issues in residential construction.

2.1 R2000

Since the 1980s the R2000 program has been the main initiative in Canada addressing energy use in low rise housing. The R-2000 Standard [11] is voluntary. It is based on an energy consumption target for each house which varies by region and a series of technical requirements for ventilation, air tightness, thermal insulation, selection of materials, water efficiency and a healthy indoor environment. The standard has been updated regularly to reflect an improvement in housing standards. The minimum EnerGuide rating of 80 must be achieved {EGH rating = 100 – ((Annual Estimated Energy Consumption/ Reference Energy Consumption) * 20)}.

R2000 homes typically require 30 percent less energy to operate than conventional new homes of the region. R-2000 features include additional insulation; double-glazed, low-emissivity, gas-filled windows with insulated spacers, an air tightness requirement (1.5 air changes per hour at 50 Pascals), and high-efficiency heating systems. Only home builders who have completed R-2000 builder training and hold a current R-2000 builder licence can build homes that can be certified to the R-2000 standard. Every home submitted for R-2000 certification must undergo a series of independent inspections and tests to verify that the requirements of the R-2000 standard have been met.

2.2 Advanced House Program

In the 1990s, Natural Resources Canada (NRCan) launched the Advanced Houses to help develop and test innovative methods of reducing energy consumption, provide better indoor environments, and to reduce the environmental impact of houses. The Advanced House Program aimed to demonstrate how to achieve a more demanding requirements than R2000 in three primary categories; total purchased energy, indoor comfort and health, and environmental features. The total purchased energy requirement for an Advanced Home was set at 50 % of the energy used in an equivalent R2000 home. The program established individual performance targets for space heating, space cooling, domestic hot water, appliances and fans, lighting, and outdoor electricity and peak loads.

To meet this standard it was necessary for design teams to explore more innovative technologies such as ground source heating and cooling systems, solar water heating, triple glazing, and high efficiency appliances. In addition to energy, the Advanced Houses focussed on providing a high standard of comfort through a detailed consideration of indoor environmental conditions and the factors that affect this, including ventilation efficiencies and emissions from materials. There was also an attempt to reduce water consumption and specify low impact materials.

Ten Advanced Houses were built under this program across Canada. Just over half the projects include solar thermal systems, 2 projects include PV rooftop systems, 3 projects use PV water pumps for their solar thermal collectors, and one project has a 10 kW wind turbine. The performance of each house was monitored and it was found that the difference between predicted and monitored performance varied.

2.3 Energy Star for homes

Since 2005, NRCan have expanded the ENERGY STAR Initiative in Canada to include energy-efficient new homes built in Ontario and Saskatchewan. Under this program, a new home receives an EnerGuide label which specifies the energy rating as well as energy consumption of the home under standard operating conditions. Initially, the standards were slightly lower than R2000 (EGH rating of 78) but recently they were brought on an equal footing. ENERGY STAR qualified new homes are approximately 30 % more energy efficient than those built to minimum Ontario Building Code standards. This program is an attempt to apply many of the lessons learned through the R2000 program to a wider housing market.

This label is being used as part of an awareness raising and market transformation program for both existing and new build housing. The Government of Canada's goal is to ensure that all new houses are built to the ENERGY STAR level of energy performance.

2.4 CMHC Healthy Housing

Healthy housing initiatives were developed in response to increasing number of people suffering from allergies. CMHC’s Healthy Housing™ is defined by five key elements: Occupant Health, Energy Efficiency, Resource Efficiency, Environmental Responsibility, and Affordability. The Healthy Housing™ Recognition Program was established to recognise builders and renovators who have a demonstrated knowledge of healthy housing practices.

2.5 Net-Zero Energy Home Coalition

In 2004, a multi-stakeholder group consisting of corporate, not-for-profit, and environmental non-governmental organizations launched the Net-Zero Energy Home Coalition [5]. They have proposed a number of new research initiatives and demonstration projects towards the goal of a net-zero energy home. CANMET Energy Technology Centre is undertaking a multi-year project to consider all existing and emerging technologies, and support the development of simulation and optimization software. This collaborative R&D project will provide in-depth analyses on the optimization of low and net-zero energy homes for Canadian climatic conditions.

2.6 International programs relevant to Canada

International programs of relevance in Canada include the US Department of Energy (DOE) Zero Net Energy Buildings Outreach and Action Plan, now in Phase II. This program aims to combine state of the art energy efficient construction and appliances with commercially available renewable energy technologies. One of the outcomes has been the biannual Solar Decathlon competition, which challenges university research teams to design, build, and operate small energy efficient houses that use solar thermal and PV technologies to meet all household energy needs [6].

The LEED™ green building rating, developed by the US Green Building Council (USGBC), does not specifically aim for zero energy but is a broader program addressing many aspects of sustainability in an effort to provide a national standard for what constitutes a "green building”. One aspect of this is to address energy efficiency and this is done by setting EnergyStar targets. A recent development is the Living Building initiative by the Cascadia Chapter of USGBC, which aims for a neutral impact building [7].

Several European programs have strong synergies with the Canadian initiatives. The European PassivHaus standard developed by the PassiveHaus Institute in Germany [8] has some similarity to the Canadian Advanced House standard. The term PassivHaus refers to a specific construction standard for residential buildings with good comfort conditions during winter and summer, without traditional heating systems and without active cooling. The PassivHaus standard focuses principally on very low energy use for space heating, typically only 15 % to 20 % of buildings meeting code requirements. One of the goals of this standard is to have sufficiently low energy use such that renewable energy technologies could be used to meet all the energy requirements. A dwelling which achieves the PassivHaus standard typically includes very good levels of thermal insulation with minimal thermal bridges, well thought out utilization of solar and internal gains using high specification glazing, excellent level of air tightness and good indoor air quality, provided by a whole house mechanical ventilation system with highly efficient heat recovery. Many PassivHaus projects do not require a traditional heating or cooling system.

The PasiveHaus standard has led to several comparable schemes which adopt similar standards in other European countries including the AECB Energy Standard in the UK and the Swiss Minergie P. There are also a few PassiveHaus projects underway and at least one completed in North America [9].

3 Net Zero Energy Housing

In July 2007, the Canada Mortgage and Housing Corporation (CMHC) launched a competition for demonstration housing projects which meet net zero energy goals and result in a healthy indoor environment (NZEHH [10]). The goal of this initiative was to develop housing projects in different regions of Canada which would be monitored and act as showcases of technologies which can be adopted to achieve net zero energy goals. The minimum EnerGuide rating required was 90 (this means 50 % energy consumption saving as compared to R2000 home) although the aim was to achieve an Energuide rating of 100 which meets a true net zero energy standard.

3.1 Design issues associated with Net Zero Energy Housing

Various components and technologies are essential to achieve the net-zero energy target and they need to be carefully integrated to work as an effective system. A design strategy is required to minimise demand for energy and then supply all energy needs from renewable sources.

The most common strategies are to build a low energy fabric adopting passive solar design, super thermal insulation, high performance windows, and airtight construction. The energy demand can then be supplied through an efficient heating, cooling and ventilation (HVAC) systems, renewable energy generation, and highly efficient appliances and lighting. In addition, to address healthy housing conditions other issues such as, sources of materials used, emissions into the environment, waste generation and water use need to be addressed and balanced against the need to minimise energy.

Whole-building simulations are necessary to optimise levels of insulation, size of heating system, desirable air tightness, etc. Costs determine the weight of various options in the optimization process. Below is a brief review of some of the principal strategies that are required to meet a net zero energy healthy home standard.

Building form and orientation

The first requirement is the design of an optimal form and orientation of the building for the particular site. This can often be challenging in an urban infill location, but other benefits may be a compact plan with reduced heat loss area through shared party walls, etc. Generally compact forms with larger elevations facing south minimise heat loss and provide opportunities for solar energy collection. Orientation and angle of pitch for solar thermal and PV panels should be considered, and appropriate glazing areas for each orientation to maximise solar benefits during the heating season but to minimise overheating in summer months. Internal layouts should promote natural ventilation. This is easier with large open spaces, openings for air to flow between floors and between north and south zones. Properly designed overhangs are used, to limit direct solar heat gain in the summer while still allowing it in the winter. Alternatively, the use of active shading devices such as motorized shutters can be considered to prevent overheating in the summer.

The following design principles are relevant:

- Adequate space provision and efficient use of space, without excessively large room sizes. The focus is on high quality design of functioning spaces so that the normal family needs are accommodated within a smaller enclosure.
- A compact plan to minimise heat loss.
- Concentration of highly serviced spaces in a central core of the house.
- Solar collection is often concentrated on the roof of the dwelling due to the difficulties of optimising orientation for solar gains in an urban infill development where other buildings interfere. This may include both active and passive solar collection systems.
- Daylight optimised within all spaces to minimise electric lighting use. All windows to have adequate glazing to provide natural daylight through most daylight hours.

- Explore the potential to create a microclimate around the buildings that is more favourable and reduces heat loss in winter and heat gain in summer.
- Glazed spaces used as solar collectors, ventilation drivers and amenity spaces.
- Planting used to provide summer shading on the south side of dwellings wherever possible.
- Provide for change, flexibility and adaptability over the life of the building.

Landscaping

Landscaping can be an important component of a low energy design by creating an appropriate micro-climate around the building and providing shading of south facing windows during the summer. On the otrher hand, it is important that landscape does not lead to shading of important solar energy collecting components.

Building fabric – insulation

The building fabric must provide a very high level of thermal resistance to minimise heat loss during the heating season. There is a diminishing benefit from insulation but most net zero energy homes have RSI values higher than 10 m^2/W/K (R-value 60) for walls and 12 m^2/W/K (R-value 70) for the roof. Innovative technologies such as SIP panels, IFC systems, double stud construction, or externally insulated masonry construction often used in Europe offer opportunites for high performance building fabric. An air tight envelope is also essential. An air-tightness standard below R-2000 standards (<1.5 air changes per hour at 50 Pascals) is necessary.

Building fabric – glazing

The glazing is a thermal weak point from the point of view of heat loss but offers the potential for heat gain from solar radiation. Even with careful design and minimization of north facing windows more 50% of heat losses are through glazing. Appropriately located high performance double or triple glazings with insulated spacers, low emissivity coatings and argon (or krypton) filled cavities are likely to be needed. The heat mirrors and tints can be used to optimize the window performance. The CSA-A440.2-04 Energy Performance of Windows and Other Fenestration Systems standard introduces the EL (energy level) scale. The glazing should have EL5 or RSI = 0.7 m^2K/W (R = 4).

Building fabric – thermal mass

In Canada most housing is timber framed with little thermal mass other than in the basement walls and floor, and this leads to significant air conditioning use in many areas. The use of thermal mass can potentially have significant benefits for both energy efficiency and comfort. Exposing heavyweight material surfaces (or phase change materials) allows the structural mass to interact thermally with the internal environment, thereby increasing the thermal inertia of the occupied spaces. These components act as a heat sink during the day absorbing excess heat, thus avoiding or reducing overheating. This can reduce or eliminate the summer mechanical cooling load. Winter heating loads can also potentially be reduced. The location of the mass is also important. It is more beneficial to locate the mass where it is directly exposed to the sun. Indirect mass requires a larger surface area. Finishes are also important as the mass should not be insulated from the occupied space by carpets, drywalls, etc. Net zero energy homes may need to integrate some additional mass to reduce in particular cooling loads.

Efficient and correctly sized HVAC systems
Selecting the most cost effective HVAC system for a net zero energy house is a complex issue. Solutions will depend on energy sources, local climatic conditions, control strategies and electricity pricing schemes that may vary with time of day. However HVAC systems should be highly efficient and not oversized. Radiant floor heating systems are often favoured due to the high radiant component and corresponding lower air temperature, and the heat distribution pattern. It is important to insulate underneath the floor and around the perimeter of the foundation to minimise heat loss. Another advantage of radiant floor heating systems is to allow for individual control of several zones within the house. For example a zone may temporarily not require heating because of southern exposure, internal gains (e.g. social gathering), or because the corresponding space is not occupied or not used during particular times. It is important to design the heating and cooling systems to allow for individual rooms or zones to be controlled. The airtight envelope requires ventilation (rate of 65 l/s) to supply fresh air. Heat recovery ventilators (HRV) with effectiveness of 80 to 85 % are required to minimize heat losses. The operation of HRV should be controlled by CO_2 or humidity sensors to modulate the rate of ventilation according to the house use (ventilation should be greatly reduced when no one is in the house, thereby limiting both the fan energy and the waste of loss of heat through ventilation).

Renewable energy sources for electricity
The alternative renewable sources for electricity include photovoltaics (PV), wind and biomass (using a combined heat and power system). These are typically considered as the only renewable sources of energy generation. Wind energy may be possible in some locations but is unlikely to be relevant for urban, low rise, infill projects. Biomass is an alternative but it poses problems with the storage on tight urban sites. The obvious alternative for the net zero energy strategy is the application of PV, either integrated into the building envelope or more likely on the roof for the optimal orientation in the urban context. This technology is still very expensive and within the guaranteed life span of 25 years, there is no positive payback. In Ontario, the economics are helped by the recently announced Standard Offer Contracts for renewable energy generation including PV. This allows for excess energy to be sold directly into the gird at a preferential rate.

Renewable energy technologies
Other renewable energy technologies can be used to generate energy. They include ground source heat pump, solar thermal water heater for domestic water and heating, solar air heating, and natural lighting. They need to be incorporated into the design in order to minimize the demand for electricity and/or gas to supply domestic hot water and auxililiary heating source for extended periods of cold weather, and for extended overcast conditions with limited solar radiation. Ground-source heat pumps can supply fluid or air at a relatively constant temperature (10 ^{o}C in southern Ontario). During the heating season a heat pump exrtracts heat from the fluid and returns colder fluid to circulate through the loop in the earth which heats it up. The opposite happens during the cooling season when the heat from inside of a house warms the liquid which is then cooled by the earth.

Solar thermal panels can generate heat for domestic hot water and possibly some space heating. With the reduction of energy used for space heating, domestic hot water becomes a large proportion of total energy demand. Solar thermal systems can supply up to about 70 % of annual hot water needs in the Toronto climate. One problem with sizing the collectors to meet both the space heating and DHW load in the winter is that in the summer, the collectors will generate too much heat. The heat needs to be discarded in order to avoid overheating in the collector. Integration of solar collectors into façade systems can avoid some of these problems and can also reduce winter heat loss through the façade. Other technologies that may be relevant include: tankless heaters that provide instant hot water at high appliance energy efficiencies, solar combi systems, smart tanks possibly integrated with solar hot water systems.

Preheating of the ventilation air drawn from the outside may be achieved, either with a SolarWall perforated cladding system which heats the air passing behind it, or by reclaiming some of the parasitic heat captured by photovoltaic systems. The first solution may not be possible in a dense urban setting. The second solution is at the edge of current research but has been proposed in some net zero energy homes.

Lighting & Appliances

To minimize the energy demand of a net zero house, lighting and appliances loads need to be minimised. Their current share of energy use in modern housing is around 17.5% [3] of the total energy consumption. Good design ensures good quality and penetration of natural lighting into the interior thus minimizes the demand for artificial light. Energy efficient lighting fixtures are important and phantom loads (i.e. small loads from clocks, electronics, etc.) should be minimized by careful appliance selection.

4 Conclusions

Canada has many temperate zones and many of them have extreme temperature variations – low temperatures during the winter and high summer temperatures. This makes building design in these regions very challenging. The conclusions will be based on two net zero energy projects in Toronto, one an infill site in downtown Toronto and the other an infill site in a suburban location originally developed 50 years ago and now well within the boundary of the city. Both are base on occupancy of a family of four.

- The energy consumption can be significantly reduced by using energy efficient appliances. At least 50% reduction in the electricity demand can be achieved by essential appliances (fridge, freezer, stove, dishwasher, clothes washing machine) if EnergyStar or better appliances are specified. It should be noted that some relatively modern equipment such as computer, large TV screen, and other electric gadgets use a substantial amount of energy. Education of occupants must be an integral part of the commissioning process. It should be noted that according to information published in the Energy Use Data Handbook [3] the total appliance use constituted 13% of the total energy use. In a net zero energy home, the appliances are even more important as they share a greater energy demand, up to 40%.
- Superiunsulated home results in savings for heating and cooling. However, the optimal insulation thickness will vary depending on local conditions and costs. After about Rsi 10 for walls the return on further insulation is small.
- The use of a geothermal heat pump means further decrease in energy demand which can be supplied by renewable sources. A net zero home requires around 30% of the total energy needs for heating, cooling and ventilation of a R-2000 home. It should be noted that an average consumption on heating, cooling and ventilation of homes surveyed in 2004 [3] is approximately three times the energy consumption of R-2000 homes.

- House designs which respond well to their surounding environment and maximize the amount of natural lighting into the interior can save up tp 85% [based on survey described in 3] of energy used provided compact fluorescent bulbs are used. It should be noted that the percentage of total energy used for lighting remained approximately the same (at around 5%). The incorporation of light controlling sensors is still in its infancy; motion activated sensor are annoying to occupants, prone to errors and rather expensive.
- The demand on domestic hot water can be decreased by using low-flow shower heads and faucets. This can reduce the demand for hot water by at least 50%.
- While it is feasible to achieve a EGH rating of 95, it is not easy to get to 100. The difference between the two ratings is the energy which has to be generated on site. This presents a number of challenges, including local by-laws, cost and physical space. It was identified that the most feasible on-site energy generation in urban areas is with photovoltaic panels It was found that the required amount PV panels could be placed on roof of each of the two projects. It is more challenging to accommodate them on a tight site with limitations on orientation. Alternatively, the purchase of off-site generated green power may be appropriate.
- The climatic control of various zones of a house according to their use is essential to the optimization of the energy use.

5 Recommendations

- The environmental assessment of all construction materials and construction process should be carried out for alternative material specifications. The selection of materials should either be optimized to minimize greenhouse gas emissions or savings over a standard housing construction practice should be offset against the impact of the on-site energy generation.
- The achievement of net zero energy is difficult and in urban setting there are very limited alternatives. The on-site energy generation should be looked in the context of larger community. Although this may seem problematic, it may result in range of opportunities which may be economically more viable.
- The results of monitoring of pilot projects should be disseminated and used to develop strategies for wider application to net zero energy housing.

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