OPTIMIZATION OF NET ZERO ENERGY HOUSES

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ABSTRACT

Designing a Net Zero Energy House (NZEH) is easy - the difficulty lies in achieving the goal of zero net energy use without spending an excessive amount of money. This requires careful analysis with an emphasis on quantitative design optimization - how much insulation to use in the various envelope components, how much glazing to employ, what type of mechanical systems to use, etc? And, perhaps most importantly, knowing when to stop using energy conservation and knowing when to switch to renewable energy sources to supply the balance of the house's energy.

This paper examines the issue of NZEH design optimization for houses located in Canada. Over 50 different Energy Conservation Measures (ECM) were evaluated by performing annual energy analyses for three representative house types in four different climatic zones. By comparing energy savings and incremental construction costs, detailed recommendations were produced for each of these house/location combinations. The intent is that these guidelines can be used to produce a first draft of the energy-related design features of a NZEH house which can then be further refined by modeling the actual house, with its unique architectural details, in its intended geographic location. In addition, a procedure was developed which permits the designer to identify at what point renewable energy sources should be used in lieu of further energy conservation upgrades.

Key Words: Net Zero Energy Houses, optimization

THE EVOLUTION OF NET ZERO ENERGY HOUSING

Net Zero Energy Housing (NZEH) represents the ultimate goal of the modern low energy housing movement which began well over a quarter century ago. A house which can exist with independence from increasing energy costs has a technical and philosophical purity which can be very enticing. However, almost all of our understanding about the energy performance of residential buildings has been developed using conventional and energy efficient structures - such as those constructed to the R-2000 Standard. Although there are no major technical obstacles to designing and building Zero Energy houses, it is unclear how to reach this goal without incurring significant and (for most consumers) prohibitive costs. For example, one recent design analysis of a proposed Zero Energy House for the Canadian prairies found that the incremental cost, beyond that required to construct the house to the R-2000 Standard, was about \$166,000 (CDN) for a two storey, 167 m^2 (1800 ft^2) house with a full basement (Proskiw and Hockman, 2006). Depending on location, this represents an incremental cost of between 50%

and 75% of the selling price of the house - exclusive of land. Obviously, we need a better understanding of how to stretch the energy performance of houses without incurring excessive cost. In other words, we need a better understanding of how to optimize the design of Zero Energy Houses.

OBJECTIVES

This study was designed to build upon the work which began with the 2006 NZEH project described above but with an expanded scope in terms of technologies, design options, geographic locations, etc. The specific objectives were to develop optimization guidelines for the design of NZEH structures based on the energy performance of various design options, their attendant costs and the costs of renewable energy alternatives.

Since almost any house can theoretically achieve near-NZEH status provided the occupants are prepared to forgo the comfort, health and safety benefits of modern housing, an implicit caveat of the project objectives was that the occupants should not have to live "cold, dark and unwashed".

NZEH DESIGN PRINCIPLES: CURRENT STATE-OF-THE-ART

Contrary to popular belief, designing a house which can operate comfortably and safely without purchased energy is easy - at least from a conceptual perspective (the details get a little tricky). While only a handful of NZEH houses have been designed or constructed in Canada, there is general agreement about the overall approach to be followed and the features which should be included in the building.

- Minimize heat loss through the building envelope by using a simple architectural layout, massive amounts of insulation and a high degree of airtightness.
- Select the most efficient types of space heating, water heating and ventilation systems available.
- Use energy efficient lighting and appliances, and minimize exterior energy use, thereby reducing the base loads as much as possible.
- Maximize passive solar gains by using as much south-facing glazing as possible while still maintaining the so-called "6%" rule for glazing (limiting the area of south-facing glazing to no more than 6% of the floor area).
- Use renewable sources of energy to provide the balance of the energy requirements. For urban applications, this can include photovoltaics and solar thermal systems while in rural areas wind power and other sources of energy may also be considered.

The observant reader will notice that these five design principles are listed above based on their relative cost-effectiveness. This is important since it defines for the designer the order in which various measures should be implemented. Low cost measures which provide significant energy savings (such as most energy conservation options) should be implemented first followed by the remaining measures. Renewables, despite their philosophical purity, should only be used after other measures have been exhausted since they are usually expensive sources of energy relative to conservation alternatives.

The very observant reader will also notice that these five principles are largely *qualitative* guidelines with little *quantitative* detail. What are "massive" amounts of insulation, what is a "high degree of airtightness", etc. It is that topic which was the subject of this project.

COST OPTIMIZATION OF NZEH HOUSES

To improve a building's energy performance, NZEH designers have two options at their disposal - various types of conservation measures and renewable energy systems. Conservation measures have several advantages: they are well understood, generally have an established track record of performance, are relatively economic and are (for the most part) durable. They can also be applied to virtually any house without major modifications to the design or impact on the occupant's lifestyle. Adding moderate levels of conservation measures tends to initially produce significant savings at modest incremental cost. However, as the level of conservation increases, the rate of further savings declines and the costs increase. This trend continues until a point is reached at which the cost of saving energy using conservation is greater than the cost of producing new energy from renewables. At this point, the designer should direct further energy investments into renewable energy sources, even though there cost may be high since they are still less expensive than the competing conservation alternatives.

Cost optimization of NZEH houses can be defined as the process of selecting ECM's and renewable options based on both their costs and energy performance, such that the incremental cost of upgrading the house to achieve NZEH performance is as small as possible. Since this is a quantification process, we need a suitable metric to compare options. An appropriate optimization metric which can be used is the incremental cost of the measure divided by its energy savings. This will be defined as the "Value Index".

ECM Value Index = (incremental cost of the measure) / (annual energy savings) (1)

A slightly different version of the same metric can be used for renewable energy sources. For example, the most common renewable energy source used in NZEH houses is photovoltaics. Currently, photovoltaic arrays cost about $7 to $8 per Watt of rated capacity, while the complete system (which includes the array, inverter, controls, wiring and other components) averages approximately $8/W to $10/W (Howell, 2008). In southern Canadian locations with current technology, these systems will produce about 1000 to 1200 Wh/yr per Watt of rated capacity. By combining these two parameters we get...

PV Value Index = (PV system cost) / (annual energy production) (2)
= ($/W) / (Wh/yrXW)

= $ / (kWh/yr)

If we substitute the current, average values for the PV system cost ($9/W) and performance (1100 Wh/yr per W) into Eq. (2), we get the cost to generate 1.0 kWh per year...

= [(9 $/W) / (1100 Wh/yrXW)]

= [(9 $/W)] / (1.1 kWh/yr•W)]

Current (2008) PV Value Index = $8 per kWh/yr

In other words, the cost of a installing a PV system capable of producing 1.0 KWh/yr would average about $8 using 2008 prices. Therefore, any conservation measure which saves 1.0 kW/yr can be economically justified, relative to the PV option, if its cost does not exceed $8. If the conservation measure's cost is greater than $8, then the PV option is more economic. Since the goal of a NZEH house is to consume zero, net energy the Value Index becomes the only economic tool required. No information is required (or needed) on the usual economic variables typically associated with life-cycle costing such as interest rates, energy escalation rates, inflation rates, amortization periods, etc. These factors will determine how *long* it takes the NZEH house to pay back its investment, but have no effect on *what* measures, or *how much* of them, should be incorporated into the design.

To summarize, the Value Index has two applications: comparing the cost-effectiveness of competing Energy Conservation Measures and comparing the cost-effectiveness of ECM's against renewal energy options.

METHODOLOGY

To perform the energy analysis, three archetype houses were modeled in HOT2000, version 10.31. These ranged in size from 112 m^2 (1200 ft^2) to 279 m^2 (3000 ft^2), were equipped with full basements and were architecturally conventional, merchant-built houses. Initial insulation and airtightness levels, mechanical system details, etc. were typical of levels that would be used for a NZEH house in Canada. Since Canada has a wide variety of climate regions, four different locations were used:

Maritime - Vancouver (2925 Celsius Heating Degree-Days) was selected to represent the maritime climate found on both the east and west coasts of the country.

Prairie - Winnipeg (5900 HDD) was used to represent the cold, dry prairie climate found in most parts of Manitoba, Saskatchewan and Alberta.

Eastern - Toronto (3650 HDD) was used to represent the eastern climate found in central Canada. It is also the largest population centre in the country with the largest homebuilding industry, so the results apply to a large percentage of new home construction.

Northern - Located in the North-West Territories, Yellowknife (8500 HDD) was selected as a good example of a northern, arctic climate. While the Canadian north has a very small population it has extremely high energy costs and may represent one of the better applications for NZEH housing.

A list of approximately 50 ECM's was then assembled and their costs estimated. Each ECM was analyzed by modeling every house/location combination with and without the measure. Energy savings were calculated and upgrade costs estimated to produce the Value Indices. This permitted design decisions to be made based on cost-effectiveness - rather than on historical precedent or an intuitive sense of what should be done. Approximately one thousand HOT2000 annual simulations were performed.

To illustrate how this process worked consider the use of thermal mass as a design option. Its impact was evaluated by modeling the twelve house/location combinations using the most common mass level normally encountered in new construction (to establish a base case) and then sequentially upgrading each house to higher mass levels (a further three in this case). The energy impact of each mass level was then assessed using the change in the house's annual energy consumption relative to the base case. This information was then combined with the estimated, incremental costs so that the Value Indices could be calculated for each ECM/house/location combination.

Finally, the ECM Value Indices were compared to the PV Value Index ($8 per kWh/yr) to determine the cost-effectiveness of each measure relative to the photovoltaic option. Using this procedure, the most cost-effective architectural, building envelope and mechanical system options were selected. From these results, recommendations were developed to produce the most economic design package guidelines for each of the 12 house/location combinations.

DESIGN GUIDELINES FOR NET ZERO ENERGY HOUSES

The final design guidelines are summarized in Tables 2 to 5. Each ECM (for insulation levels, types of mechanical systems, etc.) was selected to give the lowest energy use while still having a Value Index that was less than PV Value Index. As such, each represents the optimum measure for that component.

The intent is that these recommendations can be used by NZEH designers to create a first draft of the energy-related, design features including the primary architectural design features, preliminary RSI values for the major envelope components and performance characteristics of the mechanical systems. Once these have been identified, the actual, proposed house design, with all its unique architectural and size-related features, can be modeled in HOT2000 (or other software) and the design fine-tuned. It is hoped that this will expedite the entire process and help the designer arrive at a design which is closer to the economic optimum than would otherwise occur - thereby reducing the overall cost of the building.

Development of guidelines for windows was a more complicated process since window performance depends (mainly) on two variables (thermal resistance and the Solar Heat Gain Coefficient) whereas most other envelope or mechanical system measures generally depend on only one variable - usually the thermal resistance or the mechanical system efficiency. In fact, it was because of this complexity that the concept of the Energy Rating (ER) for windows was developed. The ER is a single-value metric which describes the net energy flux of the window over the heating season with due consideration for the effects of the thermal resistance, Solar Heat Gain Coefficient and air leakage. Recognizing the utility of the ER concept, a procedure was developed for optimizing window selection decisions in NZEH houses which only requires knowledge of the ER numbers for competing windows along with their attendant costs. This process is described in detail in Proskiw (2008).

One note of caution however, is that the Value Indices were calculated using a costing data base created using Winnipeg data effective March, 2008. While the differences in incremental costs of conservation measures are believed to be much less dependent on geographic location than (say) the cost of new houses, some differences will obviously occur. Therefore, before using the specific recommendations, the reader should examine the costing data used, make any appropriate modifications and recalculate the affected ECM Value Indices. Likewise, the PV Value Index should be challenged and updated as necessary.

SOME ADDITIONAL FINDINGS

While the primary intent of this project was to develop quantitative guidelines, some additional thoughts and observations arose from the analysis. These are discussed below.

Cost Of Energy - It is commonly believed that the cost of energy has a direct bearing on the design of Net Zero Energy Houses - with additional conservation or renewable energy sources being justified in areas with very expensive energy. This is untrue. Utility rates (i.e. the cost of purchased energy) have no impact on the design of a Net Zero Energy House - provided one caveat is satisfied. By definition, the house will produce as much energy as it consumes. Therefore, while the utility rates will affect the gross energy bill (the energy purchased from the utility) it will have no impact on the net energy bill since the house will produce and sell back to the utility exactly the same amount of energy. *Therefore, provided the utility will purchase energy at the same rate as it sells it to the house, the net energy bill will be zero and therefore the cost of energy (the utility rates) has no impact on the design or operation of a NZEH.*

Thermal Mass - The impact of increasing the house's thermal mass on the overall energy performance was found to be relatively modest, typically producing savings of 100 to 700 kWh_e/yr, although the latter would only be achieved if the house were upgraded from light weight framing (which probably describes 90% to 98% of all new Canadian houses) to very heavy concrete construction. These savings represent about 1% to 2% of the total, annual energy consumption of the house. Interestingly, with the possible exception of Maritime climates (which have the mildest climates of the four studied in the analysis) the percentage savings were relatively unaffected by house size.

Orientation - Perhaps the most interesting observation regarding house orientation (defined as the direction which the majority of the glazing faces) was that the percentage savings were surprisingly consistent regardless of geographic location. For example, changing the house's orientation from south to south-east or south-west only increased total energy consumption by 1% to 2% regardless of house size or location. Significant performance reductions did not occur until the orientation exceeded 90% off south. This means that energy consumption is not overtly affected by small changes in orientation.

South-Facing Glazing Area - Although increasing the amount of south-facing glazing area is often touted as a practical method for reducing energy use in a NZEH house, the analysis found that the cost-effectiveness of this practice was very poor if a high-quality window was used - which presumably would be the case for a NZEH house. Basically, the cost of purchasing an additional square metre of south-facing glass was less than the energy savings which would result or which could be provided by other conservation measures. Further, these results were generated assuming unfettered solar access. If any shading was encountered (due to adjacent buildings, vegetation or from the house itself), then the benefits of south-facing glazing would be further eroded.

Airtightness - Improved airtightness was found to be one of the most cost-effective methods of improving the overall energy efficiency of NZEH houses, even though the base case scenario used in the analysis assumed an airtightness of 1.50 ac/hr_{50}, the maximum permitted by the R-2000 Standard. For example, reducing the leakage to half this value (0.75 ac/hr_{50}) produced savings of over 1000 kWh_e/yr in six of the 12 house/location combinations studied. In fact, a design goal for NZEH houses of 0.50 ac/hr_{50} was recommended even though it may be difficult for some builders to achieve, at least initially. Not only will an airtight envelope save significant amounts of energy but it will improve the structure's durability and comfort, reduce the transmission of outdoor noise, and provide other benefits. The significance of these conclusions became increasingly pronounced as the climate became more severe (i.e. colder).

Exterior Walls - The economics of upgrading exterior wall systems was found to be heavily dependent on the climate in which the house was located. Relative to the photovoltaic option, the optimum insulation level for milder climates, such as those in Maritime or Eastern Canadian climates, was about RSI 5.28 (R-30). In colder climates, such as those in Prairie or Northern climates, the optimum level would about RSI 8.81 (R-50). However, it was important that the economics of wall upgrades also be compared to those of other conservation alternatives which the designer may be considering.

Attics - Upgrading attic insulation proved to be a surprisingly cost-effective measure despite the fact that the assumed base case attic insulation level was already RSI 11.01 (R-62.5). Value indices for higher insulation levels were less than the PV Value Index for most of the location/house size combinations studied. The only exception was for a small house located in Maritime climates.

Basement Walls - Contrary to expectations, the basement wall upgrades routinely displayed high Value Indices and hence poor cost-effectiveness. For all four locations studied, the most economical basement wall insulation scheme was only RSI 4.23 (R-24). This was due to the beneficial effects of the surrounding soil coupled with the high relative cost of exterior insulation used in some of the options.

Basement Floor Slab - Surprisingly, the benefits of insulating the basement floor slab were not as significant as had been anticipated. In milder climates, including Maritime and Eastern locations, the recommended treatment was to leave the slab uninsulated whereas in colder climates, such as on the Prairies or in the North, a perimeter skirt of RSI 1.76 (R-10) insulation was recommended.

Windows - Several interesting conclusions were developed about the behaviour of windows in NZEH houses. First, it was found that the Energy Rating (ER) number was a valid metric for comparing the thermal performance of windows in NZEH houses, even though the ER concept had been developed for conventional houses. Basically, the window with the best (highest) ER number had the lowest energy consumption, although this does not necessarily mean it was the most cost-effective choice. Second, a simple method was developed which permitted the cost-effectiveness of various window designs to be quickly compared using only their respective costs and ER numbers. Finally, it was found that this method could also be used to compare the cost-effectiveness of window options to that of the photovoltaic option.

Space Heating Systems - Selection of the optimum space heating system was very location dependent. In Maritime locations, electric baseboard heating was the most cost-effective system identified. In Prairie and Northern locations, either electric baseboards or a Ground Source Heat Pump (GSHP), with a minimum rated COP of 4.0 was recommended. Results for Eastern Canadian locations were similar to those of the Prairies except the GSHP was only recommended for larger houses.

Domestic Hot Water Heating - Several of the DHW options were surprisingly cost-effective compared to the photovoltaic option. In all cases, a high-efficiency electric tank coupled with a Greywater Heat Recovery unit and a thermal solar energy system was recommended. In addition, it was concluded that designers could also consider using a self-contained heat pump which extracts heat from the indoor air and uses it to preheat the DHW. A minimum COP of 1.50 was recommended. This system may also provide a supplemental benefit of helping to dehumidify the indoor air and thereby improve comfort during the cooling season.

Space Cooling - Although the cooling load in NZEH houses represents a relatively small part of the overall energy budget in Canadian locations, overheating can cause serious comfort issues. If a space cooling system is included in the design, then for most houses a (relatively) conventional, mechanical air-conditioning system is recommended with as high a SEER value as possible. If the house uses a GSHP, then it can be used to provide the cooling

Base Loads - Base loads were one of the most cost-effective ways of reducing energy use in a NZEH house. Basically, any device or control strategy which can reduce the amount of energy being used for lighting or appliances, either inside or outside the house, should be aggressively explored and considered for inclusion in the final design - even if the costs are quite high. These conclusions were most significant in warmer, rather than more extreme, climates since there was less opportunity for parasitic heat losses from the lights and appliances to offset the space heating load.

REFERENCES

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Measure	Cost
Airtightness (N = no. of floors)	
Upgrade from 2.0^{+} ac/hr_{50} to 2.0 ac/hr_{50}	$110 x N
Upgrade from 1.5^{+} ac/hr_{50} to 1.5 ac/hr_{50}	$147 x N
Upgrade from 1.5 ac/hr_{50} to 1.0 ac/hr_{50}	$147 x N
Ceilings	
Add RSI 0.88 (R-5)	$1.64/m^2$
Add RSI 1.76 (R-10)	$3.26/m^2$
Add RSI 2.64 (R-15)	$4.87/m^2$
Add RSI 3.52 (R-20)	$6.51/m^2$
Add RSI 4.40 (R-25)	$7.70/m^2$
Add high-heel trusses	$581
Walls & Exposed Floors	
Upgrade from RSI 3.52 TO 3.87 (R-20 to R-22)	$0.80/m^2$
Upgrade from RSI 3.52 TO 4.84 (R-20 to R-27.5)	$19.57/m^2$
Upgrade from RSI 3.52 TO 5.28 (R-20 to R-30.0)	$27.40/m^2$
Upgrade from RSI 3.52 TO 5.72 (R-20 to R-32.5)	$36.22/m^2$
Windows	
Add 2 insulated spacers	$15.37/m^2$
Add 1 Argon fill	$19.00/m^2$
Add 1 Low E coating	$38.01/m^2$
Add 1 layer of glazing	$70.57/m^2$
Foundation Walls	
Upgrade from (R-12 to R-20)	$5.23/m^2$
Upgrade from (R-12 to R-24)	$8.41/m^2$
Upgrade from (R-12 to R-32)	$13.60/m^2$
Upgrade from (R-20 to R-24)	$3.02/m^2$
Upgrade from (R-20 to R-32)	$8.41/m^2$
Add RSI 2.11 (R-12) & framing	$28.48/m^2$
Basement Or Crawl Space Floor Slab	
Add RSI 0.88 (R-5)	$12.44/m^2$
Add RSI 1.76 (R-10)	$24.87/m^2$
Add RSI 2.64 (R-15)	$37.31m^2$

Measure	Cost
Ventilation Systems	
Central exhaust system	$2,315
Mid-efficiency HRV	$3,455
High-efficiency HRV	$4,337
Space Heating Systems	
Induced draft gas furnace (w/o ductwork)	$2,463
Condensing gas furnace (w/o ductwork)	$3,234
Domestic Hot Water Heating Systems	
Electric tank, conventional, 40 I.G.	$625
Naturally aspirated gas tank	$698
Induced draft gas tank	$1,470
Greywater heat recovery system	$735

Notes:

1. All costs are retail values effective March, 2008 and include applicable taxes and builder profit and overhead.
2. Costs are based on net areas (e.g. windows and door area is subtracted from gross wall area).

TABLE 1: Summary Of Costing Data Base

	Small	Medium	Large
Architectural Features			
Thermal Mass	Light or medium weight framing	Light weight framing	Light or medium weight framing
Orientation	South. See text for other orientations	South. See text for other orientations	South. See text for other orientations
South-Facing Glazing Area	6% of floor area	6% of floor area	6% of floor area
Building Envelope			
Airtightness	0.50 ac/hr_{50} or as tight as possible	0.50 ac/hr_{50} or as tight as possible	0.50 ac/hr_{50} or as tight as possible
Main Walls	RSI 5.28 (R-30)	RSI 5.28 (R-30)	RSI 5.28 (R-30)
Attic	RSI 10.57 (R-60)	RSI 12.33 (R-70)	RSI 14.09 (R-80)
Basement Walls	RSI 4.23 (R24)	RSI 4.23 (R24)	RSI 4.23 (R24)
Basement Floor Slab	Uninsulated	Uninsulated	Uninsulated
Windows	see text	see text	see text
Mechanical and Systems			
Heating System	Electric baseboards	Electric baseboards	Electric baseboards
DHW System	a) Cons. package & b) GWHR & c) thermal solar & d) DHW heat pump system (possibly)	a) Cons. package & b) GWHR & c) thermal solar & d) DHW heat pump system (possibly)	a) Cons. package & b) GWHR & c) thermal solar & d) DHW heat pump system (possibly)
Ventilation System	Mid-eff. HRV	Ultra high-eff. HRV	Ultra high-eff. HRV
Base Loads	40% of R-2000 defaults or lower	40% of R-2000 defaults or lower	40% of R-2000 defaults or lower
Cooling System	A/C, SEER=18	A/C, SEER=18	A/C, SEER=18

TABLE 2: NZEH Design Guidelines For Canadian Maritime Climates

House Type	Small	Medium	Large
Architectural Features			
Thermal Mass	Light or medium weight framing, or heavy masonry	Light or medium weight framing, or heavy masonry	Light or medium weight framing, or heavy masonry
Orientation	South. See text for other orientations	South. See text for other orientations	South. See text for other orientations
South-Facing Glazing Area	6% of floor area	6% of floor area	6% of floor area
Building Envelope			
Airtightness	0.50 ac/hr_{50} or as tight as possible	0.50 ac/hr_{50} or as tight as possible	0.50 ac/hr_{50} or as tight as possible
Main Walls	RSI 10.57 (R-60)	RSI 10.57 (R-60)	RSI 10.57 (R-60)
Attic	RSI 14.09 (R-80)	RSI 14.09 (R-80)	RSI 14.09 (R-80)
Basement Walls	RSI 4.23 (R24)	RSI 4.23 (R24)	RSI 4.23 (R24)
Basement Floor Slab	RSI 1.76 (R-10), per.	RSI 1.76 (R-10), per.	RSI 1.76 (R-10), per.
Windows	see text	see text	see text
Mechanical and Systems			
Heating System	Electric baseboards or GSHP, COP = 3.0	Electric baseboards or GSHP, COP = 3.0	Electric baseboards or GSHP, COP = 3.0
DHW System	a) Cons. package & b) GWHR & c) thermal solar & d) DHW heat pump system (possibly)	a) Cons. package & b) GWHR & c) thermal solar & d) DHW heat pump system (possibly)	a) Cons. package & b) GWHR & c) thermal solar & d) DHW heat pump system (possibly)
Ventilation System	Ultra high-eff. HRV	Ultra high-eff. HRV	Ultra high-eff. HRV
Base Loads	40% of R-2000 defaults or lower	40% of R-2000 defaults or lower	40% of R-2000 defaults or lower
Cooling System	A/C, SEER=18	A/C, SEER=18	A/C, SEER=18

TABLE 3: NZEH Design Guidelines For Canadian Prairie Climates

House Type	Small	Medium	Large
Architectural Features			
Thermal Mass	Light or medium weight framing, or heavy masonry	Light or medium weight framing, or heavy masonry	Light or medium weight framing, or heavy masonry
Orientation	South. See text for other orientations	South. See text for other orientations	South. See text for other orientations
South-Facing Glazing Area	6% of floor area	6% of floor area	6% of floor area
Building Envelope			
Airtightness	0.50 ac/hr_{50} or as tight as possible	0.50 ac/hr_{50} or as tight as possible	0.50 ac/hr_{50} or as tight as possible
Main Walls	RSI 10.57 (R-60)	RSI 10.57 (R-60)	RSI 10.57 (R-60)
Attic	RSI 14.09 (R-80)	RSI 14.09 (R-80)	RSI 14.09 (R-80)
Basement Walls	RSI 4.23 (R24)	RSI 4.23 (R24)	RSI 4.23 (R24)
Basement Floor Slab	Uninsulated	Uninsulated	Uninsulated
Windows	see text	see text	see text
Mechanical and Systems			
Heating System	Electric baseboards	Electric baseboards	Electric baseboards or GSHP, COP = 3.0
DHW System	a) Cons. package & b) GWHR & c) thermal solar & d) DHW heat pump system (possibly)	a) Cons. package & b) GWHR & c) thermal solar & d) DHW heat pump system (possibly)	a) Cons. package & b) GWHR & c) thermal solar & d) DHW heat pump system (possibly)
Ventilation System	Ultra high-eff. HRV	Ultra high-eff. HRV	Ultra high-eff. HRV
Base Loads	40% of R-2000 defaults or lower	40% of R-2000 defaults or lower	40% of R-2000 defaults or lower
Cooling System	A/C, SEER=18	A/C, SEER=18	A/C, SEER=18

TABLE 4: Design Guidelines For Eastern Canadian Climates

House Type	Small	Medium	Large
Architectural Features			
Thermal Mass	Light or medium weight framing, or heavy masonry	Light or medium weight framing, or heavy masonry	Light or medium weight framing, or heavy masonry
Orientation	South. See text for other orientations	South. See text for other orientations	South. See text for other orientations
South-Facing Glazing Area	6% of floor area	6% of floor area	6% of floor area
Building Envelope			
Airtightness	0.50 ac/hr_{50} or as tight as possible	0.50 ac/hr_{50} or as tight as possible	0.50 ac/hr_{50} or as tight as possible
Main Walls	RSI 10.57+ (R-60+)	RSI 10.57+ (R-60+)	RSI 10.57+ (R-60+)
Attic	RSI 14.09+ (R-80+)	RSI 14.09+ (R-80+)	RSI 14.09+ (R-80+)
Basement Walls	RSI 8.81(R-50)	RSI 8.81 (R-50)	RSI 8.81 (R-50)
Basement Floor Slab	RSI 1.76 (R-10), per.	RSI 1.76 (R-10), per.	RSI 1.76 (R-10), per.
Windows	see text	see text	see text
Mechanical and Systems			
Heating System	Electric baseboards or GSHP, COP = 4.0	Electric baseboards or GSHP, COP = 4.0	Electric baseboards or GSHP, COP = 4.0
DHW System	a) Cons. package & b) GWHR & c) thermal solar & d) DHW heat pump system (possibly)	a) Cons. package & b) GWHR & c) thermal solar & d) DHW heat pump system (possibly)	a) Cons. package & b) GWHR & c) thermal solar & d) DHW heat pump system (possibly)
Ventilation System	Ultra high-eff. HRV	Ultra high-eff. HRV	Ultra high-eff. HRV
Base Loads	40% of R-2000 defaults or lower	40% of R-2000 defaults or lower	40% of R-2000 defaults or lower
Cooling System	A/C, SEER=18	A/C, SEER=18	A/C, SEER=18

TABLE 5: Design Guidelines For Northern Canadian Climates