Performance of Low-Energy Homes During Power Interruptions

Moderating the impact of sustained energy interruptions

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Power failures lasting even one or two days can cause serious problems in modern homes. In addition to the discomfort experienced when the temperature inside the house drops, there is the possibility of water pipes within the home freezing, causing them to burst. This paper will show that, from the perspective of preventing such damage during winter storms, it is good practice to increase thermal insulation values. For the cities of Toronto, Edmonton, and Vancouver, a house will be modeled to the provincial building code. Another will be modeled to the Model National Energy Code for Houses (MNECH) issued by the Canadian government. A third will be built to a more sustainable, "advanced design". The time taken for the temperature to drop to levels where water in pipes might freeze in each of these houses will then be examined and compared. A further comparison between the houses will be made to determine how much heat would be required to maintain the house at a reasonable temperature over an extended period of time (such as the 1998 Ice Storm, which killed 45 people in eastern Canada and the United States).
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INTRODUCTION

Many climatologists believe that global warming and associated climate change may be leading to an increase in the frequency and the severity of extreme weather events. In many cases, extreme weather events can lead to the interruption in the supply of energy to our homes. The ice storm of January 1998 that struck much of Eastern Canada revealed how vulnerable we are when such extreme weather events occur, particularly in the winter. This massive ice storm caused widespread and sustained electricity interruptions to homes in the provinces of Ontario and Quebec. Since the storm occurred in January, and since many homes in the area were primarily heated with electricity, many homes were without heat for more than a week. When such interruptions occur, plumbing pipes can freeze leading to property damage. However, sustained energy interruptions can also have far more serious effects. Sustained interruptions can adversely affect human health. The elderly and the young are particularly vulnerable to sustained low temperatures. Poorly insulated homes are particularly problematic. Depending upon the exterior conditions, poorly-insulated homes can experience below freezing interior conditions within 12 hours if the energy required for heating is interrupted.

It is possible to reduce our vulnerability to such energy interruptions by building better homes. This paper will show that by building energy-efficient homes, it is possible to reduce our vulnerability. Using computer simulations, this paper compares the model performance of current building code compliant homes to a more "advanced" low-energy home when heating energy is suddenly interrupted during the winter. Three Canadian cities were chosen for this study: Toronto, Edmonton, and Vancouver. For each city, "cooling curves" were generated to determine the time required for the interior temperatures to reach two defined threshold temperatures: one based on occupant thermal comfort and another based on freezing of the plumbing system. In addition to creating these cooling curves, the amount of supplemental energy required to maintain the test homes above the critical temperatures was also estimated.

THE CASE FOR BETTER BUILT BUILDINGS

In spite of international commitments to cut greenhouse gas emissions, Canadians continue to consume hydrocarbons in ever-increasing quantities. This is true in the housing industry as well. Canadian homes built today are energy-inefficient. Current minimum requirements prescribed by current building codes do not produce houses with adequate energy efficiency to face the expected energy supply challenges in the near future [1]. As a result, future homeowners will continue to unnecessarily bear the burden of high energy bills, while ensuring that unnecessary environmental degradation will occur well into the future. In 2007, there were over 200,000 housing starts in Canada [2]. This represents over two hundred thousand missed opportunities to save money and reduce pollution.

It should be noted that the savings achievable by building better now are significant: one study [1] showed that building a home to R-2000 standards costs only $5,561 more and resulted in energy savings of 32%. The payback period was reported to be a modest 6.8 years. Indeed, with a return of 14.16% per annum, this investment is very competitive with the long-term returns of higher-risk investments.

Better designs are easily achievable: one house profiled by the Government of Canada, located just south of Ottawa, uses 30% less energy than even the benchmark R-2000 home [3]. In addition to the energy cost savings, the homeowners, unlike their neighbours, were able to stay warm during the 1998 Ice Storm: the homeowners were able to maintain a comfortable indoor temperature of 20ºC with a small fire in the fireplace [3]. The maintaining of comfortable conditions was possible due to increased insulation levels, better windows, and tighter construction to minimize air leakage – the same characteristics possessed by the "advanced design" suggested in this study.

Other case studies have also documented impressive energy savings potential: an Ontario Ministry of Energy study found that another "Advanced House" design could reduce energy use by 73%, as compared to a similar dwelling constructed to minimum code requirements [4].

Clearly, it makes sense economically and environmentally to build better now.

SIMULATION DETAILS

To conduct this study, simulation of the test houses was conducted using the whole building simulation software Energy 10 (Version 1.7) available from the Sustainable Buildings Industry Council (SBIC) [5]. The houses modeled using Energy 10 had the following characteristics:

- Two-storey building, each storey 9 feet tall;
- 1000 square feet per floor;
- Width and depth are the same;
- Attic roof;
- Four occupants;
- Slab on grade foundation;
- 2"x4" walls, 2"x10" floors;
- Four windows on each side of the house, each 600mm by 600mm;
- Two doors, one each on the north and east sides;
- No basement;
- An estimated leakage area (ELA) of 244.6cm^2; and
- A gas furnace.

To create the desired conditions, the house's HVAC system was turned off for the simulation. To simulate the effect of a power shutdown, a custom outdoor climate was created using Weathermaker Version 1.0.2 available from the Sustainable Buildings Industry Council (SBIC) [6]. The outdoor temperature was modeled at a constant at 25.5ºC (78ºF) for several days. Once the indoor temperature had adjusted to match the outdoor temperature, the outdoor temperature was modeled at a constant -17.8ºC (0ºF). The time subsequently taken for the indoor temperature to reach the freezing point was then noted (rounded down to the previous hour). It should be noted that the warming effect of sunlight was not included in the simulation. The effect of sunlight would depend upon the time of the power failure, and would skew the results because solar radiation would likely keep the indoor temperature just above freezing throughout the afternoon, regardless of which model was being simulated. Further, severe storms and associated power interruptions occur during cloudy conditions. For this simulation, the choice of an outdoor air temperature of 0ºF was arbitrary; the fact that temperature fluctuates throughout the day is not reflected in the results obtained.

To determine the required size for a secondary heat source to ensure that pipes did not freeze during a power failure, the houses were modeled with manually-established sizes of HVAC equipment. After each simulation, the equipment was resized based upon the results obtained until the software reported that the current heating equipment, running continuously at maximum power, provided sufficient energy to keep the house at or just above the noted desired temperature.

BUILDING CODES & BEST PRACTICE DESIGN

The details of the thermal resistance levels required by the provincial building codes and the MNECH in addition to the advanced design are shown in Table 1. The advanced design house was designed to use approximately one-third as much energy as the house built to provincial codes. To determine what levels of thermal resistance and air leakage would meet this requirement, the "code houses" were modeled using Hot2000 Version 9.33, available from Natural Resources Canada (NRC) [7]. The levels of thermal resistance were gradually increased, and the leakage area decreased, until the desired performance had been reached.

RESULTS AND DISCUSSION

The simulation results demonstrate the importance of building better now. Houses built to the current provincial codes simply cannot keep sufficient heat in a home to prevent severe discomfort in the event of a sustained power failure, as shown by Figure 1 and Table 2. This is especially true in Alberta, where the building code is less stringent than in either of the other provinces, however, the climate is more severe. British Columbia leads the other provinces in this respect; British Columbia has a comparatively stringent building code, which requires greater insulating levels than even the MNECH.

Table 1: Required levels of thermal resistance (RSI).[1]

	Ontario (Zone A)	**Alberta (Zone B)**	**British Columbia (Zone C)**
Provincial Building Codes [8,9,10]			
Walls (above grade)	3.0	2.1	3.5
Ceiling (Attic)	5.6	6.0	7.0
Windows	0.3	-	-
Doors	0.7	-	-
Foundation/Slab	1.4*	2.1*	1.8**
Model National Energy Code for Houses [11]			
Walls (above grade)	2.9	3.0	2.9
Ceiling (Attic)	5.40	5.8	5.9
Windows⁺	ER -3	ER -3	ER -15
Doors	-	-	-
Foundation/Slab	1.6⁺⁺	1.08*	1.08#
Advanced House Design			
Walls (above grade)	6.0	5.0	6.0
Ceiling (Attic)	7.5	8.0	9.0
Windows⁺	0.6	0.6	0.6
Doors	0.7	0.7	0.7
Foundation/Slab	5.0⁺⁺	4.0⁺⁺	5.0⁺⁺
ELA Reduction	50%	50%	50%

**Perimeter only*
***Around slab edge and 0.5m vertically or horizontally*
⁺Denotes Energy Rating of window
⁺⁺Full area
#Perimeter only for first 0.6m

Better-insulated houses with less air leakage have the ability to maintain comfortable conditions for much longer periods of time. As the above results demonstrate, a house built to an advanced design can maintain the indoor temperature above freezing for 2.7 to 3.4 times longer than a house built to the provincial code. With the possible exception of the longest-lasting disasters (those lasting more than 5-6 days) an advanced house built to the specifications given in Table 1 should be able to keep occupants reasonably comfortable, and ensure that the mechanical and plumbing equipment will not be damaged by freezing temperatures. When longest-lasting disasters do occur or when occupants chose to leave their homes during sustained power interruption, an additional option would be to drain the plumbing back to the municipal line, effectively minimizing the risk for damage within the house.

Equally importantly, the amount of energy required to prevent pipe damage during a major disaster is significantly reduced in an advanced design as can be seen in Table 3.

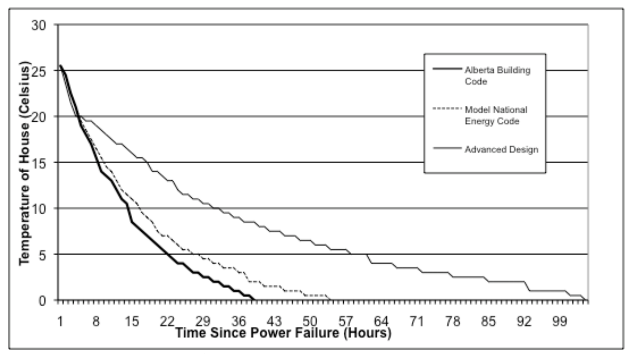

Figure 1: Lowest house temperature experienced during a power failure by failure duration and house design for the City of Edmonton.

Table 2: Length of time in hours (h) required to cool to 0°C location and house type.

	Ontario	**Alberta**	**British Columbia**
Provincial Code	45	38	51
Model National Energy Code for Houses	58	53	47
Advanced Design	152	103	169

As was demonstrated empirically in a report presented by the Government of Canada [3], building more efficient homes would enable the homeowner to maintain normal temperatures through the use of a small secondary heat source such as a fireplace. This result was verified in the simulations that were conducted. Table 4 shows that an advanced design house can be kept at a temperature most heavily clothed occupants will find acceptable by as little as 2,150W to 2,500W. This

[1] *This research was conducted in 2007. All values listed reflect pre-2007 prescribed Code requirements. All current values are similar to those published.*

limited requirement for heat could easily be met through a backup heater. This would have two benefits: first, individuals would be less likely to succumb to the cold temperatures and, second, individuals would be less likely to use their barbeques inside to generate heat [12], resulting in a potential accumulation of lethal concentrations of carbon monoxide.

Table 3: Heating power in Watts (W) required to prevent pipe freezing (5℃) by location and housing type.

	Ontario	**Alberta**	**British Columbia**
Provincial Code	3,750	4,100	3,250
Model National Energy Code	2,400	3,450	3,750
Advanced Design	1,000	1,250	950

Table 4: Amount of heat in Watts (W) required to maintain thermal comfort (12℃) by location and housing type.

	Ontario	**Alberta**	**British Columbia**
Provincial Code	7,000	7,300	6,350
Model National Energy Code	4,950	6,600	7,050
Advanced Design	2,200	2,500	2,150

There are also economic benefits to building better now; several studies, such as [13] have shown that upgrading one's house can be a great investment. The return on investment can be greater than 10% due to the reduced consumption of fossil fuels. Therefore, it can be argued that improved insulation is not only a means of winter power failure mitigation, but also a fiscally and environmentally sound decision to make.

CONCLUSION

Today's buildings are energy *in*efficient. As a result, homeowners bear the burden of high energy bills and the environment is unnecessarily degraded. Further, such homes rapidly become uninhabitable in the event of a power failure during the winter. Building better homes could keep the occupants warm and prevent pipe damage in such circumstances. Better homes would also reduce energy bills and environmental degradation. As residential heating and cooling requirements represent one-tenth of Canada's energy use [2], better, more energy-efficient homes would also significantly help Canada meet its international obligations on climate change.

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