Reducing the Energy Consumption of Existing Houses by 40%

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ABSTRACT

This paper describes the results of a project that studied the reduction of purchased energy of existing houses by 40% with the cost of the retrofit measures being acceptable to the homeowners. The five houses examined in this project are located in Saskatoon, Saskatchewan, Canada. The houses varied in age, being built between 1911 and 1986, and contained a wide variety of styles, occupancies, etc. After one year of post-retrofit monitoring, the total energy consumption (electricity and natural gas) of the houses was reduced by up to 39.6%.

INTRODUCTION

The annual new housing starts in Canada in recent years represent less than 2% of the existing housing stock (Statistics Canada 2003). Therefore, any attempts to improve the energy efficiency of the housing stock must improve the condition of existing houses as well as new houses.

The Building Performance Section of the Saskatchewan Research Council (SRC) was contracted by the Canada Mortgage and Housing Corporation (CMHC) to conduct a project titled "Case Studies of Major Home Energy Retrofits." The project was designed to produce clear and demonstrable energy savings in existing houses through energy retrofitting so that these houses could be used as benchmarks for energy savings.

A general target chosen by CMHC for the houses selected for the project was that all post-retrofit energy consumption, from all sources, should be at least 40% lower than the pre-retrofit levels. Another major objective was to have reasonable costs for the retrofit measures, as they were the responsibility of the homeowners.

This paper discusses the five houses that were retrofit during this project, starting with the pre-retrofit condition of the houses and their pre-retrofit energy consumption values. Next, the recommended retrofits are discussed and the actual retrofits performed are presented. Then the post-retrofit energy consumption values are presented and discussed. Finally, some significant lessons learned from the project are provided.

THE HOUSES INVOLVED IN THE PROJECT

Initially, seven homeowners willing to participate in the research project were located. The homeowners were informed that they would be responsible to pay for the retrofits on their homes. After preliminary analysis, one of the homes was rejected as it was a nontypical construction with inadequate energy records. A second homeowner withdrew from the research for personal reasons. The five remaining houses were of different styles, ages, sizes, and initial conditions. The main benefits to the homeowners were the advice and guidance of the Building Performance Section staff, along with a small honorarium, and the future energy savings.

Two methods of accounting for variations in the annual weather were used during this project. The first method consisted of normalizing the energy consumption values with the long-term average heating degree-days (6077°C days / year for Saskatoon, Saskatchewan). The second method involved the use of five control houses. The five control houses

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located for this project were required to not have had any major energy retrofits in the previous two years nor have any plans for retrofits or changes to occupancy during the research project time frame. Normalizing to either the long-term climatic averages or to the control houses produced similar results.

Tables 1a and 1b show the pre-retrofit characteristics of the five retrofit houses.

Table 1a. Pre-Retrofit Characteristics of the Retrofit Houses

House Code	D1	G1	G2	G3	G4
General					
Year built	1973	Built 1911 Moved 1985	1912	1986	Built 1920 Moved 1960
Stories	1	2	1.75	Split	2
Floor area (excluding basement)	83.6 m^2 (900 ft^2)	135.3 m^2 (1456 ft^2)	130.1 m^2 (1400 ft^2)	146 m^2 (1571 ft^2)	213.7 m^2 (2300 ft^2)
Basement floor area	83.6 m^2 (900 ft^2)	67.6 m^2 (728 ft^2)	65.0 m^2 (700 ft^2)	93.7m^2 (1008 ft^2)	106.8 m^2 (1150 ft^2)
Exterior wall finish	Vinyl siding and stucco	Vinyl siding	Asphalt tile	Wood siding and brick	Wood siding
Number of occupants	2	4	6	4	5
Combustion air	No	No	No	No	No
Fireplace(s)	No	No	1 natural gas	1 wood	No
Crawl space	No	No	No	No	No
Orientation	Faces south	Faces south	Faces north	Faces west	Faces west
Number of bathrooms	1	2	1.5	4	3
Winter window condensation	Slight	Slight	Yes	Slight	Yes
Attic ventilation			Turbine ventilator		Turbine ventilator
Envelope					
Attic insulation	RSI 3.5 (R 20)	RSI 1.8 (R10) RSI 5.3 (R 30)	RSI 7.0 (R40) RSI 0 (R 0)	RSI 6.2 (R 35)	RSI 7.0 (R40)
Wall insulation	RSI 2.1 (R 12)	Wood shavings	RSI 2.1 (R)	RSI 3.5 (R20)	RSI 0 (R0)
Windows	Alum, slider	Old and new	Some new	Casement	Some low-e argon
Basement walls	Uninsulated	Uninsulated	RSI 2.1 (R 12)	Insulated	Insulated
Basement floor	Uninsulated	Uninsulated	Uninsulated	Uninsulated	Uninsulated
Airtightness (AC/H at 50 Pa)	1.76	6.34	7.71	1.95	6.26
Weatherstripping			Poor		Average
Doors	New		One poor		Steel insul.
Attached garage	No	No	No	Yes – two-car	No
Heating					
Warm air NG furnace	1970 vintage	Old	1960s	1986 new	Old
Setback thermostat	Yes	Yes	No	Yes	No
Duct leakage	Some taping	Probable	No returns	Probable	Probable
Ventilation					
Bathroom fans	Standard fan	No fans	Standard fans	Standard fans	No fans

Table 1b. Pre-Retrofit Characteristics of the Retrofit Houses

House Code	D1	G1	G2	G3	G4
Lighting					
T8	None	None	None	None	None
CFL	None	None	None	None	None
Dimmers	None	None	Two	One	None
Occupancy sensors	None	None	None	One	None
Domestic Hot Water					
Shower heads	Low flow	Regular	1 Regular 1 Low flow	Regular	Low flow
Aerators		Yes	Yes		Yes
DHW tank insul.	No	No	No	RSI 0.7 (R4)	No
Water heater	1995	Old	~1980	1986	<10 yrs old
Pipe insulation	None	None	None	None	None
Appliances					
Washer	1992 top load	New front load	Old top load	Front load	Top load
Dryer	1989 Nat. gas	Electric	Old electric	1980 vintage	Electric
Refrigerator(s)	1971	Two years old	~1990	Two	1992 double
Stove	Electric	Electric	Elec.> 20 yrs	Nat. gas	Electric
Dishwasher	Yes	1987	No	Old	Yes – new
Freezer(s)	1994	1980	1985	Two-old units	Yes – chest
Central A.C.	Yes 10 SEER	No	No	Yes	No
Furnace fan motor	Direct drive	Belt	Belt	Direct drive	Belt
Range hood	No	No	Recirculating	Exh. to outside	Recirculating
Electronic air filter	No	No	No	Yes	No
Nat. gas BBQ	No	No	No	Yes	No
Vehicle block heater timer		Yes		No - has insul. garage	
Water Consumption					
Toilets	1 × 6.1 L / flush	2 × 13.3 L/flush	2 × 18.9 L/flush	4 × 6.1 L / flush	3 × 18.9 L/flush
Toilet dams	None	None	None	None	None
Landscaping		No sprinklers	No sprinklers	Underground sprinklers	Underground sprinklers

To assist in the process of determining suitable retrofits for the houses, each house was modeled using the HOT2000 residential energy consumption modeling software (Natural Resources Canada 2000). The software was used to create a base case model of each of the houses that matched the pre-retrofit energy consumption values. Measurements obtained on site (airtightness level, electrical use of major appliances, furnace and hot water heater combustion efficiencies, etc.) were used in the model. The program was then run multiple times on each house changing individual variables (e.g., attic insulation, airtightening, compact fluorescents, etc.) to see the effect that they would have on the energy consumption of each of the houses. Based on the HOT2000 results, the following were changes that were recommended for each of the houses:

- Upgrade the efficiencies of the existing natural gas furnaces. Four of the five existing furnaces had a combustion efficiency measurement performed (with the exception of home D1 where the furnace was changed soon after the project started). These measurements showed that the combustion efficiencies ranged from a low of 74.1% to a high of 76.3%. In all cases, it was recommended that a higher efficiency furnace or heating source be used to replace the existing unit. In all cases, the heating equipment was at least fourteen years old.

The smallest furnace in the existing houses was 26.4 kW (90,000 Btu/h).

- In each house, it was recommended that the lighting efficiency be improved by using compact fluorescent lamps instead of incandescent lamps. Typical reductions in wattage were on the order of two-thirds to three-fourths for those lamps that were changed.
- Water heater insulating blankets were recommended and provided by the SRC. The measured water heater combustion efficiencies ranged from a low of 74.1% to a high of 82.0%.
- The installation of one meter of pipe insulation for each of the water lines into and out of the water heaters was recommended.
- The replacement of inefficient appliances was recommended.
- The use of motion-sensing wall switches was considered and recommended if the occupancy patterns allowed their use.
- Water conservation devices, such as low-flow shower heads, toilet dams, fill cycle diverters, and faucet aerators, were recommended for all of the houses. Of these devices, only the faucet aerators and low-flow shower heads were expected to reduce energy consumption by reducing hot water use.

The following recommendations were only made for some of the homes, as they may not have been cost-effective or even necessary for the other homes:

- Install a power-vented water heater
- Remove the chimney after a condensing furnace and power-vented water heater are installed
- Insulate the basement walls
- Add additional attic insulation
- Add acrylic panes to some of the windows to improve the thermal performance
- Perform air sealing
- Remove the second refrigerator
- Install an energy-efficient washing machine
- Replace the existing freezers with energy-efficient ones
- Install a device to provide intermittent furnace fan use for air circulation in the home

The energy consumption of the houses in the pre-retrofit condition was determined from utility company meter readings taken every three months over multiple years prior to the project (during which time the homeowners had made no major changes to their homes). Table 2 shows the pre-retrofit annual energy consumption values of the homes.

RETROFIT RESULTS

Nearly all of the recommended retrofits were performed at each of the houses. Some items were not implemented, such as unplugging a second refrigerator, not adding insulation to the attic, and not installing a continuously operating ventilation fan.

Keeping the costs of the required retrofits at a value that the homeowners were willing to pay was one of the objectives of this project. Table 3 shows the costs incurred by the homeowners during this project.

Before looking at the total reduction in energy that was achieved in the houses, it is of interest to look at the reduction in electrical consumption of some of the appliances that were replaced. One of the households replaced one of their two refrigerators, which reduced the electrical consumption of the two refrigerators from 2,083 kWh/yr to 791 kWh/yr. Another household unplugged their second refrigerator, which saved them 1,121 kWh/yr. Two of the other households also managed to reduce their electrical consumption by at least 400 kWh/yr by replacing their refrigerators. One household replaced their freezer, which used 681 kWh/yr, with a new unit only using 279 kWh/yr. House G3 removed both of their freezers (consuming 2,339 kWh/yr) and replaced them with a single larger freezer that only consumes 432 kWh/yr.

The natural gas reduction for the houses is best shown by plotting the natural gas consumption versus heating degree-days for both the pre- and post-retrofit periods (see Figure 1).

As shown in Figure 1, the natural gas consumption is quite linear with respect to heating degree-days. For the house shown, there is a large reduction in natural gas consumption from the pre-retrofit to the post-retrofit condition (45.0%).

The energy reductions for each of the five houses after the retrofit measures were implemented are presented in Table 4. The values in the table have been normalized to the long-term annual average heating degree-days for Saskatoon (6077°C days with base 18°C).

Table 2. Pre-Retrofit Annual Energy Consumption Values

House Code	D1	G1	G2	G3	G4
Electrical use	9,598 kWh	5,811 kWh	8,614 kWh	13,089 kWh	7,681 kWh
Natural gas use	44,301 ekWh	43,401 ekWh	47,281 ekWh	33,153 ekWh	67,261 ekWh
Total consumption	53,899 kWh/yr (194 GJ/yr)	49,212 kWh/yr (177 GJ/yr)	55,895 kWh/yr (201 GJ/yr)	46,242 kWh/yr (166 GJ/yr)	74,942 kWh/yr (202 GJ/yr)

Note: ekWh means equivalent kilowatt hours.
Based on the results of the HOT2000 simulations, the houses were all predicted to reduce their energy consumption by 40% or more after the retrofit measures were implemented.

Table 3. Retrofit Costs

House Code (cost, $)	D1 ($)	G1 ($)	G2 ($)	G3 ($)	G4 ($)
New refrigerator	860	---	2,555	---	1,100
New freezer	---	---	Included above	600	---
Clothes washer	---	1,680	Included above	1,095	1,050
Clothes dryer	---	Included above	Included above	---	---
Furnace*	1,900	3,455	3,335	3,500	3,500
Water heater	---	1,115	1,115	1,425	1,100
Attic insulation	---	150	150	350	---
Basement insulating†	1,500	1,730	---	---	---
Air tightening	---	Included above	5	---	25
CFLs	90	20	155	175	270
Water heater insulation kit	50	50	50	50	50
Pipe insulation	10	10	10	10	10
Insulate cold air return	---	---	75	---	---
Entrance doors	---	---	1,910	---	---
Motion sensors	---	---	25	---	---
Window shrink film	10	---	---	10	---
Toilet dams	---	10	10	30	20
Low-flow showerheads	---	20	20	---	20
Totals =	4,420	8,240	9,415	7,245	7,145

* Cost includes new thermostat, if required, and installation costs, including permits.
† Cost includes framing and insulating, but no labor (labor provide by homeowner).

The project objective of 40% reduction in energy consumption was attained in one house, one house was in the 30% range, and the lowest was at 23.9%.

DISCUSSION

All of the homeowners were satisfied with the project and the levels of savings. The owner of House G4, with the lowest percentage reduction, appreciated that 40% was not attained because of the furnace size and the type he chose (larger than recommended) and because of lifestyle changes.

Based on the savings achieved and the amount of money spent by each of the homeowners to perform the retrofits, the simple payback periods ranged from 8.4 to 16.5 years (using the 2003 utility rates). There were a few simple reasons why three of the houses have payback periods longer than ten years. One of the homeowners did not perform all of the retrofit measures, and some of the equipment installed was not sized according to the recommendations. Another house with a longer payback period had very low utility bills to begin with, reducing the dollar value of saving 40% of total purchased energy. The third homeowner purchased expensive exterior doors and more appliances than were recommended.

Homeowners were very interested to see how much electricity was being consumed by their major appliances. Electricity savings will pay for the new freezer in House G3 in three years.

The project provided impetus for the owners of houses D1 and G1 to complete (frame, insulate, and gypsum board) their basements, making them more comfortable and usable.

There were a few major deficiencies and lessons learned during this project. The actual measured furnace combustion efficiencies for the new equipment were lower than manufacturers' claims. Modeled reductions in airtightness levels were not achieved. In some cases, the homeowners did not complete all of the recommended retrofit measures. The utility-supplied water temperature in Saskatoon for the winter of 2002/2003 was colder than normal due to maintenance being performed by the water company. The savings predicted by the computer model, and the actual savings were not always in agreement. Model input values, such as levels of airtightness and expected electricity usage, were not attained. The new power-vented water heaters used electricity for the vent motors, which was not in the modeling software.

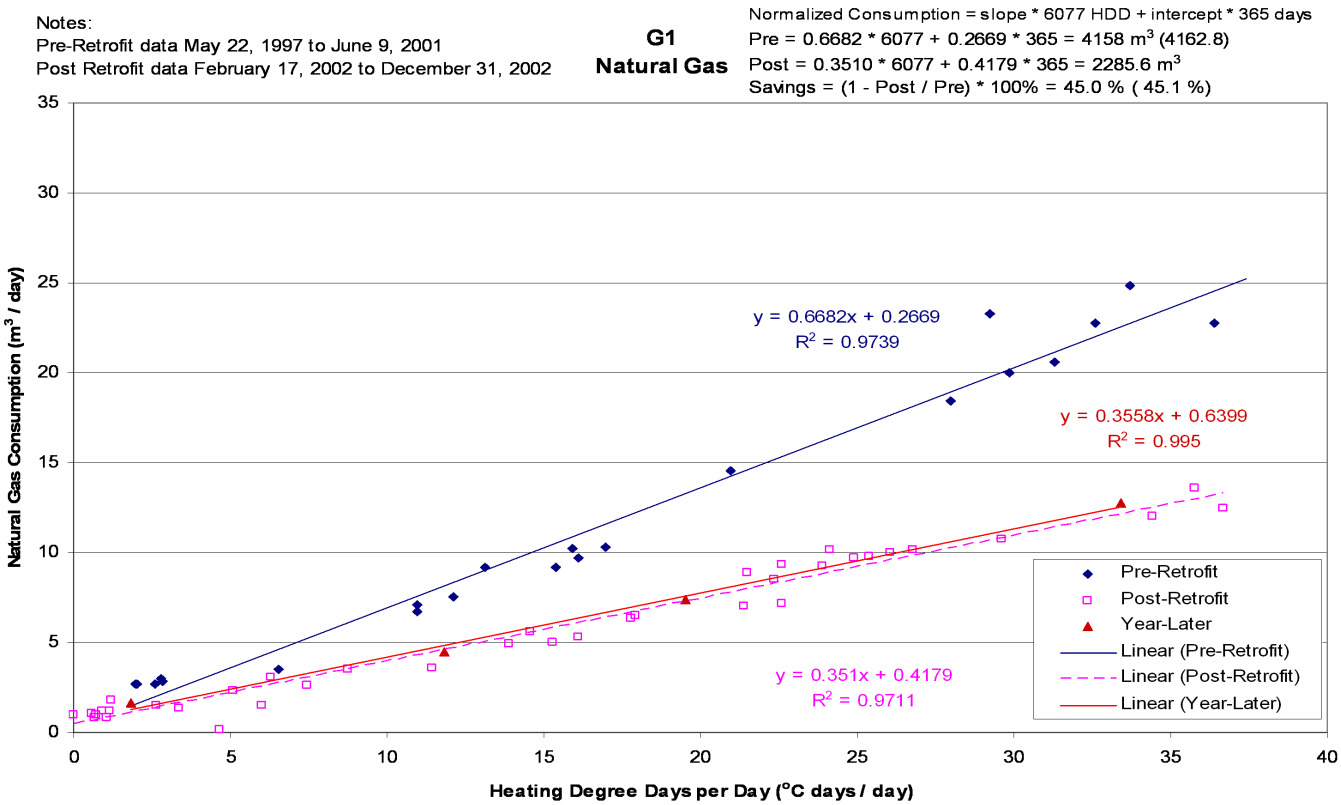

Figure 1 *Natural gas consumption of House G1 (pre- and post-retrofit).*

Table 4. Energy Consumption Reduction Amounts

House Code	D1	G1	G2	G3	G4
Natural Gas Reduction, %	30.4	45.0	29.0	27.5	25.9
Electrical Reduction, %	9.1	2.4	15.4	40.8	6.4
Total Energy reduction, %	26.5	39.9	26.9	30.8	23.9

The owner of House G4 purchased a larger-than-recommended furnace with a large blower motor (approximately 800 watts). Any savings in electricity from the new appliances were eliminated by the new furnace fan motor. This homeowner did not add attic insulation as recommended, but the style of the house would not have allowed much to be added regardless.

The owner of House G3 was initially reluctant to unplug the refrigerator in the basement but consented to do so during the post-retrofit period. The owner of House D1 decided to not unplug the basement refrigerator. For this house, HOT2000 predicted that a mid-efficiency furnace would be sufficient to attain the 40% savings if the combustion efficiency of the mid-efficiency furnace could be improved to 85%. It was determined that it was not possible to achieve that combustion efficiency with the furnace that was installed. This homeowner also continued to use continuous fan circulation on the furnace, which was the single largest electrical load in the house.

In summary, it was found that energy consumption in existing houses could be reduced substantially with the implementation of retrofits that homeowners were comfortable with paying for themselves. Although the goal of a 40% reduction was only achieved in one house, it would have been relatively simple to have all of the houses achieve a minimum of 30% reduction in their energy consumption by the simple application of a few more retrofit measures.

NOMENCLATURE

°C = degrees Celsius

SRC = Saskatchewan Research Council

CMHC = Canada Mortgage and Housing Corporation

RSI = insulation value in metric units

R	=	insulation value in imperial units
ACPH	=	air changes per hour
Pa	=	pascals
CFL	=	compact fluorescent lamp
T8	=	T8 fluorescent lamp
A.C.	=	air conditioning
BBQ	=	barbecue
SEER	=	seasonal energy efficiency ratio
L	=	liters
m^2	=	square metres
ft^2	=	square feet
kW	=	kilowatt
Btu/h	=	British thermal units per hour
kWh	=	kilowatt hour
ekWh	=	equivalent kilowatt hour
Elec.	=	electricity
Insul.	=	insulated
Excl	=	excluding
GJ	=	gigajoule
Nat. gas	=	natural gas

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