RESEARCH REPORT

Case Studies Major Home Energy Retrofits

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FINAL REPORT

Case Studies of Major Home Energy Retrofits

for

Canada Mortgage and Housing Corporation
Ottawa, Ontario

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technology is our business

ABSTRACT

The Saskatchewan Research Council (SRC), Building Performance Section (BPS), 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.

The retrofit measures were implemented over a period of time by the homeowners with SRC's advice. Pre retrofit and post retrofit monitoring and testing was performed.

As weather during the test period could deviate from historical temperatures, five control houses were also found for the project where regular monitoring of the utility meters was done. Graphing of the pre retrofit and post retrofit energy consumption was done over approximately the same time period as for the five case houses.

Results of comparing the pre retrofit period to the post retrofit period show that for the five case houses natural gas consumption declined by 25.9% to 45.0%, electricity consumption declined by 2.4% to 40.8%, and the total energy consumption (natural gas and electricity) declined by 23.9% to 39.9%. These results were normalized to 6077 annual heating degree days, the long term annual figure for Saskatoon.

For the five control houses for the same time period, natural gas consumption increased in three houses from 1.5% to 36.5%. One house decreased by 1% while the fifth house decreased its consumption by 14.8% but it had different occupancy during the monitoring period. Electricity consumption decreased by 3.0% and 6.6% in two of the houses and increased in three of the houses by 1.7% to 25.7%. The results of the control houses show that total gas consumption of the four control houses (excluding C-L1) between the pre and post monitoring period increased by 7.7% due to more severe weather. Therefore, the decline in total energy consumption of the case houses when corrected using the control house results is 26.0% to 39.6%.

EXECUTIVE SUMMARY

The Saskatchewan Research Council (SRC), Building Performance Section (BPS), 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.

The project was divided into two parts. The first part was to locate and confirm the participation of four suitable houses for the project. Six houses were located and an interim report prepared presenting the results. The second part of the project was to meet with the homeowners to detail the retrofit measures required to attain the desired energy savings based on modelling using HOT2000. Subsequently, one homeowner opted out of the project due to a job change.

The retrofit measures were implemented over a period of time by the homeowners with SRC's advice. Pre retrofit and post retrofit monitoring and testing were performed.

As weather during the test period could deviate from historical temperatures, five control houses were also found for the project where regular monitoring of the utility meters was done. Graphing of the pre retrofit and post retrofit energy consumption was done over approximately the same time period as for the five case houses.

The five case houses and five control houses ranged in year of construction from 1911 to 1986 and had a wide variety of different styles, occupancies, etc.

The post retrofit monitoring concluded December 31, 2002. Meter readings were done in the post retrofit period approximately once a week. For the pre retrofit period, information was obtained from the local utility companies. Results of comparing the pre retrofit period to the post retrofit period show that for the five case houses natural gas consumption declined 25.9% to 45.0% on a heating degree day normalized basis. Electricity consumption declined 2.4% to 40.8%, and the total energy consumption (natural gas and electricity) declined 23.9% to 39.9% on a heating degree day normalized basis.

For the five control houses for the same time period, natural gas consumption increased in three houses by 1.5% to 36.5%. One house decreased its consumption by 1% while the fifth house decreased its consumption by 14.8%, but it had different occupancy during the monitoring period. Electricity consumption decreased by 3.0% and 6.6% in two of the houses and increased in three of the houses by 1.7% to 25.7%. The results of the control houses show that gas consumption between the pre and post monitoring period increased by 7.7% (excluding C-L1) due to more severe weather. Therefore, the decline in total energy consumption of the case houses when corrected using the control house results is 26.0% to 39.6%.

The report presents data on the characteristics of the houses, graphs of the natural gas, electricity, and water consumption for all ten houses, appliance electricity consumption, blower door testing, combustion efficiency testing, and various other parameters of the pre retrofit and post retrofit testing.

Case Studies of Major Home Energy Retrofits

RÉSUMÉ

La Building Performance Section (BPS) du Saskatchewan Research Council (SRC) a été retenue par la Société canadienne d'hypothèques et de logement (SCHL) pour mener l'étude Case Studies of Major Home Energy Retrofits. L'étude avait pour objectif de faire la démonstration d'économies d'énergie réelles dans des maisons existantes à l'aide de travaux de rattrapage éconergétiques, de manière à ce que ces maisons puissent servir de modèles d'économies d'énergie.

La cible choisie par la SCHL consistait en une réduction de 40 % de la consommation d'énergie, de toute provenance, dans toutes les maisons après l'exécution des travaux de rattrapage éconergétiques. Un deuxième objectif exigeait que le coût des travaux soit raisonnable, puisque ce sont les propriétaires-occupants qui en assumeraient la responsabilité.

L'étude a été scindée en deux parties. La première consistait à assurer la participation des propriétaires de quatre maisons. Les chercheurs ont retenu six maisons et un rapport provisoire a été rédigé. La deuxième étape de la recherche comprenait des rencontres avec les propriétaires-occupants afin de mettre au point les travaux de rattrapage éconergétiques requis pour atteindre la cible énergétique en se fondant sur le modèle informatique HOT2000. Par la suite, un des propriétaires-occupants s'est retiré de l'étude en raison d'un changement d'emploi.

Les travaux de rattrapage ont été mis en œuvre sur une certaine période par les propriétaires-occupants suivant les conseils du SRC. Les chercheurs ont effectué un suivi et des essais, avant et après les travaux.

Puisque les conditions climatiques durant les essais pouvaient différer des données historiques, cinq maisons témoin ont été choisies afin d'y effectuer des relevés de compteur. Les rendus graphiques de la consommation tant avant qu'après les travaux de rattrapage éconergétiques ont été effectués pendant la même période que celle des maisons à l'étude.

La date de construction des maisons d'essai et des maisons témoin allait de 1911 à 1986; les maisons présentaient une vaste gamme de styles, d'occupations, etc.

La période de suivi après les travaux s'est terminée le 31 décembre 2002. La lecture du compteur était effectuée environ une fois par semaine durant la période suivant les travaux. En ce qui a trait à la période précédant les travaux, les renseignements ont été obtenus des services publics. La comparaison des résultats obtenus avant les travaux avec ceux obtenus après les travaux indiquent que la consommation de gaz naturel dans les cinq maisons à l'étude a diminué de 25,9 % à 45,0 %, tandis que la consommation d'électricité reculait de 2,4 % à 40,8 %, sur la base de degrés-jours de chauffage normalisés. La consommation totale (gaz naturel et électricité) a affiché une baisse de 23,9 % à 39,9 %.

Durant la même période, la consommation de gaz naturel dans les cinq maisons témoin augmentait de 1,5 à 36,5 %. Une maison affichait une diminution de 1 %, tandis que la consommation diminuait de 14.8 % dans la cinquième maison, mais celle-ci était occupée par un nouveau ménage durant la période de suivi. La consommation d'électricité a diminué de 3,0 % et de 6,6 %, respectivement, dans deux maisons, et a augmenté dans trois maisons de 1,7 à 25,7 %. La consommation de gaz naturel dans les maisons témoin avant et après les travaux durant les périodes de suivi a subi une augmentation de 7,7 % (la C-L1 non

comprise) en raison de conditions climatiques plus rigoureuses. La baisse de consommation totale d'énergie dans les maisons à l'étude, corrigée en fonction des maisons témoin, se situe donc dans une fourchette de 26,0 à 39,6 %.

Le rapport présente les données sur les caractéristiques des maisons, les graphiques de la consommation de gaz naturel, d'électricité et d'eau pour les dix maisons, les essais d'infiltrométrie, les essais de rendement de la combustion, et différents autres paramètres relatifs aux essais effectués avant et après les travaux.

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Thanks also go to Mr. Don Fugler, CMHC Project Officer, for his assistance in planning and ongoing development of the project.

DISCLAIMER

This study was conducted by the Saskatchewan Research Council for Canada Mortgage and Housing Corporation under Part IX of the National Housing Act. The analysis, interpretation, and recommendations are those of the consultants and do not necessarily reflect the views of Canada Mortgage and Housing Corporation or those divisions of the Corporation that assisted in the study and its publication.

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AC, A.C.	air conditioning
ACH@50 Pa	air changes per hour at 50 pascals pressure difference
AFUE	annual fuel utilization efficiency
Apr	April
Aug	August
BPS	Building Performance Section
Btu/h	British thermal units per hour
CFL	compact fluorescent lamp
CGSB	Canadian General Standards Board
cm^2	square centimetres
CMHC	Canada Mortgage and Housing Corporation
CO_2	carbon dioxide
cons.	consumption
DC	direct current
DD	degree-days
dec	decrease
Dec	December
DHW	domestic hot water
ΔP	differential pressure
ΔT	temperature differential
EL, elec.	electricity, electrical, electric
ELA	equivalent leakage area
Envir.	Environment
excl.	excluding
Feb	February
GJ	gigaJoules
HDD	heating-degree-days
HOT2000	residential energy usage modelling software
inc	increase
insul.	insulated

interm.	intermittent
Jan	January
kW	kilowatts
kWh	kilowatt hour
L/s	litres per second
L	litres
m^2	square metres
m^3	cubic metres
Mar	March
MJ	megaJoules
mm	millimetre
N/A	not applicable
N.G., nat. gas	natural gas
N / M	not measured
No.	number
Nov	November
Oct	October
Pa	pascals
R	insulation value in imperial units
recirc.	recirculating
reg	regular
RFP	request for proposal
RSI	insulation value in metric units
SEER	seasonal energy efficiency ratio
Sept	September
sq. ft	square feet
SRC	Saskatchewan Research Council
T8	T8 fluorescent lamp
uninsul.	uninsulated
y-int	Y intercept
yrs	years
°C	degrees Celsius

1 INTRODUCTION

The Saskatchewan Research Council (SRC), Building Performance Section (BPS), 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 the cost of the retrofit measures reasonable as the homeowners would be paying for the retrofit costs.

The project was divided into two parts.

For Part 1 of the project, the SRC was to locate and confirm the participation of four suitable houses for the study. The report, SRC Publication Number 11375-1C00, November, 2000, presented the results of that portion of the project. The report described the methodology used for the project and that six houses, rather than four houses as requested in the RFP, were located and subsequently studied.

Part 2 of the project involved meeting with homeowners to detail the retrofits that were required for their homes to attain the desired energy savings. Recommended retrofit strategies were developed based on the energy savings calculated. All of the retrofit measures were to be implemented at the homeowners' expense except for a small honorarium of $1000 per house to help cover the time and inconvenience associated with the testing and monitoring. SRC assisted with the selection of energy conserving appliances. Following implementation of all of the retrofit measures, SRC staff performed extensive testing and monitoring on each house. Regular utility meter readings were taken during the project both by the homeowners and by SRC staff.

During the initial house testing, one homeowner (H1) decided to withdraw from the project because of a job change. The remaining five houses were retrofit and monitored.

CMHC also requested that a number of control houses, located in Saskatoon, be monitored for energy consumption as the winter weather in the test period could vary greatly from historical temperatures. Basically, if the post retrofit winter was far warmer (or colder) than the pre retrofit winter, there would be energy savings (or expenditures) that were unrelated to the retrofits. Control houses, which are unchanged during the monitoring periods, help to account for these variabilities in weather. Five volunteers were found and utility monitoring performed. Utility records were also obtained for the pre retrofit period of the project from the home owners and from the utility companies. The analysis was used to compare the energy consumption trends in the case houses (the ones being retrofit) and control houses (the ones not being retrofit) over the same monitoring period.

The houses that were retrofit ranged in year of construction from 1911 to 1986 and had a variety of different styles, sizes, insulation levels, ages, occupancy levels, air tightness values, furnace efficiencies, window types, etc.

2 PREVIOUS WORK

A previous well-documented Canadian retrofit project was identified following a literature search. A 1985 Manitoba study (Unies, 1985) reported the following results for house energy retrofits and the cost effectiveness of the potential retrofit measures.

Table 2.1. Cost Effectiveness of Retrofit Measures

Retrofit Measure	Relative Cost Effectiveness (simple payback period, years)	Rank by Cost Effectiveness (1=best, 10=worst)
Air Leakage Sealing Caulking, etc	1 to 13	1
Exterior walls Insulating empty cavities	2 to 8	2
Insulating Attics and Ceilings Bungalow, two storey	3 to 10	3
Insulating Attics and Ceilings 1.5, 1.75, 2.5 storey	5 to 12	4
Heating, Ventilating Systems Natural gas furnaces replaced with higher efficiency units	8 to 16	5
Insulating Attics and Ceilings Cathedral ceiling	8 to 25	6
Windows Triple pane retrofit	10 to 23	7
Exterior walls Other wall retrofits	12 to 43	8
Door Retrofits Existing door replaced with new door	19 to 48	9

Retrofit Measure	Relative Cost Effectiveness (simple payback period, years)	Rank by Cost Effectiveness (1=best, 10=worst)
Windows Double glazed replaced with triple	"Extremely poor"	10

3 OBJECTIVE

The objectives of the project were to study several houses in depth which were retrofitted to reduce energy consumption and to prepare documentation and reports on the retrofits that are suitable for government or media use.

4 SCOPE

The original project scope was for SRC to locate and confirm the participation of four suitable houses for the project. The houses had to have a reasonable potential for a minimum of 40% energy savings compared with current consumption (adjusted for annual heating degree-days). The homeowners needed to be aware of the predicted costs of equipment and/or labour to attain the savings, and had to be willing to cover those expenses.

Subsequently, SRC offered to expand the study, as a contribution in kind, to include as many as six houses total in the project.

SRC also located and monitored five houses in Saskatoon that were used as control houses.

5 METHODOLOGY

5.1 General

The project involved several tasks. They included:

1. Six suitable homeowners were found who were willing to undertake energy retrofits. The homeowners were made aware that the retrofit costs were their financial responsibility. The main benefits to the homeowners were the advice and guidance of SRC along with a small honorarium. The houses were different in style, age, size, and initial condition.

2. Pre retrofit house characterization, testing, and documentation was performed. This included blower door testing, measurements of house physical dimensions, combustion efficiencies, and appliance electrical use, as well as HOT2000 modelling. Utility records for the pre retrofit periods (electricity, natural gas, and water) were obtained for the HOT2000 modelling, and graphing of utility use.

3. Using the HOT2000 models, retrofit plans for each house were developed to meet the performance goal. Homeowners were provided with a list of necessary changes.

4. A press conference was hosted to publicize the project. Every local television station was present along with the local print media.

5. The retrofit work was inspected as it progressed. Documentation of the completed work using photography was done.

6. Post retrofit characterization, testing, and documentation was done. This included blower door testing, measurement of furnace and water heater combustion efficiencies, measurement of electrical consumption of new appliances and furnace blower motors, counting of new CFLs, characterization of furnaces including temperature rise, pressure drops, and motor operation; measurement of hot water temperature, cost of retrofit measures, and clothes dryer and exhaust fan air volumes.

7. Using the meter readings taken by the homeowners and by SRC staff, comparisons were made of the post retrofit energy consumption to the pre retrofit energy consumption. Post retrofit meter readings were taken starting in the winter of 2001/2002 through to the project end at a minimum of once per month and as often as once per week (most cases).

8. Five control houses were located, past utility records were obtained, and the natural gas, electricity, and water consumption values were monitored for a period of time similar to the retrofitted houses. The utility readings were done for this group of houses approximately every two weeks.

9. All of the utility data and Saskatoon heating degree day data was input into a spreadsheet. Graphs were prepared of the pre retrofit and post retrofit periods. Slopes and Y-intercept values were calculated for comparison purposes. The natural gas and electricity consumption values for the pre retrofit and post retrofit periods for all of the case and control houses were normalized to 6077 Celsius annual heating degree days, the long term annual average figure for Saskatoon. (Unless otherwise stated all of the natural gas and electricity data and results presented in this report have been normalized by the 6077 annual heating degree days value.)

5.2 HOT2000 Modelling

The most recently available (at the project start) HOT2000 program (Version 8.5) was purchased and used to model the energy usage. In the Part 1 report, a list of possible retrofit measures that could be implemented on each of the houses was presented. Once the computer modelling was completed, a finalized retrofit measures list was developed for each house.

Estimates had to be made for some of the inputs to the computer modelling program. For instance, the following measures had to be estimated for each of the houses.

1. Hot water consumption
2. Thermostat settings
3. Pilot light natural gas consumption of the water heaters and furnaces
4. Hours of use of various appliances and lighting
5. Amount of electrical or natural gas energy used by the clothes dryers

Detailed retrofit plans were developed for each of the houses including space heating and water heating equipment changes, replacement of major appliances, lighting changes, set back thermostat installation and use, air tightening, increasing insulation levels, etc.

The following upgrade measures were identified for all the houses:

5.2.1. Upgraded Furnaces

All of the houses had natural gas fired space and water heating equipment. The existing natural gas furnaces were retrofit to either high efficiency condensing furnaces or mid-efficiency furnaces. Condensing natural gas furnaces have Annual Fuel Utilization Efficiency (AFUE) values in the range of 90 to 96%. The existing atmospheric-vented gas furnaces in the test homes had estimated AFUE values in the range of about 55 to 65% based on measured combustion efficiencies. In choosing replacement furnaces, it was important that the units were properly sized for the heating loads. The graphs (see Part 1 report) of natural gas consumption versus Celsius heating degree days/day that were done on the houses were used along with the computer model to properly size the replacement furnaces. Furnace oversizing is a common feature of many Canadian homes, resulting in decreased performance due to the reduced efficiency at part load values.

The installation of condensing furnaces reduced or eliminated the amount of house air being ventilated up the chimney as they allowed the chimney to be capped or removed.

For the tighter houses it was important to ensure that sufficient ventilation air was being supplied to maintain proper air quality.

Carbon monoxide detectors were provided to homeowners that did not have one already in place.

5.2.2. Compact Fluorescent Lighting

The cost of compact fluorescent lamps (CFLs) has declined dramatically. The IKEA store chain is now marketing integrally ballasted CFLs in the range of 8 to 20 watts input at a price of $7.50 plus taxes.

Home Depot now has a CFL that has a faster on time than the IKEA selection that is selling for $6.98 plus taxes. Home Depot and other retail chains are selling two-packs of CFLs for $16.99 plus taxes.

Typical compact fluorescent lamp life is advertised as 10,000 hours, or ten times the life of normal incandescent lamps. Over the 10,000 hour life of the lamp, a 15 watts CFL that replaces a 60 watts incandescent lamp will save $36 at Saskatoon's marginal electricity price of approximately nine cents per kilowatt hour (kWh).

It was strongly recommended to the homeowners that all lamps with a burn time greater than approximately two hours per day be retrofit with CFLs. In addition to saving energy, the return on investment is very attractive for this retrofit measure.

5.2.3. Low-cost Measures

Because of their demonstrated cost-effectiveness, the following measures were implemented on all of the houses that did not already incorporate the features:

a. Low flow shower head(s)
b. Domestic hot water (DHW) tank insulation
c. Insulate the pipes near the DHW tank
d. Toilet dams
e. Toilet fill cycle diverters
f. Automatic setback thermostats

While the toilet dams and toilet fill cycle diverters do not provide energy savings, they do conserve water at a nominal cost for the devices. Also, they are easily installed. The low flow showerheads provide hot water savings.

Some published studies have indicated that the energy savings from the use of automatic setback thermostats are rather low, while our HOT2000 models indicated that reasonable savings could be achieved. The main reason that the thermostats were recommended though was to ensure the comfort of the home owners after their heating systems were reduced in size. Many of the homeowners performed manual temperature setback during the pre retrofit period and it was a concern that they would find the increased recovery time of their new, smaller heating systems to be uncomfortable. The automatic thermostats allow the heating systems to be setback to lower temperatures over night and when unoccupied and start warming the house up again before the homeowners arise or return home.

5.2.4. Other Measures

Other energy efficiency measures for the houses were specified on a case-by-case basis. The addition of attic and/or basement wall insulation, the installation of wall-mounted motion switches, and the replacement of old major appliances are examples.

5.3 House Characteristics

Interviews were conducted with each homeowner to compile information on the operation of their house, historical information, appliance information, etc. to determine if the house was eligible for the project. Five houses are presented in the table. House H1 withdrew from the project for personal reasons and has not been included in the table. SRC staff also visited each house to assess the suitability of the house for the retrofits.

Table 5.3.1: House Characteristics in Pre-Retrofit Condition

House Codes	D1	G1	G2	G3	G4
ENVELOPE					
Attic insulation	RSI 3.5	½ attic; Estimated RSI 1.8 in sloped part; RSI 5.3 in flat part	RSI 7.0 flat RSI 0 sloped	RSI 6.2	RSI 7.0
Walls	RSI 2.1	Wood shavings	RSI 0 to RSI 2.1 - RSI 3.5 porch	RSI 3.5	RSI 0 to RSI 0.7 new siding

House Codes	D1	G1	G2	G3	G4
Windows	Aluminum sliders + 2 new bay	Mix of older and new	Some new	Casement	New 5 yrs ago - low E argon on 2nd floor
Basement walls	Uninsulated	Uninsulated	Finished - insulated RSI 2.1	Finished - insulated	Finished - insulated
Basement floor	Uninsulated	Uninsulated	Uninsulated	Uninsulated	Uninsulated
Air tightness	Average	Leaky	Leaky	Back-drafting will occur	Leaky
Weatherstripping			Poor		Average
Doors	New		One poor		Steel insul.
Attached garage	No - detached	No - detached	No - detached	Yes - two car	No - detached
HEATING					
Warm air natural gas furnace type	Original 1970 vintage	Old Coleman	1960s	1986 new	Old
Set back thermostat	Yes	Yes	No	Yes	No
Duct leakage	Some taping done	Probable	No returns	Probable	Probable
DOMESTIC HOT WATER (DHW)					
Shower head	Low flow	Regular	1 Regular 1 Low flow	Regular	Low flow
Aerators		Yes	Yes		Yes
Tank insulation	No	No	No	Yes RSI 0.7 (R4)	No
New DHW tank	1995	Old	~1980	1986	<10 yrs old
Pipe insulation	None	None	None	None	None
Toilet dams	None	None	None	None	None
Jet tub	No	No	No	Yes	No
LIGHTING					
T8	None	None	None	None	None
CFL	None	None	None	None	None
Toroidal Fluorescent	None	None	None	None	None
Dimmers	None	None	Two	One	None
Occupancy sensors	None	None	None	One	None

House Codes	D1	G1	G2	G3	G4
APPLIANCES					
Washer	1992 top load	New front load	Old top loader	Front load	Top loader
Dryer	1989 nat. gas	Elec.	Old - elec.	1980 vintage - elec.	Elec.
Refrigerator(s)	1971	Two years old	~1990	Two	Double door 1992
Stove	Elec.	Elec.	Elec. >20 yrs old	Nat. gas	Elec.
Dishwasher	Yes	1987	No	Old	Yes - new
Freezer(s)	1994	1980	1985	Two-older units	Yes - chest
Central A.C.	Yes - 2 ton - 10 SEER	No	No	Yes	No
Furnace fan motor	Direct drive	Belt	Belt	Direct drive	Belt
Green Plug	No	No	No	No	No
Range hood	No	No	Recirc.	Exhausts to outside	Recirc.
Electronic air filter	No	No	No	Yes	No
Nat. gas barbecue	No	No	No	Yes	No
Auto block heater timer		Yes		No; house has insulated garage - not heated	
VENTILATION					
Energy efficient, quiet fan	Standard bathroom	No fans	Standard bathroom	Standard bathroom	No fans
WATER CONSUMPTION					
Toilets	6.1 litres/flush	Approx 13.3 litres/flush	Two regular (18.9 litres/flush)	6.1lLitres/flush	3 regular (18.9 litres/flush)
Landscaping		No automatic or under-ground sprinklers	No sprinklers	Under-ground sprinklers-manual control	Sprinklers
GENERAL					
Year built	1973	1911	1912	1986	1920 built 1960 moved
Number of storeys	1	2	1.75	Split	2
Floor area (excl. basement)	83.6 m^2 (900 sq.ft)	135.3 m^2 (1456 sq.ft)	130.1 m^2 (1400 sq.ft) + porch	146 m^2 (1571 ft^2)	213.7 m^2 (2300 sq.ft)

House Codes	D1	G1	G2	G3	G4
Basement floor area	83.6 m^2 (900 sq.ft)	67.6 m^2 (728 sq.ft)	65.0 m^2 (700 sq.ft)	93.7 m^2 (1008 ft^2)	106.8 m^2 (1150 sq.ft)
Total Floor Area (square metres)	167	203	195	240	321
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 to furnace	No	No	No	No	No
Fireplace(s)	No	No	1 - nat. gas	1 wood burning	No
Crawl space	No	No	No	No	No
Orientation	Front faces South	Front faces South	Front faces North	Front faces West	Front faces West
Number of bathrooms	1	2	1.5	4	3
Window Condensation problems	Slight	Slight	Yes	Slight	Yes
House ventilation	No- continuous furnace fan	No	No	No	No
Attic ventilation			Whirlybird		Whirlybird
Eavestrough			Need repair - poor drainage		Poor shape - slight drainage problems

5.4 Retrofit Measures For Consideration

Some of the guiding principles used in determining which retrofits to recommend were:

1. The measures recommended should not be experimental. A track record of acceptable performance was needed.
2. The measures recommended should be readily available and able to be replicated on a larger scale.
3. The measures recommended should not compromise the health, safety, or indoor environment in the houses.
4. The simple payback periods for the various individual retrofit measures be less than 10 to 15 years.
5. The homeowners themselves would have to pay for these measures, and therefore the changes recommended would have to be acceptable to the homeowners.

There were some changes that were recommended for all the houses.

1. Upgrade the efficiencies of the existing natural gas furnaces. The existing furnaces each had a combustion efficiency measurement performed (with the exception of House D1*) which 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 14 years old.
2. 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 in the order of 2/3 to 3/4 for those lamps that were changed.
3. 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 are expected to reduce energy consumption, by reducing hot water use.
4. Water heater blankets were recommended and provided by SRC.
5. The installation of one metre of pipe insulation for each of the water lines into and out of the water heaters was recommended.
6. The replacement of inefficient major appliances was recommended.
7. The use of motion sensing wall switches was considered and recommended if the occupancy patterns allowed their use.

* After preliminary discussion with homeowner D1, the homeowner replaced their furnace with a mid-efficiency model before SRC staff had an opportunity to measure the operating characteristics of the old furnace.

5.5 HOT2000 Pre Retrofit Modelling Results

Each home was thoroughly inspected and measured, combustion efficiencies of the furnace and water heater were measured, and a blower door test was performed.

Table 5.5.1: House Combustion Efficiency and Air Tightness Measurements Used as Inputs to HOT2000 Models

	D1	G1	G2	G3	G4
Furnace combustion efficiency, %	75	87 (76.3 actual)	76	88 (76.2 actual)	77.8
Water heater combustion efficiency, %	82	74.1	76.2	75	76.3
Air tightness, ACH @ 50 Pa	1.76	6.34	7.71	1.95	6.26

Note: the values in brackets are the actual measured combustion efficiencies, while the higher values (not in brackets) were used in the base case models to cause the modelled energy consumption to match the actual energy consumption.

The acquired data were input into the base case HOT2000 models. Several runs were then conducted for each house changing variables to identify energy savings. These runs were then analysed and a retrofit plan was developed for each house. The results from the modelling and the recommendations are presented in the following table.

Table 5.5.2: HOT2000 Results and Some House Characteristics - Pre-Retrofit

House Code	D1	G1	G2	G3	G4	Average for five houses
Base Energy Consumption (N.G. + EL), (kWh/yr)	53,899	49,212	55,895	46,242	74,942	56,038
Base (N. G. + EL) Consumption, (GJ/yr)	194	177	201	166	270	202
Base Electrical Consumption, (kWh/yr)	9,598	5,811	8,614	13,089	7,681	8,959
Number of Occupants	2	4	6	4	5	4.20
Central Air Conditioning (AC)	Yes	No	No	Yes	No	Note: New furnaces must have sufficient air flow for AC
Continuous Fan Circulation	Yes	No	No	Yes	No	
Existing Furnace Input Capacity, kW (Btu/h)	35.2 (120,000)	26.4 (90,000)	29.3 (100,000)	38.1 (130,000)	58.6 (200,000)	37.5 (128,000)

House G3 (the newest [1986] of the five houses) had the highest electricity consumption (13,089 kWh/year) and the lowest base energy consumption (166 GJ/year). House G1 had the lowest electricity consumption at 5,811 kWh/year. House G4 had the highest base energy consumption at 270 GJ/year.

Recommended retrofit measures based on the HOT2000 modelling results are presented in the following table.

Table 5.5.3: Recommended Retrofit Measures

Measure	D1	G1	G2	G3	G4
Condensing Furnace	No Induced Draft 75,000 Btu/h input 22.0 kW 80% to 85% efficient	Yes 60,000 Btu/h input 17.5 kW	Yes 60,000 Btu/h input 17.5 kW	Yes 60,000 Btu/h input 17.5 kW	Yes 90,000 Btu/h input 26.4 kW
Power Vented Water Heater	No - insulate tank	Yes - insulate tank	Yes - insulate tank	Yes - insulate tank	Yes - insulate tank
Chimney	Leave as is	Eliminate	Eliminate	Eliminate	Eliminate
Basement Wall Insulation	Yes	Yes	No	No	Yes - uninsulated portions
Attic Insulation	No	Yes add RSI 3.3 (R19) to flat part	Yes add RSI 3.3 (R19)	Yes add RSI 2.8 (R16)	Yes add RSI 2.8 (R16)
Windows	Add acrylic pane in living room	Add acrylic pane	Add acrylic pane		
Air Sealing		Yes	Yes		Yes
New Major Appliances					
Refrigerator	Yes	No	Yes	No	Yes old one uses 1164 kWh/yr
Disconnect Refrigerator in Basement	Yes			Yes - uses 1121 kWh/yr	
Stove	No	No	No	No	No

Measure	**D1**	**G1**	**G2**	**G3**	**G4**
Clothes Washer (front loading)		Yes		Yes	Yes
Dryer			New		
Dishwasher			New		
Freezers				Existing ones use 1472 and 867 kWh/yr. Replace with EE unit-approx 500 kWh/yr	
Compact Fluorescent Lighting	Yes	Yes	Yes	Yes	Yes
Water Conservation Measures					
Toilet Dams	Yes	Yes	Yes	Yes	Yes
Low Flow Showerheads	Yes	Yes	Yes	Yes	Yes
Other					
Panasonic Fan	Yes	Yes	Yes	Yes	Yes
Other Items	Switch to interm. furnace fan operation, consider Air Cycler™*				Consider Air Cycler™ for summer use of furnace fan
Landscaping - redirect surface water away from house					Yes

Note * - Air Cycler™ is a device that can be programmed to run the furnace fan intermittently when it is not required for heating or air conditioning. Both the run time and the time between runs can be set from one minute up to sixty minutes.

Many computer simulations were conducted for each of the five case houses testing the predicted effectiveness of implementing various retrofit measures. The predicted energy savings based on the HOT2000 modelling presented in the following table are the results. Information on the HOT2000 modelling inputs are presented in Appendix F.

Table 5.5.4: HOT2000 Modelling Results

	D1	G1	G2	G3	G4
Natural gas consumption reduction, %	46.4	44.0	38.5	28.3	41.5
Electricity consumption reduction, %	31.7	23.7	46.9	69.8	30.9
Total energy consumption reduction, %	43.8	42.0	39.8	40.0	40.1

5.6 Retrofit Planning Example

The recommendations for House D1 are presented as an example of the thought process that was used for designing a retrofit plan. House D1 is a bungalow built in 1970.

1. Ceiling insulation. The ceiling had approximately RSI 8.8 (R50) insulation, no changes were recommended.
2. Basement insulation. The basement was totally uninsulated (cast-in-place concrete walls). It was recommended that RSI 1.4 plus RSI 2.1 (R8 plus R12) glass fibre batts be installed in a 38 mm x 89 mm wood frame stud wall and that the headers be insulated and air-sealed. Gypsum board (12.5 mm) was recommended for the interior finish.
3. Above grade wall exterior insulation. The main floor walls above the basement had RSI 2.1 (R 12) insulation. The cost of improving wall insulation is fairly substantial. Adding exterior insulation would cost approximately $50 per square meter of wall surface including the new exterior siding. In **none** of the cases was this measure recommended.
4. Lighting. It was recommended that compact fluorescent lamps be installed.
5. Temperature setback. No changes were recommended to the daytime house temperatures as one of the occupants works out of the home, and did not want a temperature setback. Night setback was recommended with the programmable thermostat in place.
6. Electrical appliances and general electrical use. It was recommended that the upstairs refrigerator be replaced and the use of the downstairs refrigerator be discontinued. Other electrical using devices such as the central air conditioner had no changes recommended other than a cleaning of the heat exchanger surfaces. The air conditioner is a two ton unit and the annual usage is approximately 730 kilowatt hours per year which is relatively modest for the house.
7. Air leakage of the building. The existing building was quite tight at 1.76 air changes per hour at 50 Pascals (the R2000 standard is 1.5 air changes per hour at 50 Pascals). No further air tightening was recommended other than the basement wall construction.
8. Furnace fan motor. It was recommended that an auto cycling device (Air Cycler™) be put on the furnace fan to provide intermittent use of the fan throughout the year. It was also recommended to investigate whether a higher efficiency furnace fan motor might be used. One of the relatively large users of electricity is the furnace fan motor. The furnace fan

motor is a large user of electricity consuming approximately 2628 kilowatt hours per year. As the home owner operates the furnace fan continuously any reduction in furnace fan size would dramatically reduce the electrical consumption.

9. Windows. Existing windows were double glazed windows. No changes were recommended other than the adding of a third pane or window film to the large living room window.
10. Exhaust fan. It was recommended that a continuous operation exhaust fan be installed in the bathroom. A Panasonic or equivalent fan which uses approximately 20 watts of electricity was recommended for the house.
11. Furnace. The furnace that was recommended for retrofit was an induced draft unit with a 22.0 kilowatts input. It has intermittent ignition and an induced draft fan. As this house had an un-insulated basement in the base condition the computer model estimated that it was possible to achieve the target reduction in energy use without going to the additional expense of installing a condensing furnace, provided that the furnace combustion efficiency could be increased to 84% by careful tuning.
12. Water heater. No changes were recommended to the natural gas water heater other than increasing the insulation on the water tank to RSI 3.5 (R20) and insulating the hot and cold water pipes for one metre adjacent to the tank.

5.7 Media Coverage and Publicizing of the Project

The local televison and print media were invited to a press conference, presented at house G4 on January 17, 2001, to hear about the project and about the contribution of the major sponsors. Dr. Robert Dumont spoke about the project and energy conservation. Ms. Wanda Brown of SRC's Communications/Marketing Section coordinated a very successful media event which all three national television stations as well as local print media personnel attended. The CTV AM national network program broadcast the story as well. Stories of the project were on all three local television stations as well as stories in two local newspapers. Ms. H. Tataryn, CMHC Calgary, spoke at the media event. The owner of House G4 gave an enthusiastic presentation of the merits of the project.

A paper (Appendix A) on the start of the project was presented at the 2001 SESCI Conference in Regina, SK, September, 2002, Leislar, T.J., Dumont, R.S., Makohon, J.T., Snodgrass, L.J., "Reducing the Energy Consumption of Six Houses By 40% Each".

Extensive digital camera and 35 mm film photography were used to record project progress.

5.8 Control Houses

Five houses were located in Saskatoon to act as control houses for the project. Requirements for the control houses included that they had not performed any "energy related" changes to their houses in the pre retrofit period of the case houses, the occupancy remained the same, and that no retrofits were planned until after the completion of the post retrofit period. The control houses' utility data were obtained from the utility providers and graphed using the same method as used for the case houses. Meter readings were obtained bi-weekly for the duration of the project. These data were used to compare with the data for the case houses, for weather-related effects.

Table 5.8.1: Control Houses - House Characteristics

	C-GW1	C-L1	C-M1	C-M2	C-Y1
Age	unknown*	1978	1971	1978	1960
Style	Two storey	Bungalow	Two storey	Two storey	Split level
Number of occupants	3	2	2	4	3
Furnace	ICG HAS 150 150,000 Btu/hr	Clare Brothers HBG-138-M 125,000 Btu/hr	Lennox G24M/4-100R-2 100,000 Btu/hr	Lennox G8-180-1 180,000 Btu/hr	Olsen HBS-130 130,000 Btu/hr
Water heater	Conventional**	Conventional	Conventional	Conventional	Conventional
Attached garage	No	Yes	Yes	Yes	Yes

* the volunteers for this project are only renting the house so they do not know when it was built
** conventional water heater is an atmospheric vented unit with a standing pilot light

6 RETROFIT MEASURES AND IMPLEMENTATION RESULTS

The following table summarizes the recommended retrofits for the case houses and indicates which ones were implemented.

Table 6.1: Retrofit Measures Implementation

✓ = recommended ✔ = implemented ✗ = not implemented

Retrofit Measure	D1		G1		G2		G3		G4	
Furnace	✓	✔	✓	✔	✓	✔	✓	✔	✓	✔
Water heater			✓	✔	✓	✔	✓	✔	✓	✔
Water heater blanket	✓	✔	✓	✔	✓	✔	✓	✔	✓	✔
Water heater pipe insulation	✓	✔	✓	✔	✓	✔	✓	✔	✓	✔
DHW pre-heat tank							✓	✔	✓	✔
Set back thermostat	✓	✔	✓	✔	✓	✔	✓	✔	✓	✔
Basement wall insulation	✓	✔	✓	✔						
Attic insulation			✓	✔	✓	✔	✓	✔	✓	✗
Air sealing			✓	✔	✓	✔			✓	✗
Add window "shrink" film	✓	✔					✓	✔		
Clothes dryer			✓	✔	✓	✔				
Front loading clothes washer			✓	✔	✓	✔	✓	✔	✓	✔
Refrigerator	✓	✔			✓	✔			✓	✔
Dishwasher						✔				
Freezer					✓	✔	✓	✔		
Disconnect two old freezers - replace with one new one							✓	✔		
Discontinue downstairs refrigerator use	✓	✗					✓	✔		
Compact fluorescent lighting	✓	✔	✓	✔	✓	✔	✓	✔	✓	✔
Motion sensor for downstairs lighting					✓	✔				

Retrofit Measure	D1		G1		G2		G3		G4	
Toilet dams	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Low flow showerheads	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Continuously operating ventilation fan	✓	✗	✓	✗	✓	✗	✓	✓		
Central air conditioner tuneup	✓	✓					✓	✓		

7 RESULTS

7.1 Utility Data Results

By utilizing the weekly meter readings (post retrofit) and the utility-supplied meter readings (pre retrofit), the measured energy consumption totals were calculated. Graphs were prepared for each house for the pre retrofit and post retrofit situations (see Appendix B). Figure 7.1.1, 7.1.2, and 7.1.3 show representative pre retrofit plots of the natural gas, electricity, and water consumption values, respectively (plots for House G1).

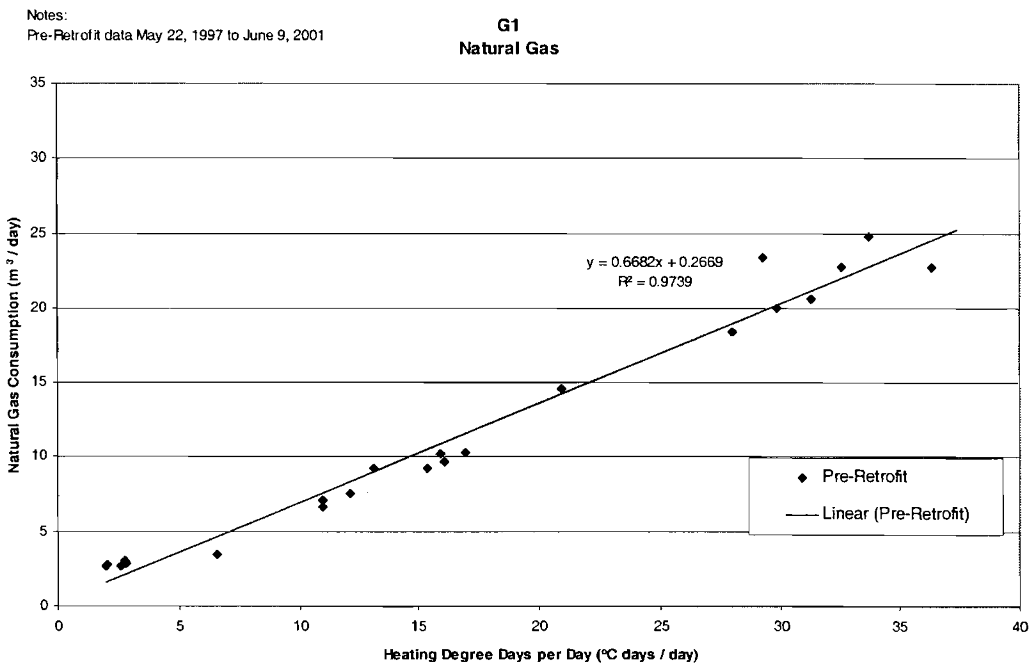

Figure 7.1.1: G1 Pre Retrofit Natural Gas Consumption Values

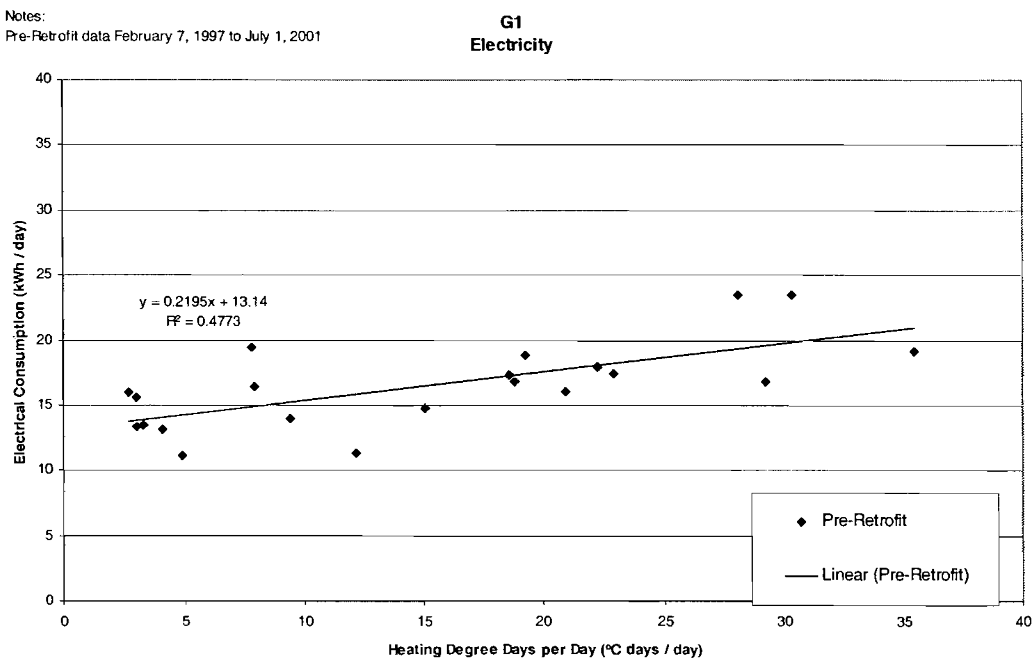

Figure 7.1.2: G1 Pre Retrofit Electrical Consumption Values

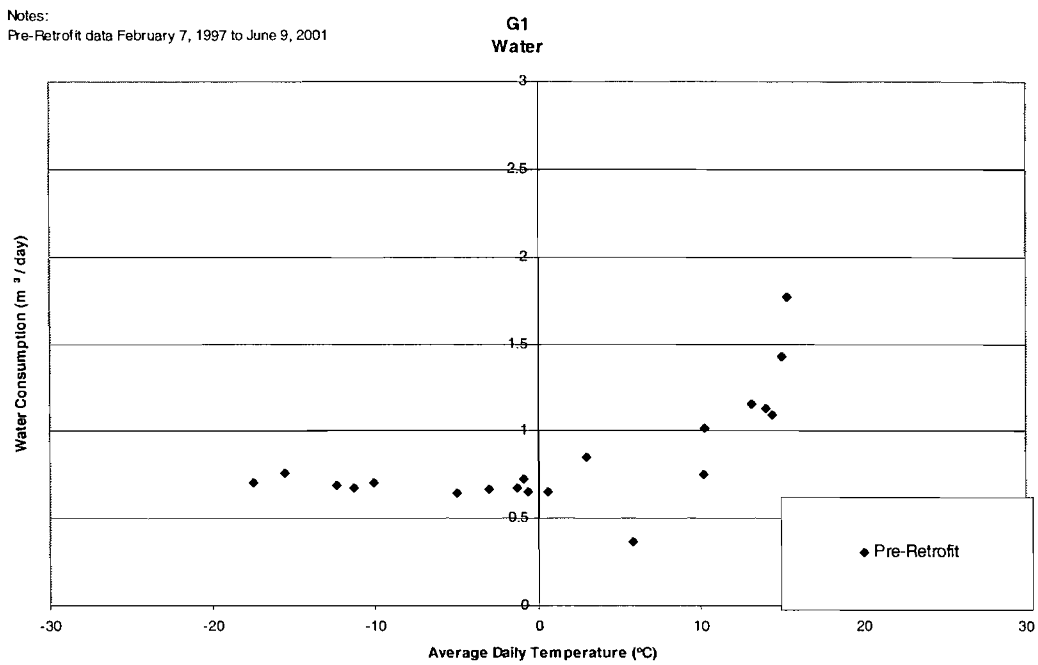

Figure 7.1.3: G1 Pre Retrofit Water Consumption Values

There is, understandably, a strong relationship between natural gas consumption and heating degree days (more gas consumed as it gets colder [heating degree days increase]). The relationship between heating degree days and electrical consumption is a much weaker relation. The electrical consumption in most of the homes increases slightly during the winter months due to the increased use of lights and the operation of the furnace. If a home owner operates the furnace fan year round then the dependence of electricity on heating degree days is decreased even further.

Figure 7.1.3 shows the total water consumption, not just the hot water consumption. Therefore, the increase in water use at higher average daily temperatures is due to watering of lawns and plants.

7.2 Retrofit Costs

The cost of the retrofit measures were of considerable importance to the project. The following table presents the costs not including the $1000 honorarium paid to each of the homeowners.

Table 7.2.1: Cost of Retrofit Measures

	Cost, $				
	D1	**G1**	**G2**	**G3**	**G4**
Refrigerator	860	---	2,555	---	1,100
Freezer	---	---	included above	600	---
Clothes washer	---	1,680	included above	1,095	1,050
Clothes dryer	---	included above	included above	---	---
Dishwasher	---	---	gift	---	---
Furnace and thermostat	1,900	3,455	3,335	3,500	3,500
Water heater	---	1,115	1,115	1,425	1,100
DHW pre-heat tank	---	---	---	0*	80*
Attic insulation	---	150	150	350	---
Basement wall framing and 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
Cold air return insulate	---	---	75	---	---
Entrance doors	---	---	1,910	---	---
Basement lighting motion sensor	---	---	25	---	---
Window shrink film	10	---	---	10	---
Toilet dams	---	10	10	30	20

	Cost, $				
	D1	G1	G2	G3	G4
Low flow showerheads	---	20	20	---	20
Totals =	4,420	8,240	9,415	7,245	7,225

* metal skin and insulation removed from old water heater

7.3 Electricity Consumption

Prior to the start of the retrofits, the electricity consumption values of the various appliances that might be replaced in each house were measured either using a kilowatt hour meter for a period of seven days or an instantaneous watt meter (on devices such as the furnace blower motor).

Table 7.3.1: Measured Electrical Consumption Values (Pre Retrofit and Post Retrofit)

Appliance	Electricity Consumption									
	D1		G1		G2		G3		G4	
	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post
Refrigerator 1 (kWh/year)	1616	324	426	not changed	1741	413	487	not changed	1164	543
Refrigerator 2 (kWh/year)	467	not changed	N / A	N / A	N / A	N / A	1121	unplugged	N / A	N / A
Clothes washer (kWh/year)		not changed		52.1		67.8		39.5		54.3
Freezer 1 (kWh/year)	318	not changed	574	not changed	681	279	1472	432	672	not changed
Freezer 2 (kWh/year)							867	removed	N / A	N / A
Furnace fan (low), watts		280	N / A		N / A		270		N / A	
Furnace fan (high), watts		560	703	323	290	380	420	230	360	800

Note - the values in this table are not normalized using heating degree days values

7.4 Furnace Combustion Efficiency

Furnace combustion efficiencies were measured with a combustion efficiency meter. Measurements were taken near the furnace and also at the end of the exhaust pipe to determine the effect on the efficiency as the exhaust air cools as it leaves the house.

Table 7.4.1: Furnace Combustion Efficiency (Post Retrofit)

Case House	Combustion efficiency near furnace	Combustion efficiency near end of exhaust pipe
D1	78.8	N / A
G1	92.6	92.3
G2	91.4	93.3
G3	92.3	92.3
G4	90.9	92.3

Using the same combustion efficiency meter, carbon dioxide values and the temperature rise of the combustion gases were also measured.

Table 7.4.2: Furnace Carbon Dioxide Concentration and Temperature Difference (Post Retrofit)

Case House	Carbon dioxide concentration, %	Temperature rise of combustion gases, ΔT (°C)
D1	5.6	166
G1	4.7	13.9
G2	5.2	13.3
G3	5.0	15.0
G4	5.7	17.2

Note: House D1 is the only house that installed a mid-efficiency furnace instead of a high-efficiency furnace. All of these temperature rises fall within manufacturer specifications.

7.5 Water Heaters

Combustion efficiency measurements were taken pre retrofit and post retrofit at each of the case houses (pre retrofit combustion efficiencies are listed in Table 5.5.1).

Table 7.5.1: Water Heaters

	CASE HOUSE				
	D1	**G1**	**G2**	**G3**	**G4**
Post retrofit combustion efficiency, %	80.5	83.4	71.9*	80.2	83.8
Post retrofit - Make	State	Giant	John Wood	John Wood	Rheem
Post retrofit - Model	no change	UG40-36LEPV-NIU	JW402NVH-08	SuperFlue	1000J06008
Peak electricity consumption, watts (glow plug on)	N / A	650	503	500	N / M
Steady state electricity consumption, watts**	N / A	83	95	90	69

* very high combustion air flow - large diameter exhaust path contributes to low reading
** during steady state operation the glow plug is off and only the blower fan is drawing electricity

7.6 Case Houses - Energy Consumption

The following table presents the energy consumption reduction for the five case houses after the retrofit measures were installed.

Table 7.6.1: Case Houses - Energy Consumption Reduction, %

Note: The values in this table have been normalized to the long term annual average heating degree days (6077).

	D1	G1	G2	G3	G4
Natural gas consumption reduction, %	30.4	45.0	29.0	27.5	25.9
Electricity consumption reduction, %	9.1	2.4	15.4	40.8	6.4
Total energy consumption reduction, %	26.5	39.9	26.9	30.8	23.9

7.7 Control Houses - Energy Consumption

The following table presents the changes in energy consumption for the five control houses (inc = increase, dec = decrease) over the same period of time as for the case houses.

Table 7.7.1: Control Houses - Energy Consumption

	C-GW1	C-L1	C-M1	C-M2	C-Y1
Annual Measured Consumption					
Natural gas consumption, %	1.0 dec	14.8 dec	36.5 inc	1.5 inc	6.8 inc
Electricity consumption, %	25.7 inc	6.6 dec	1.7 inc	3.0 dec	17.6 inc
Total energy consumption, %	3.0 inc	13.2 dec	26.8 inc	0.6 inc	8.6 inc
Annual Heating Degree Day Normalized Consumption					
Natural gas consumption, %	2.9 inc	6.4 dec	2.4 inc	6.8 inc	2.8 inc
Electricity consumption, %	7.5 inc	3.3 dec	0.2 dec	5.5 dec	5.8 inc
Total energy consumption, %	3.7 inc	5.8 dec	1.8 inc	4.3 inc	3.2 inc

Note: The values in the last three rows of this table have been normalized to the long term annual average heating degree days (6077).

8 DISCUSSION

The discussion is divided into several sections starting with the case houses for the pre retrofit and post retrofit periods. Following those sections, general discussion sections are presented of other project parameters including the Saskatoon weather data.

8.1 Utility Data Results - Case Houses

This section is divided into the pre retrofit and post retrofit periods for the five case houses.

8.1.1 Case Houses - Pre Retrofit

Pre retrofit graphs of the electricity, natural gas, and water consumption for the five case houses are presented in Appendix B. Project participants each signed an "Authorization to Release Billing Data" form enabling SRC to obtain utility information from the utility companies. The utility companies in Saskatchewan estimate the consumption values for the months when meter readings are not performed. For this research only the "actual" meter readings were used for the graphs. Occupancy levels did not change for any of the houses from the pre retrofit to the post retrofit.

The actual meter readings were input into a spreadsheet that calculated consumption per day for the appropriate time period. A lookup table with Saskatoon heating degree-days was used to plot consumption versus the degree days (base 18 degrees C).

8.1.1.1 Pre Retrofit - House D1

House D1 was built in 1973. The basement was completely unfinished. The furnace fan was run continuously. Central air conditioning was in place. A second refrigerator was in use. The house had two occupants. Only a small number of pre retrofit water consumption values were available from the utility.

8.1.1.2 Pre Retrofit - House G1

House G1 was built in 1911. The basement was completely unfinished. The house had four occupants that were very energy conscious. The house was not very air tight as it had been moved onto its present foundation from a previous location in the city.

8.1.1.3 Pre Retrofit - House G2

House G2 was built in 1912. It had six occupants. It had one natural gas-fueled fireplace. The basement was almost completely insulated and finished.

8.1.1.4 Pre Retrofit - House G3

House G3 was the newest house in the project (built in 1986) and as such had the highest level of wall insulation and was the most airtight of the case houses. Electricity consumption was high as there was central air conditioning in place as well as two old chest-type freezers and a second refrigerator in use. Deep setback (4.5 °C) was used on the thermostat for both daytime and nighttime periods. The basement of the split-level house was completely finished. The family room had one wood-burning fireplace. There were four occupants in this house.

8.1.1.5 Pre Retrofit - House G4

House G4 was built in 1920 and moved to its present location in 1960. The basement was almost completely finished. It had five occupants.

8.1.2 Case Houses - Post Retrofit

Utility meters were read by the SRC staff on a once a week basis. Project participants also provided some utility meter readings. In a manner similar to the pre retrofit calculations, the actual meter readings from the homeowners and SRC staff were input into a spreadsheet for processing with Saskatoon heating degree-days and used in plots. The graphs are presented in Appendix B.

8.1.2.1 Post Retrofit - House D1

Most of the recommended retrofit measures were implemented including the framing and insulating of the complete basement perimeter, the purchase of a new refrigerator, the use of compact fluorescent lighting, the installation of a medium-efficiency furnace, the insulating of the existing water heater, and use of a setback thermostat. Retrofit measures not implemented included unplugging of the second refrigerator (in the basement), installation of window film, and reduction in furnace fan run times. Strips of polystyrene insulation were added to the bottom 150 mm of most of the windows on the exterior (practice employed in Saskatoon to reduce condensation on the interior windows).

An Air Cycler™ for the furnace fan operation was provided to the homeowner but was not installed due to installation problems on the two speed furnace fan motor.

Natural gas consumption decreased by 30.4% (HOT2000 prediction = 46.4%) in the post retrofit period. This reduction was largely due to the new furnace and the insulating of the basement walls.

Electricity consumption decreased by 9.1% (HOT2000 prediction = 31.2%). The replacement of the refrigerator and the use of CFLs were the major portion of the decrease. The use of the continuously running furnace fan was the major factor that prevented reaching the predicted reduction.

It was anticipated that the combustion efficiency of the retrofit furnace could be increased to 84% by decreasing the gas input flow to the furnace, and increasing the furnace warm air flow. Both measures were implemented by an experienced furnace service person, but neither measure had an appreciable effect on the furnace efficiency, which remained in the 78% range.

The overall energy consumption decrease for electricity and natural gas was 26.5% (HOT2000 prediction = 43.8%) for the post retrofit period (All consumption values have been normalized to long term annual heating degree day values). Reasons for the variance between actual and predicted include the following:

a) increased central air conditioning use. The summer of 2002 (183.6 annual cooling degree days) was warmer than 2001 (168.9 annual cooling degree days),
b) the use of the continuously running furnace fan, and
c) the inability to improve the furnace combustion efficiency from 78% to 84%.

This house had three CFL lamp failures (purchased from Home Depot - brand name - Pricemark).

8.1.2.2 Post Retrofit - House G1

All of the recommended retrofit measures were implemented including the major ones such as installation of a new high efficiency condensing furnace with setback thermostat, power vented water heater, the sealing of the old chimney, the purchase of a front loading clothes washer, and the framing and insulating of the entire basement perimeter. Air tightening was also a focus during the basement construction process. The entire rim joist was sealed as the house has tongue and groove flooring extending to the outside wall. To accomplish this the homeowner removed vinyl siding panels to expose the ends of the sub-floor board. The air tightness improved from 6.34 air changes per hour at 50 Pascals to 3.88 air changes per hour at 50 Pascals.

Natural gas consumption decreased by 45.0% (HOT2000 prediction = 44.0%). This was largely due to the new furnace, the elimination of two pilot lights, the insulating of the water heater, the air tightening of the building envelope, and the insulating of the basement walls. The combustion efficiency of the furnace was measured at 92.3% which is lower than the rated efficiency of 94%.

Electricity decreased by 2.4% (HOT2000 prediction = 23.7%). The small decrease is partly explained by the addition of the power vent motors on the furnace and water heater, and the use of a limited number of CFLs due to problems with size. The downsizing of the furnace input capacity meant that the furnace would have been on for longer periods of time. This house had the lowest electricity consumption, in the pre retrofit period, of the case houses, which made electrical savings more difficult.

The total energy consumption decrease for electricity and natural gas was 39.9% (HOT2000 prediction = 42.0%) for the post retrofit period.

8.1.2.3 Post Retrofit - House G2

Most of the recommended retrofit measures were implemented including the installation of a high efficiency condensing furnace, a power vented water heater, a new front loading clothes washer, refrigerator, freezer, attic insulation, CFLs, three new insulated entrance doors, and removal of the old chimney. The air tightness only improved slightly, however, reducing from 7.71 ACH @ 50 Pa to 7.22 ACH @ 50 Pa. The entire house, with the exception of the furnace room, was finished, making it very difficult to access the air leakage areas at the floor joists.

Natural gas consumption decreased by 29.0% (HOT2000 prediction = 38.5%). The savings were largely due to the new furnace and insulated water heater. Limited air tightening was performed due to accessibility problems. Insulation was added to the old cold air returns in this balloon-framed house. More hot water was expected to have been used in the post retrofit period due to the addition of a new dishwasher and an expected increase in number and duration of showers taken by teen age children.

Electricity decreased by 15.4% (HOT2000 prediction = 46.9%). This variance is partly attributable to the addition of a dishwasher in the post retrofit period and the addition of two power vent motors (high efficiency furnace and power vent water heater).

Total energy consumption decreased by 26.9% (HOT2000 prediction = 39.8%) for the post retrofit period.

Problems encountered during the post retrofit period included the failure of some Home Depot - brand name - Pricemark CFL lamps and the failure of the gas valve on the water heater which led to a flood in the basement requiring a service company to come in and clean up the whole basement. The gas valve stuck when the water temperature was turned up which then caused the burner to run continuously until the pressure relief valve opened causing the flood. Following the repair to the water heater, solid copper pipe was plumbed from the relief valve to the floor drain (located at a high spot in the floor).

One motion sensing wall switch was installed in the basement family room to control wall-mounted light fixtures. The homeowner indicated that these fixtures were often left on in the pre retrofit period. The motion sensor switch worked satisfactorily in this application.

8.1.2.4 Post Retrofit - House G3

Most of the recommended retrofit measure were implemented for this house. Major measures included the installation of a sophisticated, variable capacity, high efficiency, condensing furnace (with a DC variable speed blower fan motor), power vented water heater, CFLs, a front loading clothes washer, and the purchase of one new energy efficient freezer to replace two old inefficient freezers.

The natural gas consumption decreased by 27.5% (HOT2000 prediction = 28.3%). The savings were largely due to the new furnace and water heater and the installation of insulation on the new water heater. The old water heater was stripped of the exterior metal skin and insulation to act as pre-heat tank.

The electricity consumption decreased by 40.8% (HOT2000 prediction = 69.8%). The pre retrofit electricity consumption totalled 12,732 kWh/year and decreased to 7,541 kWh/year for the post retrofit period. This is mostly attributable to the new freezer replacing the two old ones, the new low wattage furnace blower motor, CFLs (including three dimmable ones), and the unplugging of the second refrigerator in the basement.

The total energy consumption decreased by 30.8% (HOT2000 prediction = 40.0%). Shorter periods of temperature setback during the heating season and the hot summer in 2002 which increased central air conditioning use contributed to the difference between actual and predicted.

8.1.2.5 Post Retrofit - House G4

Most of the recommended retrofit measures were implemented with the exception of attic insulation and air tightening measures. The home owner had a larger furnace than recommended installed in their home (Installed: 30.8 kW (105,000 Btu/hr) Recommended: 26.4 kW (90,000 Btu/hr)). The blower fan motor in the new furnace draws 800 watts of electricity while the original furnace blower fan motor used 413 watts. Some of the measures that were implemented included the power vented hot water heater, front loading clothes washer, refrigerator, extensive use of CFLs, and water conserving devices.

Some other factors that affected the energy reductions include a small flood in the basement, in the spring of 2002, that required the use of the furnace fan as well as some other large fans for six days, removal of the window trims to facilitate new window coverings, and the move of one of the children into the basement where additional lighting was used, and the addition of a second computer that is on all the time (using some of the power down features).

The air tightness of the house was improved from 6.26 ACH @ 50 Pa to 5.72 ACH @ 50 Pa. As with house G2, the house was almost completely finished, and access to the walls for air sealing was not possible.

For the post retrofit period the electricity consumption decreased by 6.4% (HOT2000 prediction = 30.9%). The main reasons for this discrepancy are the largely oversized furnace blower fan motor and the move of the daughter into the basement.

The natural gas consumption decreased by 25.9% (HOT2000 prediction = 41.5%). The main reasons for this discrepancy was the lack of air tightening performed and the possibility that the hot water temperature was set higher than necessary for most of the post retrofit period.

Total energy consumption decreased by 23.9% (HOT2000 prediction = 40.1%) for the post retrofit period.

8.2 Case House Energy Reduction Using Control Houses Data

The utility data of the five control houses were obtained from the utility companies similar to the case houses. The post retrofit date of December 2001 was used as the start for all of the post retrofit graphs. The control house data was not normalized using heating degree days. The occupancies did not change in the control houses during the pre retrofit and post retrofit periods, except that the occupants in house C-L1 were away on holidays for the month of May in 2002.

The pre retrofit and post retrofit graphs are presented in Appendix C.

Three of the five control houses had higher natural gas consumption in the post retrofit period than in the pre retrofit period. Heating degree-days were 12.8% higher in 2002 (6044.9 HDD) than in 2001 (5358.8 HDD).

The post retrofit annual natural gas consumption of all five of the control houses increased by 3.7% (627.8 m^3 / year) on average compared with the pre retrofit consumption (mainly due to the post retrofit period being colder than the pre retrofit period). The post retrofit electricity consumption of all five of the control houses increased by 6.3% (2581 kWh/year) on average compared with the pre retrofit consumption (due, in part, to the increased use of heating systems due to the colder post retrofit period). If house C-L1, whose occupancy changed from the pre retrofit to the post retrofit periods (one month of holidays away from home), is ignored the increases in total natural gas and electricity consumption become 7.7% (1077 m^3 / year) and 9.2% (3084 kWh / year), respectively.

Assuming that the natural gas and electricity consumption values for each of the case houses increased by the same percent as for the control houses the percent savings for each of the case houses would be as shown in the following table.

Table 8.2.1: Corrected Energy Use Reductions for the Case Houses

	D1	G1	G2	G3	G4
Using data from all control houses					
Natural gas savings corrected	33.8%	40.5%	36.2%	27.0%	23.8%
Electricity savings corrected	14.6%	5.4%	30.7%	49.3%	9.3%
Total savings corrected	*29.1%*	*35.0%*	*34.4%*	*32.3%*	*21.4%*
Ignoring control house C-L1					
Natural gas savings corrected	38.9%	45.6%	41.4%	32.2%	29.0%
Electricity savings corrected	18.0%	8.8%	34.1%	52.8%	12.7%
Total savings corrected	*33.7%*	*39.6%*	*39.0%*	*36.9%*	*26.0%*

Note: these values were determined by a direct addition of the average percent change in the control house annual consumption amounts to the average percent change in the case house annual consumption amounts.

8.3 Retrofit Costs

Table 7.2.1 presented the costs of the various retrofit measures for each case house. The values were obtained from the project participants.

G1, G2, G3, and G4 had high efficiency condensing furnaces installed in their homes. Thus the furnace costs are similar. The installed costs of the furnaces ranged from $3,335 to $3,500. Similarly, the same houses had power vented water heaters installed. The installed costs for the water heaters ranged from $1,115 to $1,425.

House G2 purchased more major appliances than was recommended to meet the project objectives. As well, they were also given a dishwasher as a gift, so the cost of that appliance upgrade is not included in the totals. The same house had three new steel entrance doors installed at a total cost of $1,910.

House D1 had the lowest total for retrofit costs as the house was modelled as not requiring a high efficiency condensing furnace to meet the project objectives. House D1 did not purchase a new water heater.

Houses D1 and G1 both framed and insulated the total perimeter of their basements. Sweat equity for the labour is not included in the cost of this retrofit measure as both homeowners performed all of the construction themselves.

SRC provided water heater insulation kits, toilet dams, pipe insulation, some CFLs, and some window shrink film to the project participants. These costs are included in the totals. SRC also provided carbon monoxide detectors to homes that did not already have one.

8.4 Electricity Consumption

Table 7.5.1 presented pre retrofit and post retrofit measured electricity consumption values for each of the major electricity using appliances for each house. Kilowatt hour meters or instantaneous watts meters were used to measure the actual electricity use of the appliances for an approximate one week period for the pre retrofit and post retrofit periods. The instantaneous watts meter was used to measure the wattage of the furnace fan motors, the furnace power vent motors, and the water heater power vent motors.

Major electricity savings were obtained by replacing the refrigerators or freezers for three of the houses. House G3 removed two old freezers and replaced them with one more efficient model. This reduced consumption from 2339 kWh/year to 432 kWh/year.

Electricity consumption values are presented in Appendix F for some of the power vent motors for the four new condensing furnaces. Those values ranged from 52 watts to 101 watts. Also shown was the electricity consumption for the power vent motors for the new water heaters. Those values ranged from 69 watts to 95 watts.

8.5 Furnace Combustion Efficiency

Furnace combustion efficiencies were studied as part of the project. Measurements made near the envelope penetration point on the exhaust system indicated higher combustion efficiencies than closer to the condensing furnaces in two of the houses. One house had a slightly lower combustion efficiency at the envelope penetration point while the fourth house with a condensing furnace had the same efficiency at both locations.

8.6 Water Heaters

Four of the houses installed power vented water heaters. The combustion efficiencies of the water heaters ranged from 71.9% (House G2) (see explanation Table 7.5.1) to 83.8% (House G4).

The temperature of the water delivered to Saskatoon homes during the fall and early winter of 2002 was considerably colder than usual because of ongoing repairs at the water treatment facility. Typically the water is delivered in the eight to ten degrees Celsius range but lately it has been in the three to four degrees Celsius range. This would increase the run time of the water heaters.

Chimneys were removed or capped when power vented hot water heaters were used in conjunction with side-wall vented, high efficiency, condensing furnaces.

8.7 Weather Data

Weather is an overall factor for all of the houses in the project. Data was collected for Saskatoon for 2001 and 2002 to determine how heating degree days, cooling degree days, hours of sunshine, and global radiation impacted on the energy consumption for the case and control houses. For the year 2002, heating degree days were higher (6044.9) than the year 2001 (5358.8) by 12.8%. This would translate into higher natural gas and electricity use in the post retrofit period. Although natural gas (and electricity) consumption values were normalized to the annual heating degree days they were also influenced by annual hours of sunshine and cooling degree days. The consumption values have only been normalized by the heating degree days throughout this report.

The annual sunshine hours in 2002 (2361.5 hours) were 6.2% lower than those experienced in 2001 (2518.1 hours), while the cooling degree days in 2002 (183.6) were 8.7 % higher than in

2001 (168.9). The lower sunshine hours in 2002, combined with higher cooling degree days would both tend to increase the annual energy consumption.

The weather data for the years are presented in the following table.

Table 8.8.1: Saskatoon - Heating Degree Days (HDD) and Hours of Sunshine (Environment Canada Data)

Month/Year	HDD	HDD Normal	Cooling Degree-Days	Cooling Degree-Days Normal	Sunshine (hours)	
					Duration	Normal
Jan/2002	1011.7	1103.8	0	0	89.9	104.6
Feb	745.9	902.8	0	0	150.5	134.1
Mar	980.6	776.8	0	0	204.3	174.6
Apr	555.7	423.0	0	0.3	249.3	229.4
May	287.4	209.9	4.0	7.0	349.1	285.7
June	69.5	81.8	48.9	21.9	242.1	297.2
July	28.5	36.4	92.1	42.0	328.4	330.3
Aug	77.3	61.4	34.5	40.9	244.3	295.2
Sept	202.3	207.4	4.1	4.7	216.4	184.4
Oct	585.1	420.1	0	0	131.6	160.7
Nov	670.4	726.2	0	0	89.3	100.9
Dec	830.5	1001.8	0	0	66.3	83.7
TOTALS 2002	**6044.9**	**5951.4**	**183.6**	**116.8**	**2361.5**	**2380.8**
Jan/2001	835.6	1103.8	0	0	96.3	104.6
Feb	997.4	902.8	0	0	134.8	134.1
Mar	654.3	776.8	0	0	222.5	174.6
Apr	404.4	423.0	3.2	0.3	204.1	229.4
May	177.0	209.9	4.8	7.0	303.6	285.7

Month/Year	HDD	HDD Normal	Cooling Degree-Days	Cooling Degree-Days Normal	Sunshine (hours)	
					Duration	Normal
June	88.9	78.4	11.5	24.0	286.9	297.2
July	16.1	30.9	67.3	48.2	308.4	330.3
Aug	19.5	60.1	76.0	41.9	368.4	295.2
Sept	128.9	210.1	6.1	5.5	275.4	184.4
Oct	485.0	409.0	0	0	148.2	160.7
Nov	578.6	721.1	0	0	86.2	100.9
Dec	973.1	1018.2	0	0	83.3	83.7
TOTALS 2001	**5358.8**	**5944.1**	**168.9**	**126.9**	**2518.1**	**2380.8**

9 RECOMMENDATIONS FOR OTHER SIMILAR STUDIES

Future research projects of this type should monitor the temperature of the water being delivered to research homes.

Meter readings should be taken monthly for the pre retrofit period as well as the post retrofit period to ensure that the data is statistically significant (the residential utility meters in Saskatoon are read by the utilities only four times a year).

10 LESSONS LEARNED

a. Electricity consumption varied widely for the furnace blower motors in the high efficiency condensing furnaces. House G4 had a very high electricity consuming motor (800 Watts) while G3 had the most efficient motor (230 Watts, DC variable capacity motor).

b. It would have been interesting to study the use of a tankless instantaneous water heater in one of the houses in place of a power vented water heater.

c. It appears that the power vented water heaters deliver very little energy savings when you factor in the use of the power vented motor. The power vented water heaters are safer than atmospheric vented models as there is no backdrafting and the chimney can be eliminated if a side-wall vented furnace is used.

d. Homeowner cooperation is crucial to a project of this type where the cost of the retrofits are their responsibility. It is very important to keep them informed and a part of the project as the monitoring and testing in their homes is inconvenient to them.

e. Do not rely on homeowners to take regular utility meter readings.

f. There were a number of CFL failures (brand name Pricemark purchased from Home Depot) during the project. At an approximate cost of $8.00 each, the failed CFLs provided a very poor rate of return. Size and start time are two considerations when purchasing CFLs. The duty cycle of the CFL should also be considered.

g. One homeowner had three furnaces installed before the correct model was installed. Neither the local heating contractor nor the manufacturer could satisfactorily explain the subtle model number differences so the homeowner insisted in getting what he ordered.

h. The project participants with the power vented water heaters find them very noisy.

i. When paying an honourarium to project participants, do not pay it until all the retrofit work is completed (for this project it was paid after the majority of the retrofits were performed; as a consequence there was no motivating factor for the home owners to finish the retrofits).

j. With a project of this type, it would have been desirable to have a longer period of time with regular meter readings for the pre retrofit period. Utility company readings are sometimes lacking, due to the low frequency of actual meter readings performed by the utility, leading to a shortage of data points.

k. Sub-metering on appliances, furnace, and water heater would have provided much more detailed and interesting data, and allow for a more accurate comparison of pre retrofit and post retrofit performance.

l. Water heater insulation kits were not available commercially at the insulating values desired. RSI 0.7 (R 4) insulating kits are available but the project called for RSI 3.5 (R 20) insulation to be added to the hot water heaters. Therefore, RSI 3.5 (R 20) fibreglass batts were cut into barrel staves and held against the hot water heater using foil backed bubble insulation.

m. The electricity consumption of various major appliances turned out to be very interesting. The replacement or non-use of certain appliances provided an attractive rate of return.

n. The air tightness projected values input in HOT2000 were difficult to attain due to accessibility problems, as a number of house were almost completely finished on the inside.

o. The temperature of the water delivered to the houses is important. The temperature of the water delivered to the houses in the fall/winter of 2002 was considerably colder than normal due to ongoing equipment problems at the Saskatoon water treatment facility.

11 CONCLUSIONS

11.1 Project objective for energy savings

The project objectives of 40% savings were attained in one house, one was in the 30% range, and the lowest at 23.9% (when looking at the annual heating degree days normalized data). The results obtained using the control houses (excluding C-L1) show that one house reached the objective with savings of 39.6%, three others were in the 30% range (39.0%, 36.9% and 33.7%), while the remaining house had savings of 26.0%.

11.2 Homeowner satisfaction

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

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

The project provided impetus for House D1 and G1 to complete their basements making them more comfortable and usable.

11.3 Major deficiencies

There were a few major deficiencies.

The computer model predicted savings and the actual savings were not always in agreement. Model input values, such as levels of air tightness and expected electricity usage, were not attained.

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

House G3 was initially reluctant to unplug the refrigerator in the basement but consented to do so during the post retrofit period.

House D1 refused to unplug the basement refrigerator. For this house, HOT200 predicted that a mid-efficiency furnace would be sufficient to attain the 40% savings if the combustion efficiency could have been raised to 85%. This proved to not be attainable. This house also continued to use continuous fan circulation on the furnace. This was the single largest electrical load in the house.

12 REFERENCES

Unies Ltd. Energy Demo: Home Energy Saving Demonstration Program. 1985. Manitoba Energy and Mines

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APPENDIX A

Solar Odyssey 2001, SESCI Conference Technical Paper
"Reducing the Energy Consumption of Six Houses by 40% Each"

by

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Reducing the Energy Consumption of Six Houses by 40% Each

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ABSTRACT

The Building Performance Section of the Saskatchewan Research Council undertook a Canada Mortgage and Housing Corporation contract in 2000 aimed at reducing the energy consumption in six existing houses by 40% or more. According to the request for proposal the project is

designed to produce clear and demonstrable energy savings in existing houses through energy retrofitting, so that these houses can be used as benchmarks (CMHC, 2000).

Homeowners in Saskatoon were solicited for involvement in the program either directly or through word of mouth. The six homes chosen to participate in the project have construction dates ranging from 1911 up to 1986 and are of many different designs (split level, one storey, two storeys, walkout basement, and one and three quarter storeys).

At the start of the project each house was examined to determine its energy characteristics. Consumption meters were used to determine the energy use of the appliances in the homes, and a combustion efficiency meter was used to obtain the combustion efficiencies of the furnaces and hot water heaters. Readings of the natural gas, electricity, and water meters were also collected. Blower door tests were performed on each of the homes. Each home was then modeled in the NRCAN software package HOT2000. This software models the energy use of a home and provides a quick method to determine which retrofit options will provide the greatest energy savings.

Based on the computer model of each house a retrofit package was created for each of the home owners and presented to them over the course of the summer of 2001. At the time of this writing all of the home owners are proceeding with the retrofit options suggested. Over the course of the next year the utility meters at each of the homes will be monitored to determine the actual reduction in energy consumption. Other performance measures such as the air tightness of the house, combustion efficiencies of new furnaces and water heaters, and electrical appliance use will also be measured.

INTRODUCTION

The Building Performance Section (BPS) of the Saskatchewan Research Council (SRC), undertook a Canada Housing and Mortgage Corporation (CMHC) contract in 2000 looking at reducing the energy consumption in existing houses by 40% or more. To entice homeowners to perform the retrofits, the costs had to be kept reasonable.

One of the driving forces behind this research is Canada's involvement in the Kyoto Protocol. The Kyoto Protocol provides legally binding limits on the production of greenhouse gases with a goal of reducing total world production of greenhouse gases to levels 5% lower than those of 1990. The CMHC report "Residential Retrofit Potential in Canada" (1996) indicates that 82% of the current houses in Canada would need to have their total energy use reduced by 40% if Canada's residential greenhouse gas production is to be returned to the 1990 levels.

The project guidelines called for the homes to be of varied design, age, size, initial conditions, constructions, etcetera. The homeowners chosen had to be willing to pay all of the costs of the energy retrofits themselves.

A similar project was undertaken in Manitoba in 1985 (Unies 1985). The Manitoba Energy Demo: Home Energy Demonstration Program looked at eighty-three privately owned, single family, detached houses of varying age, size, and construction with the energy use reduction goal of 40%. The actual energy savings measured in the home sample averaged at 26.3%. The Manitoba project found that insulation of basements and other areas that were found to be cool during the heating season mainly created an increased level of comfort in those areas, and smaller energy savings were realized than anticipated.

For the current project, recruitment of home owners was performed within SRC and through word of mouth. At the end of the selection period four homeowners from within SRC and two from outside of SRC were chosen. Upon completion of the renovations each homeowner will receive a $1000 honorarium from SRC. Following is a brief summary of the six houses chosen for the project.

The first house was built in 1973. This one storey house has approximately 167 m^2 total floor area including the basement. There are two occupants. The house faces North-South. The pre-retrofit normalized annual natural gas consumption was 4,271 m^3. The pre-retrofit normalized annual electricity consumption was 9,598 kWh.

The second house was built in 1911. This two storey house has approximately 203 m^2 total floor area and four occupants. The house faces North-South. The pre-retrofit normalized annual natural gas consumption was 4,009 m^3 and the electrical consumption was 5,811 kWh.

The third house was built in 1912. This one and three quarter storey house has 195 m^2 total floor area. There are six occupants. There is a natural gas fireplace. The house faces North-South. The pre-retrofit normalized annual natural gas consumption was 4,524 m^3 and the normalized annual electrical consumption was 8,614 kWh.

The fourth house was built in 1986. This split level house has 253 m^2 total floor area. There are four occupants and one wood fireplace. The house faces East-West. The pre-retrofit normalized annual natural gas consumption was 3,185 m^3 and the normalized annual electrical consumption was 13,089 kWh.

The fifth house was built in 1920 and moved into its current location in 1960. This two storey house has 321 m^2 total floor area. There are five occupants. The house faces East-West. The pre-retrofit normalized annual natural gas consumption was 6,472 m^3 and the normalized annual electrical consumption was 7,681 kWh.

The last house was built in 1949 and is a one storey house with a walkout basement. The total floor area is 229 m^2. There are two occupants. The house faces East-West. The pre-retrofit normalized annual natural gas consumption was 5,093 m^3 and the normalized annual electrical consumption was 8,477 kWh.

The annual energy consumption of the six houses ranged from 170 kWh/m^2 of floor area to 298 kWh/m^2 of floor area, with an average of 231 kWh/m^2 of floor area.

METHODOLOGY

To determine the initial energy consumption of the homes, past utility records were secured from the natural gas, electricity, and water utilities.

An examination of the appliances in each of the homes was performed. The electrical consumption of appliances in the homes which were likely to be replaced were measured (fridges, freezers, furnace fan motors). The combustion efficiency of the furnaces and hot water heaters in each home was measured using a combustion efficiency meter. During a walk through of each home SRC staff recorded the location, type, wattage, and approximate usage time of all lights.

To determine the air tightness of each home a blower door test was performed using a blower door assembly. This assembly, which consists of an adjustable support frame, an airtight fabric, the variable speed blower fan, and two micro manometers (used to measure the pressure across the assembly), was installed in an exterior door of the house. With the fan running a negative pressure is created in the home. By walking around the inside of the house and checking around windows, outlets, doors, floors, ceilings, attic hatches, etc., on exterior walls prominent leakage paths can be located. The pressure measurements across the fan allow for the calculation of the Air Changes per Hour at 50 Pascals (ac/h @ 50 Pa) and Equivalent Leakage Areas (ELA). Reducing the ac/h, by sealing air leakage paths, reduces the heating load in a building. Care must be taken to ensure that adequate ventilation is available to very air tight buildings. The ELA provides an estimate, in square centimetres (cm^2) of the leakage area in the building. The air tightness of the homes varied from a low of 1.76 ac/h @ 50 Pa to 7.7 ac/h @ 50 Pa.

Modeling of each home was performed using the NRCAN software package HOT2000 v8.600. Once each home's specifications were entered into the program it was confirmed that the energy consumption reported by the program agreed to within 3% of the actual energy consumption determined from the utility meter readings. Retrofit options were run through the modeling software to determine the best retrofit package for each home.

RESULTS & DISCUSSION

In the summer of 2001 each of the home owners was presented with the retrofit package for their home. The retrofits were discussed and explained. All of the home owners indicated they were still willing to go ahead with the retrofits.

As an example of some of the retrofit options examined, the retrofit measures for the fifth house are presented below.

The ceilings in the fifth house are a combination of flat and cathedral types. The cathedral type ceilings are filled with shavings; adding insulation to these ceilings would be quite costly. The flat ceilings on the other hand are currently RSI 7.0 (R 40) and would benefit from the addition of another RSI 2.6 (R 16).

The walls on the floors above the basement are filled with shavings; it would also be quite costly to increase the insulation in these walls. The basement is heated and most of the basement walls are finished with an insulation value of RSI 2.1 (R 12), but the north wall is not. It is recommended that this wall be insulated and finished.

The blower door test on this house provided an air leakage rate of 6.26 ac/h @ 50 Pa, which is quite high for Saskatoon houses, and an ELA of 1481 cm^2. This rate is predicted to be cut down to approximately 4.0 ac/h @ 50 Pa by performing air sealing in the attic, insulating and air sealing of the one accessible basement wall, installation of outlet and switch gaskets, and the removal of the chimney.

The conventional atmospheric vented domestic hot water heater is being replaced with an induced draft sidewall venting unit. The existing hot water heater will have its insulating jacket removed and be used as a preheat tank in the water line leading to the new unit.

The current atmospheric vented (vintage 1960) natural gas furnace with standing pilot light is being replaced with a condensing furnace, side wall vented. By having both the furnace and the hot water heater sidewall vented the need for a chimney is eliminated. A study done in 1989 by MacInnes (MacInnes, 1989) looking at 49 furnace upgrades found an average space heating saving of 34% when an atmospheric furnace was replaced with a condensing furnace (savings varied from a low of 18% to a high of 50%). Another item recommended to reduce the energy consumption of the furnace is a programmable clock thermostat. A programmable clock thermostat allows the temperature to be setback for specific periods of time when the house can be maintained at a cooler temperature, for example over night or during the day if the house is unoccupied. It has been suggested that use of a programmable clock thermostat can save as much as 10% of space heating energy use.

The electrical loads in the house are made up of the appliances, the lighting, and other minor devices. Replacement of some of the appliances will reduce the electrical loads substantially. The current refrigerator has an approximate annual measured consumption of 1360 kWh while a new unit would have a consumption in the region of 440 kWh. The home's current top loading washing machine uses approximately 900 kWh per year while the new front loading washing machine is rated at 260 kWh per year. Front loading washing machines have a higher spin cycle speed which tends to reduce the amount of water remaining in clothes after washing. This reduces the energy required by the clothes dryer to properly dry the clothes. This home has approximately 20 lights that can be changed from incandescent to compact fluorescent which are estimated to reduce the lighting load from 1500 kWh per year to 500 kWh per year. The lighting load will also be reduced by the installation of motion sensor switches in three locations inside the home.

The house has 25 windows, one of which is a bay window. Some of the upstairs windows were replaced a short time before the project began and are double glazed, argon filled, windows with a low-E coating. Windows tend to be quite expensive to replace and as such are only recommended as a retrofit option when they are to be replaced for other reasons.

The costs of the retrofits for house five are estimated at $8640; subtracting the $1000 honorarium provides a net retrofit cost to the owner of $7640. The expected annual energy savings for this same house are $990. The rate of return for this house is therefore 11.5% (not counting the honorarium) which correlates to a simple payback period of about nine years.

The retrofit costs, savings, rate of return, and payback period for each house is shown in Table 1.

Table 1: Costs and Returns of Retrofits

House #	Retrofit Cost ($)	Annual Energy Savings ($)	Rate of Return (%)	Payback Period (Years)
1	$5,790	$950	16.4%	6.1
2	$8,880	$750	8.4%	11.8
3	$9,415	$1,040	11.0%	9.1

House #	Retrofit Cost ($)	Annual Energy Savings ($)	Rate of Return (%)	Payback Period (Years)
4	$9,370	$1,070	11.4%	8.8
5	$8,640	$990	11.5%	8.7
6	$6,200	$1,085	17.5%	5.7

As of August 31, 2001 some of the home owners have started having the retrofits installed while others were still receiving quotes.

CONCLUSIONS

According to the HOT2000 model each of the six houses examined in this test will be able to achieve a 40% reduction in their energy consumption at a reasonable price. The upcoming year of measurements will show if the retrofits manage to reduce the energy consumption by 40% (normalized to long term weather conditions).

ACKNOWLEDGMENTS

The authors acknowledge the financial support of Canada Mortgage and Housing Corporation, and the assistance of Mr. Don Fugler, who is the project manager at CMHC. The enthusiastic cooperation of the six families involved is also gratefully acknowledged.

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APPENDIX B

Graphs of Natural Gas, Electricity, and Water Consumption
Pre- and Post-Retrofit Case Houses

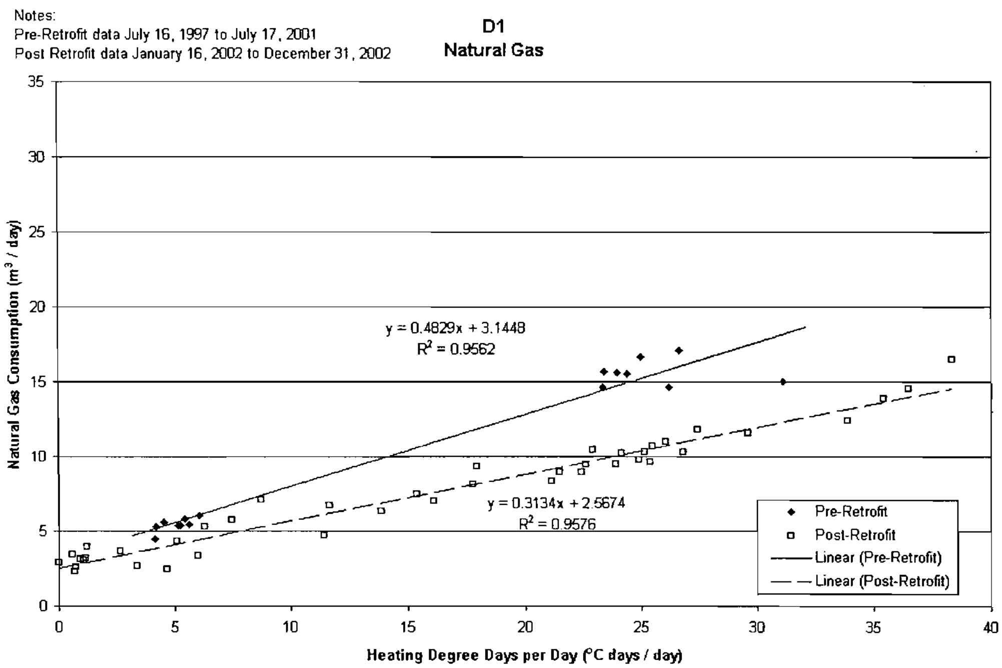

Figure B.1: House D1 Pre Retrofit and Post Retrofit Natural Gas Plot

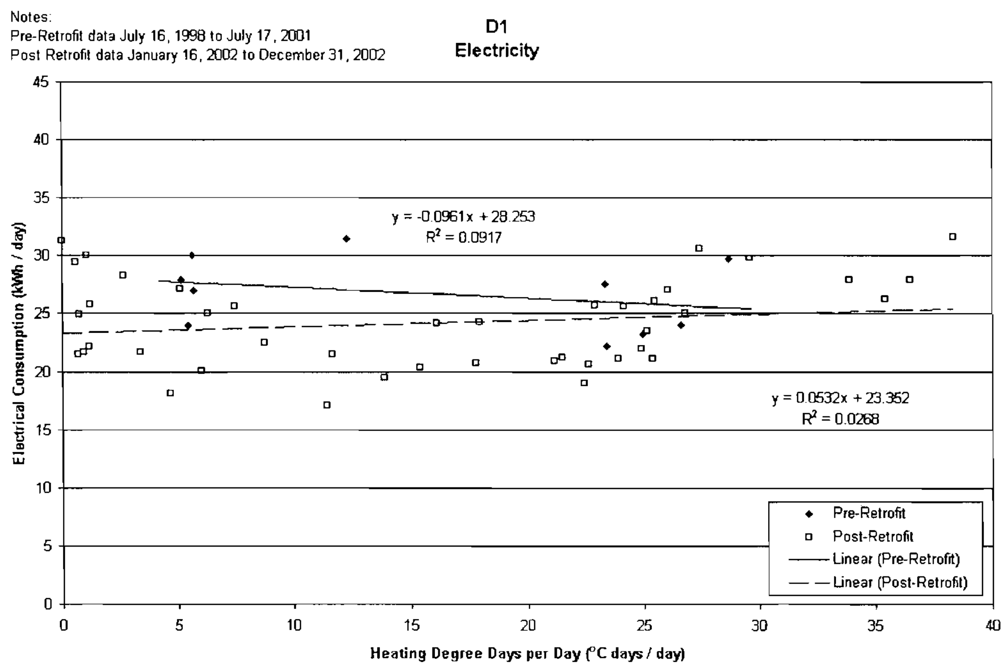

Figure B.2: House D1 Pre Retrofit and Post Retrofit Electricity Plot

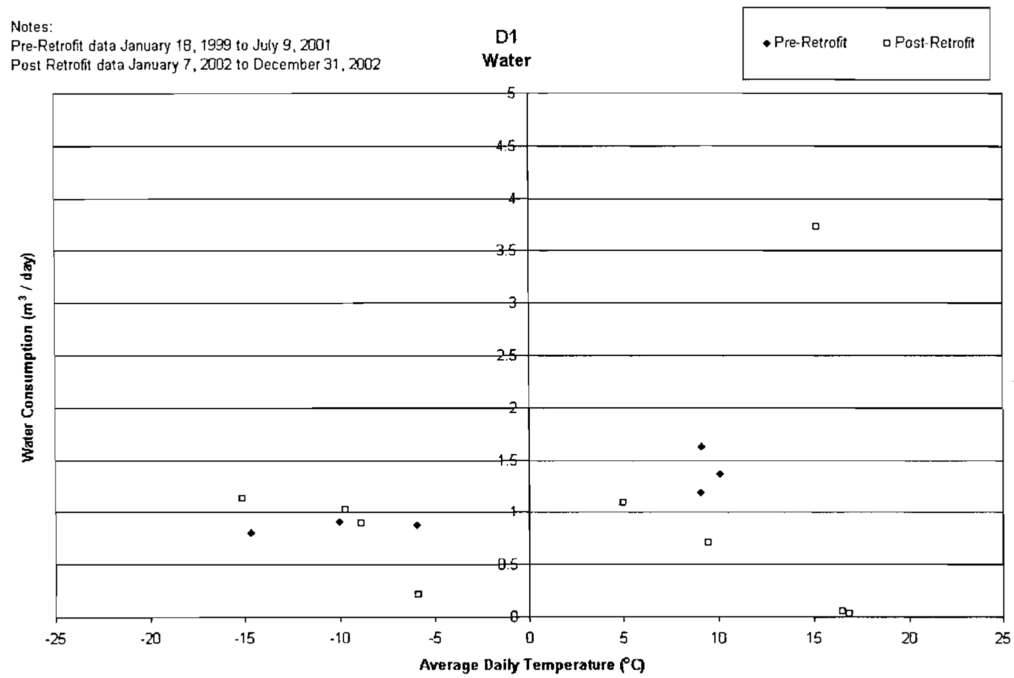

Figure B.3: House D1 Pre Retrofit and Post Retrofit Water Plot

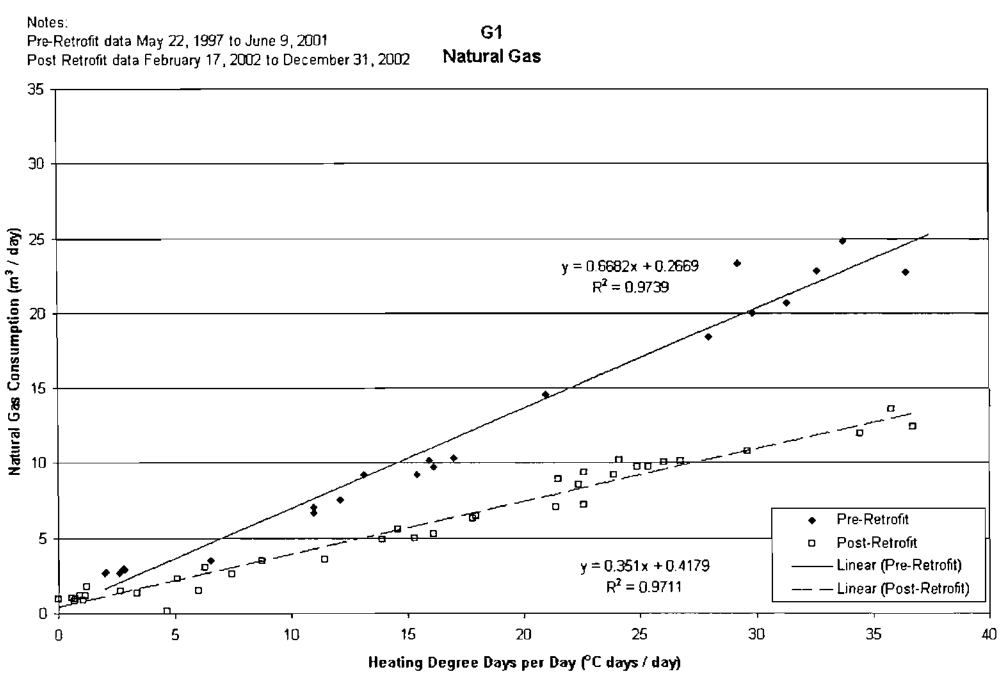

Figure B.4: House G1 Pre Retrofit and Post Retrofit Natural Gas Plot

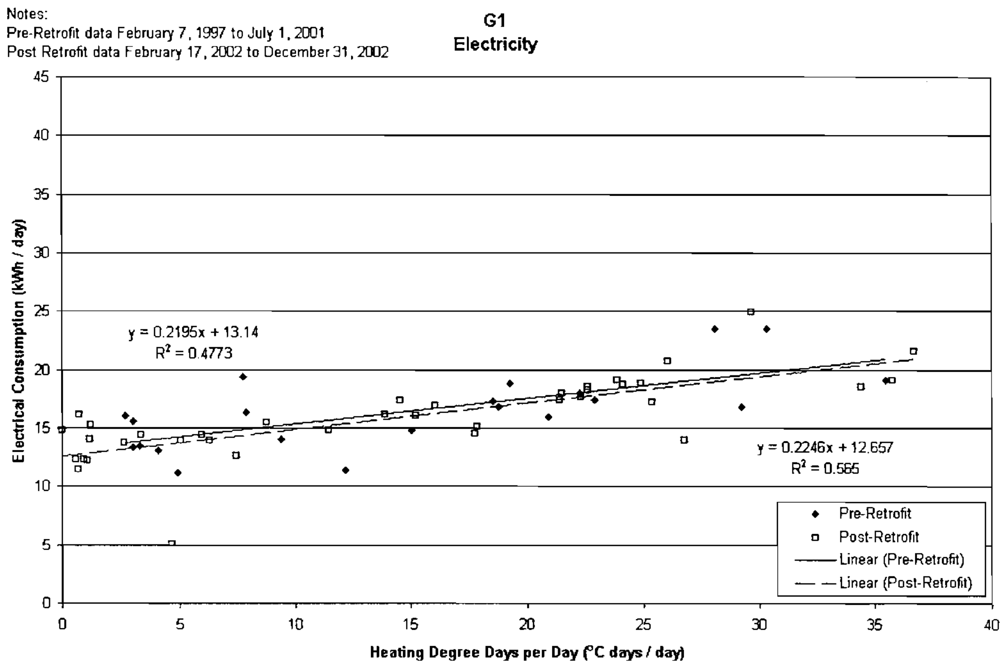

Figure B.5: House G1 Pre Retrofit and Post Retrofit Electricity Plot

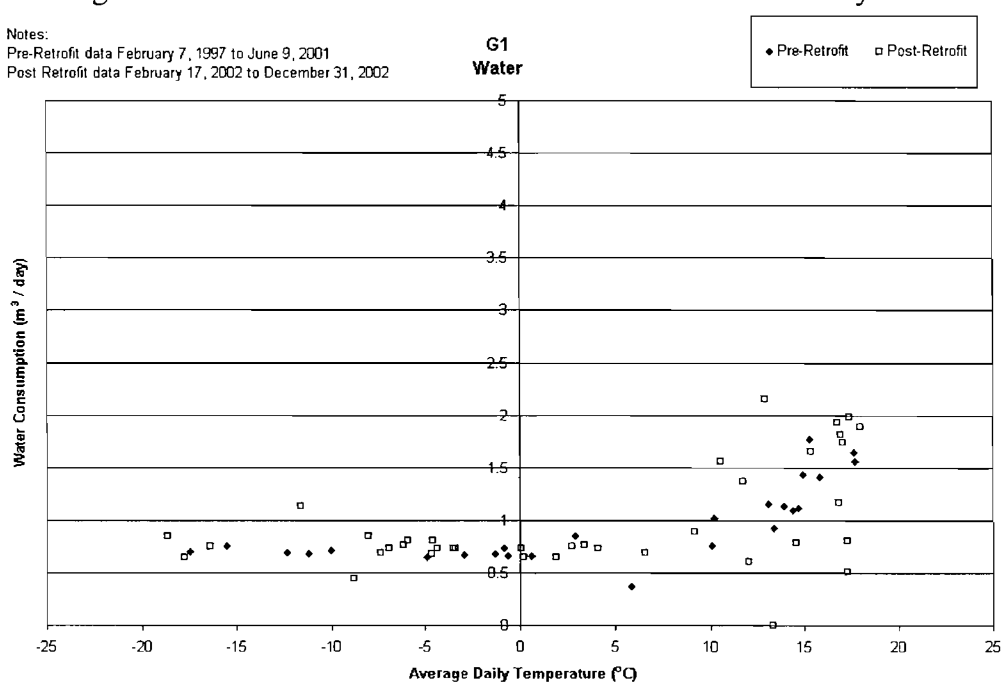

Figure B.6: House G1 Pre Retrofit and Post Retrofit Water Plot

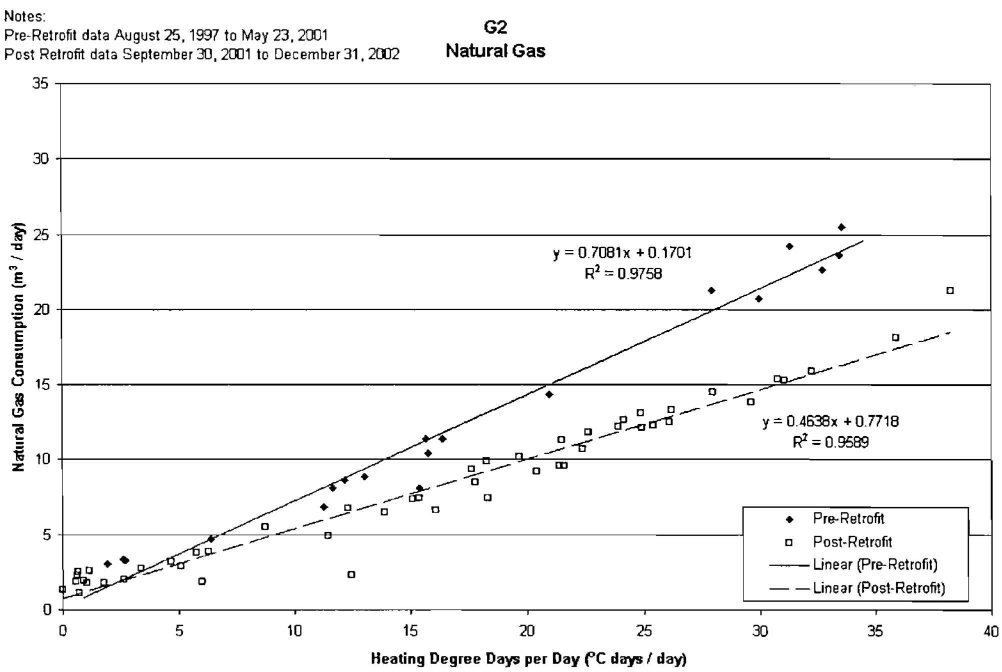

Figure B.7: House G2 Pre Retrofit and Post Retrofit Natural Gas Plot

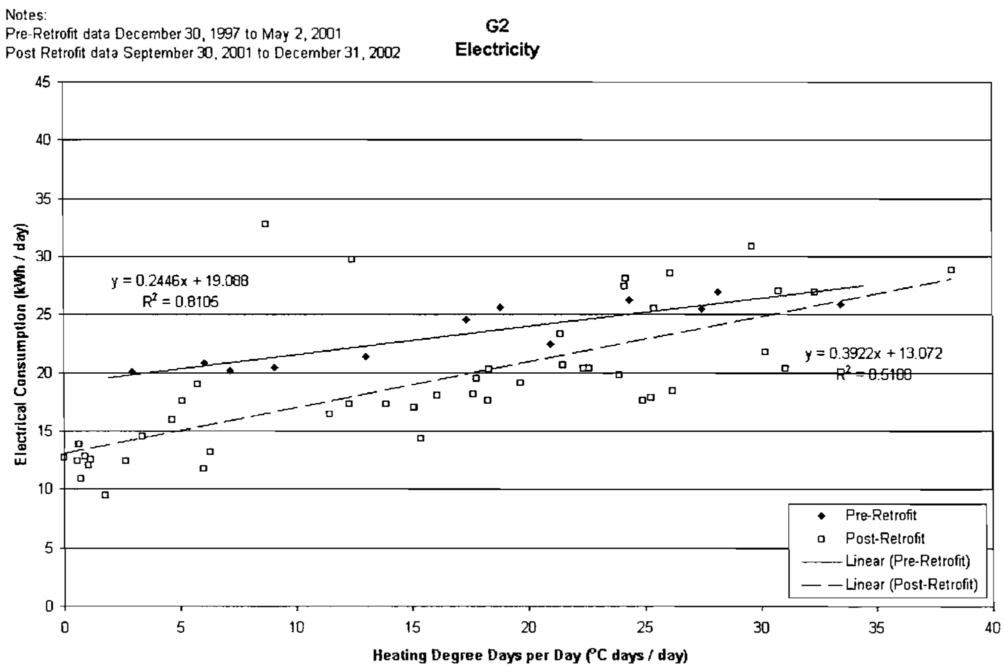

Figure B.8: House G2 Pre Retrofit and Post Retrofit Electricity Plot

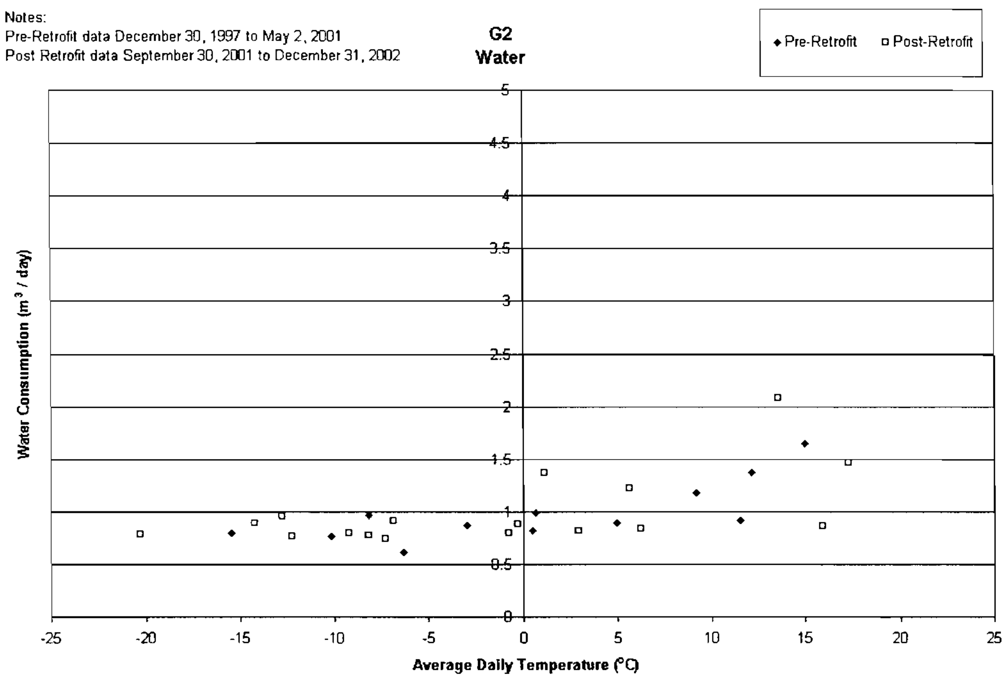

Figure B.9: House G2 Pre Retrofit and Post Retrofit Water Plot

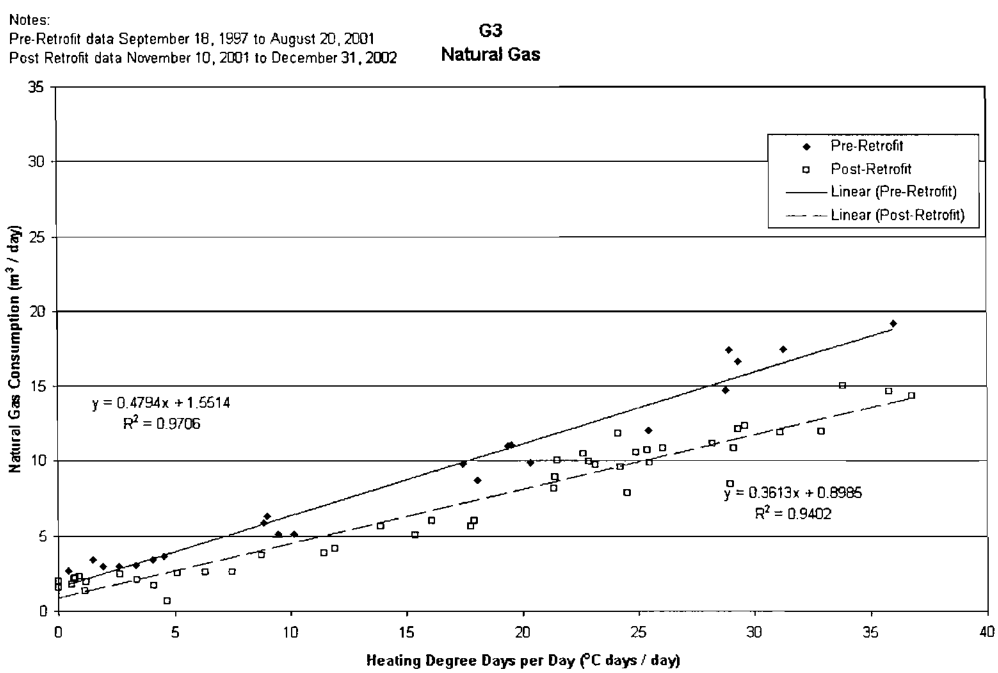

Figure B.10: House G3 Pre Retrofit and Post Retrofit Natural Gas Plot

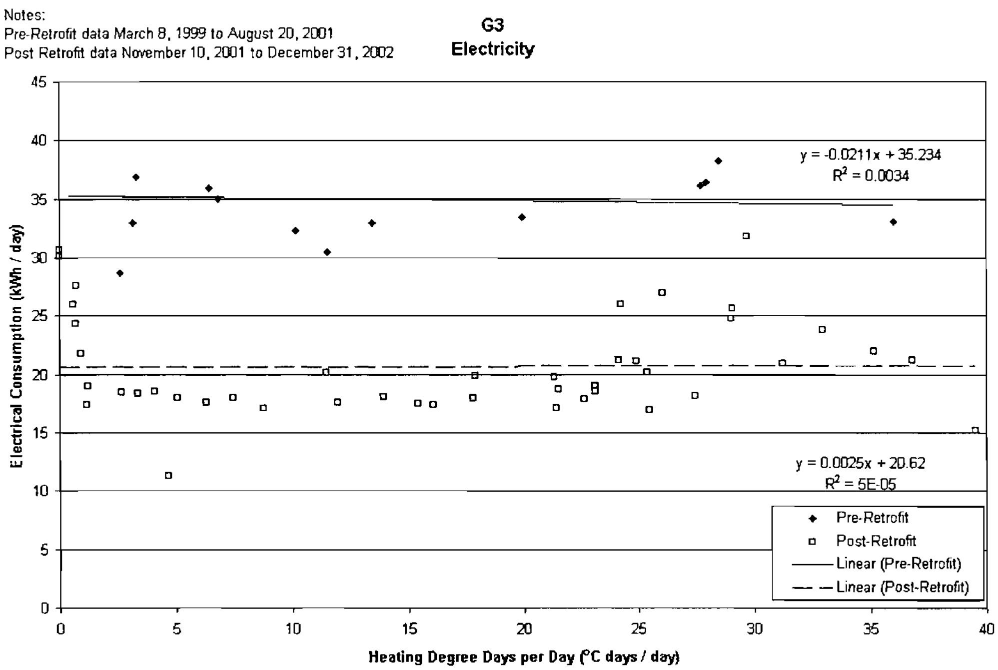

Figure B.11: House G3 Pre Retrofit and Post Retrofit Electricity Plot

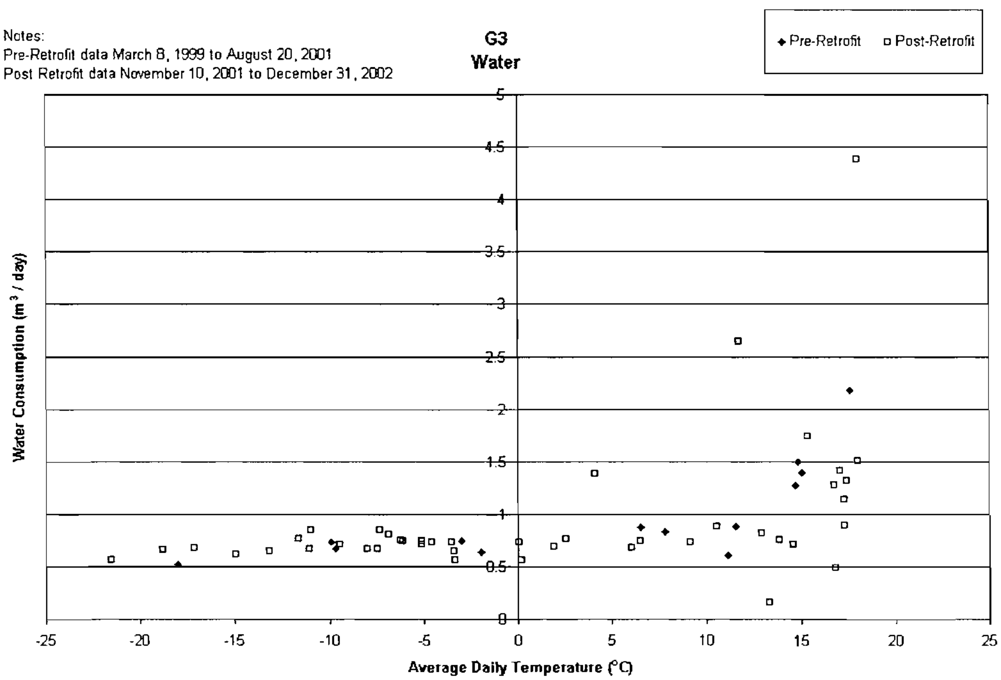

Figure B.12: House G3 Pre Retrofit and Post Retrofit Water Plot

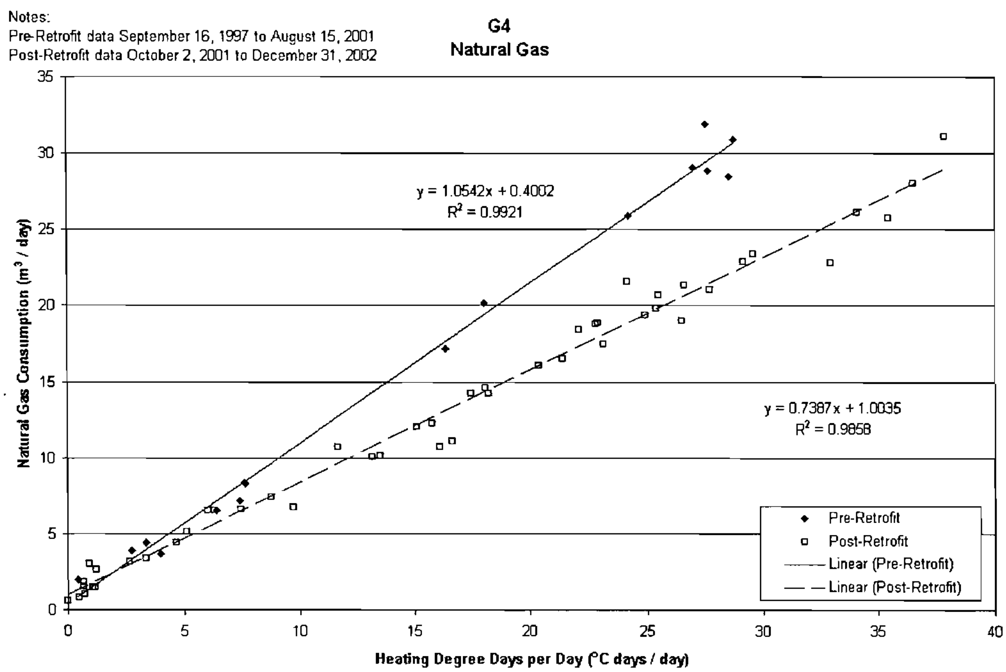

Figure B.13: House G4 Pre Retrofit and Post Retrofit Natural Gas Plot

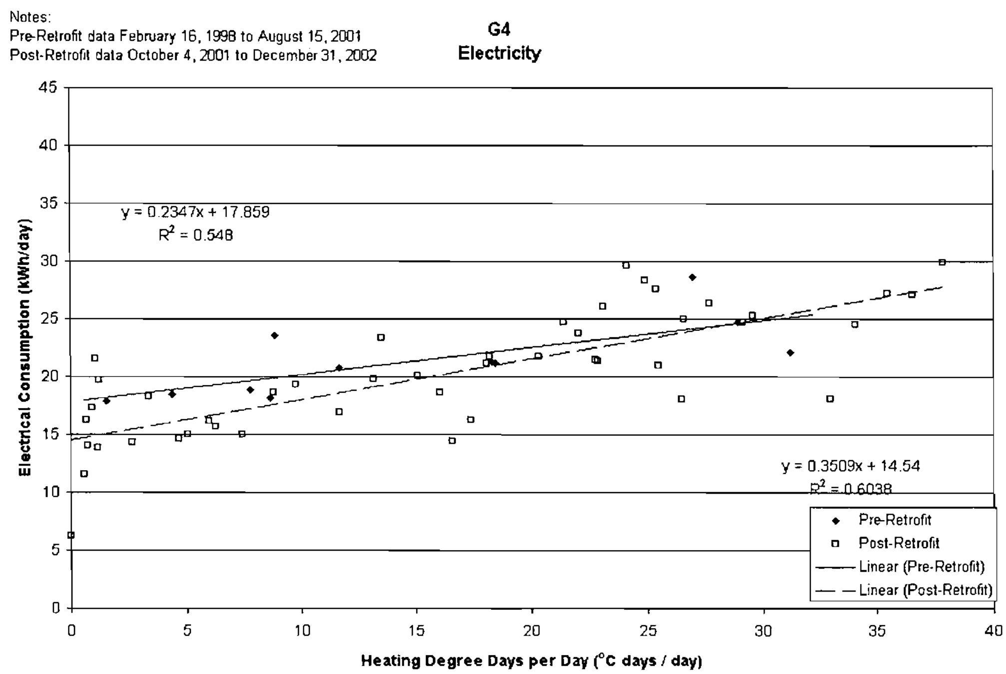

Figure B.14: House G4 Pre Retrofit and Post Retrofit Electricity Plot

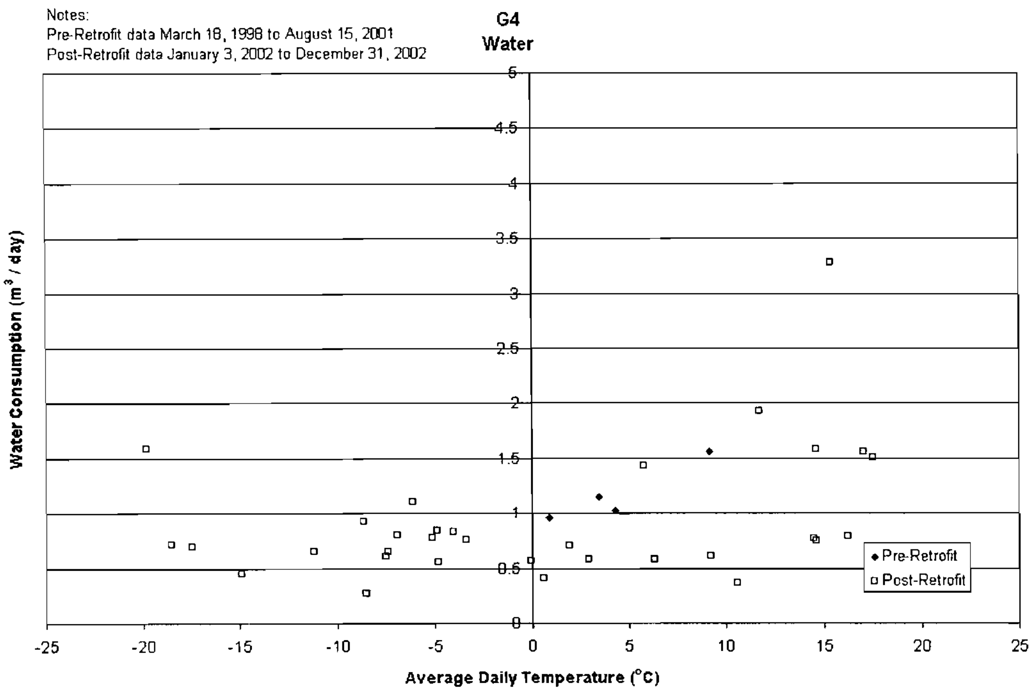

Figure B.15: House G4 Pre Retrofit and Post Retrofit Water Plot

APPENDIX C

Graphs of Natural Gas, Electricity, and Water Consumption
Pre- and Post-Retrofit Control Houses

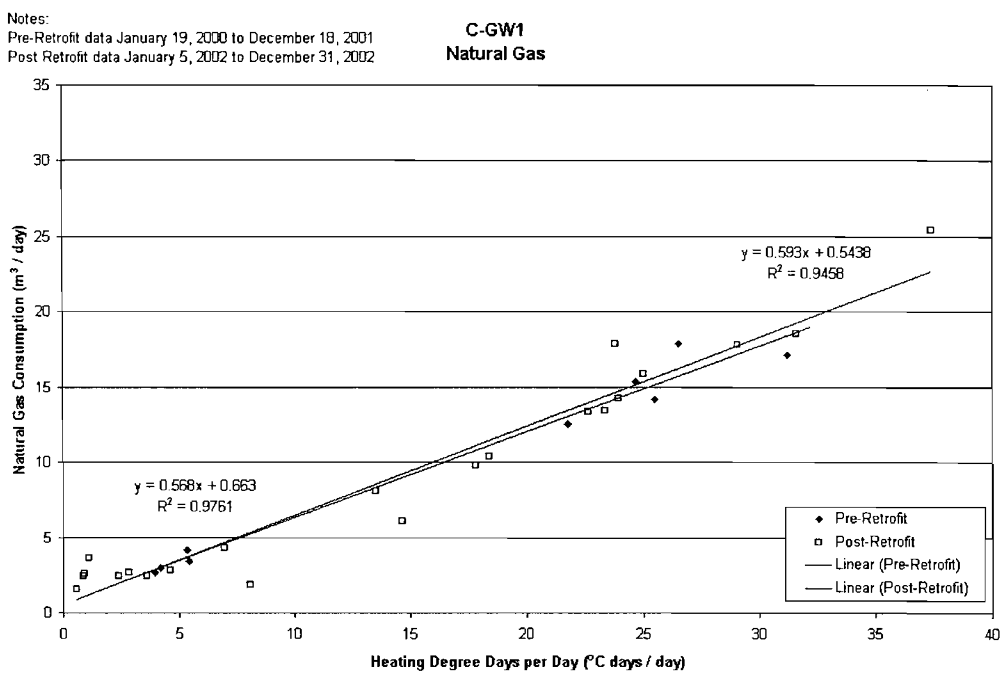

Figure C.1: House C-GW1 Pre Retrofit and Post Retrofit Natural Gas Plot

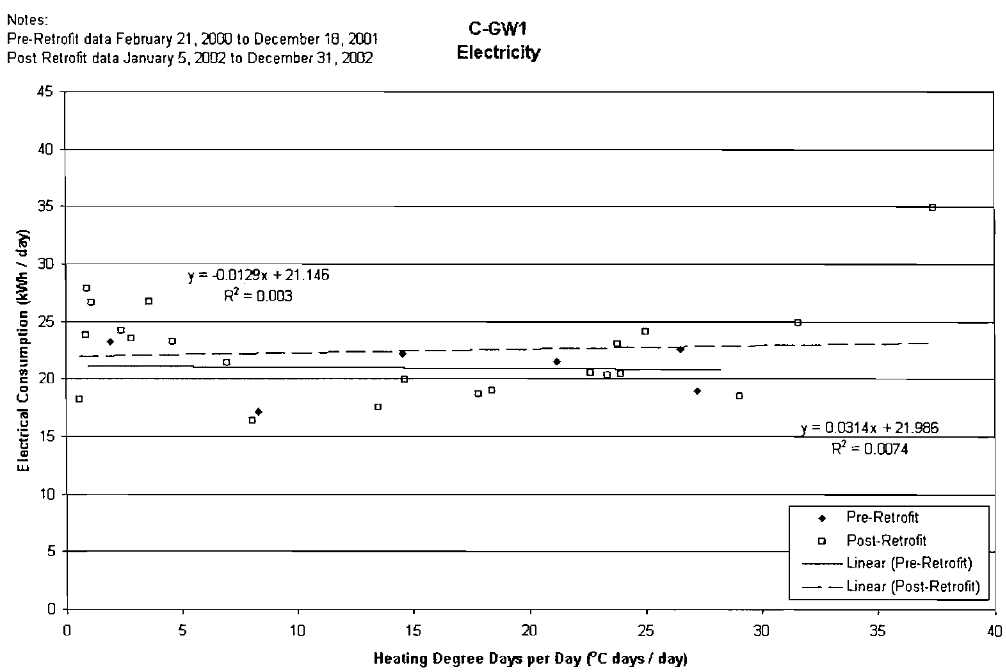

Figure C.2: House C-GW1 Pre Retrofit and Post Retrofit Electricity Plot

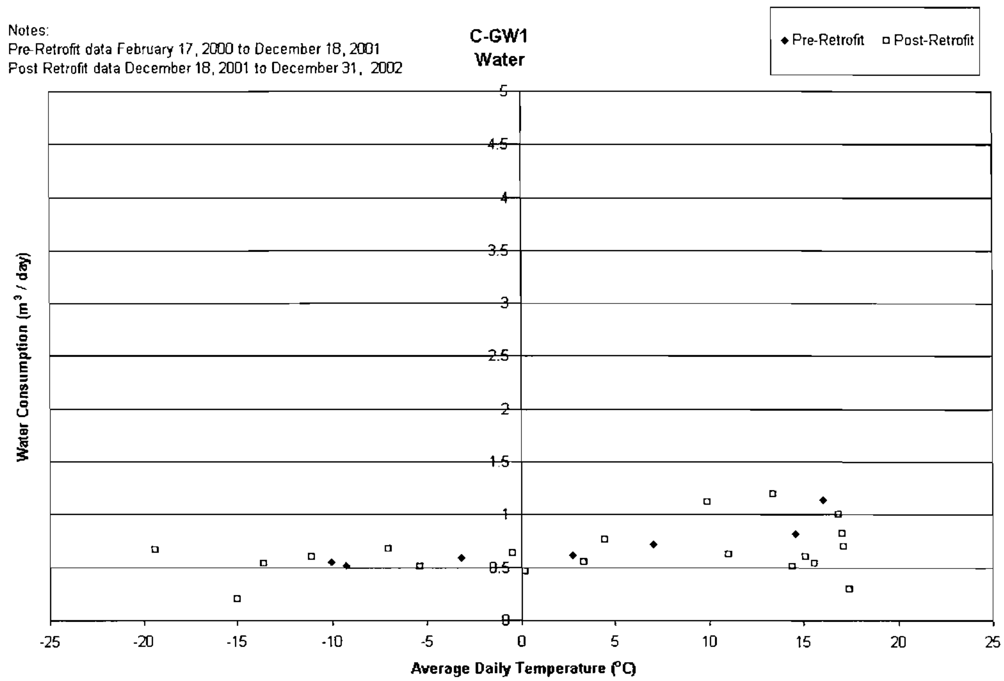

Figure C.3: House C-GW1 Pre Retrofit and Post Retrofit Water Plot

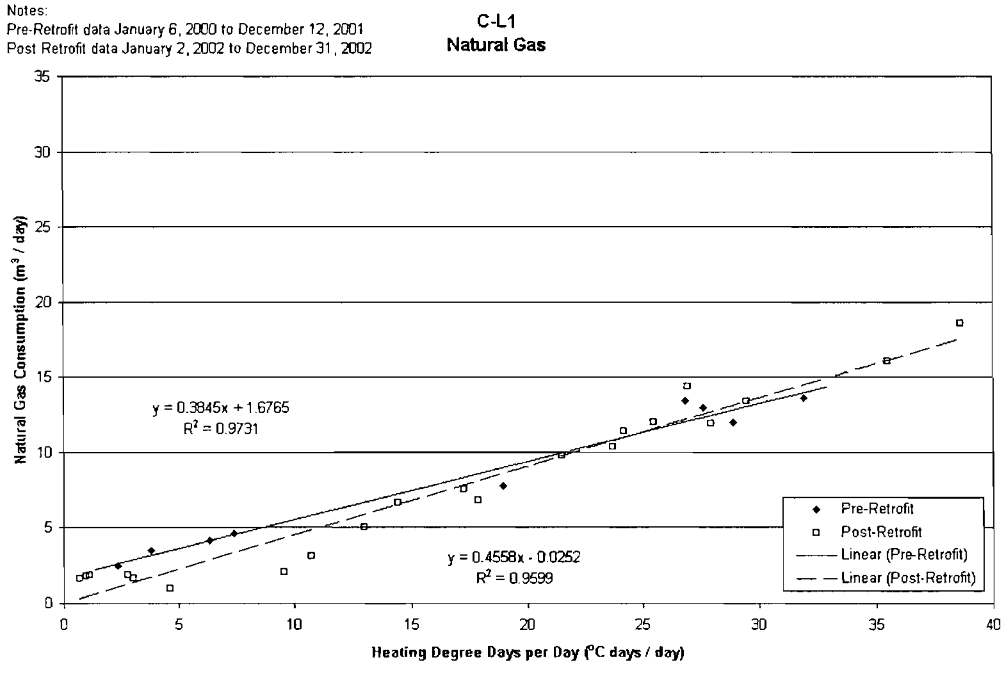

Figure C.4: House C-L1 Pre Retrofit and Post Retrofit Natural Gas Plot

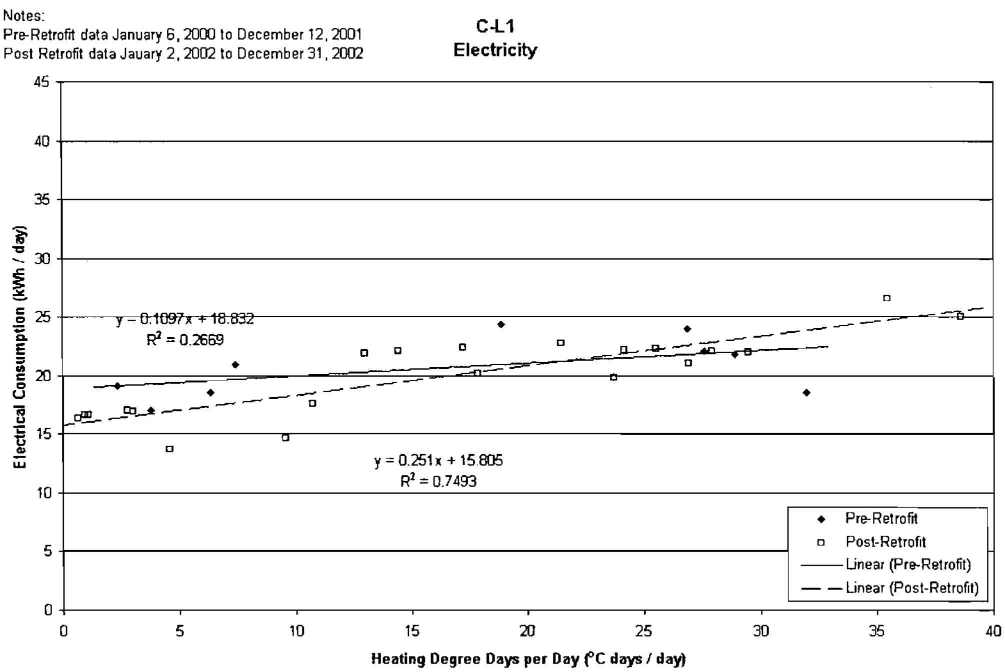

Figure C.5: House C-L1 Pre Retrofit and Post Retrofit Electricity Plot

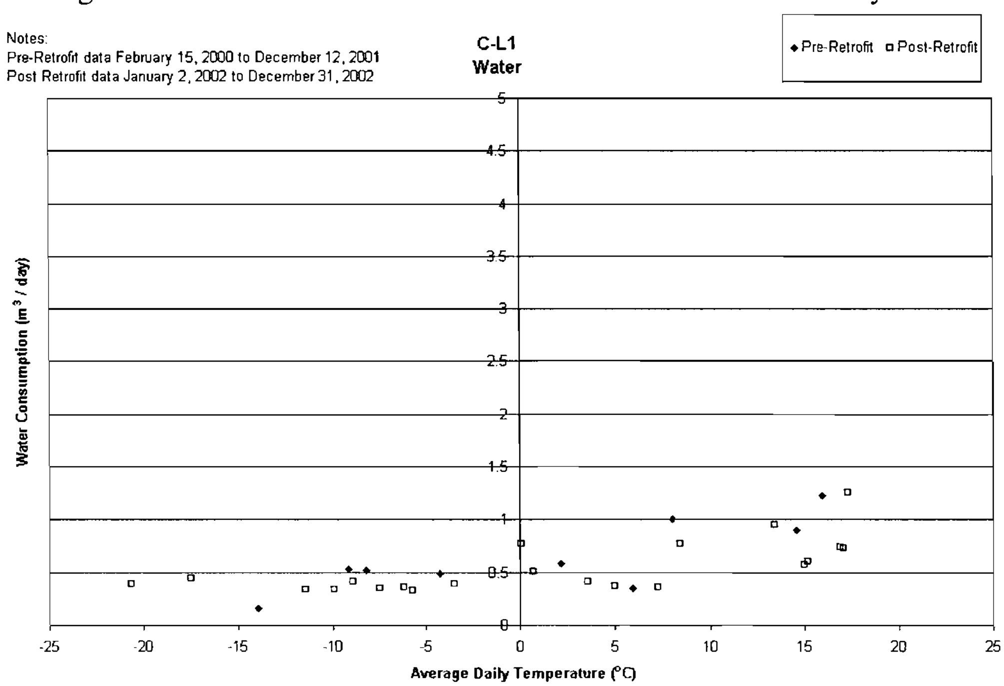

Figure C.6: House C-L1 Pre Retrofit and Post Retrofit Water Plot

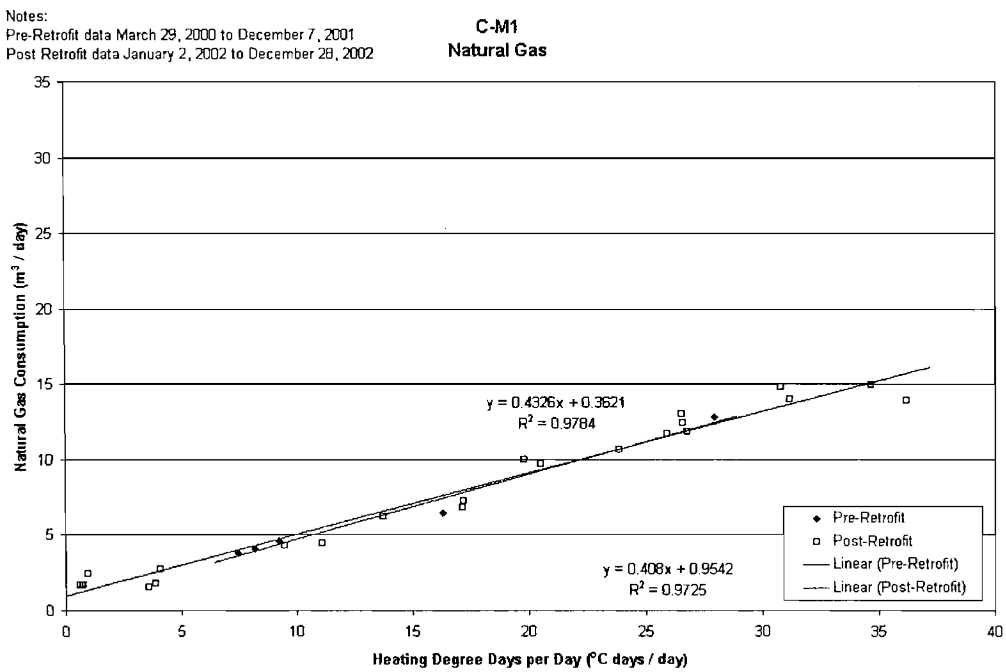

Figure C.7: House C-M1 Pre Retrofit and Post Retrofit Natural Gas Plot

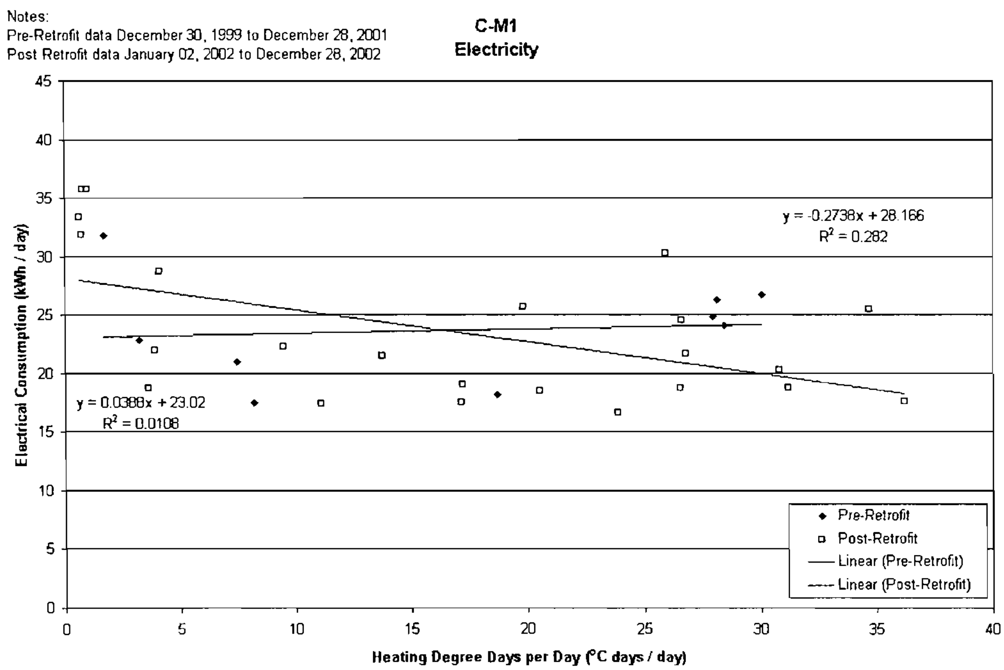

Figure C.8: House C-M1 Pre Retrofit and Post Retrofit Electricity Plot

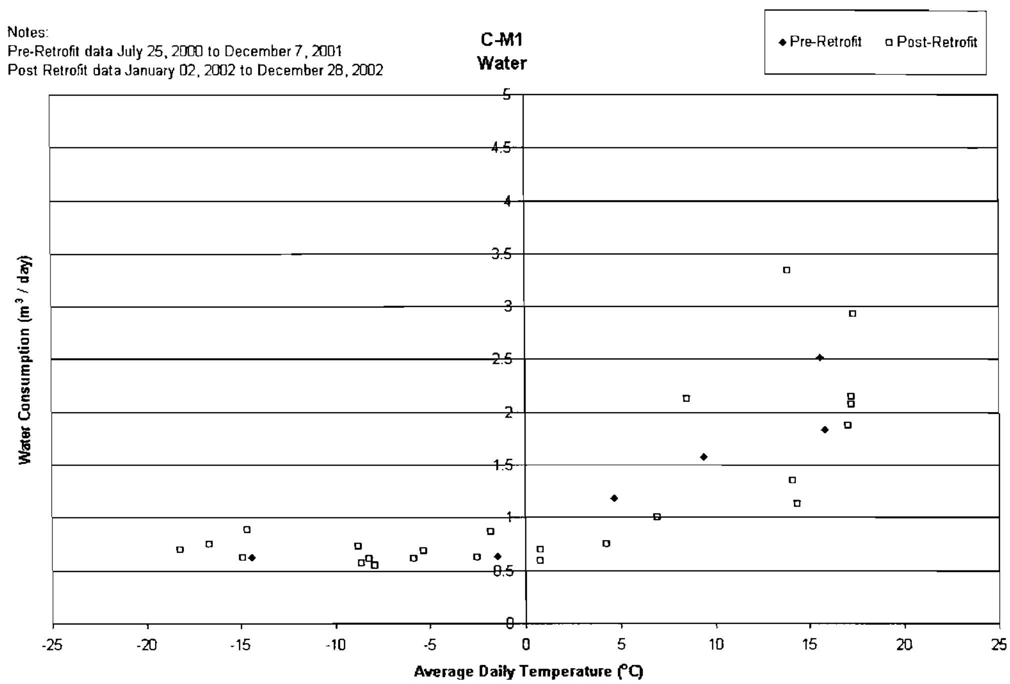

Figure C.9: House C-M1 Pre Retrofit and Post Retrofit Water Plot

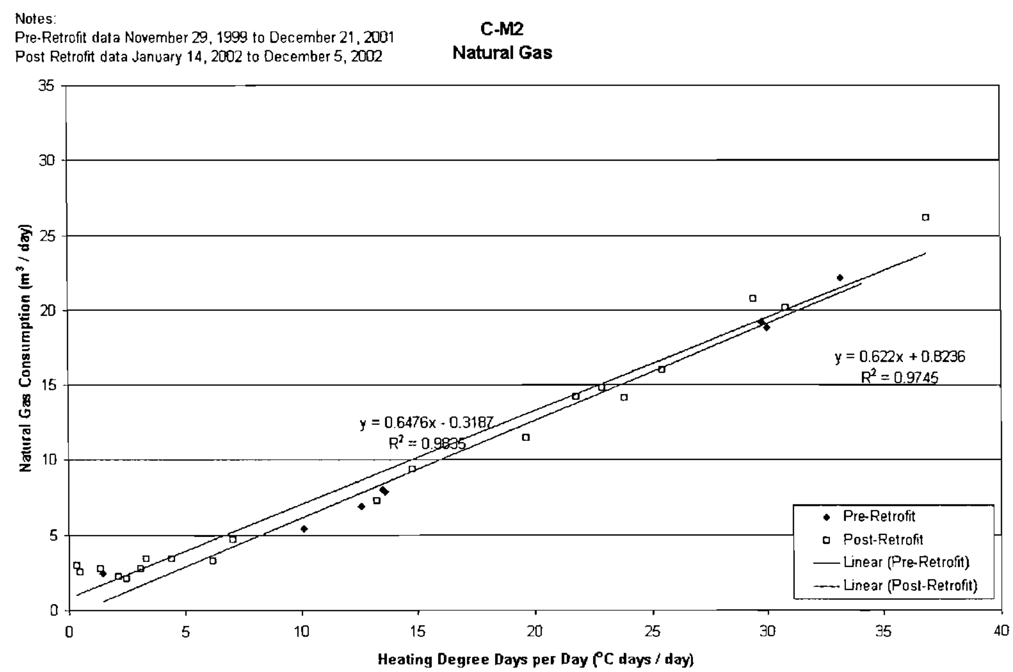

Figure C.10: House C-M2 Pre Retrofit and Post Retrofit Natural Gas Plot

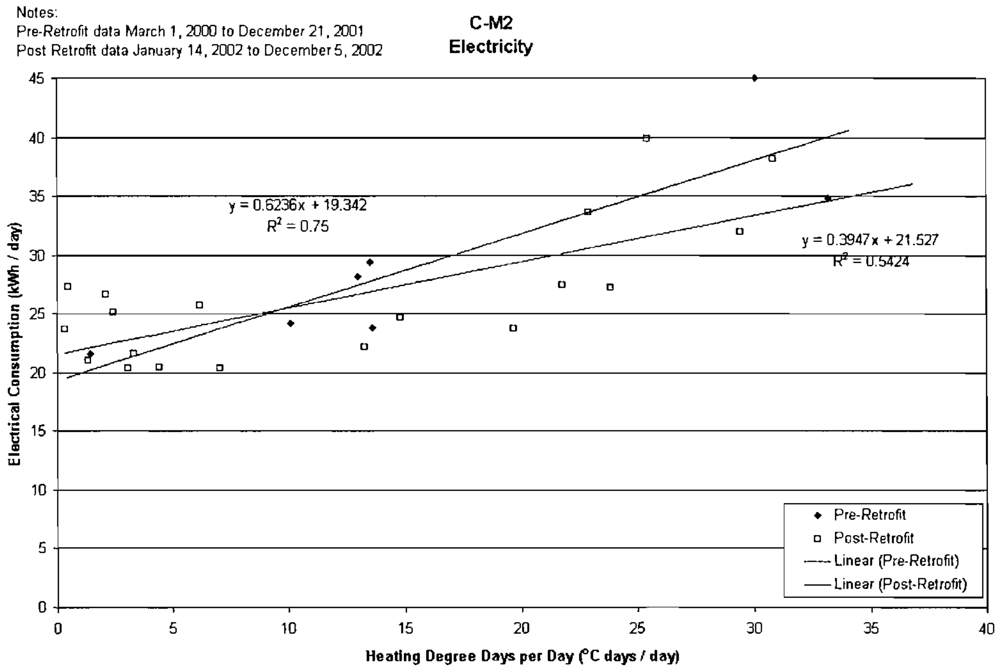

Figure C.11: House C-M2 Pre Retrofit and Post Retrofit Electricity Plot

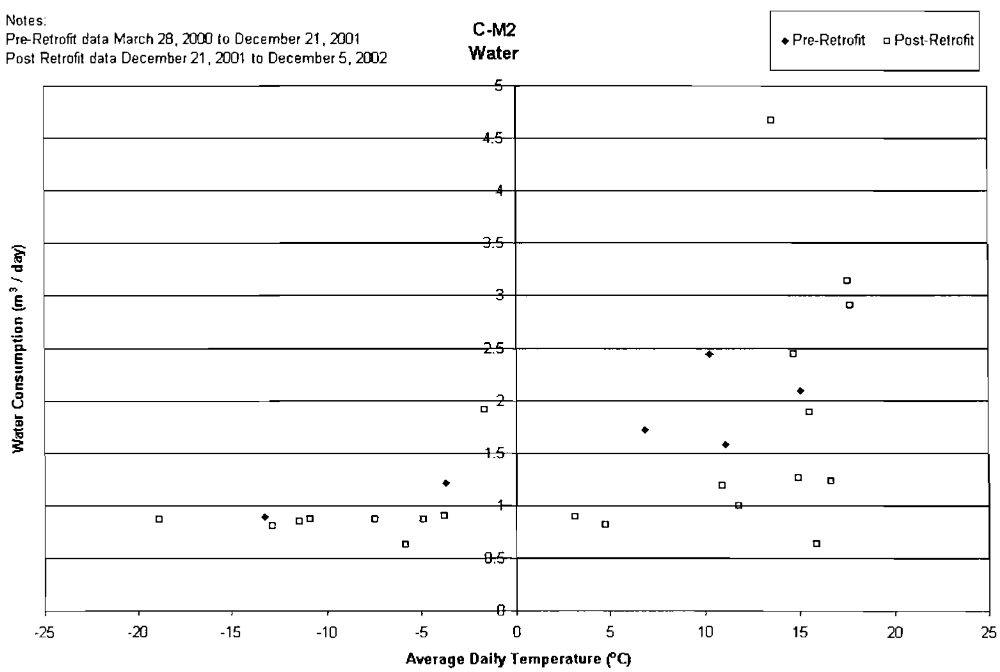

Figure C.12: House C-M2 Pre Retrofit and Post Retrofit Water Plot

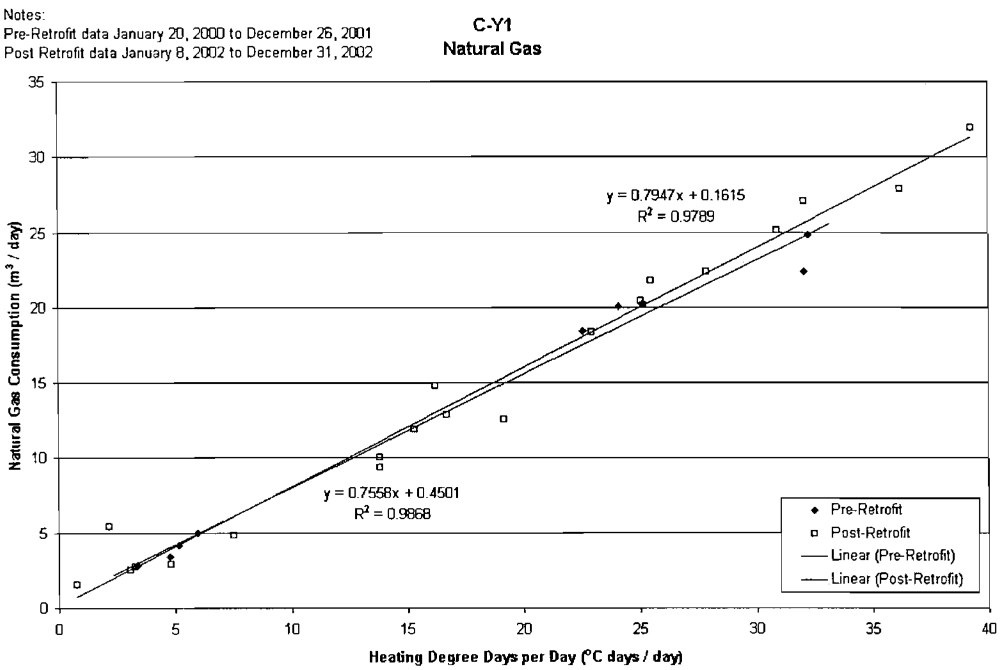

Figure C.13: House C-Y1 Pre Retrofit and Post Retrofit Natural Gas Plot

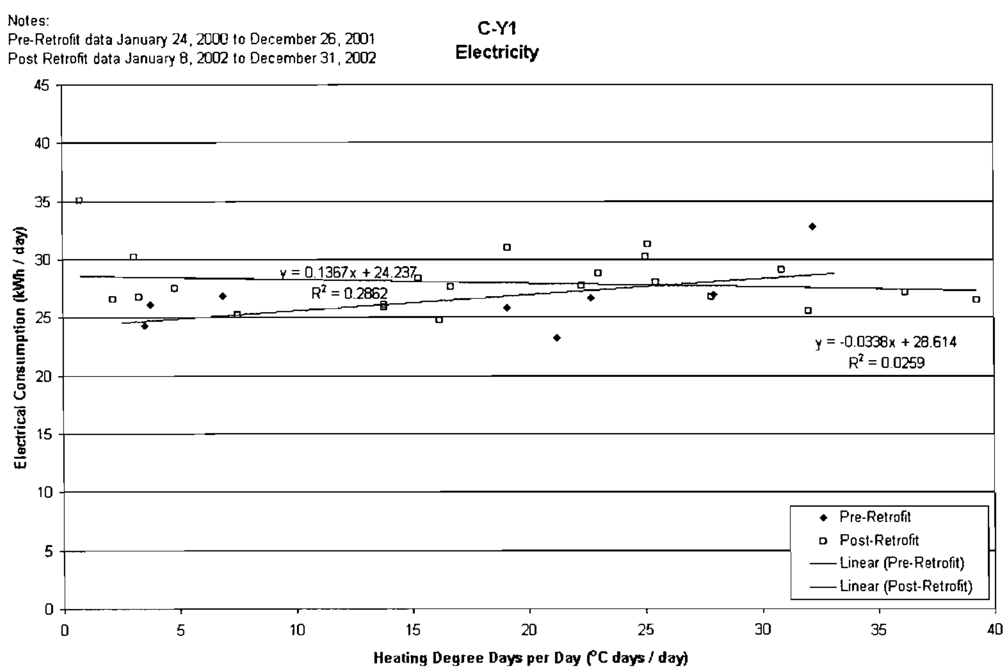

Figure C.14: House C-Y1 Pre Retrofit and Post Retrofit Electricity Plot

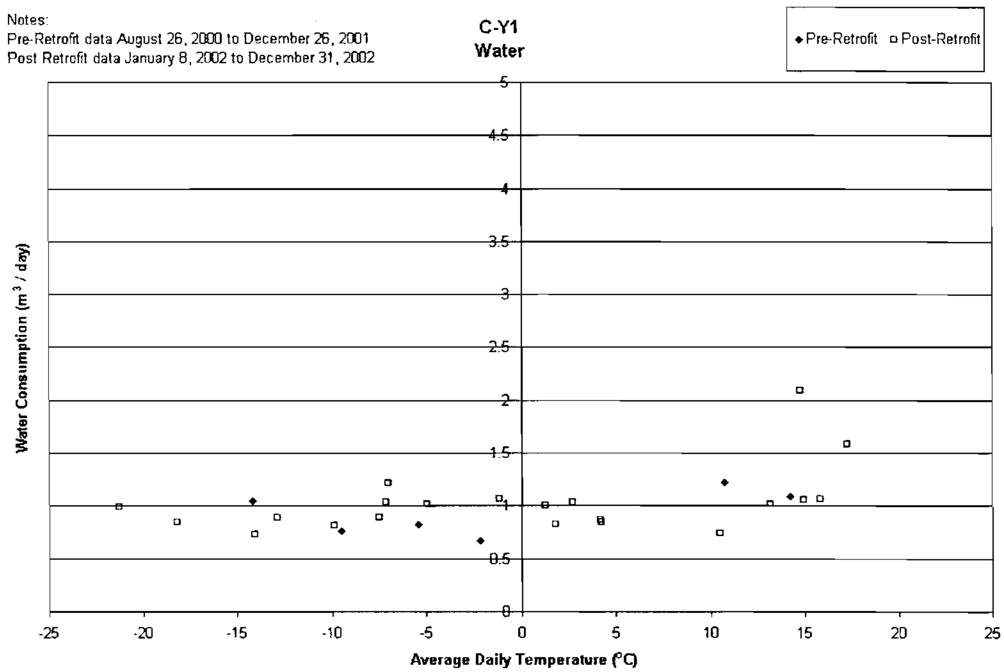

Figure C.14: House C-Y1 Pre Retrofit and Post Retrofit Water Plot

APPENDIX D

Case and Control Houses Energy Consumption and
Ratios of Pre and Post Retrofit

The following tables presents data on the pre retrofit and post retrofit natural gas and electricity consumption. The slope and Y-intercepts are obtained from the graphing of the meter readings versus the heating degree days for Saskatoon. The heating degree days values were obtained from the Environment Canada weather station located at the Saskatoon Airport.

Case Houses Energy Consumption (Pre Retrofit and Post Retrofit)

	CASE HOUSES				
	D1	**G1**	**G2**	**G3**	**G4**
Pre retrofit natural gas					
Slope, m^3/DD	0.4829	0.6682	0.7081	0.4794	1.0542
Y-int., m^3/day	3.1448	0.2669	0.1701	1.5514	0.4002
Normalized annual cons., m^3	4082	4158	4365	3480	6552
Pre retrofit electricity					
Slope, kWh/day	-0.0961	0.2195	0.2446	-0.0211	0.2347
Y-int., kWh/DD	28.253	13.14	19.088	35.234	17.859
Normalized annual cons., kWh	9728	6130	8454	12732	7945
Total - Pre retrofit natural gas and electricity					
Pre retrofit N.G. and elec. total, MJ	194237	184233	200676	181539	284147
Post retrofit natural gas					
Slope, m^3/DD	0.3134	0.351	0.4638	0.3613	0.7387
Y-int., m^3/day	2.5674	0.4179	0.7718	0.8985	1.0035
Normalized annual cons., m^3	2842	2286	3100	2524	4855
Post retrofit electricity					

	CASE HOUSES				
	D1	**G1**	**G2**	**G3**	**G4**
Slope, kWh/day	0.0532	0.2246	0.3922	0.0025	0.3509
Y-int., kWh/DD	23.352	12.657	13.072	20.62	14.54
Normalized annual cons., kWh	8847	5985	7155	7541	7440
Total - Post retrofit natural gas and electricity					
Post retrofit N.G. and elec. total, MJ	142672	110682	146665	125569	216141
Ratio - normalized electricity, post retrofit / pre retrofit	0.909	0.976	0.846	0.592	0.936
Ratio - normalized natural gas, post retrofit / pre retrofit	0.696	0.550	0.710	0.725	0.741
Ratio - total, normalized post retrofit / pre retrofit	0.735	0.601	0.731	0.692	0.761

Similar to the case houses, the data for the five control houses are presented in the following table.

Control Houses Energy Consumption (Pre Retrofit and Post Retrofit)

	CONTROL HOUSES				
	GW1	**L1***	**M1**	**M2**	**Y1**
Pre retrofit natural gas					
Slope, m^3/DD	0.5680	0.3845	0.4326	0.6476	0.7558
Y-int., m^3/day	0.6630	1.6765	0.3621	-0.3187	0.4501

	CONTROL HOUSES				
	GW1	**L1***	**M1**	**M2**	**Y1**
Normalized annual cons., m^3	3694	2949	2761	3819	4757
Pre retrofit electricity					
Slope, kWh/day	-0.0129	0.1097	0.0388	0.6236	0.1367
Y-int., kWh/DD	21.146	18.832	23.020	19.342	24.237
Normalized annual cons., kWh	7640	7540	8638	10849	9677
Total - Pre retrofit natural gas and electricity					
Pre retrofit N.G. and elec. total, MJ	171559	142138	138779	188004	220372
Post retrofit natural gas					
Slope, m^3/DD	0.593	0.4558	0.408	0.622	0.7947
Y-int., m^3/day	0.5438	-0.0252	0.9542	0.8236	0.1615
Normalized annual cons., m^3	3802	2761	2828	4081	4888
Post retrofit electricity					
Slope, kWh/day	0.0314	0.251	-0.2738	0.3947	-0.0338
Y-int., kWh/DD	21.986	15.805	28.166	21.527	28.614
Normalized annual cons., kWh	8216	7294	8617	10256	10239
Total - Post retrofit natural gas and electricity					
Post retrofit N.G. and elec. total, MJ	177860	133926	141300	196061	227505
Ratio - normalized electricity, post retrofit / pre retrofit	1.075	0.967	0.998	0.945	1.058

	CONTROL HOUSES				
	GW1	**L1***	**M1**	**M2**	**Y1**
Ratio - normalized natural gas, post retrofit / pre retrofit	1.029	0.936	1.024	1.068	1.028
Ratio - total, normalized post retrofit / pre retrofit	1.037	0.942	1.018	1.043	1.032

* the house was unoccupied during May 2002 while the owners were on holidays. They turned down the temperature setting on their hot water heater during this period.

APPENDIX E

Case Houses Characteristics

	D1	G1	G2	G3	G4
Volume (m^3)	360	469	431	620	714
Surface Area (m^2)	317	359	316	486	478
AC/h @ 50 Pa (CGSB Sealed) (Pre retrofit)	1.76	6.34	7.71	1.95	6.26
Normalized Leakage Area (cm^2/m^2)	0.628	2.37	3.16	0.785	3.17
C (L/s-m^2-Pa^n)	8.03	30.1	38.2	15.5	65.1
n	0.791	0.846	0.814	0.787	0.754
Energuide Rating		50		65	
Existing Furnace Input Capacity (Btu/h)	90,000 Lennox	120,000 Coleman	100,000 Homart	130,000 Olsen	200,000 Fairbanks Morse
Extrapolated Peak Natural Gas Demand (Btu/h)	46,403	49,355	54,855	36,817	83,207
Ratio of Extrapolated Demand to Furnace Input Capacity	2.59	2.43	1.82	3.53	2.41
Measured Furnace Combustion Efficiency(%)	N / A	76.2	74	76.2	76.7
HOT-2000 Peak Space Heating Requirement (kW) (assuming 100% efficiency) (House pre-retrofit)	12.1 (41,297 Btu/h)	18.9 (64,505 Btu/h)	16.9 (57,680 Btu/h)	13.2 (45,052 Btu/h)	24.0 (81,912 Btu/h)

	CONTROL HOUSES				
	GW1	**L1***	**M1**	**M2**	**Y1**
Pre retrofit natural gas					
Slope, m^3/DD	0.5680	0.3845	0.4326	0.6476	0.7558
Y-int., m^3/day	0.6630	1.6765	0.3621	-0.3187	0.4501
Normalized annual cons., m^3	3694	2949	2761	3819	4757
Pre retrofit electricity					
Slope, kWh/day	-0.0129	0.1097	0.0388	0.6236	0.1367
Y-int., kWh/DD	21.146	18.832	23.020	19.342	24.237
Normalized annual cons., kWh	7640	7540	8638	10849	9677
Total - Pre retrofit natural gas and electricity					
Pre retrofit N.G. and elec. total, MJ	171559	142138	138779	188004	220372
Post retrofit natural gas					
Slope, m^3/DD	0.593	0.4558	0.408	0.622	0.7947
Y-int., m^3/day	0.5438	-0.0252	0.9542	0.8236	0.1615
Normalized annual cons., m^3	3802	2761	2828	4081	4888
Post retrofit electricity					
Slope, kWh/day	0.0314	0.251	-0.2738	0.3947	-0.0338
Y-int., kWh/DD	21.986	15.805	28.166	21.527	28.614
Normalized annual cons., kWh	8216	7294	8617	10256	10239

	CONTROL HOUSES				
	GW1	**L1***	**M1**	**M2**	**Y1**
Total - Post retrofit natural gas and electricity					
Post retrofit N.G. and elec. total, MJ	177860	133926	141300	196061	227505
Ratio - normalized electricity, post retrofit / pre retrofit	1.075	0.967	0.998	0.945	1.058
Ratio - normalized natural gas, post retrofit / pre retrofit	1.029	0.936	1.024	1.068	1.028
Ratio - total, normalized post retrofit / pre retrofit	1.037	0.942	1.018	1.043	1.032

APPENDIX F

HOT2000 Inputs and Measured Actuals

HOT2000 Modelling and Retrofit Actuals

The following tables list the inputs used in the HOT2000 software prior to the start of the retrofit work. The Base inputs represent the values before the retrofits.

Table F.1: Interior Air Temperature - Main Floor Temperature Rise

Code	Main Floor Temperature Rise (°C)	
	Hot 2000 Base	Hot 2000 Retrofit
D1	2.8	2.8
G1	2.8	2.8
G2	2.8	2.8
G3	2.8	2.8
G4	2.8	2.8

Table F.2: Main Floor Set Temperature

Code	Main Floor Set Temperature (°C)		
	Hot 2000 Base	Hot 2000 Retrofit	Retrofit Actual
D1	23	23	22
G1	16	17	17
G2	18	18	18
G3	18	16	18
G4	19	19	19

Table F.3: Basement Temperature

Code	Basement Temperature (°C)		
	Hot 2000 Base	Hot 2000 Retrofit	Retrofit Actual
D1	22	22	22
G1	14	16	16
G2	18	18	18
G3	18	16	18
G4	18	18	18

Table F.4: Electrical Appliances, Furnace Fan Motors, and Lighting

Code	Electric Appliances (kWh/Day)			Lighting (kWh/Day)		Other (kWh/Day)		
	Hot 2000 Base	Hot 2000 Retrofit	Retrofit Actual	Hot 2000 Base	Hot 2000 Retrofit	Hot 2000 Base	Hot 2000 Retrofit	Retrofit Actual
D1	13.7	8.2	10.6	2.7	0.9	0	0	0
G1	8.4	7.3	5.4	3	1	0	0	0
G2	15.95	9	11.2	3	1	1.32	1.32	1.32
G3	16.4	6	6.4	3	1.5	0	0	0
G4	15	10.4	16.8	3	1.5	0	0	0

Table F.5: Internal Gains and Dryer/Stove

Code	Internal Gains (kWh/Day) (People)		Dryer/Stove (kWh/Day)	
	Hot 2000 Base	Hot 2000 Retrofit	Hot 2000 Base	Hot 2000 Retrofit
D1	# 0.15	# 0.15	2.7d	2.7d
G1	# 0.15	# 0.15	0	0
G2	# 0.15	# 0.15	*1.94	??
G3	# 0.15	# 0.15	1.94s	1.94s
G4	# 0.15	# 0.15	0	0

Default value for 2 adults and 2 children at 50% occupancy
* Inadvertently modeled as a gas stove instead of an electric stove
d Electric dryer
s Gas Stove

Table F.6: Average Exterior, Hot Water Load, and Water Temperature

Code	Avg. Exterior (kWh/Day)		Water Temperature °C			Hot Water Load (L/Day)	
	Hot 2000 Base	Hot 2000 Retrofit	Hot 2000 Base	Hot 2000 Retrofit	Retrofit Actual	Hot 2000 Base	Hot 2000 Retrofit
D1	0.5	0.5	55	55	64	150	150
G1	2.7	2.7	55	55	51	150	128
G2	2.7	0.5	55	55	60	310	250
G3	2.2	1.74	55	55	61	210	140
G4	2.2	2.2	51	51	62	260	175

Table F.7: Domestic Hot Water

Code	Type			Power Vent Motor (watts)		
	Hot 2000 Base	Hot 2000 Retrofit	Retrofit Actual	Hot 2000 Base	Hot 2000 Retrofit	Retrofit Actual
D1	Conventional	Conventional	Conventional (State)	0	0	0
G1	Conventional	Induced Draft	Power Vent (Giant)	0	Hot 2000 Library	83
G2	Conventional	Induced Draft	Power Vent (John Wood)	0	Hot 2000 Library	95
G3	Conventional	Condensing	Power Vent (John Wood)	0	Hot 2000 Library	90
G4	Conventional	Condensing	Power Vent (Rheem)	0	Hot 2000 Library	69

Note: DHW preheat tanks not modeled in Hot 2000 for G3 and G4
Base = House prior to retrofit

Table F.8: Domestic Hot Water Tank Size and Insulation

Code	Size (L)			Extra Tank Insulation (RSI)		
	Hot 2000 Base	Hot 2000 Retrofit	Retro fit Actual	Hot 2000 Base	Hot 2000 Retrofit	Retrofit Actual
D1	151.4	151.4	151.4	1.2	3.5	3.5
G1	151.4	151.4	151.4	0	3.5	3.5
G2	113.6	151.4	151	0	3.5	3.5
G3	151.4	113.6	151	0.7	1.5	3.5
G4	189.3	151.4	189	0	0	3.5

Table F.9: DHW Chimney and Pilot Light

Code	Flue Diameter (m m)			Pilot Light (MJ/Day)		
	Hot 2000 Base	Hot 2000 Retrofit	Retro fit Actual	Hot 2000 Base	Hot 2000 Retrofit	Retrofit Actual
D1	76.2	76.2	76.2	* 0	17.7	17.7
G1	76.2	76.2	51	* 0	0	0
G2	76.2	76.2	51	25.3	0	0
G3	76.2	76.2	51	20	0	0
G4	76.2	0	51	17.7	0	0

Table F.10: DHW Energy Factor and Combustion Efficiency

Code	Energy Factor			Combustion Efficiency (%)		
	Hot 2000 Base	Hot 2000 Retrofit	Retrofit Actual	Hot 2000 Base	Hot 2000 Retrofit	Retrofit Actual
D1	0.554	0.554	0.554	82	Hot 2000 Library	80.5 no fan
G1	0.554	0.571	0.56	74.1	Hot 2000 Library	77.3 after fan 83.4 at ext wall
G2	0.573	0.571	0.58	76.2	Hot 2000 Library	71.9 before fan
G3	0.554	0.86	0.58	75	Hot 2000 Library	80.2 before fan 73.5 after fan
G4	0.535	0.86	0.53	76.3	Hot 2000 Library	83.8 before fan 74.2 after fan

*inadvertently not modeled in HOT2000 base case

Table F.11: Furnace Type and Blower

Code	Type of Furnace			Furnace Blower Operation		
	Hot 2000 Base	Hot 2000 Retrofit	Retrofit Actual	Hot 2000 Base	Hot 2000 Retrofit	Retrofit Actual
D1	Standard	Induced draft mid effic.	Induced draft mid effic.	Cont.	Cont.	Cont.
G1	Standard	Condensing	Condensing	Auto	Auto	Auto
G2	Standard	Condensing	Condensing	Auto	Auto	Auto
G3	Standard	Condensing	Condensing	Cont.	Auto	Auto/ Cont.
G4	Standard	Condensing	Condensing	Auto	Auto	Auto

Base = House prior to retrofit
* = actual combustion efficiency
H = Horizontal
V = Vertical

Table F.12: Furnace Blower and Power Vent Motor

Code	Furnace Blower Motor Power (Watts)			Furnace Power Vent Motor (Watts)		
	Hot 2000 Base	Hot 2000 Retrofit	Retrofit Actual	Hot 2000 Base	Hot 2000 Retrofit	Retrofit Actual
D1	300 Hi	300 Hi	560 Hi	0	Hot 2000 Library	N / A
G1	703 Hi	350 Hi	323 Hi	0	Hot 2000 Library	80
G2	290 Hi	237 Hi	380 Hi	0	Hot 2000 Library	80
G3	413 Hi	243 Hi	230 Hi	0	Hot 2000 Library	52
G4	413 Hi	150 Hi	800 Hi	0	Hot 2000 Library	101

Table F.13: Furnace Output and Combustion Efficiency

Code	Furnace Output (kW)			Furnace Combustion Efficiency (%)			
	Hot 2000 Base	Hot 2000 Retrofit	Retrofit Actual	Hot 2000 Base	Hot 2000 Retrofit	Retrofit Actual at Furnace	Retrofit Actual Down Stream
D1	21	13.2	17.6	75	85	78.8	N / A
G1	28	16	17.5	*76.3 87	94	92.6	92.3
G2	28.1	17.5	17.5	76	94	91.4	93.3
G3	30.5	17.5	17.6 Hi 11.4 Lo	*76.2 89	90	92.3	92.3
G4	46.9	26.4	28	77.8	94	90.9	92.3

* measured values, compared with the values entered into HOT2000

Table F.14: Furnace Pilot Light and Flue Diameter

Code	Pilot Light (MJ/Day)			Flue Diameter (mm)		
	Hot 2000 Base	Hot 2000 Retrofit	Retrofit Actual	Hot 2000 Base (Vertical)	Hot 2000 Retrofit	Retrofit Actual
D1	25.3	0	0	152.4	0	150
G1	25.3	0	0	152.4	0	51 H ABS
G2	25.3	0	0	152.4	0	51 H ABS
G3	25.3	0	0	152.4	0	51 H ABS
G4	25.3	0	0	203	0	83 H ABS

Table F.15: Ventilation - Air Changes per Hour and Exhaust Flow Volume

Code	ACH @ 50 pa (Chimney Sealed)			ELA cm^2 @ 10 pa (Chimney Sealed)		
	Hot 2000 Base	Hot 2000 Retrofit	Retrofit Actual	Hot 2000 Base	Hot 2000 Retrofit	Retrofit Actual
D1	1.76	1.76	1.63	199	199	181
G1	6.34	3.17	3.88	849	425	438
G2	7.71	3.85	7.22	999	495	931
G3	1.95	1.95	1.98	381	381	348
G4	6.26	4	5.72	1481	946	1544

Table F.16: Ventilation Fan Operation and Continuous Exhaust

Code	Ventilation Fan Operation (Not the Furnace)			* Continuous Exhaust Air Flow (L/s)		
	Hot 2000 Base	Hot 2000 Retrofit	Retrofit Actual	Hot 2000 Base	Hot 2000 Retrofit	Retrofit Actual
D1	0	Cont.	0	0	10	0
G1	0	0	0	0	0	0
G2	0	0	0	0	0	0
G3	0	Cont.	0	0	5	0
G4	0	0	0	0	0	0

Table F.17: Ventilation Power and Dryer Flow Volume

Code	* Ventilation Fan Power (watts)			* Dryer Air Flow (L/s)		
	Hot 2000 Base	Hot 2000 Retrofit	Retrofit Actual	Hot 2000 Base	Hot 2000 Retrofit	Retrofit Actual
D1	0	0	0	0	1.2	N / M
G1	0	0	0	0	0	N / M
G2	0	0	0	0	0	N / M
G3	0	0	0	0	0	N / M
G4	0	0	0	0	0	28.3

* assuming continuous operation throughout the year