

NRC Publications Archive Archives des publications du CNRC

Assessment of the impact of a natural gas fireplace on heating energy consumption and room temperatures at the Canadian Centre for Housing Technology

Armstrong, M. M.; Swinton, M. C.; Szadkowski, F.

For the publisher's version, please access the DOI link below./ Pour consulter la version de l'éditeur, utilisez le lien DOI ci-dessous.

Publisher's version / Version de l'éditeur:

<https://doi.org/10.4224/20375005>

Client Report (National Research Council Canada. Institute for Research in Construction); no. B-6039, 2009-11-02

NRC Publications Archive Record / Notice des Archives des publications du CNRC :

<https://nrc-publications.canada.ca/eng/view/object/?id=34924b02-c935-404f-b884-24e82bd982ec>

<https://publications-cnrc.canada.ca/fra/voir/objet/?id=34924b02-c935-404f-b884-24e82bd982ec>

Access and use of this website and the material on it are subject to the Terms and Conditions set forth at

<https://nrc-publications.canada.ca/eng/copyright>

READ THESE TERMS AND CONDITIONS CAREFULLY BEFORE USING THIS WEBSITE.

L'accès à ce site Web et l'utilisation de son contenu sont assujettis aux conditions présentées dans le site

<https://publications-cnrc.canada.ca/fra/droits>

LISEZ CES CONDITIONS ATTENTIVEMENT AVANT D'UTILISER CE SITE WEB.

Questions? Contact the NRC Publications Archive team at

PublicationsArchive-ArchivesPublications@nrc-cnrc.gc.ca. If you wish to email the authors directly, please see the first page of the publication for their contact information.

Vous avez des questions? Nous pouvons vous aider. Pour communiquer directement avec un auteur, consultez la première page de la revue dans laquelle son article a été publié afin de trouver ses coordonnées. Si vous n'arrivez pas à les repérer, communiquez avec nous à PublicationsArchive-ArchivesPublications@nrc-cnrc.gc.ca.



**Canadian Centre
for Housing Technology**

**Centre canadien des
technologies résidentielles**

**ASSESSMENT OF THE IMPACT OF A NATURAL GAS FIREPLACE
ON HEATING ENERGY CONSUMPTION AND ROOM TEMPERATURES
AT THE CANADIAN CENTRE FOR HOUSING TECHNOLOGY**

Contract: B-6039

Armstrong M.M., Swinton, M.C. and Szadkowski, F.

March 31, 2010

Canada

The Canadian Centre for Housing Technology (CCHT)

Built in 1998, the Canadian Centre for Housing Technology (CCHT) is jointly operated by the National Research Council, Natural Resources Canada, and Canada Mortgage and Housing Corporation. CCHT's mission is to accelerate the development of new technologies and their acceptance in the marketplace.

The Canadian Centre for Housing Technology features twin research houses to evaluate the whole-house performance of new technologies in side-by-side testing. The twin houses offer an intensively monitored real-world environment with simulated occupancy to assess the performance of the residential energy technologies in secure premises. This facility was designed to provide a stepping-stone for manufacturers and developers to test innovative technologies prior to full field trials in occupied houses.

As well, CCHT has an information centre, the InfoCentre, which features a showroom, high-tech meeting room, and the CMHC award winning FlexHouse™ design, shown at CCHT as a demo home. The InfoCentre also features functioning state-of-the art equipment, and demo solar photovoltaic panels. There are over 50 meetings and tours at CCHT annually, with presentations and visits occurring with national and international visitors on a regular basis.



HOME TO CANADIANS
Canada



Natural Resources
Canada

Ressources naturelles
Canada

NRC · CNRC

Acknowledgements

The funding for Year 2 of this project was provided by Canada Mortgage and Housing Corporation. Thanks are extended to Ken Ruest (CMHC) for making this project possible and for his valuable guidance, Randy Biggs (NRCan) for assisting with fireplace operation, and to Martin Thomas (NRCan) for providing energy efficiency testing.

Project Team

Marianne Armstrong (NRC-IRC) as project manager was responsible for monitoring data collection, performing data analysis and writing this report. Mike Swinton (NRC-IRC), expert in side-by-side evaluation, oversaw operations throughout the experiment, monitored results, and provided important feedback throughout the analysis. Frank Szadkowski (NRCan Buildings Group) ensured proper operations of the CCHT Research Houses and fireplace throughout the experiments, and provided important feedback for the data analysis and report.

Acronyms

ach	air changes per hour
ANCOVA	analysis of covariance
CCHT	Canadian Centre for Housing Technology
cfm	cubic feet per minute
CMHC	Canada Mortgage and Housing Corporation
HRV	Heat Recovery Ventilator
IRC	Institute for Research in Construction
NRC	National Research Council Canada
NRCan	Natural Resources Canada

Executive Summary

Over two winters from 2008 to 2010, a series of experiments were conducted in the twin house facility at the Canadian Centre for Housing Technology (CCHT) to examine the impact of gas fireplace operation on an R-2000 house. The interaction of the fireplace with the central heating system was explored, including impact on furnace natural gas and electrical consumption, and room and surface temperature effects.

Three different modes of fireplace operation were examined: continuous evening fireplace operation from 18:00 to 24:00 with the furnace providing continuous air circulation; continuous evening fireplace operation from 18:00 to 24:00 with no continuous air circulation provided by the furnace; and fireplace operation by dedicated thermostat. Additionally, the impact of pilot light operation, and the impact of having an open fireplace vent were also investigated.

Evening operation of the fireplace heated the family room well above the temperature setpoint of the furnace thermostat (22°C), exceeding 25°C during the experiment. To operate for six hours, the fireplace required an average consumption of 144 MJ/day natural gas and 0.256 kWh/day to operate its circulation fan. Operating the fireplace decreased furnace operation, reducing furnace gas consumption by an average 106 MJ/day (39.4%) over the experiment period, and reducing furnace fan electrical consumption by 0.86 kWh (8.0%) with continuous circulation and 1.7 kWh (30.9%) without continuous circulation. Overall, evening fireplace operation resulted in an increase in total energy consumption of 36.4 MJ/day (12.5%) with continuous furnace fan operation and 29.9 MJ/day (11.6%) without continuous fan operation. When efficiencies of the furnace and fireplace were taken into account, the net energy supplied to the house by the fireplace and the furnace increased by an average 2.8% from the benchmark case, and was up to 12% greater on the warmest days of testing.

During evening fireplace operation, air temperature in bedrooms on the second floor dipped by as much as 2°C. This effect was most pronounced in the bedrooms furthest away from the fireplace location. Despite these daily dips in air temperature, minimal differences in surface temperatures were measured on the second floor of the house – the biggest difference was noted on the exterior wall of the bedroom closet, where the minimum surface temperature was reduced by 0.7°C due to fireplace operation. Little temperature difference was noted between continuous and non continuous air circulation.

Operation of the fireplace by thermostat control resulted in a large reduction in furnace operation – due to the close proximity of the fireplace to the central thermostat of the home. On average, the fireplace consumed 249 MJ/day of natural gas and 1.28 kWh of electricity, and reduced furnace consumption by 208 MJ/day (59.3%) of natural gas and 0.85 kWh of electricity, for an overall increase of 38 MJ/day (9.8%) in total heating energy consumption. Despite this increase in consumption, the total heat output was 2.3% lower with fireplace operation. This may have contributed to cooler temperatures on the second floor (1 to 2°C cooler), as the furnace did not cycle frequently to provide heat to the home.

Pilot light operation also had an impact on the home. To keep the pilot light lit, the fireplace consumed on average 38 MJ/day of natural gas. The pilot light also decreased furnace natural gas consumption by 19 MJ/day (5.6%), and furnace fan electrical consumption by 0.19 kWh/day (1.7%) for a total increase in energy consumption of 18 MJ/day (5.0%). A $\sim 0.3^{\circ}\text{C}$ temperature increase in the family room (where the fireplace was located) and a small temperature decrease on the second floor of the house ($\sim 0.2^{\circ}\text{C}$) were detected.

The impact of having the opening of the fireplace vent was also examined, but for only four days in relatively mild weather ($>0^{\circ}\text{C}$). A small increase in energy consumption for heating was detected (3.6% increase), however, more data are needed to fully understand this effect.

Table of Contents

1	Introduction	1
2	Objective	1
3	Background.....	1
3.1	CCHT Twin House Facility	1
3.2	Fireplace Description	4
4	Methodology	5
4.1	Side-by-side testing procedure.....	5
4.2	Test Dates.....	7
4.3	Instrumentation	8
	Electrical and Natural gas Consumption.....	8
	Temperature measurement.....	8
	Weather data	9
4.4	Statistical Analysis	10
5	Results from Year 1 - Fireplace operation from 18:00 – 24:00 with and without continuous air circulation.....	11
5.1	Outdoor Temperature and Solar Conditions	11
5.2	Energy Consumption.....	13
	Natural Gas Consumption	13
	Electrical Consumption.....	16
	Total Energy Consumption for Heating.....	17
5.3	Family Room Temperature.....	2
5.4	Second floor room temperature.....	5
5.5	Surface Temperatures	12
6	Results from Year 2 – Fireplace with thermostat control, pilot light only and fireplace vent open	17
6.1	Outdoor Temperature and Solar Conditions	17
6.2	Energy Consumption.....	19
	Natural Gas Consumption	19
	Electrical Consumption.....	22
	Total Energy Consumption for Heating.....	24
6.3	Room Temperatures	27
7	Summary and Discussion.....	35
7.1	Year 1	35
7.2	Year 2.....	36
7.3	Recommendations for future work.....	37
8	References.....	37
Appendix A.	CCHT Research Houses	39
Appendix B.	Simulated Occupancy.....	40
Appendix C.	Savings Calculation Method	42
Appendix D.	Floor Plans of the CCHT Twin Houses	43
Appendix E.	Year 1 Summary Tables of Consumption Data.....	46
Appendix F.	Year 2 Summary Tables of Consumption Data.....	54
Appendix G.	Year 2 Room Temperatures, cloudy days.....	59
Appendix H.	Year 1 Surface Temperature Cumulative Frequency and Probability Distribution Diagrams.....	72
Appendix I.	Analysis of Covariance (ANCOVA) Results	75
Appendix J.	Fireplace Efficiency Testing.....	85

Table of Figures

Figure 1 – First floor layout of the CCHT Experimental House, showing fireplace and thermostat locations	2
Figure 2 – Second floor layout of the CCHT Experimental House	3
Figure 3 - CCHT Twin-House Facility during winter (Experimental House shown at right)	4
Figure 4 - The Experimental House fireplace.....	4
Figure 5 - Sealed fireplace vent during Benchmarking	6
Figure 6 - Air temperature measurement in the family room	8
Figure 7 – North face of the CCHT Reference House, showing the location of the outdoor temperature sensor.	9
Figure 8 – South face of CCHT Reference House, showing location of the precision spectral pyranometer to measure incident solar radiation.....	9
Figure 9 - Outdoor temperature and solar radiation during Year 1 of the experiment.....	12
Figure 10 – Outdoor temperature and solar radiation during Year 1 of the experiment (cont.).....	12
Figure 11 – Sample Experimental House furnace and fireplace natural gas consumption, condition (a) fireplace operation from 18:00 – 24:00 with continuous circulation.....	13
Figure 12 - Year 1 – Reduction of daily furnace natural gas consumption due to fireplace operation	14
Figure 13 - Year 1 - Overall increase of furnace and fireplace natural gas consumption due to fireplace operation.....	15
Figure 14 - Year 1 Reduction of daily furnace fan electrical consumption due to fireplace operation	16
Figure 15 - Year 1 Overall increase in total heating system gas and electrical consumption due to fireplace operation.....	17
Figure 16 – Year 1 Experimental House Energy Consumption for Heating.....	18
Figure 17 – Year 1 Experimental House Heating System Output	1
Figure 18 - Sample family room air temperature during Year 1 Benchmarking	2
Figure 19 - Sample family room air temperature during a) Operation from 18:00 – 24:00 with continuous circulation	3
Figure 20 – Probability Distribution of Family Room air temperature, Year 1	4
Figure 21 – Cumulative Frequency of Family Room air temperature, Year 1	4
Figure 22 – Sample air temperatures in Bedroom 2, measured during Year 1 benchmarking with doors closed	5
Figure 23 – Comparison of Experimental House Bedroom 2 and family room temperature during Year 1 Benchmarking with doors closed.....	6
Figure 24 - Sample air temperatures in Bedroom 2, measured during fireplace condition (a) Operation from 18:00 – 24:00 with continuous air circulation	6
Figure 25 - Comparison of Experimental House Bedroom 2 and family room temperature during fireplace condition (a) Operation from 18:00 – 24:00 with continuous air circulation.....	7
Figure 26 – Sample air temperatures in Bedroom 4, measured during Year 1 benchmarking with doors closed	8
Figure 27 – Comparison of Experimental House Bedroom 4 and family room temperature during Year 1 Benchmarking with doors closed.....	8
Figure 28 - Sample air temperatures in Bedroom 4, measured during fireplace condition (a) Operation from 18:00 – 24:00 with continuous air circulation	9

Figure 29 - Comparison of Experimental House Bedroom 4 and family room temperature during fireplace condition (a) Operation from 18:00 – 24:00 with continuous air circulation.....	9
Figure 30 – Sample bedroom closet surface temperatures during the Year 1 Benchmark with doors closed	14
Figure 31 – Sample bedroom closet surface temperatures during a) Operation from 18:00 – 24:00 with continuous circulation.....	14
Figure 32 - Sample bathroom cupboard surface temperatures during the Year 1 Benchmark with doors closed.....	15
Figure 33 - Sample bathroom cupboard surface temperatures during a) Operation from 18:00 – 24:00 with continuous circulation.....	15
Figure 34 - Sample living room wall corner surface temperatures during the Year 1 Benchmark with doors closed.....	16
Figure 35 - Sample living room wall corner surface temperatures during a) Operation from 18:00 – 24:00 with continuous circulation.....	16
Figure 36 - Outdoor Temperature and Solar Radiation during Year 2 of the experiment	18
Figure 37 - Outdoor Temperature and Solar Radiation during Year 2 of the experiment (cont.).....	18
Figure 38 - Sample furnace and fireplace natural gas consumption in the Experimental House, Condition (c) Fireplace operation with thermostat control.....	19
Figure 39 - Sample furnace and fireplace natural gas consumption in the Experimental House, Condition (d) Pilot light only.....	20
Figure 40 - Year 2 – Reduction in daily furnace natural gas consumption due to fireplace operation and pilot light operation.....	21
Figure 41 - Year 2 - Overall increase of furnace and fireplace natural gas consumption due to fireplace operation and pilot light operation	22
Figure 42 – Sample furnace and fireplace electrical draw in the Experimental House, Condition (c) Fireplace operation with thermostat control.....	23
Figure 43 - Year 2 Reduction of daily furnace fan electrical consumption due to fireplace operation and pilot light operation.....	23
Figure 44 – Year 2 – Overall increase in total heating system gas and electrical consumption due to fireplace and pilot light operation	24
Figure 45 – Year 2 Experimental House Consumption for Heating.....	25
Figure 46 - Year 2 Experimental House Heating System Output	26
Figure 47 - Sample family room air temperatures during benchmarking	29
Figure 48 - Sample family room air temperatures during c) fireplace operation with thermostat control	29
Figure 49 - Sample master bedroom air temperatures during Year 2 benchmarking	30
Figure 50 - Comparison of Experimental House master bedroom and family room temperature on a sample day during Year 2 Benchmarking	30
Figure 51 - Sample bedroom air temperatures during c) fireplace operation with thermostat control	31
Figure 52 - Comparison of Experimental House master bedroom and family room temperature on a sample day during c) fireplace operation with thermostat control.....	31
Figure 53 - Probability Distribution of master bedroom air temperature, Year 2.....	33
Figure 54 - Probability Distribution of master bedroom air temperature – cloudy days only, Year 2.....	33
Figure 55 - Cumulative Frequency of master bedroom air temperature, Year 2.....	34
Figure 56 - Cumulative Frequency of master bedroom air temperature – cloudy days, Year 2	34

Figure C-1 Graphic Representation of the Savings Calculation Method	42
Figure D-1. Floor plan - CCHT Research House first floor.....	43
Figure D-2. Floor plan - CCHT Research House second floor	44
Figure D-3. Floor plan - CCHT Research House basement.....	45
Figure G-1. Cumulative Frequency Diagram, Year 2 cloudy days - Bedroom 2	59
Figure G-2. Probability Distribution, Year 2 cloudy days - Bedroom 2	59
Figure G-3. Cumulative frequency diagram, Year 2 cloudy days - Bedroom 3.....	60
Figure G-4. Probability Distribution, Year 2 cloudy days - Bedroom 3	60
Figure G-5. Cumulative frequency diagram, Year 2 cloudy days - Bedroom 4.....	61
Figure G-6. Probability Distribution, Year 2 cloudy days - Bedroom 4	61
Figure G-7. Cumulative frequency diagram, Year 2 cloudy days – Second floor bathroom.....	62
Figure G-8. Probability distribution, Year 2 cloudy days – Second floor bathroom.....	62
Figure G-9. Cumulative frequency diagram, Year 2 cloudy days – Master bedroom	63
Figure G-10. Probability distribution, Year 2 cloudy days – Mater bedroom.....	63
Figure G-11. Cumulative frequency diagram, Year 2 cloudy days – Ensuite	64
Figure G-12. Probability distribution, Year 2 cloudy days – Ensuite.....	64
Figure G-13. Cumulative frequency diagram, Year 2 cloudy days – Laundry room	65
Figure G-14. Probability distribution, Year 2 cloudy days – Laundry room.....	65
Figure G-15. Cumulative frequency diagram, Year 2 cloudy days – Living room	66
Figure G-16. Probability distrubtion, Year 2 cloudy days – Living room	66
Figure G-17. Cumulative frequency diagram, Year 2 cloudy days – Powder room	67
Figure G-18. Probability distribution, Year 2 cloudy days – Powder room.....	67
Figure G-19. Cumulative frequency diagram, Year 2 cloudy days – Dining room	68
Figure G-20. Probability distribution, Year 2 cloudy days – Dining room.....	68
Figure G-21. Cumulative frequency diagram, Year 2 cloudy days – Top landing of stairs	69
Figure G-22. Probability distribution, Year 2 cloudy days – Top landing of stairs.....	69
Figure G-23. Cumulative frequency diagram, Year 2 cloudy days – Middle landing of stairs	70
Figure G-24. Probability distribution, Year 2 cloudy days – Middle landing of stairs	70
Figure G-25. Cumulative frequency diagram, Year 2 cloudy days – Family room.....	71
Figure G-26. Probability distribution, Year 2 cloudy days – Family room	71
Figure H-1. Cumulative frequency diagram, Year 1 – Bathroom cupboard surface	72
Figure H-2. Probability distrubtion, Year 1 – Bathroom cupboard surface.....	72
Figure H-3. Cumulative frequency diagram, Year 1 – Bedroom closet surface	73
Figure H-4. Probability distribution, Year 1 – Bedroom closet surface	73
Figure H-5. Cumulative frequency diagram, Year 1 – Living room corner surface	74
Figure H-6. Probability distribution, Year 1 – Living room corner surface.....	74

List of Tables

Table 1 - Operating Conditions for the Benchmark	5
Table 2 – Year 1 Experiment and Benchmark Dates	7
Table 3 – Year 2 Experiment and Benchmark Dates	7
Table 4 - Outdoor Temperature and Solar Radiation during Year 1 of the experiment... 11	
Table 5 – Maximum family room temperature during Year 1	2
Table 6. Average Second Floor Air Temperatures During Year 1 of the Fireplace Experiment.....	10
Table 7. Minimum Second Floor Air Temperatures During Year 1 of the Fireplace Experiment.....	11
Table 8 – Average Surface Temperatures During Year 1	13
Table 9 – Minimum Surface Temperatures During Year 1	13
Table 10 - Outdoor Temperature and Solar Radiation during Year 2 of the experiment. 17	
Table 11 - Average room air temperature during Year 2 (cloudy days only, vertical solar gains < 15000 kJ/m ² /day).....	28
Table B-1 CCHT Simulated Occupancy Schedule.....	41
Table E-1. Year 1 Natural Gas Consumption, MJ.....	46
Table E-2. Year 1 Electrical Consumption, kWh	48
Table E-3. Year 1 Total Heating System Consumption (Electrical and Gas), MJ	50
Table E-4. Year 1 Total Heating System Energy Output, MJ	52
Table F-1. Year 2 Natural Gas Consumption, MJ	54
Table F-2. Year 2 Electrical Consumption, kWh	55
Table F-3. Year 2 Total Heating System Consumption (Electrical and Gas), MJ	56
Table F-4. Year 2 Total Heating System Energy Output, MJ	57
Table I-1. ANCOVA of Furnace Gas Consumption from:	75
Table I-2. ANCOVA of Total Gas Consumption from:	76
Table I-3. ANCOVA of Total Heating Gas and Electrical Consumption from:	77
Table I-4. ANCOVA of Furnace Gas Consumption from:	78
Table I-5. ANCOVA of Total Gas Consumption from:	79
Table I-6. ANCOVA of Furnace Electrical Consumption from:	80
Table I-7. ANCOVA of Total Heating Gas and Electrical Consumption from:	81
Table I-8. ANCOVA of Furnace Gas Consumption from:	82
Table I-9. ANCOVA of Furnace Electrical Consumption from:	83
Table I-10. ANCOVA of Total Heating System Gas and Electrical Consumption from: ..	84

1 Introduction

Gas fireplaces are prevalent in homes across Canada. In the 2007 Survey of Household Energy Use (NRCan, 2007) almost a quarter of all homes (23%) reported having a gas-burning fireplace, up from a reported 19% in 2003. Of these homes, 22% reported using the fireplace every day during the heating season.

When a fireplace is operated in close proximity to the house's central thermostat, the heat introduced by the fireplace can cause the heating system to delay its normal cycle of operation – affecting energy consumption and temperatures in the home. Over two winters from 2008 to 2010, researchers at the Canadian Centre for Housing Technology undertook a project to examine the impact of operating a gas fireplace in an R-2000 house. Under a variety of operating conditions, they explored the interaction of the fireplace with the central thermostat, the impact on energy consumption for heating, and changes in room air and surface temperatures. Additionally, impact of the fireplace's standing pilot light and open vent were explored. The results from this project are described in this report.

2 Objective

The objectives of this project were:

- To evaluate the impact of operating a natural gas fireplace on house energy consumption.
- To monitor the resulting room air temperatures, wall and window surface temperatures, to determine if the risk of condensation and mould growth has been increased.
- To monitor any change in furnace operation due to fireplace operation.

3 Background

3.1 CCHT Twin House Facility

Built in 1998, the Canadian Centre for Housing Technology (CCHT) (www.ccht-cctr.gc.ca) is jointly operated by National Research Council (NRC), Natural Resources Canada (NRCan), and Canada Mortgage and Housing Corporation (CMHC). CCHT's mission is to accelerate the development of new technologies and their acceptance in the marketplace.

The Canadian Centre for Housing Technology features twin research houses to evaluate the whole-house performance of new technologies in side-by-side testing (Figure 3). These houses were designed and built by a local builder to the R-2000 standard. The houses are a popular model currently on the market in the region, and were built with the same crews and techniques normally used by the builder. The houses are described in more detail in Appendix A. The houses feature an open-plan layout on the main floor as shown in Figure 1 and Figure 2, and Appendix D.

The CCHT twin houses are fully instrumented and are unoccupied. To simulate the normal internal heat gains of lived-in houses, these houses feature identical 'simulated occupancies'. The simulated occupancy strategy is described in Appendix B.

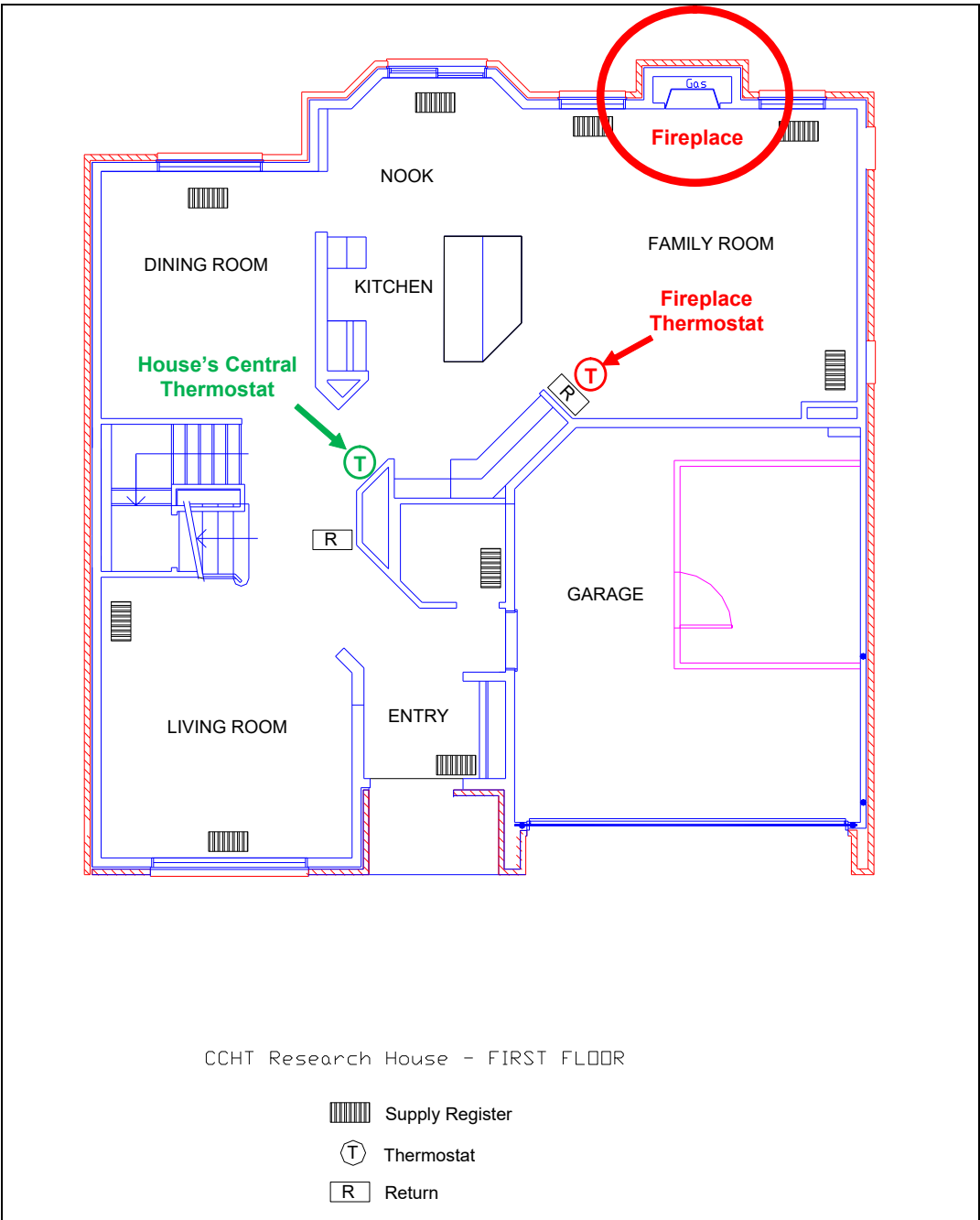


Figure 1 – First floor layout of the CCHT Experimental House, showing fireplace and thermostat locations

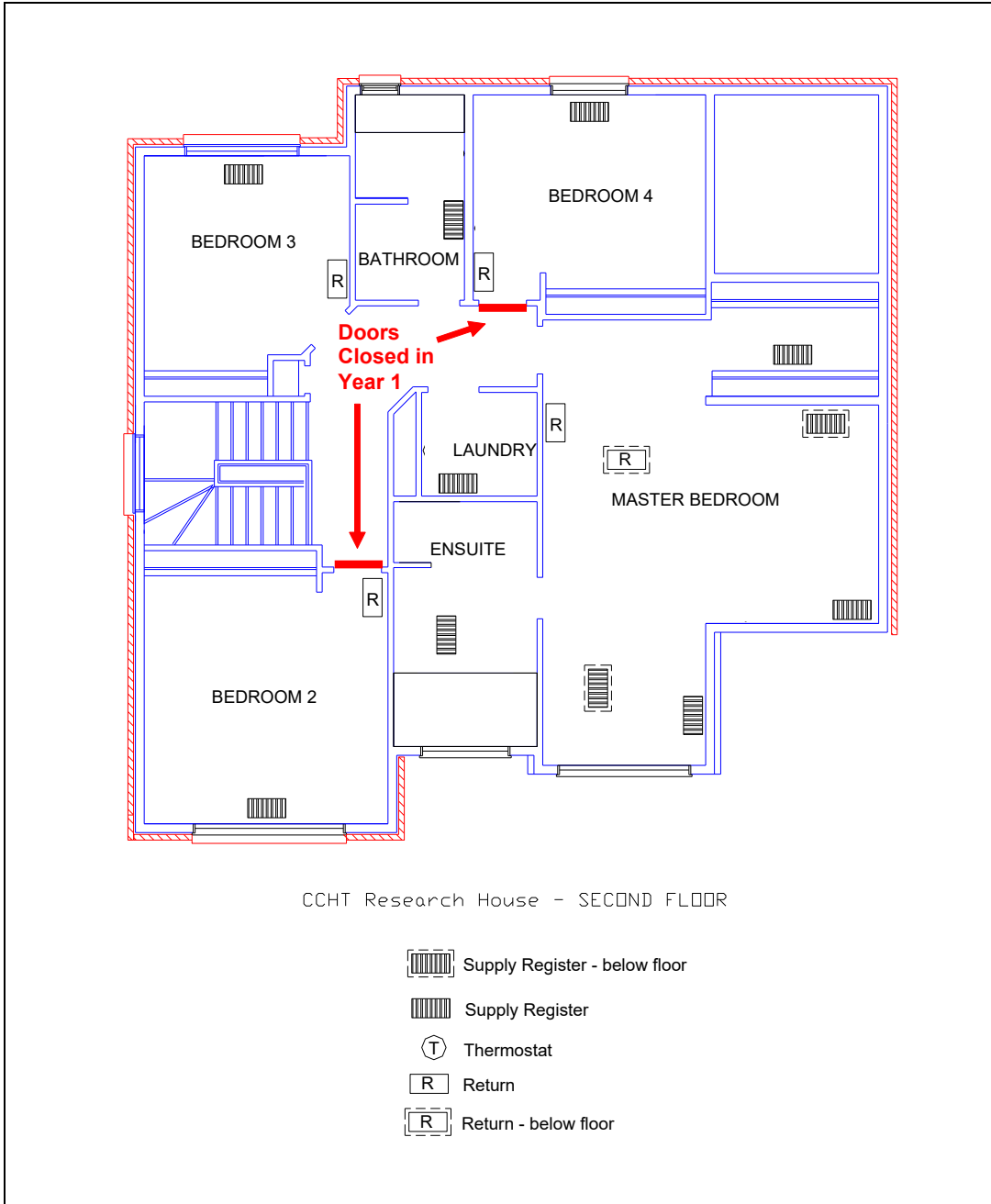


Figure 2 – Second floor layout of the CCHT Experimental House



Figure 3 - CCHT Twin-House Facility during winter (Experimental House shown at right)

3.2 Fireplace Description

The technology examined in this study is a direct-vent, zero clearance, natural gas fireplace, with a standing pilot light and 48W circulating fan. The fireplace has a maximum input of 20,000 Btu/h with a measured steady state efficiency of rated fireplace efficiency of 76.1%. See Appendix J for steady state efficiency testing results. According to Natural Resources Canada, a well designed non-condensing gas-fireplace should be able to achieve a Steady State Efficiency in the region of 82 to 85%. The fireplace installed in both the CCHT Experimental House and Control House at the time of construction (1998), but was not activated until this experiment. The fireplace is located in the main floor family room, recessed into the North wall (see Figure 1 for the main floor plan with fireplace location).



Figure 4 - The Experimental House fireplace

4 Methodology

4.1 Side-by-side testing procedure

CCHT's twin houses are referred to for this experiment as the "Experimental House" and the "Control House".

For all side-by-side experiments, the twin houses are benchmarked in identical configuration at the start and periodically throughout the heating season. By quantifying the small differences between the houses during benchmarking, all additional differences in house performance during an experiment can be attributed to the technology being assessed. The benchmark configuration is described in Table 1. Note that the benchmark changed between Year 1 and Year 2 of the fireplace study. The Year 1 benchmark did not include any exterior shades, whereas the Year 2 benchmark included exterior shades on the largest two south-facing windows of both houses. This change was made to accommodate other projects in the 2009-2010 heating season. The configuration in the first year represents a passive solar R-2000 house and the configuration in the second year represents an R-2000 house that has considerable shading on the south side.

Table 1 - Operating Conditions for the Benchmark

	System	Setup
1	Heating system	Forced air system, heating provided by a high efficiency single-stage condensing gas furnace with split capacitor motor; circulation fan "on" at standby.
2	House Thermostat	Standard central location, 22°C setpoint
3	Heat Recovery Ventilator (HRV)	On continuous 65 cfm, with two high speed cycles per day at the same time as the simulated shower events
4	Interior Doors	All Open
5	Window Shading	Year 1: no exterior shades, Interior Venetian blinds down with slats in the horizontal position Year 2: exterior shades on the two largest south-facing windows
7	Simulated Occupancy	Standard Schedule (see Appendix B)
8	Humidifier	Off
9	Hot Water Heater	Standard Gas
10	Fireplace	Vent sealed (as shown in Figure 5), fireplace and pilot light off



Figure 5 - Sealed fireplace vent during Benchmarking

During the experiment portion of side-by-side testing, a change is made to the Experimental House. In this experiment, a scenario of fireplace operation was introduced. A total of five different scenarios were examined in the fireplace experiment, as described below:

a) Year 1 – Fireplace operation from 18:00 – 24:00 with continuous air circulation

The fireplace was run continuously for six hours in the evening, with no thermostat control on the fireplace. The pilot light remained lit the remainder of the day when the fireplace was not running. Doors to Bedroom 2 (southwest corner of the house) and Bedroom 4 (northeast corner of the house) on the second floor were closed (see Figure 2 for bedroom locations). The furnace fan was allowed to operate normally, providing continuous air circulation (~650 cfm) at standby, and high speed airflow during heating (~1100 cfm).

b) Year 1 – Fireplace operation from 18:00 – 24:00 with no continuous air circulation

The fireplace was run continuously for six hours in the evening, with no thermostat control on the fireplace. The pilot light remained lit the remainder of the day when the fireplace was not running. Doors to Bedroom 2 and Bedroom 4 on the second floor were closed (see Figure 2 for bedroom locations). The furnace fan did not provide air circulation at standby. For this condition only, the Control House was also operated without continuous air circulation by the furnace fan.

c) Year 2 – Fireplace with thermostat control

The fireplace was connected to a dedicated thermostat, in the location shown in Figure 1. The fireplace thermostat was set to 23°C, and cycled fireplace operation to maintain this setpoint. The setpoint was chosen 2°C above the house thermostat setpoint (21°C). The setpoint was high enough to cause the fireplace to fire, but not too high to prevent the house thermostat from calling for furnace operation occasionally. All interior doors were kept open. The furnace fan provided continuous air circulation at standby.

d) Year 2 – Pilot light only

The fireplace was turned off, and the pilot light remained lit. All interior doors were kept open. The furnace fan provided continuous air circulation at standby.

e) Year 2 – Fireplace vent open, no operation

The fireplace and pilot light were shut off. The fireplace vent remained unsealed. All interior doors were kept open. The furnace fan provided continuous air circulation at standby.

4.2 Test Dates

The experiment was performed over two years. The first year of study (2008-2009) examined the continuous operation of the fireplace in the evening, with and without continuous air circulation by the furnace fan (Table 2).

The second year of study (2009-2010) examined operating the fireplace under thermostat control, the impact of the pilot light, and the impact of the fireplace vent (Table 3).

Table 2 – Year 1 Experiment and Benchmark Dates

Configuration	Date Range	Number of Days	Outdoor Temperature
a) Operation from 18:00 – 24:00 Continuous air circulation	19-Dec-08 to 27-Dec-09 and 6-Mar-09 to 11-Mar-09	15	Max. 10.3°C Min. -19.1°C
b) Operation from 18:00 – 24:00 No continuous air circulation	28 Dec-08 to 1-Jan-09 and 13-Mar-09 to 15-Mar-09	8	Max. 10.0°C Min. -18.7°C
Benchmark	22-Nov-08 to 13-Apr-09	36 (not consecutive, includes 12 days of benchmarking with Bedroom 2 and Bedroom 4 doors closed)	Max. 14.0°C Min. -20.0°C

Table 3 – Year 2 Experiment and Benchmark Dates

Configuration	Date Range	Number of Days	Outdoor Temperature
c) Thermostat control	6-Feb-10 to 14-Feb-10	9	Max. 3.8°C Min. -14.8°C
d) Pilot light only	2-Feb-10 to 4-Feb-10 and 16-Feb-10 to 18-Feb-10	6	Max. 3.9°C Min. -12.7°C
e) Fireplace vent open	26-Feb-10 to 1-Mar-10	4	Max. 8.9°C Min. 1.9°C
Benchmark	14-Oct-09 to 24-Feb-10	40 (not consecutive)	Max. 17.5°C Min. -17.9°C

4.3 Instrumentation

Electrical and Natural gas Consumption

Electric pulse-meters measured furnace and fireplace fan electrical consumption at a resolution of 1 pulse per 0.0006 kWh. Natural gas consumption of the furnace was measured by gas meters with a resolution of 1 pulse per 0.05 ft³ natural gas. The natural gas consumption of the fireplace was monitored using a gas meter with a resolution of 1 pulse per 1 ft³ natural gas. Meter data was collected at 5-minute intervals by the central data acquisition system (DAS). Total daily furnace and fireplace consumption were calculated from the 5-minute readings and this information was used in the analysis.

Temperature measurement

All air and surface temperature measurements were made by thermocouples connected to the centre DAS, with an accuracy of $\pm 0.2^{\circ}\text{C}$. The temperature of air in the family room (where the fireplace is located) was measured by thermocouple at a height of 4 feet at a central location in the room, as shown in Figure 6. Temperature data at this location was collected on a 5-minute basis.

In Year 1 of the fireplace experiment, thermocouples were deployed to measure surface temperatures in three additional locations: in the southwest corner of the living room near the floor; on the exterior wall of the closet of bedroom 2, behind a box filled with paper; and in the second floor bathroom cupboard. These surface temperature measurements were recorded once every 5 minutes. Additional measurements of room air temperature were taken at mid height and recorded once every hour.

In Year 2 of the fireplace experiment, thermocouples were deployed at a central location in each room, at a height of 4 feet (in a similar manner to the thermocouple located in the family room). These thermocouples were used to record room air temperature every 5 minutes.



Figure 6 - Air temperature measurement in the family room

Weather data

A temperature sensor mounted on the North side of the CCHT Experimental House provided outdoor temperature data in °C (Figure 7). A precision spectral pyranometer recorded solar radiation incident on the south face of the Experimental House in W/m^2 (as shown in Figure 8). A second pyranometer was mounted on a horizontal platform above the Experimental House roof and recorded radiation incident on a horizontal surface. Both solar and temperature data were recorded on a 5-minute basis by the central CCHT DAS.



Figure 7 – North face of the CCHT Reference House, showing the location of the outdoor temperature sensor.



Figure 8 – South face of CCHT Reference House, showing location of the precision spectral pyranometer to measure incident solar radiation.

4.4 Statistical Analysis

A one-way analysis of covariance (ANCOVA) was applied to sets of consumption data to determine whether one set of data was significantly different from a second set. For example: a set of gas consumption data from the benchmark was compared to a set of gas consumption data from the pilot light experiment. For all analysis, a 5% ($\alpha=0.05$) level of significance was used. The full results of the ANCOVA are provided in Appendix I. In all instances, the analysis reported no significant difference in slope of the linear regression trends being compared ($P>0.05$). The ANCOVA was subsequently used to compare the adjusted means to determine whether the trends were statistically different.

5 Results from Year 1 - Fireplace operation from 18:00 – 24:00 with and without continuous air circulation

The first year of results were analyzed over a 24-hour day beginning at 18:00 in order to capture the lingering effects of fireplace operation in the evening. For example, 19-Dec-08 refers to the 24-hour time period from 19-Dec-08 at 18:00 to 20-Dec-08 at 18:00.

5.1 Outdoor Temperature and Solar Conditions

The outdoor temperature and solar conditions from Year 1 are reported in Table 4, and plots of 5-minute data are shown Figure 9 and Figure 10. Outdoor temperatures during condition (a) ranged from -19.1°C to 10.3°C, with an average of -4.3°C. Most days during this period had low solar gains (<15000 kJ/m²/day on a vertical south-facing surface). Outdoor temperatures during condition (b) ranged from -18.7°C to 10.0 °C, with an average of -3.8°C. Condition (b) featured a majority of days with high solar gains (>15000 kJ/m²/day on a vertical south-facing surface).

Table 4 - Outdoor Temperature and Solar Radiation during Year 1 of the experiment

Date	Outdoor Temperature, °C			Global Solar Radiation, kJ/m ² /day	
	average	Min	Max	On Vertical South-facing surface	On Horizontal Surface
a) Operation from 18:00 – 24:00 Continuous Circulation					
19-Dec-08	-13.8	-15.0	-12.0	16517	6379
20-Dec-08	-14.2	-17.8	-10.2	1200	1634
21-Dec-08	-11.8	-15.5	-9.2	10194	5561
22-Dec-08	-16.0	-19.1	-11.2	3037	3788
23-Dec-08	-4.5	-11.3	2.1	733	946
24-Dec-08	1.4	-4.6	6.6	16169	6511
25-Dec-08	-9.6	-14.1	-4.5	1566	2417
26-Dec-08	-3.7	-7.0	1.4	664	1008
6-Mar-09	7.4	5.3	10.3	8555	9795
7-Mar-09	4.7	2.4	6.7	19220	15700
8-Mar-09	0.0	-3.3	4.2	6153	8088
9-Mar-09	-0.3	-5.2	4.3	4943	7716
10-Mar-09	4.2	2.1	9.0	6425	7645
b) Operation from 18:00 – 24:00 <u>No</u> Continuous Circulation					
28-Dec-08	2.3	-0.7	5.7	1688	2463
29-Dec-08	-2.8	-9.7	2.0	17128	6807
30-Dec-08	-12.7	-14.8	-9.7	12648	6069
31-Dec-08	-15.7	-18.7	-12.1	17417	6762
12-Mar-09	-7.3	-11.2	-0.4	21040	17956
13-Mar-09	-1.2	-5.7	6.8	19193	16961
14-Mar-09	4.2	0.5	10.0	17913	16640
15-Mar-09	2.7	-1.9	10.0	18452	16503

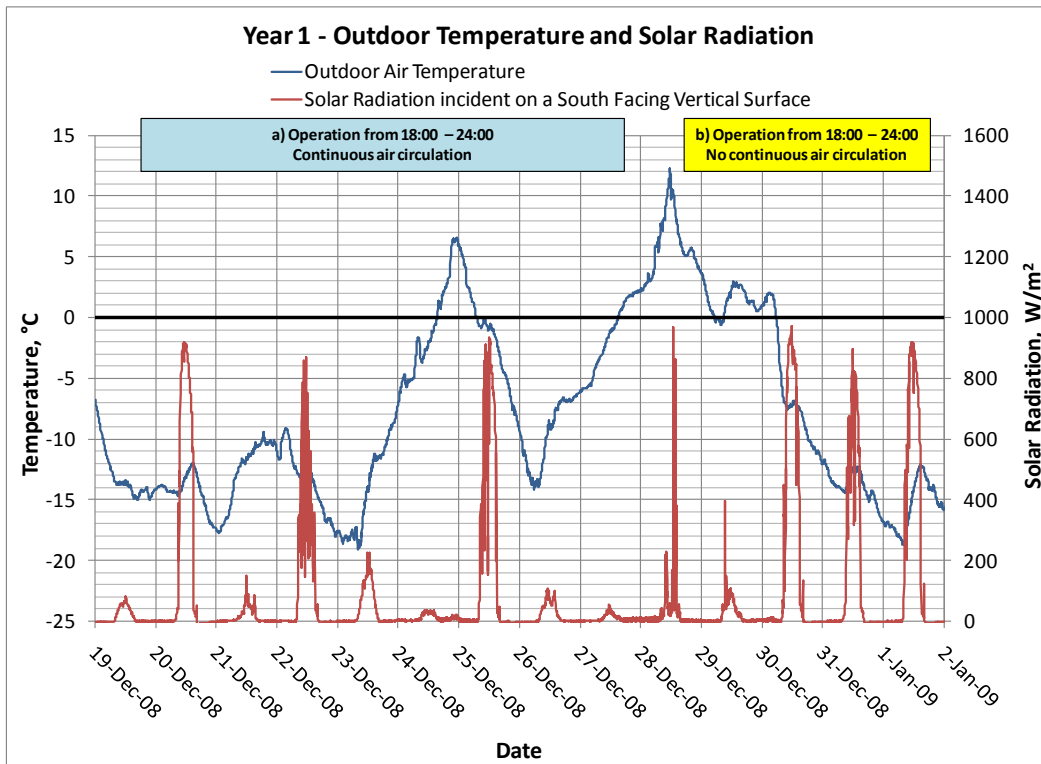


Figure 9 - Outdoor temperature and solar radiation during Year 1 of the experiment

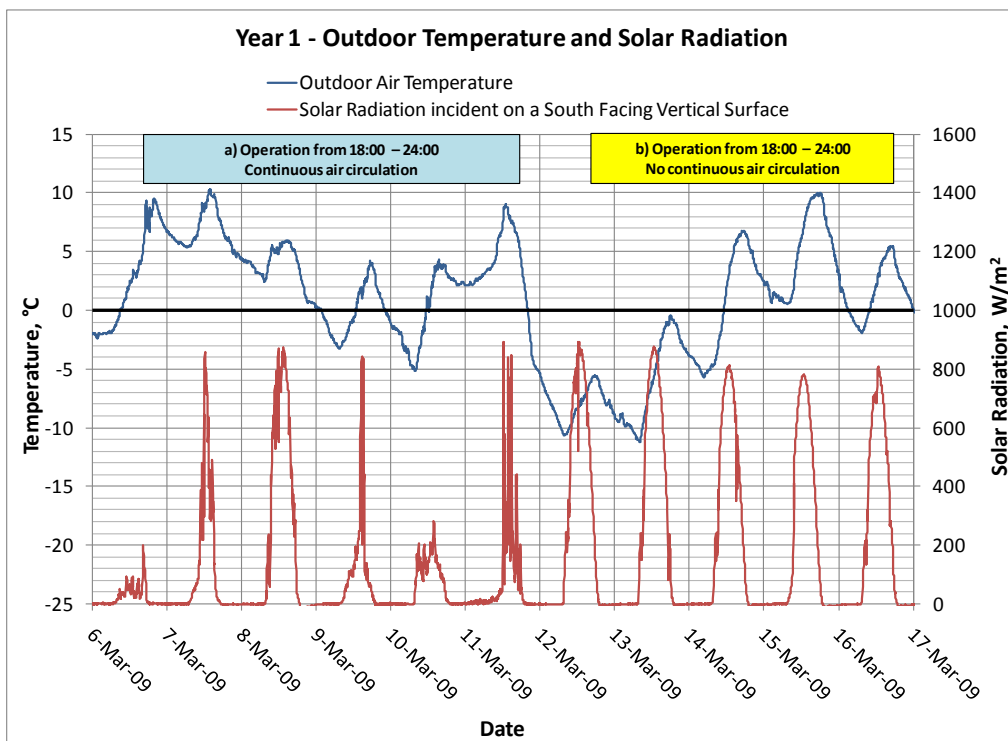


Figure 10 – Outdoor temperature and solar radiation during Year 1 of the experiment (cont.)

5.2 Energy Consumption

Natural Gas Consumption

During both condition (a) and condition (b) the fireplace was operated continuously from 18:00 to 24:00. During the remainder of the day, the pilot light remained lit. A sample graph of furnace and fireplace natural gas consumption is presented in Figure 11. When the fireplace was operating the furnace operation was reduced – with few heating cycles. During the remainder of the day the furnace cycled frequently. In this figure, the fireplace pilot light also appears to cycle – however, this effect is due to the resolution of the natural gas meter: the pilot light consumes a constant $0.025 \text{ ft}^3/\text{min}$, while the fireplace gas meter transmits one pulse per cubic foot. The furnace gas meter had a higher resolution of 1 pulse per 0.05 ft^3 .

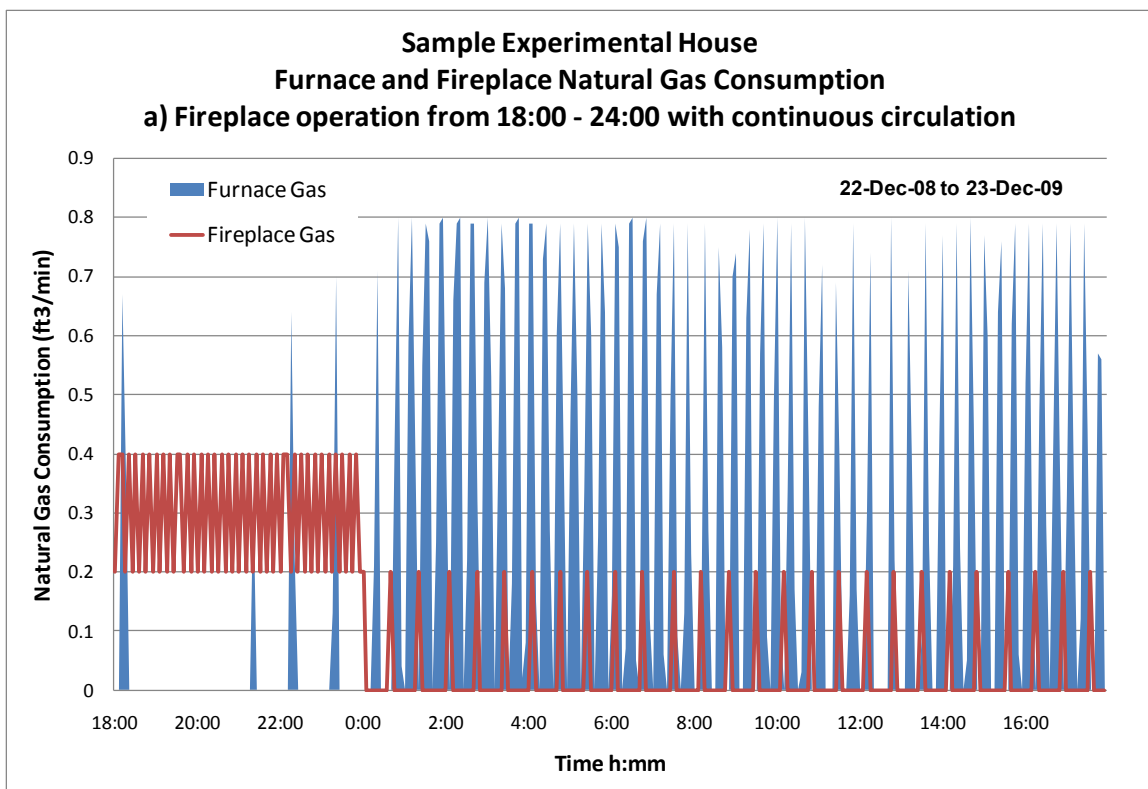


Figure 11 – Sample Experimental House furnace and fireplace natural gas consumption, condition (a) fireplace operation from 18:00 – 24:00 with continuous circulation

The effect of the fireplace on furnace operation can be calculated on a daily basis. Figure 12 presents a comparison of the furnace natural gas consumption in the Control House and the Experimental House. The Control House daily consumption per day is plotted on the x-axis. The Experimental House daily consumption is plotted on the y-axis. Each data point represents a single day of consumption. If the houses were completely identical, the resulting trend would be a perfect slope of 1 (a 45-degree angle) with an intercept of 0. The Year 1 benchmark data (shown in pink) has a slope of 0.964 and intercept of 0.575. The fact that the benchmark is not perfect is the result of small differences in the houses – if the houses were identical, there would be no reason

to benchmark. The differences in benchmarking are accounted for in the savings calculation method (refer to Appendix C for a description of this method).

Results from Year 1 of the fireplace experiment are plotted in red for condition (a) and in blue for condition (b). As indicated above, the fireplace was operated in the Experimental house, and the experiment is designed to identify any significant change in energy consumption in the Experimental House upward (more consumption) or downward (savings) compared to the benchmark line. The trend line drawn through these points for both condition (a) and (b) falls well below the benchmark trend line, indicating a decrease in furnace gas consumption due to fireplace operation in the Experimental House across the range of experiment conditions.

ANCOVA results show that the operation of the furnace fan in the home with and without continuous air circulation did not have a significant impact on furnace natural gas consumption during the fireplace experiment ($F_{1, 18}=1.72$, $P=0.206$). During the experiment period, operation of the fireplace in the Experimental House decreased furnace gas consumption by 106 MJ/day (39.4%) was operated with or without continuous circulation at standby. Summary tables of gas consumption can be found in Appendix E.

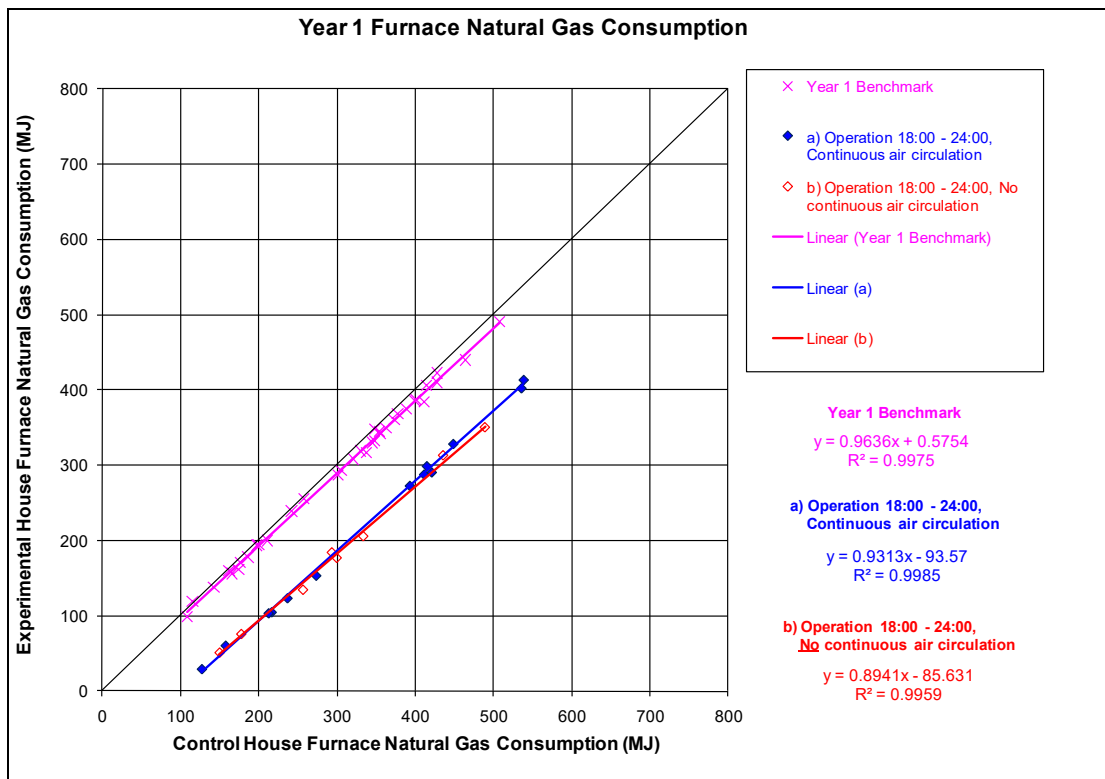


Figure 12 - Year 1 – Reduction of daily furnace natural gas consumption due to fireplace operation

In Figure 13, the natural gas consumption of the fireplace has been added to the furnace consumption in the Experimental House. The benchmark trend in this figure is identical to the benchmark in Figure 12, since the benchmark did not include any fireplace operation. The experiment trends for condition (a) and (b) lie above the benchmark line,

indicating an increase in total natural gas consumption in the Experimental House due to the operation of the fireplace.

ANCOVA results again show that there is no significant difference between the total natural gas consumption trends for condition (a) and (b) ($F_{1, 18}=3.20, P=0.091$). The fireplace consumed approximately 144 MJ of natural gas per day to operate for 6 hours continuously. As a result, the Experimental House consumed on average 38 MJ/day (15.5%) more natural gas for heating (furnace and fireplace) during the experiment.

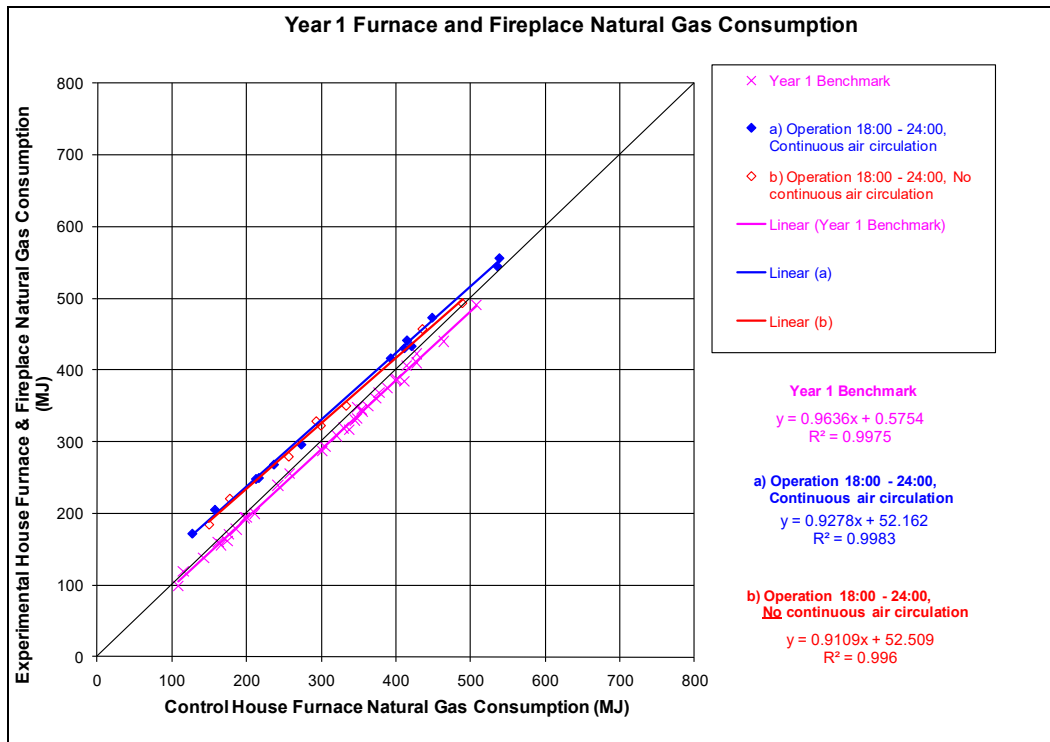


Figure 13 - Year 1 - Overall increase of furnace and fireplace natural gas consumption due to fireplace operation

Electrical Consumption

The fireplace consumed approximately 0.26 kWh/day of electricity to operate the 33 Watt circulating fan for 6 hours.

A plot of furnace fan electrical consumption is presented in Figure 14. When the fireplace ran, the furnace operated less in high speed heating mode, and there was a resultant reduction in furnace fan electrical consumption. In case (a) with continuous air circulation, furnace electrical consumption was reduced by an average of 1.12 kWh/day (10.4%). In case (b) there was no benchmark for operation without continuous air circulation, so the benchmark curve was extrapolated to calculate savings. For (b), the fireplace operation resulted in an average 1.96 kWh/day (35.7%) reduction in furnace fan electrical consumption. Summary tables of electrical consumption can be found in Appendix E.

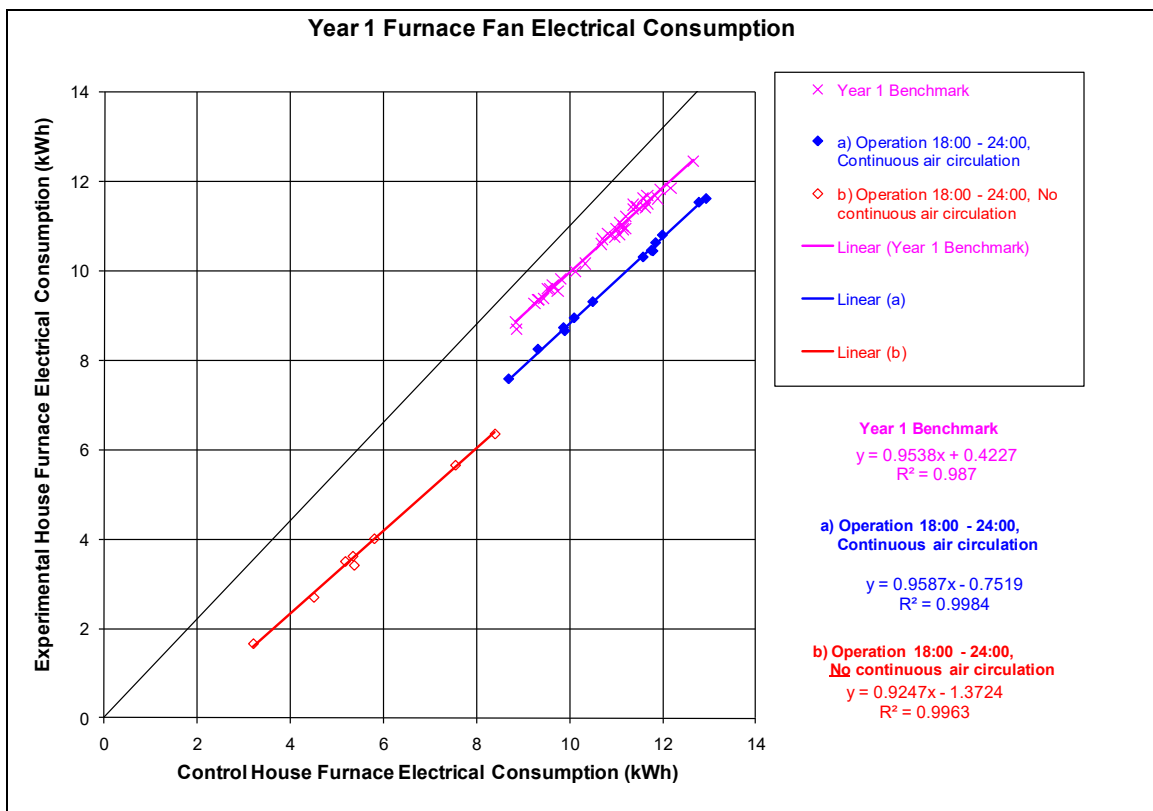


Figure 14 - Year 1 Reduction of daily furnace fan electrical consumption due to fireplace operation

Total Energy Consumption for Heating

The total heating system electrical and gas consumption is plotted in Figure 15. Throughout all conditions, the operation of the fireplace for six hours in the evening, with or without continuous circulation, resulted in an increase in total heating energy consumption. ANCOVA results show that operation of the furnace fan in the home with and without continuous air circulation did impact total heating system gas and electrical consumption during the fireplace experiment ($F_{1, 18}=8.80$, $P=0.008$).

During configuration (a) with continuous air circulation, evening fireplace operation resulted in an average increase in consumption of 36.5 MJ/day (12.5%). During configuration (b) with no continuous air circulation, evening fireplace operation resulted in an average increase in consumption of 29.9 MJ/day (11.6%). The increase in consumption was highest on the warmest days of testing (with the lowest heating loads). On these days, the fireplace potentially contributed to overheating. Summary tables of total energy consumption can be found in Appendix E.

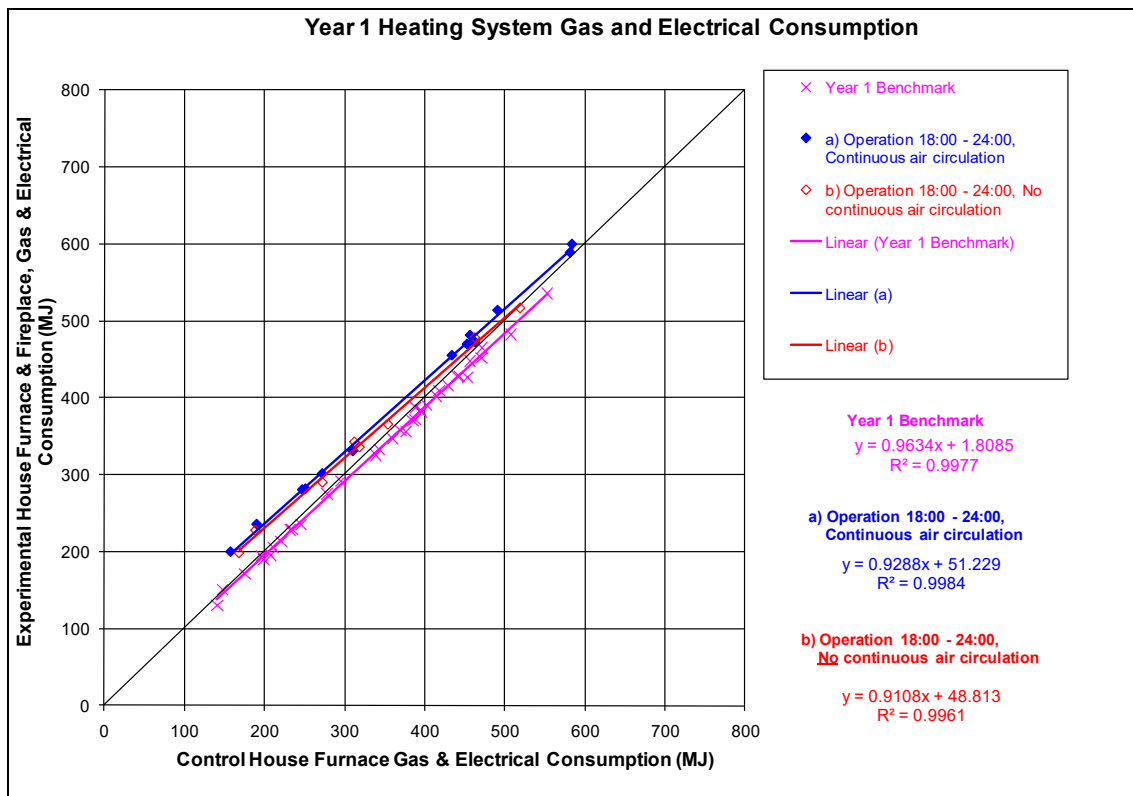


Figure 15 - Year 1 Overall increase in total heating system gas and electrical consumption due to fireplace operation

The total daily heating system gas and electrical energy consumption is presented as a bar chart in Figure 16. In this chart, the columns labeled “Bench” refer to the expected energy consumption of the Experimental House in benchmark condition, as adjusted using the benchmark correlations (as described in Appendix C). The columns labeled “Exp” show the measured daily Experimental House energy consumption from the experiment. This plot clearly shows that the fireplace use resulted in higher overall energy consumption.

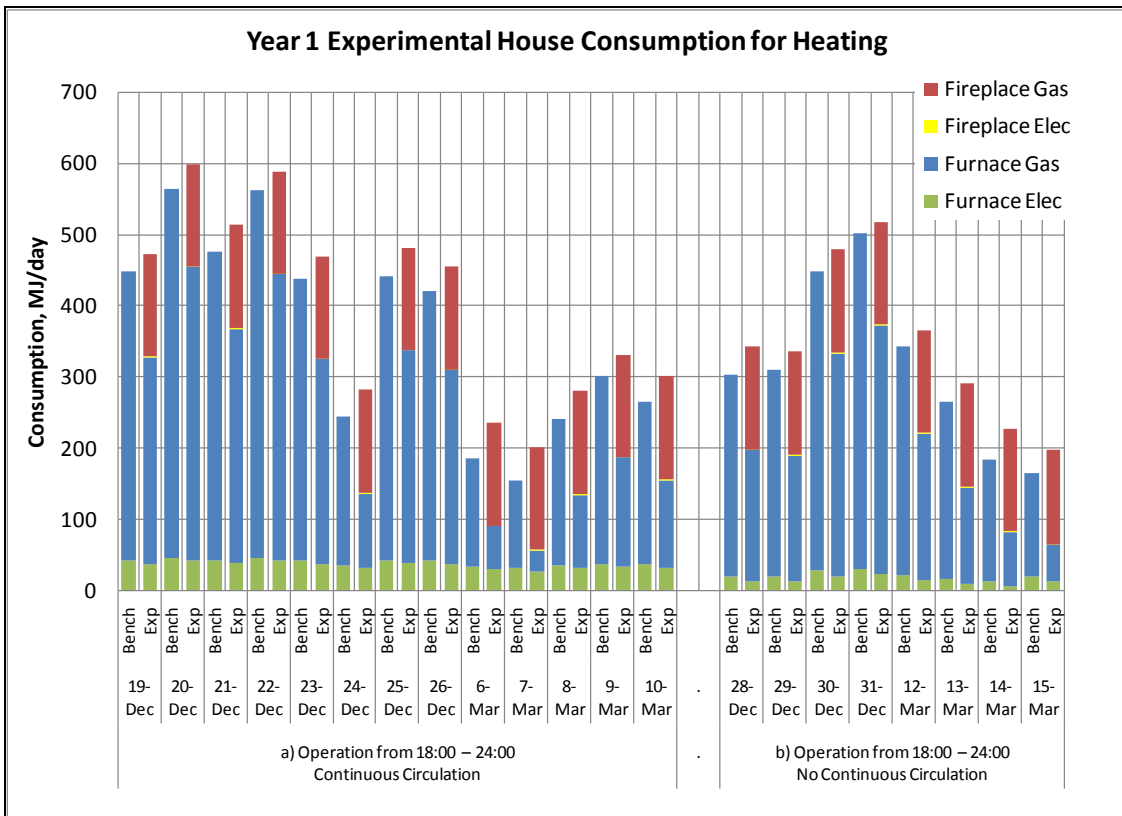


Figure 16 – Year 1 Experimental House Energy Consumption for Heating

The bar chart in Figure 17 takes into account the low efficiency of the fireplace (76.1% measured steady state), and high efficiency of the furnace (94%) to calculate the approximate total heat output to the home. On most days of the experiment, the same or slightly more heat was delivered to the home with fireplace operation. Due to fireplace operation, there was on average 8.2 MJ/day (3.5%) more heat delivered to the home (by both the furnace and fireplace) in configuration (a) with continuous air circulation, and 2.0 MJ/day (1.6%) more heat delivered during configuration (b) with no continuous air circulation.

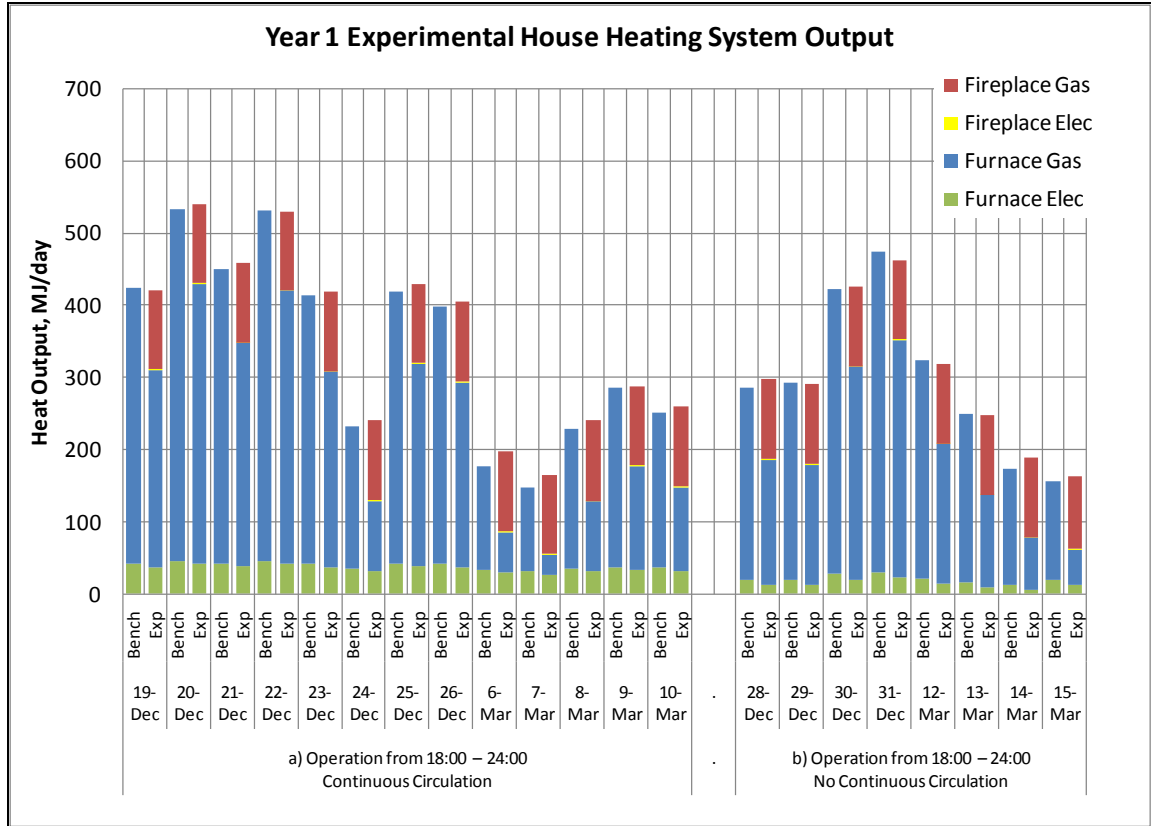


Figure 17 – Year 1 Experimental House Heating System Output

5.3 Family Room Temperature

During fireplace operation, the temperature in the family room was heated above the setpoint of the furnace. Sample family room temperatures during benchmarking and during fireplace operation with continuous circulation are plotted in Figure 18 and Figure 19. During fireplace operation with continuous circulation (a), the family room air temperature reached a maximum of 25.9°C (Table 5). During fireplace operation without continuous circulation (b), the family room air temperature reached a maximum of 26.8°C, 4.9°C above the maximum temperature of the Control House family room. Even during the period of the day when the fireplace was shut off, the room remained warmer. This could be due to the continued contribution of the pilot light to heating in the family room.

Table 5 – Maximum family room temperature during Year 1

	Family room		
	Maximum air Temperature, °C		
	Exp.	Control	Difference
Y2 Benchmark	22.4	22.2	0.3
Y2 Benchmark – doors closed	22.2	22.0	0.2
a) Continuous circulation	25.9	22.0	3.9
b) No continuous circulation	26.8	22.0	4.9

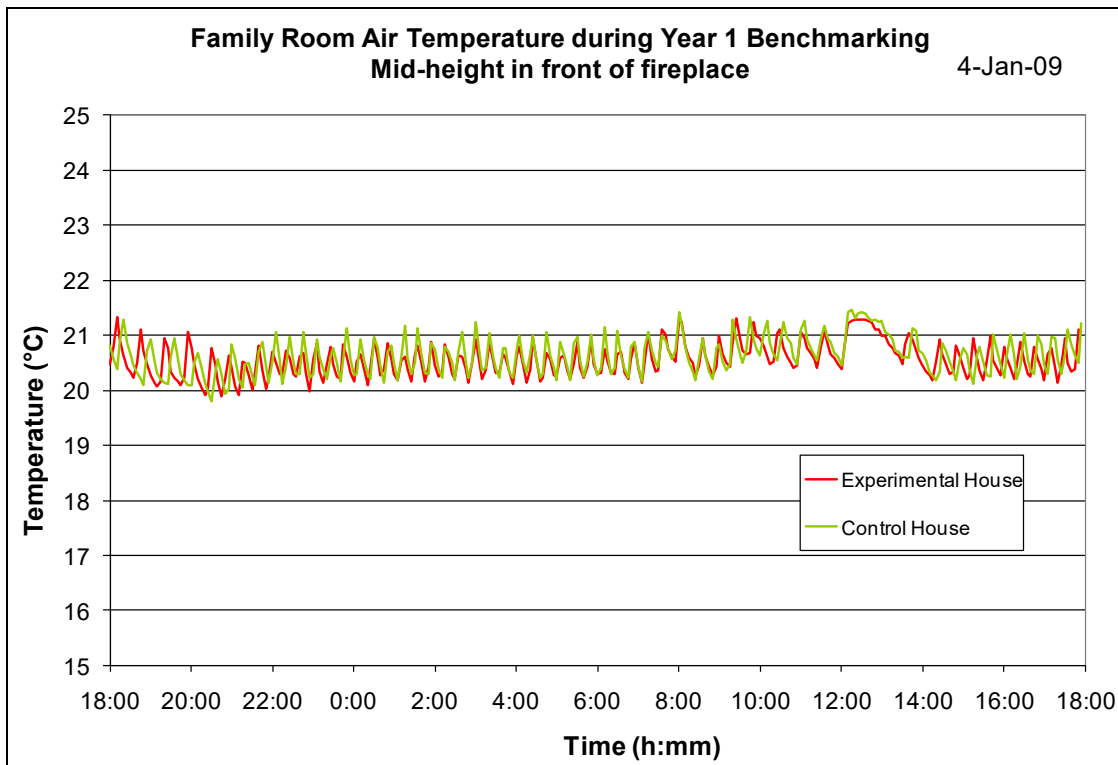


Figure 18 - Sample family room air temperature during Year 1 Benchmarking

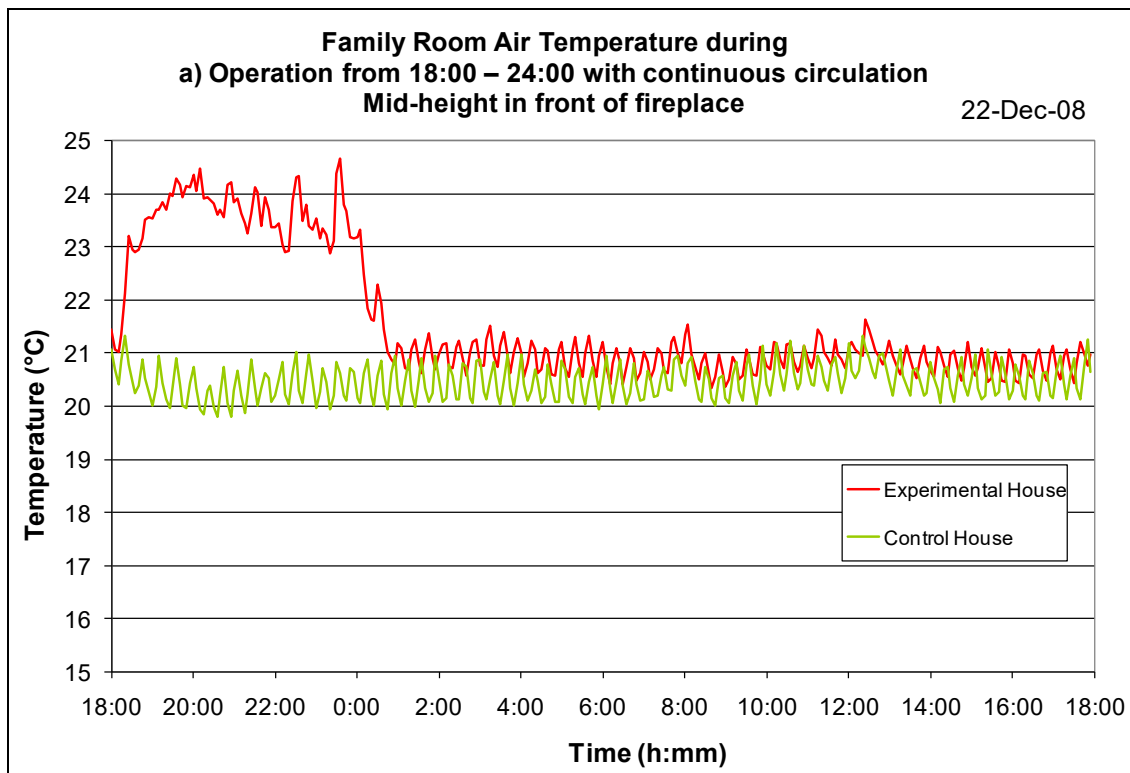


Figure 19 - Sample family room air temperature during a) Operation from 18:00 – 24:00 with continuous circulation

The probability distribution of family room temperature data is presented in Figure 20. This diagram shows the probability of the air being at any given temperature. The plot contains data from both houses, and for three different conditions: benchmarking with doors closed, (a) fireplace operation with continuous circulation, and (b) fireplace operation without continuous circulation. All three probability distribution curves for the Control House are similar – as expected, since the Control House was in benchmark configuration throughout Year 1 benchmarking and experiments. During benchmarking, the Experimental House probability distribution resembles that of the Control House. During the fireplace experiment, the probability distribution is shifted to higher temperatures by fireplace operation.

This data can also be plotted as cumulative frequency curves (Figure 21). In this form, the data shows the probability of air being at or below a given temperature. The three cumulative frequency curves for the Control House and the benchmark curve for the Experimental House are again similar. In all these cases, family room temperature was below 20.6°C ~50% of the time, and below 22.0°C ~100% of the time. The Experimental House curves during the fireplace experiment are again distinct from the Control House and benchmark curves. Both experiment curves are similar below 23.0°C, but differ at higher temperatures. During the experiment with continuous circulation (a), the family room air temperature was above 25°C ~5% of the time, while without continuous circulation (b), the air temperature was above 25°C ~10% of the time.

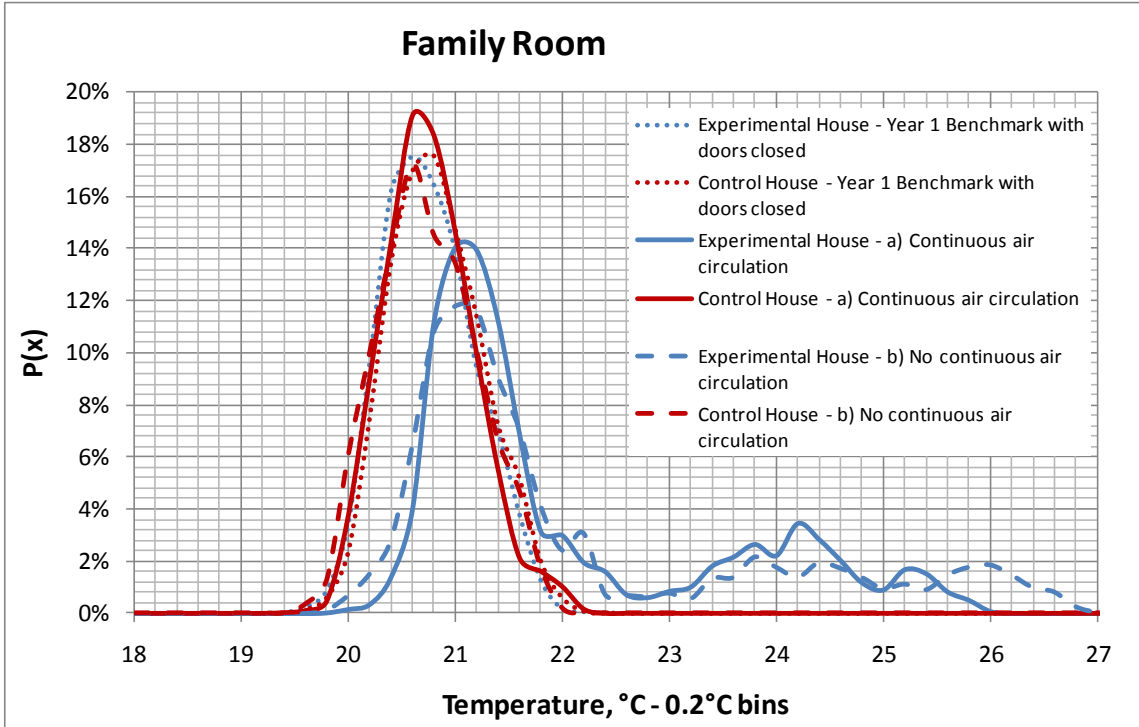


Figure 20 – Probability Distribution of Family Room air temperature, Year 1

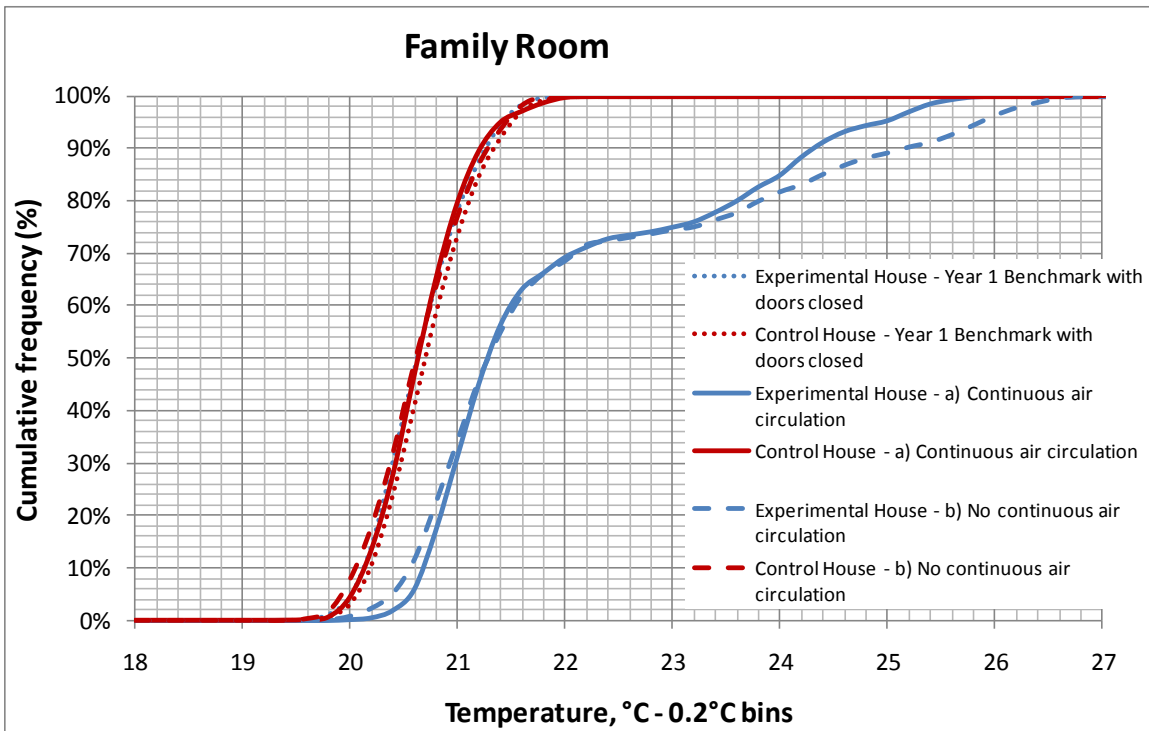


Figure 21 – Cumulative Frequency of Family Room air temperature, Year 1

5.4 Second floor room temperature

Temperatures on the second floor of the home were affected by evening fireplace operation. On evenings when the fireplace operated, the temperature of rooms on the second floor dropped. The effect was most pronounced in the master bedroom, and Bedroom 2 (Figure 24).

During Benchmarking with doors closed, Bedroom 2 air temperature was similar in the two houses (Figure 22), on average within 0.5°C (see Table 6 for average room air temperature). Note: the peaks in this graph are caused by the thermocouple being exposed to solar radiation on sunny days, and coincide with the peaks in measured solar radiation shown in Figure 10. Overnight (when there was no solar effect on temperature measurement), the temperature in Bedroom 2 was similar to the temperature in the family room (Figure 23).

During the Experiment, air temperature dropped in the evening, down to 15.4 °C on the coldest occasion (see Table 7 for minimum room air temperature). Similar drops were seen during a) with continuous circulation and b) without continuous circulation. As shown in Figure 25, the evening dips in temperature in Bedroom 2 coincide with evening peaks in temperature in the family room (as heated by the fireplace). As a result, the family room was up to ~8°C warmer than Bedroom 2 at times during fireplace operation.

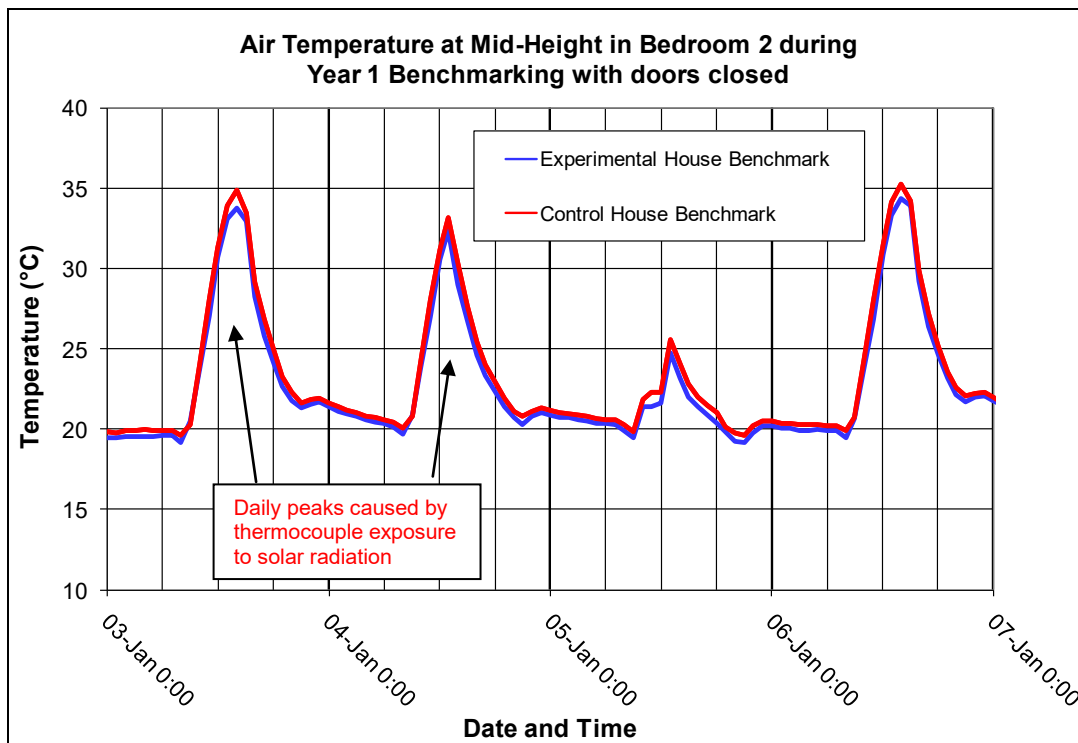


Figure 22 – Sample air temperatures in Bedroom 2, measured during Year 1 benchmarking with doors closed

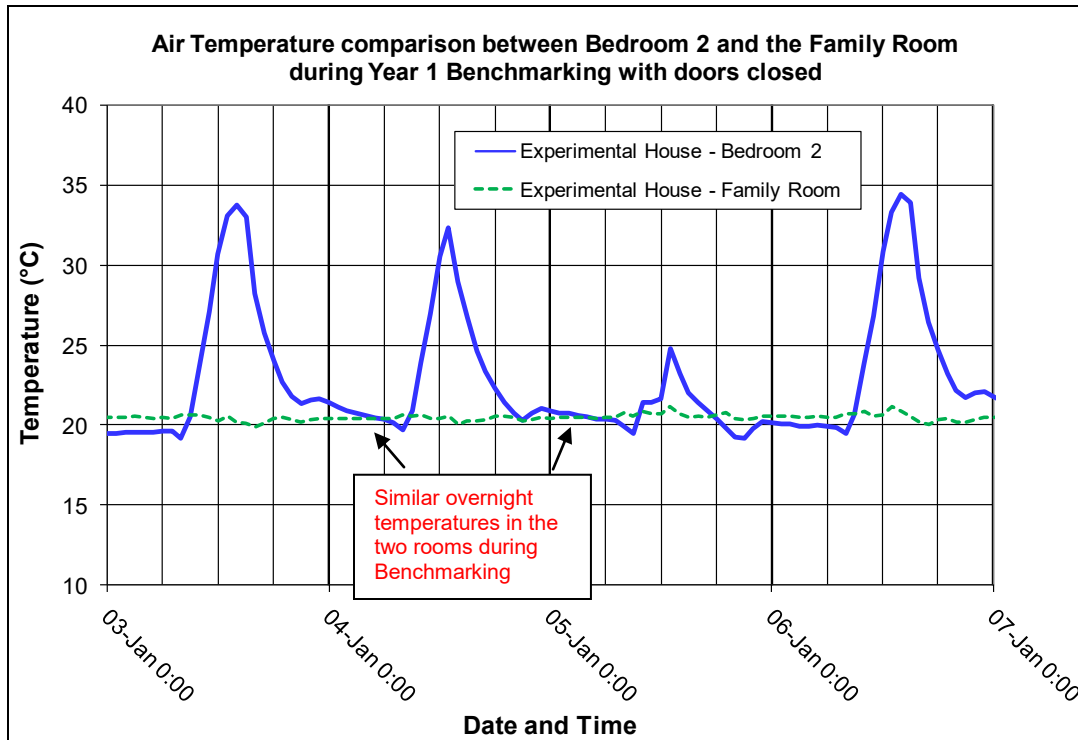


Figure 23 – Comparison of Experimental House Bedroom 2 and family room temperature during Year 1 Benchmarking with doors closed

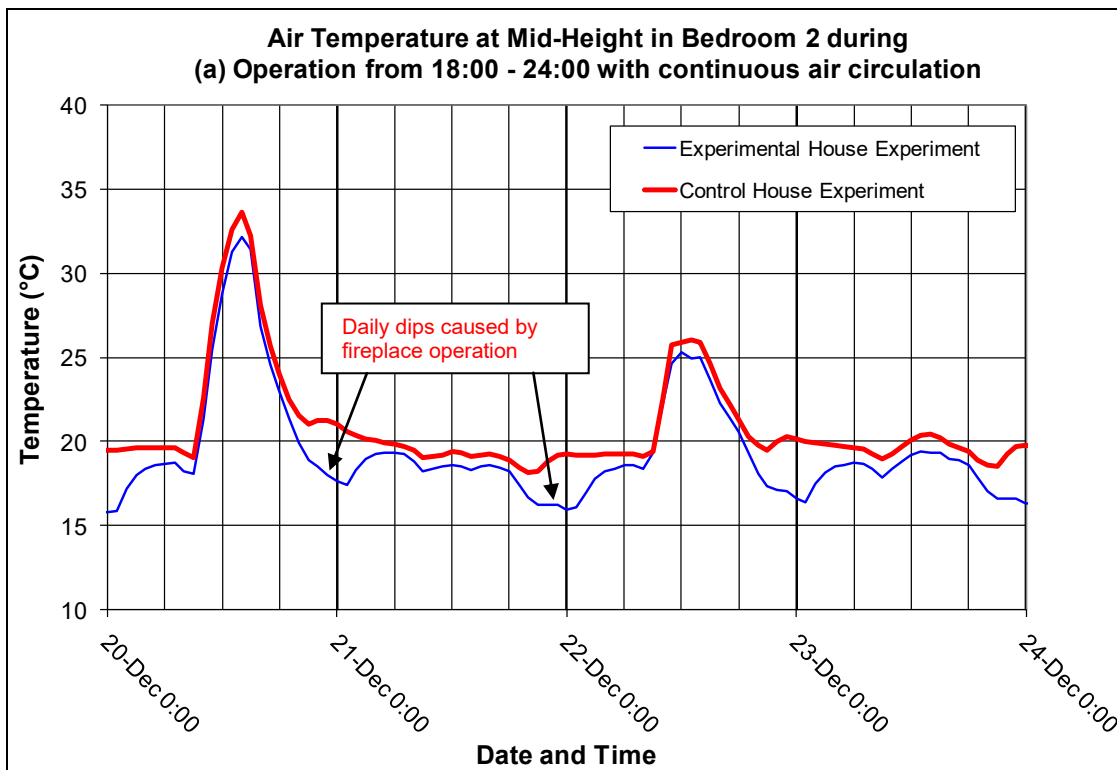


Figure 24 - Sample air temperatures in Bedroom 2, measured during fireplace condition (a) Operation from 18:00 – 24:00 with continuous air circulation

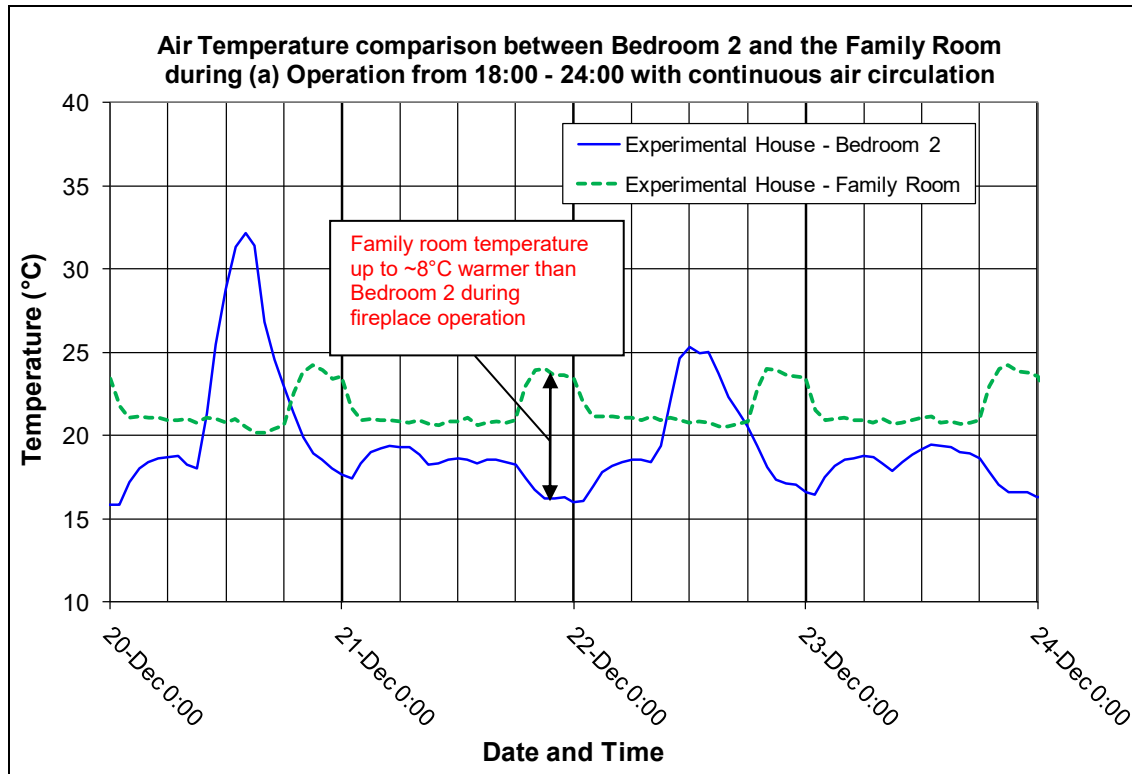


Figure 25 - Comparison of Experimental House Bedroom 2 and family room temperature during fireplace condition (a) Operation from 18:00 – 24:00 with continuous air circulation

The effect was less pronounced in the rooms above the location of the fireplace – the bathroom and Bedroom 4. Sample temperature data for Bedroom 4 during benchmarking with doors closed is presented in Figure 26. This room is located on the north side of the house, and the thermocouple measuring air temperature did not experience the same solar radiation peaks as seen for Bedroom 2. During Benchmarking, air temperature was similar in the two houses. Colder temperatures were seen in this room in both houses when the doors were closed (Table 6). Generally, the Experimental House Bedroom 4 air temperature was 2 to 3°C cooler than the family room during benchmarking with doors closed (Figure 27).

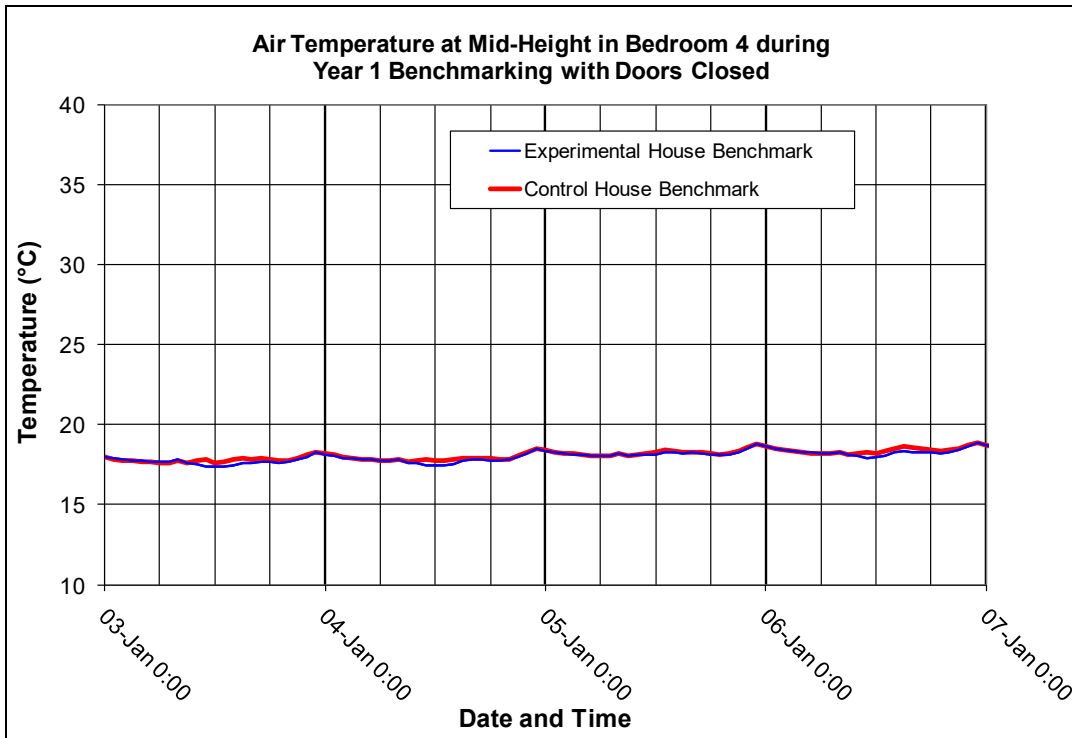


Figure 26 – Sample air temperatures in Bedroom 4, measured during Year 1 benchmarking with doors closed

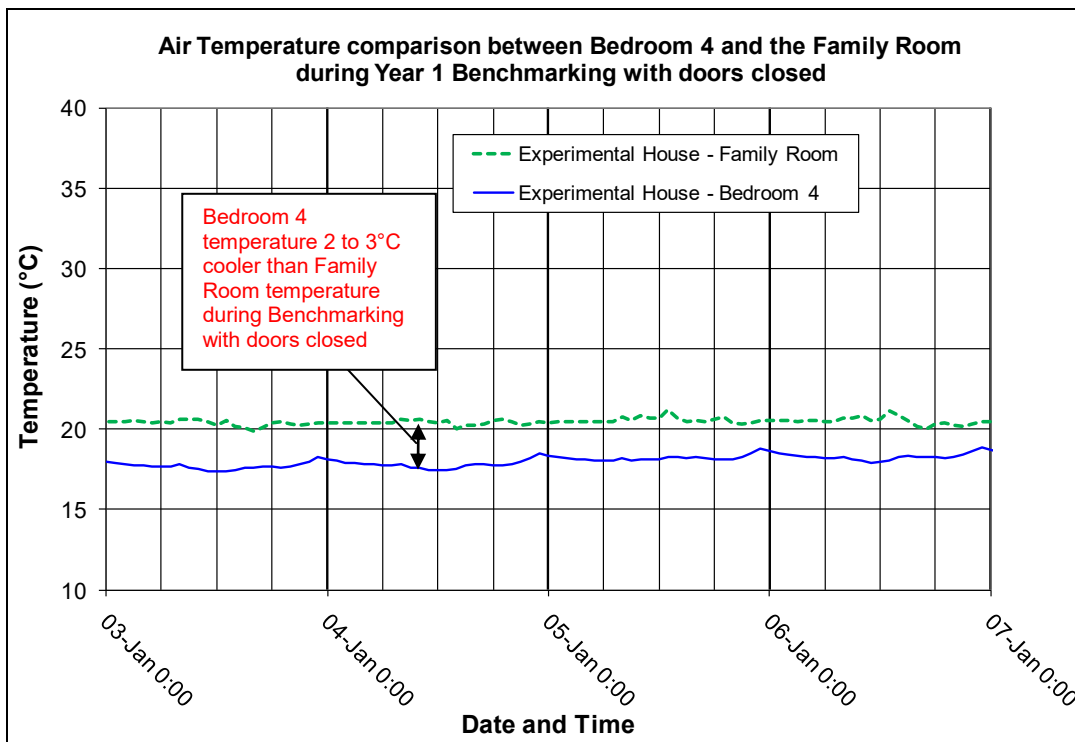


Figure 27 – Comparison of Experimental House Bedroom 4 and family room temperature during Year 1 Benchmarking with doors closed

A small dip in temperature was seen in Bedroom 4 during fireplace operation in the evening (Figure 28). However, it was small compared to other rooms on the second floor – reaching a minimum of only 0.6°C below the lowest temperature measured at the same location in the Control House. However, the small dip coincided with peaks in family room temperature due to fireplace operation. At times the family room was up to ~7°C warmer than Bedroom 4 (Figure 29).

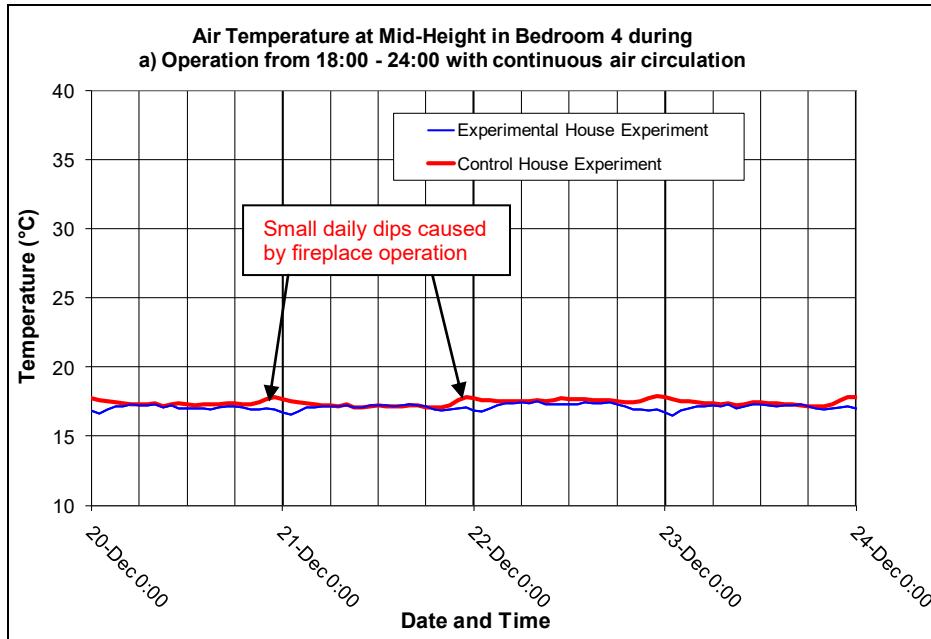


Figure 28 - Sample air temperatures in Bedroom 4, measured during fireplace condition (a) Operation from 18:00 – 24:00 with continuous air circulation

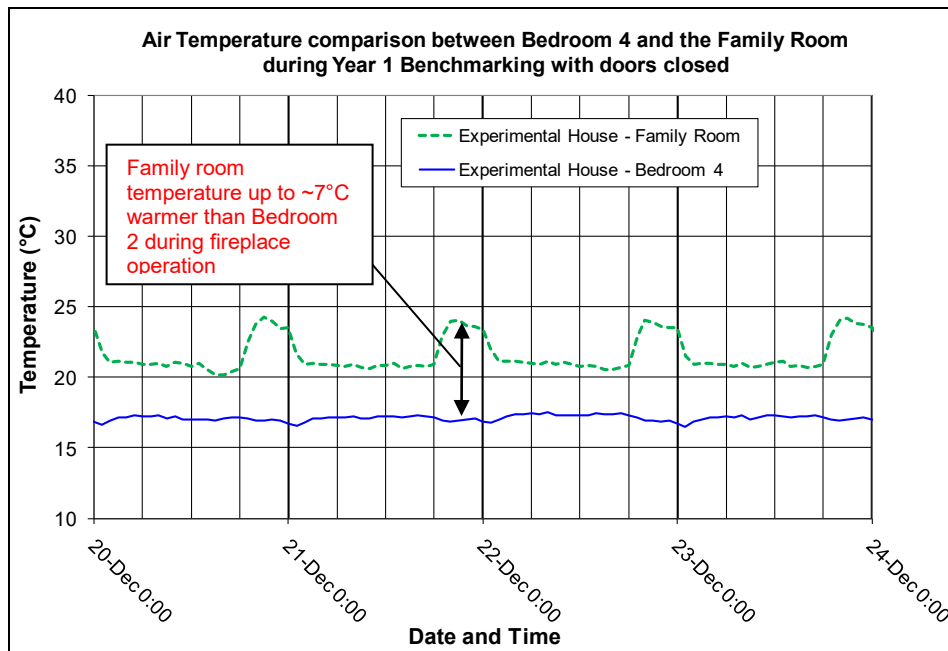


Figure 29 - Comparison of Experimental House Bedroom 4 and family room temperature during fireplace condition (a) Operation from 18:00 – 24:00 with continuous air circulation

Table 6. Average Second Floor Air Temperatures during Year 1 of the Fireplace Experiment

	Bedroom 2 Average Air Temperature °C			Bedroom 3 Average Air Temperature °C			Bedroom 4 Average Air Temperature °C		
	Mid-height			Mid-height			Mid-height		
	Exp.	Control	Difference	Exp.	Control	Difference	Exp.	Control	Difference
Y1 Benchmark	21.2	21.6	-0.4	20.3	20.7	-0.4	20.1	20.4	-0.2
Y1 Benchmark – doors closed	24.1	24.6	-0.5	20.9	21.4	-0.5	18.7	18.9	-0.2
a) Continuous circulation	20.1	21.5	-1.3	20.2	20.7	-0.5	18.2	18.5	-0.2
b) No continuous circulation	23.5	24.7	-1.2	21.2	21.6	-0.5	18.7	18.9	-0.2

	Bathroom Average Air Temperature °C			Laundry Room Average Air Temperature °C			Master Bedroom Average Air Temperature °C		
	Mid-height			Mid-height			Mid-height		
	Exp.	Control	Difference	Exp.	Control	Difference	Exp.	Control	Difference
Y1 Benchmark	20.8	20.9	0.0	21.2	21.5	-0.3	21.0	21.6	-0.7
Y1 Benchmark – doors closed	21.3	21.3	0.0	21.8	22.2	-0.4	21.8	22.5	-0.7
a) Continuous circulation	20.6	20.6	-0.1	21.0	21.6	-0.5	20.2	21.5	-1.2
b) No continuous circulation	21.5	21.5	0.0	22.0	22.5	-0.4	21.8	22.8	-1.1

	Ensuite Average Air Temperature °C		
	Mid-height		
	Exp.	Control	Difference
Y1 Benchmark	21.0	21.5	-0.5
Y1 Benchmark – doors closed	22.0	22.5	-0.5
a) Continuous circulation	20.2	21.3	-1.1
b) No continuous circulation	21.8	22.8	-1.0

Table 7. Minimum Second Floor Air Temperatures During Year 1 of the Fireplace Experiment

	Bedroom 2 Minimum Air Temperature °C			Bedroom 3 Minimum Air Temperature °C			Bedroom 4 Minimum Air Temperature °C		
	Mid-height			Mid-height			Mid-height		
	Exp.	Control	Difference	Exp.	Control	Difference	Exp.	Control	Difference
Y1 Benchmark	19.4	19.7	-0.4	19.2	19.5	-0.3	19.2	19.4	-0.2
Y1 Benchmark – doors closed	18.0	18.5	-0.5	19.4	19.8	-0.3	17.3	17.3	0.0
a) Continuous circulation	15.8	18.2	-2.4	18.7	19.6	-0.9	16.5	17.1	-0.6
b) No continuous circulation	17.7	19.0	-1.3	19.3	20.3	-1.1	16.6	17.1	-0.6

	Bathroom Minimum Air Temperature °C			Laundry Room Minimum Air Temperature °C			Master Bedroom Minimum Air Temperature °C		
	Mid-height			Mid-height			Mid-height		
	Exp.	Control	Difference	Exp.	Control	Difference	Exp.	Control	Difference
Y1 Benchmark	19.9	19.8	0.1	20.3	20.5	-0.2	19.2	19.7	-0.5
Y1 Benchmark – doors closed	20.2	20.0	0.2	20.7	21.0	-0.3	19.4	20.1	-0.6
a) Continuous circulation	19.3	19.6	-0.3	19.8	20.8	-1.0	18.3	19.8	-1.5
b) No continuous circulation	19.8	20.4	-0.5	20.4	21.2	-0.8	19.2	20.5	-1.3

	Ensuite Minimum Air Temperature °C		
	Mid-height		
	Exp.	Control	Difference
Y1 Benchmark	19.5	19.8	-0.3
Y1 Benchmark – doors closed	19.5	20.1	-0.6
a) Continuous circulation	18.1	19.8	-1.7
b) No continuous circulation	19.2	20.4	-1.2

5.5 Surface Temperatures

The impact of the fireplace on surface temperatures was monitored in Year 1. Three locations were chosen: in the second floor bathroom cupboard; the southwest corner of the living room near the floor; and on the exterior wall of the closet of bedroom 2, behind a box filled with paper. The average temperatures measured at each location, during each test condition, are listed in Table 8. Sample surface temperature profiles at the three locations from one day of benchmarking and one day of the experiment with continuous circulation are plotted in Figure 30 to Figure 35.

During benchmarking, the average surface temperatures measured in the bathroom cupboard and the living room of the Experimental House were similar to those measured in the Control House: average temperatures were within 0.1°C (See Figure 32 and Figure 34). During the experiment with and without continuous circulation, some temperature fluctuation was seen throughout the day at these two locations (Figure 33 and Figure 35). However, the average surface temperature of the bathroom cupboard and living room corner were not noticeably affected by evening fireplace operation: the surface temperature of the Experimental House was on average within 0.2°C of the average temperature in the Control House.

During benchmarking, the bedroom closet temperature was on average 1.4°C cooler in the Experimental House than the Control House (Figure 30). This difference in benchmarking temperature could be due to small differences in the two houses, which may include: thermocouple location differences (one may have been placed at the location of a stud), air circulation differences, or differences in the placement of the box in front of the thermocouple. The surface temperature in the Experimental House at this location continued to be cooler throughout the experiment: on average 1.6°C cooler than the Control House during a) with continuous circulation, and 1.5°C cooler than the Control house during b) without continuous circulation. This is a very small increase in the difference between the two houses, and within the error of the temperature measurement ($\pm 0.2^{\circ}\text{C}$).

The minimum temperatures measured at each location are listed in Table 9. Again, the coldest temperatures detected in the bathroom cupboard and in the living room were similar in the two houses throughout benchmarking and the experiment. The coldest surface temperature measured in the Experimental House bedroom closet was colder than the Control House by 1.8°C and 2.0°C during benchmark with and without doors closed respectively. This difference increased to 2.7°C and 2.5°C during the experiment – an indication of the fireplace resulting in colder minimum temperatures. The coldest temperature measured in the bedroom closet was 12.8°C , during the fireplace experiment with continuous circulation (b). This temperature is equivalent to the dew point of air at 21°C with 59% relative humidity.

Diagrams of cumulative frequency and probability distribution for surface temperatures are provided in Appendix H.

Table 8 – Average Surface Temperatures during Year 1

	Bathroom cupboard			Bedroom closet			Living room corner		
	Average surface Temperature, °C			Average surface Temperature, °C			Average surface Temperature, °C		
	Exp.	Control	Difference	Exp.	Control	Difference	Exp.	Control	Difference
Y1 Benchmark	18.7	18.7	0.0	17.3	18.7	-1.4	18.8	18.7	0.1
Y1 Benchmark – doors closed	18.7	18.7	0.0	18.4	19.8	-1.4	18.8	18.9	-0.1
a) Continuous circulation	18.2	18.1	0.1	16.3	17.9	-1.6	18.3	18.1	0.2
b) No continuous circulation	18.8	18.7	0.1	18.2	19.7	-1.5	18.7	18.6	0.1

Table 9 – Minimum Surface Temperatures during Year 1

	Bathroom cupboard			Bedroom closet			Living room corner		
	Minimum surface Temperature, °C			Minimum surface Temperature, °C			Minimum surface Temperature, °C		
	Exp.	Control	Difference	Exp.	Control	Difference	Exp.	Control	Difference
Y1 Benchmark	17.1	16.9	0.2	14.5	16.5	-2.0	16.9	16.5	0.4
Y1 Benchmark – doors closed	17.0	16.8	0.3	14.2	16.0	-1.8	16.9	16.7	0.2
a) Continuous circulation	16.4	15.9	0.5	12.8	15.5	-2.7	16.2	16.2	0.0
b) No continuous circulation	16.6	16.4	0.1	14.0	16.5	-2.5	16.4	16.5	-0.1

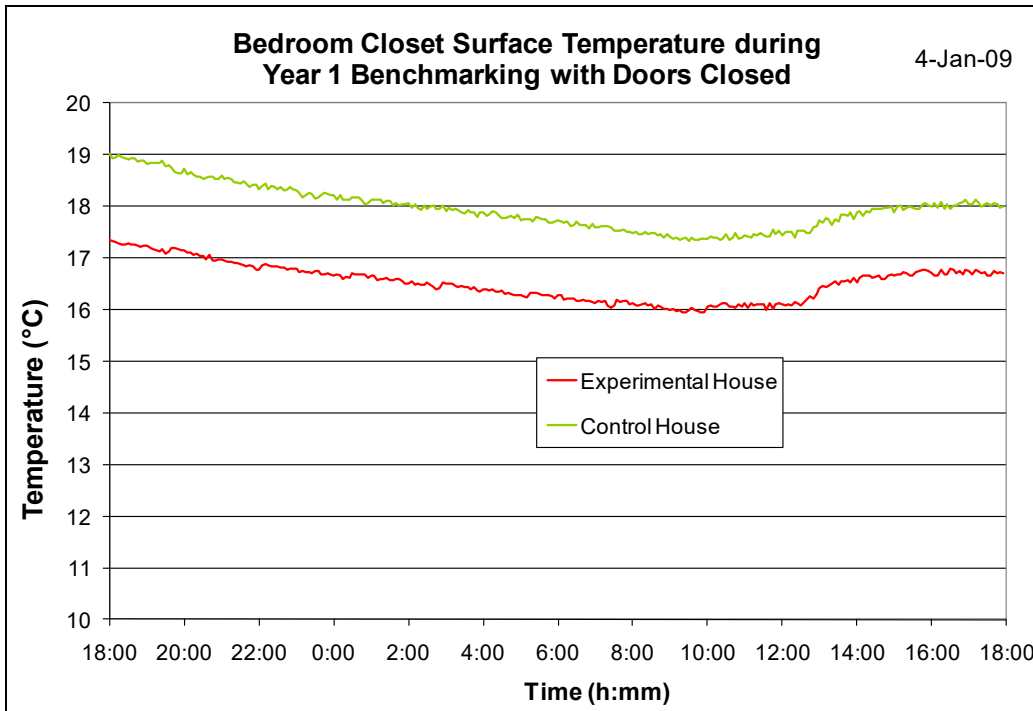


Figure 30 – Sample bedroom closet surface temperatures during the Year 1 Benchmark with doors closed

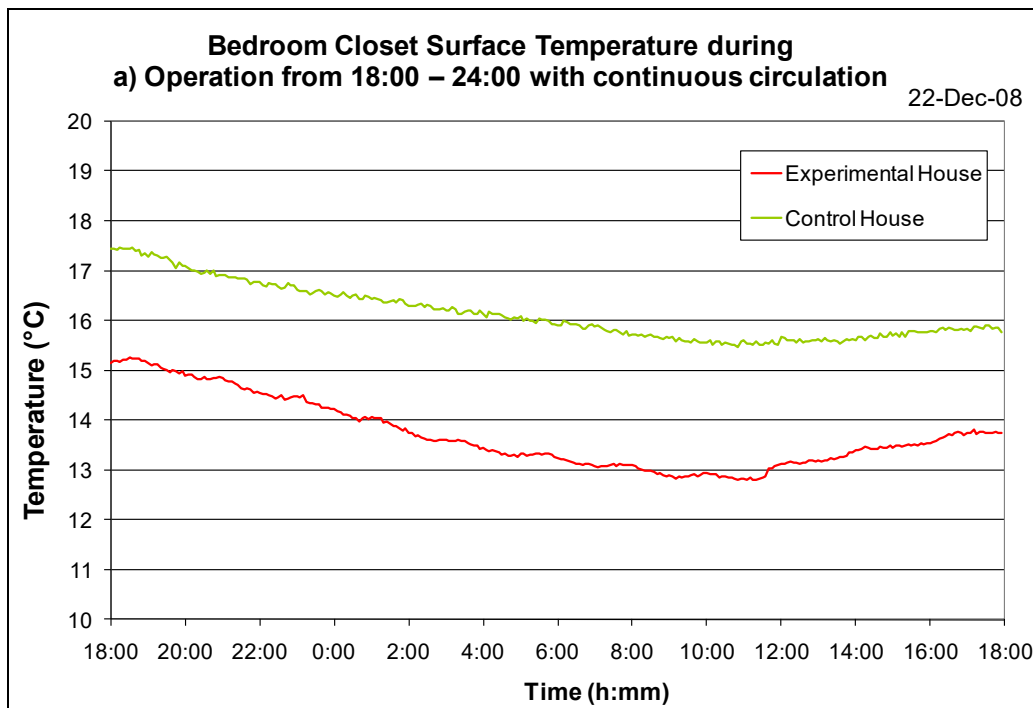


Figure 31 – Sample bedroom closet surface temperatures during a) Operation from 18:00 – 24:00 with continuous circulation

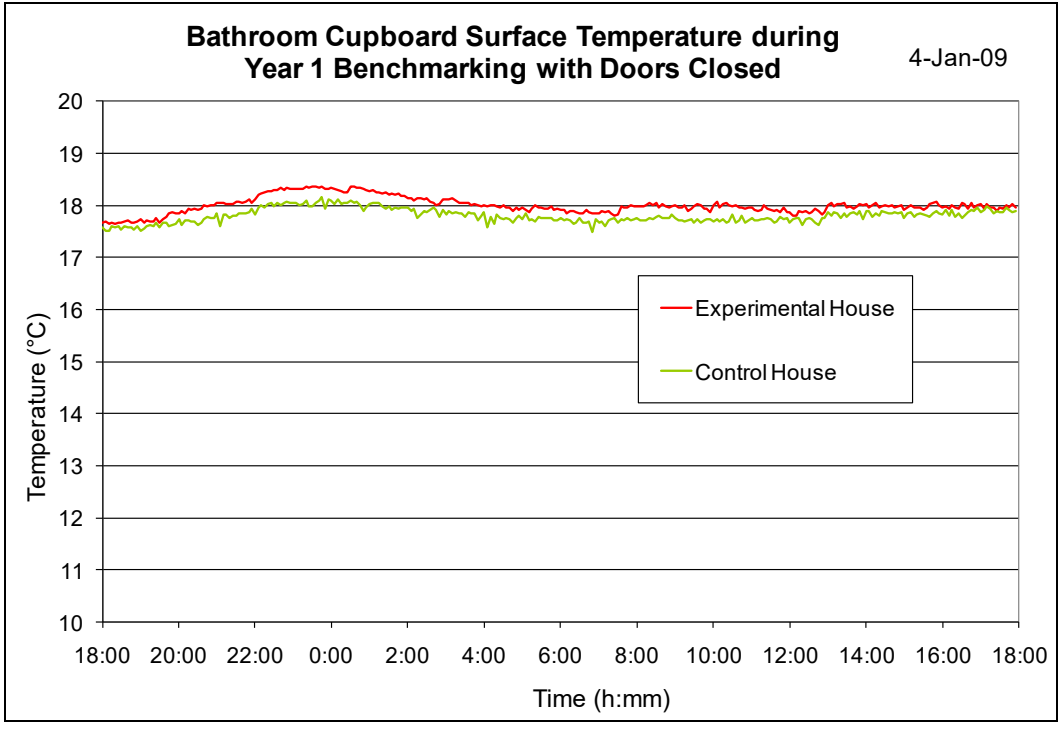


Figure 32 - Sample bathroom cupboard surface temperatures during the Year 1 Benchmark with doors closed

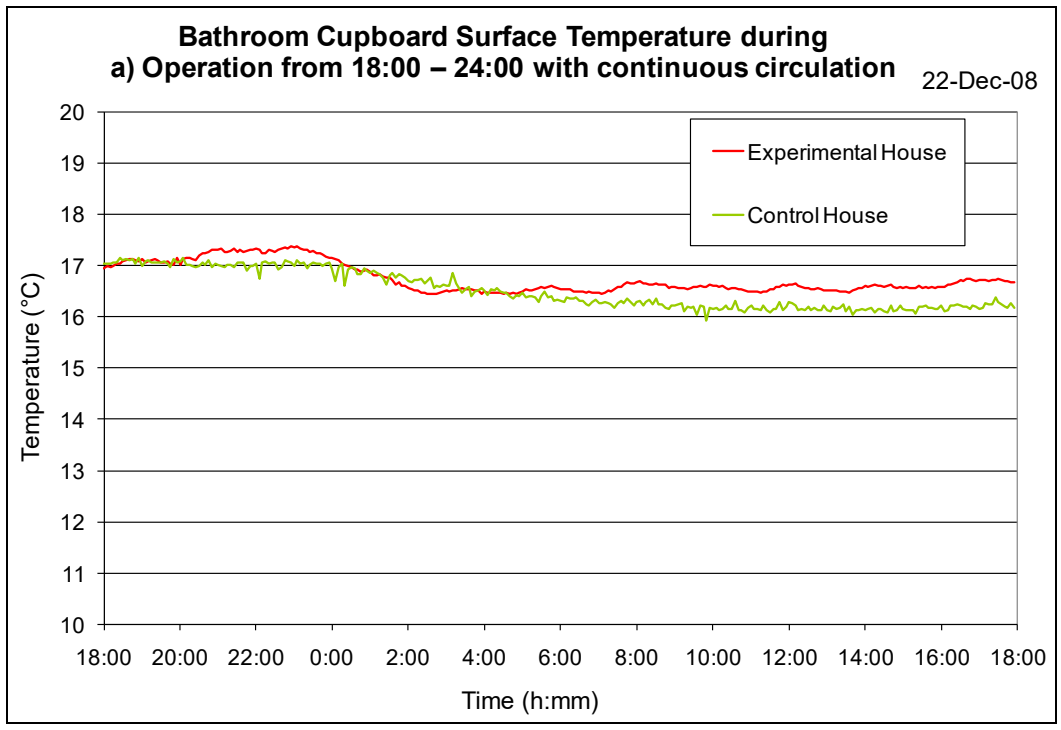


Figure 33 - Sample bathroom cupboard surface temperatures during a) Operation from 18:00 - 24:00 with continuous circulation

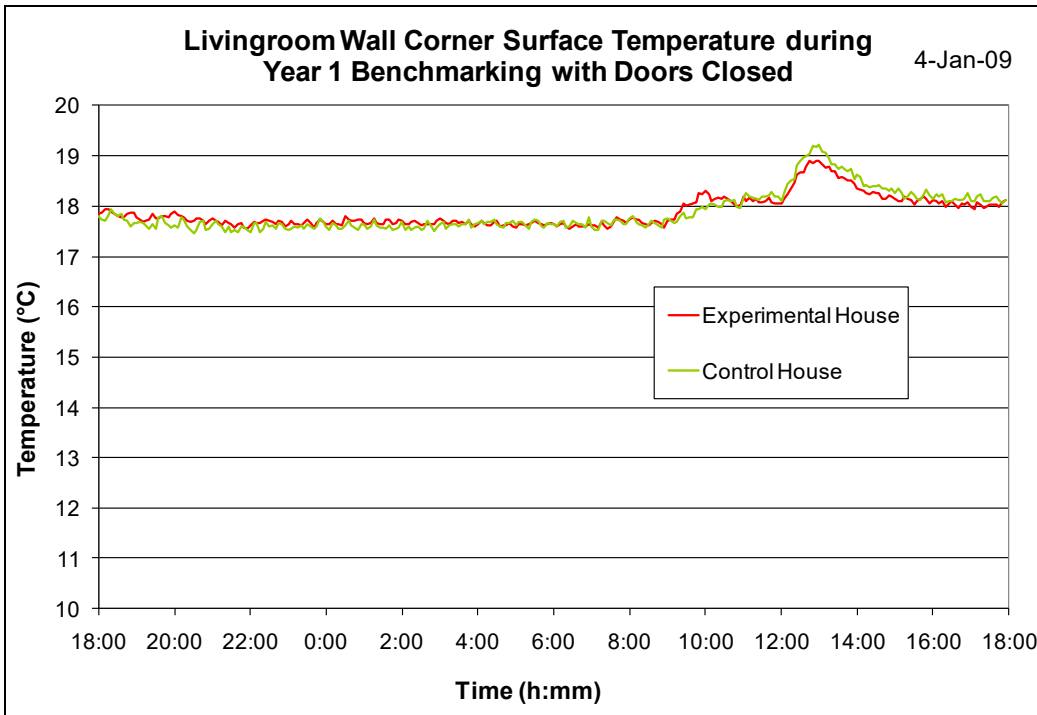


Figure 34 - Sample living room wall corner surface temperatures during the Year 1 Benchmark with doors closed

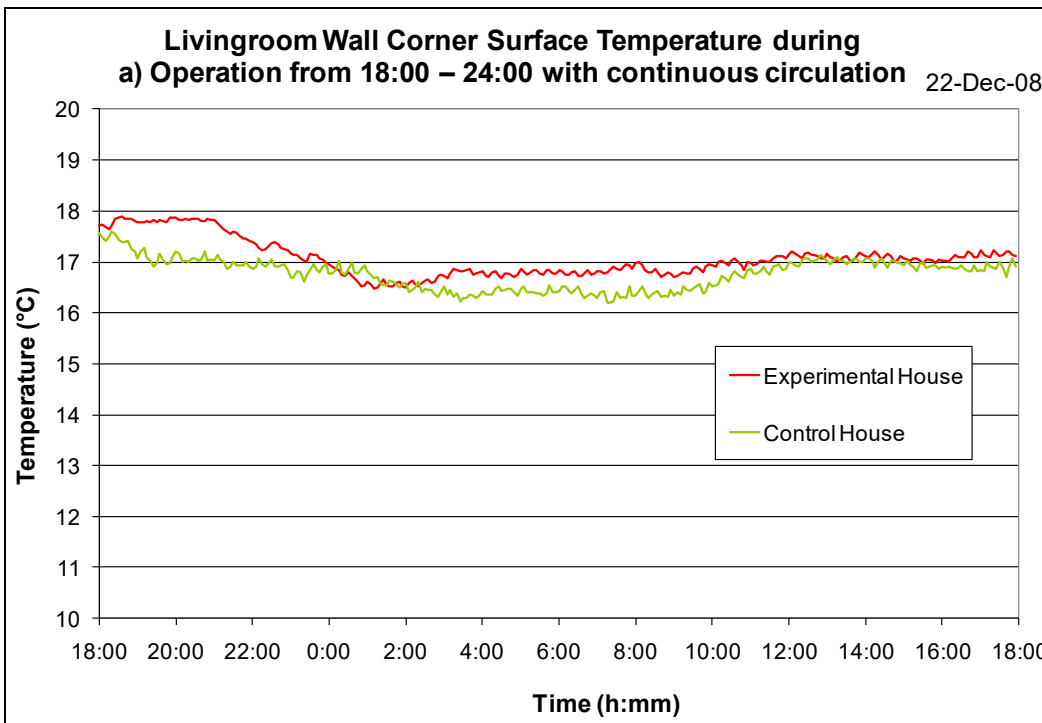


Figure 35 - Sample living room wall corner surface temperatures during a) Operation from 18:00 – 24:00 with continuous circulation

6 Results from Year 2 – Fireplace with thermostat control, pilot light only and fireplace vent open

6.1 Outdoor Temperature and Solar Conditions

The outdoor temperature and solar conditions from Year 2 are reported in Table 10, and plots of 5-minute data are shown Figure 36 and Figure 37. Outdoor temperatures during condition (c) ranged from -14.8°C to 3.8°C, with an average of -5.9°C. Most days during this period had high solar gains (>15000 kJ/m²/day on a vertical south-facing surface). Outdoor temperatures during condition (d) ranged from -12.7°C to 3.9°C, with an average of -3.9°C. Condition (d) featured days with low solar gains (<15000 kJ/m²/day on a vertical south-facing surface). Outdoor temperatures during condition (e) ranged from 1.9°C to 8.9°C, with an average of 4.7°C. Days during this period also had low solar gains.

Table 10 - Outdoor Temperature and Solar Radiation during Year 2 of the experiment

Date	Outdoor Temperature, °C			Global Solar Radiation, kJ/m ² /day	
	average	Min	Max	On Vertical South-facing surface	On Horizontal Surface
c) Operation with Thermostat Control					
6-Feb-10	-10.1	-14.8	-5.9	17101	10120
7-Feb-10	-7.1	-11.5	-2.0	19693	11046
8-Feb-10	-6.5	-8.7	-3.4	15111	9865
9-Feb-10	-4.5	-8.3	-0.6	14565	9498
10-Feb-10	-0.7	-4.1	3.8	16124	9934
11-Feb-10	-6.4	-9.9	-2.2	21748	11775
12-Feb-10	-9.6	-13.3	-6.8	20608	11704
13-Feb-10	-4.9	-7.3	-2.4	3715	5845
14-Feb-10	-3.2	-4.9	-1.5	11641	9172
d) Pilot light only					
2-Feb-10	-9.3	-11.8	-5.8	8925	7070
3-Feb-10	-5.9	-10.1	-1.2	10609	7788
4-Feb-10	-7.8	-12.7	-4.7	10455	7550
16-Feb-10	-1.2	-5.6	3.0	3775	6406
17-Feb-10	0.7	-2.1	3.9	4407	5593
18-Feb-10	0.4	-1.4	2.7	12062	9845
e) Fireplace vent open					
26-Feb-10	5.2	2.8	7.1	10348	9205
27-Feb-10	4.0	2.3	7.1	3233	4545
28-Feb-10	4.7	2.0	8.9	7466	9207
1-Mar-10	4.8	1.9	7.6	6339	8673

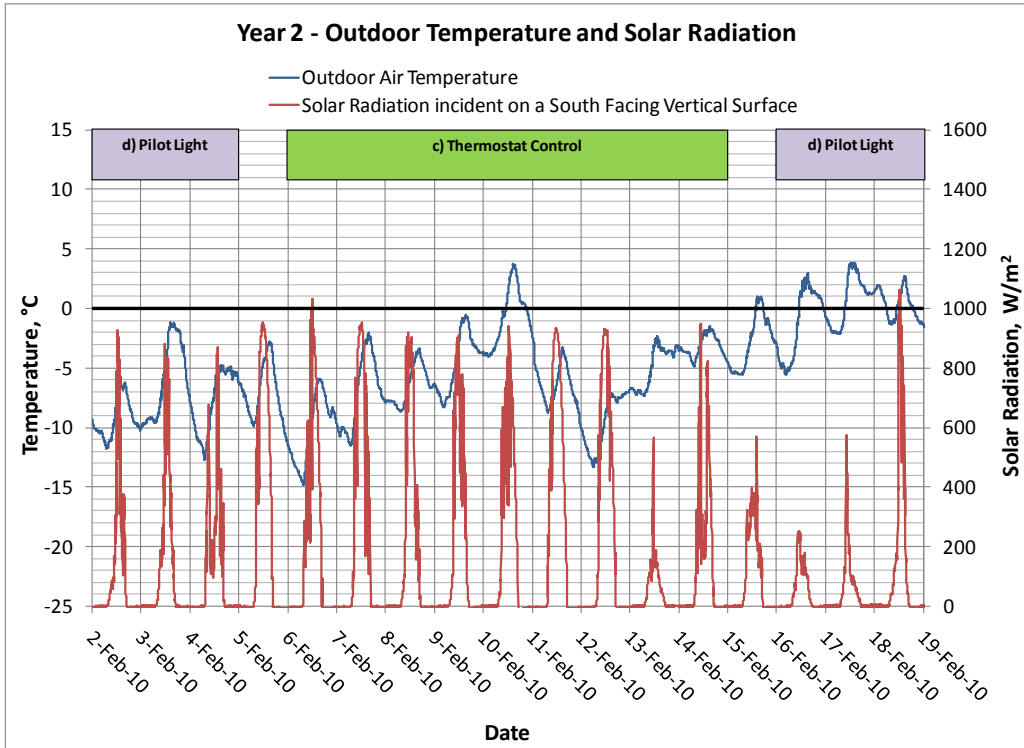


Figure 36 - Outdoor Temperature and Solar Radiation during Year 2 of the experiment

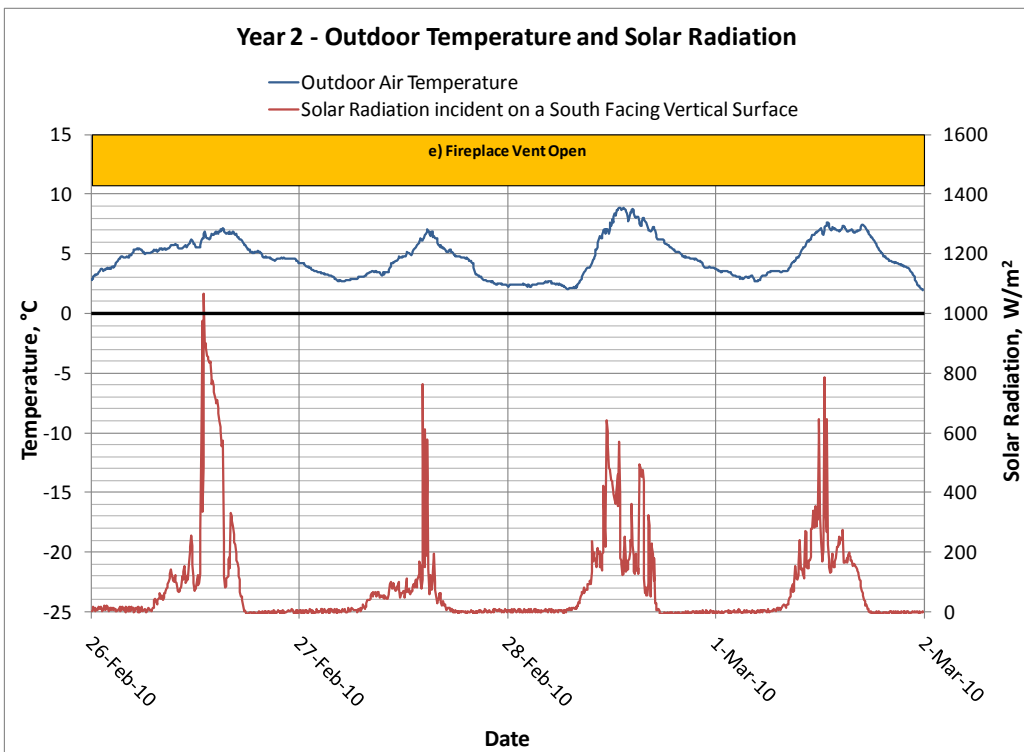


Figure 37 - Outdoor Temperature and Solar Radiation during Year 2 of the experiment (cont.)

6.2 Energy Consumption

Natural Gas Consumption

During condition (c) the fireplace was controlled by a thermostat. A sample graph of furnace and fireplace natural gas consumption is presented in Figure 38. With the fireplace operating on thermostat control, the furnace operation was reduced, although not completely eliminated. Despite the proximity of the fireplace to the centrally located house thermostat, the house thermostat still called for occasional heating cycles. The low fireplace gas meter resolution (1 pulse per cubic foot) makes it difficult to distinguish cycles of fireplace operation from the continuous consumption of the pilot light.

During condition (d) the fireplace pilot light remained lit, without fireplace operation. A sample graph of furnace and fireplace consumption is presented in Figure 39. The pilot light continuously consumed natural gas, however, the low resolution of the natural gas meter causes the 5-minute data to appear as cycling.

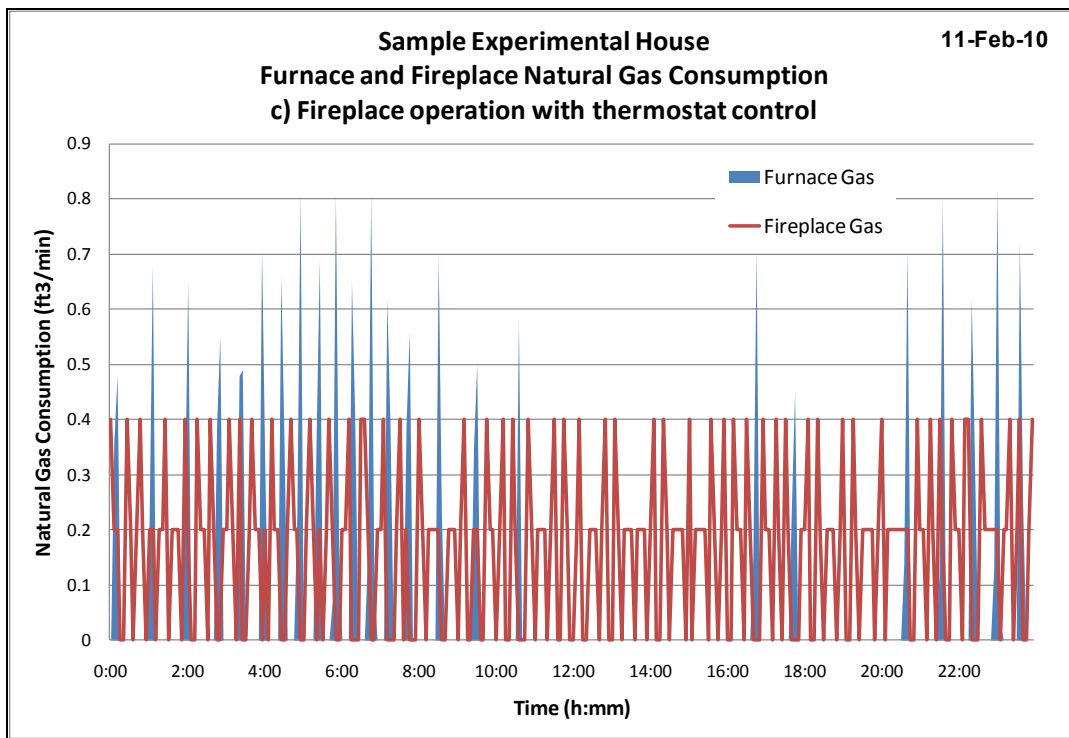


Figure 38 - Sample furnace and fireplace natural gas consumption in the Experimental House, Condition (c) Fireplace operation with thermostat control

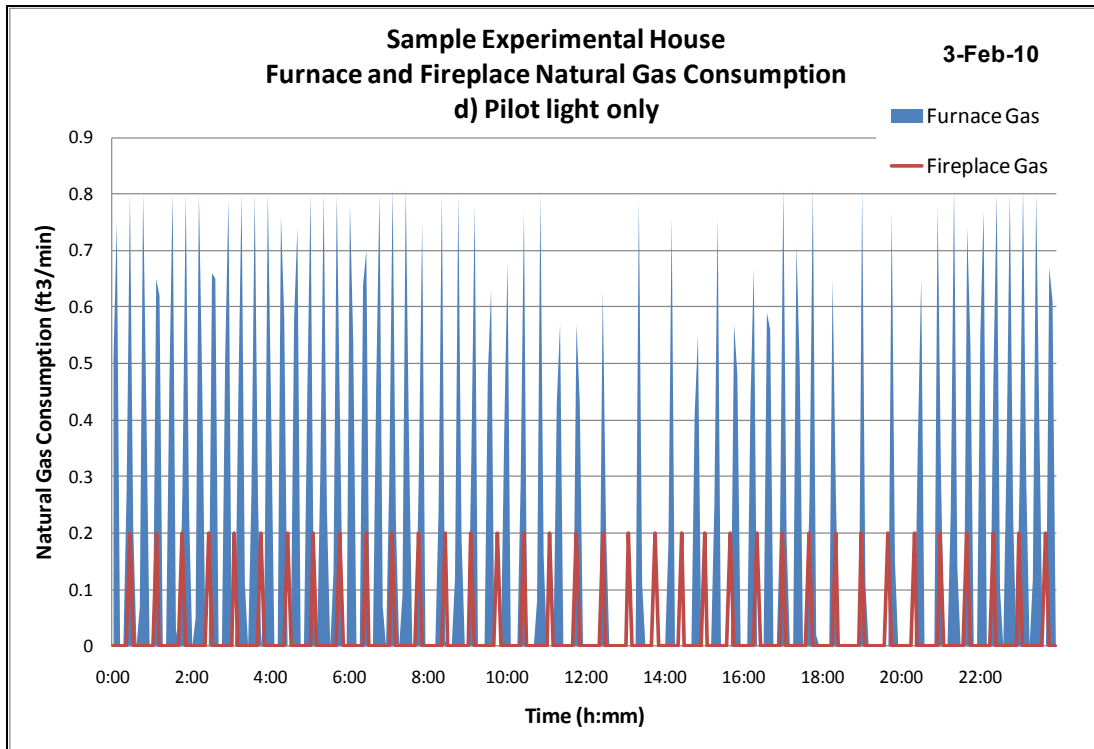


Figure 39 - Sample furnace and fireplace natural gas consumption in the Experimental House, Condition (d) Pilot light only

Figure 40 presents a comparison of the daily furnace natural gas consumption in the Control House and the Experimental House. The Control House daily consumption per day is plotted on the x-axis. The Year 2 benchmark data (shown in green) has a slope of 0.984 and intercept of -1.646. Results from Year 2 of the fireplace experiment are plotted in blue for condition (c), red for condition (d) and in pink for condition (e). When the fireplace is operated under thermostat control (c), the furnace natural gas consumption is greatly reduced. On average, during this experiment condition, furnace natural gas consumption was reduced by 207.9 MJ/day (59.3%).

The impact of operating the pilot light alone (d) also showed a detectable impact on furnace gas consumption. The average reduction in furnace fan consumption due to pilot light operation was 19.4 MJ/day (5.6%) for the experiment period. ANCOVA results show that the impact of the pilot light on furnace natural gas consumption is significant ($F_{1, 43}=56.4$, $P=2.35E-09$).

Only four days of data were collected for condition (e) with the fireplace vent open and no fireplace operation. These four points were very close to the benchmark line, and were also collected during warmer weather than the other experiment points, resulting with an average increase in furnace operation of 8.15 MJ/day (4.1%). ANCOVA results show that this result is still significant ($F_{1, 41}=7.63$, $P=0.0086$). Summary tables of gas consumption can be found in Appendix F.

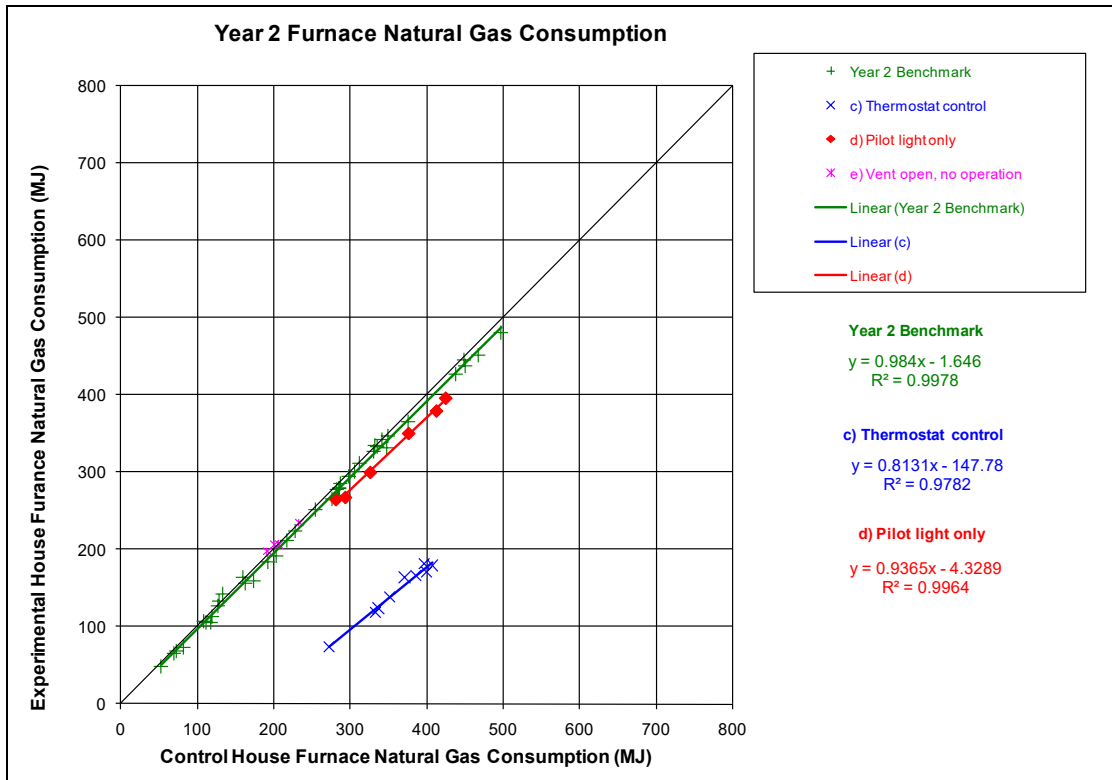


Figure 40 - Year 2 – Reduction in daily furnace natural gas consumption due to fireplace operation and pilot light operation

In Figure 41, the natural gas consumption of the fireplace has been added to the furnace consumption in the Experimental House. The benchmark trend in this figure is identical to the benchmark trend in Figure 40 since the benchmark did not include any fireplace operation.

The experiment trend for condition (c) lies above the benchmark line, indicating an increase in total natural gas consumption in the Experimental House due to the operation of the fireplace with thermostat control. The fireplace consumed on average 249.1 MJ/day of natural gas operating by thermostat control. As a result, the Experimental House consumed on average 41.2 MJ/day (11.9%) more natural gas for heating (furnace and fireplace) with the fireplace operating.

The experiment trend for condition (d) is also located above the benchmark line. The pilot light consumed on average 38.4 MJ/day natural gas, contributing to an average increase of 19.0 MJ/day (5.8%) total natural gas consumption. ANCOVA results show that the impact of the pilot light on total natural gas consumption is significant ($F_{1,43}=55.1, P=3.15E-09$).

Total gas consumption results from condition (e) with vent open were identical to furnace gas consumption results, since condition (e) involved no fireplace operation.

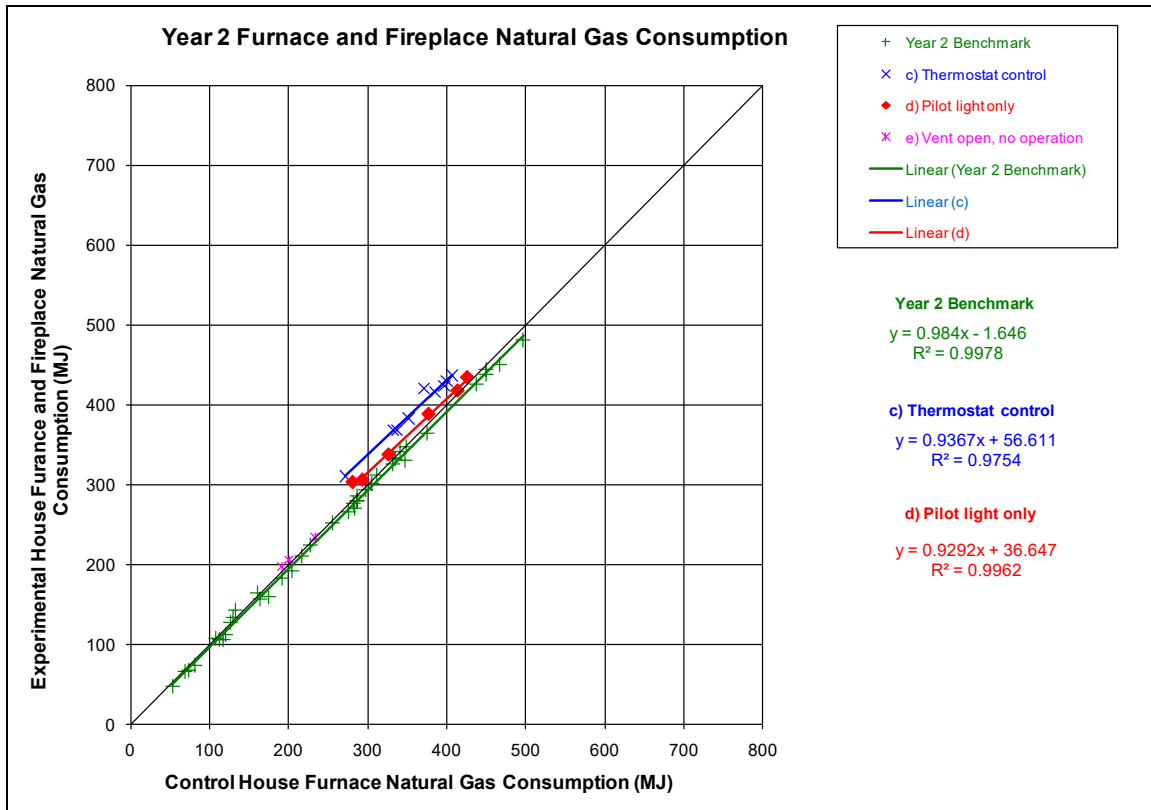


Figure 41 - Year 2 - Overall increase of furnace and fireplace natural gas consumption due to fireplace operation and pilot light operation

Electrical Consumption

The fireplace fan did not operate during condition (d) pilot light and condition (e) vent open. The fireplace fan consumed on average 1.28 kWh/day of electricity to operate by thermostat control (c). Under thermostat control, the fireplace fan tended to operate continuously, as shown in Figure 42. The fireplace would cycle, and when the burner shut off the fan would continue to operate to cool the fireplace and distribute warm air to the room. Before the completion of this cooling cycle, the fireplace would fire again.

A plot of furnace fan electrical consumption is presented in Figure 43. When the furnace operates less, there is less high speed circulation of heat, and there is a reduction in furnace fan electrical consumption. In case (c) fireplace operation with thermostat control, furnace electrical consumption was reduced by an average of 2.13 kWh/day (18.9%), for a total average decrease in furnace and fireplace electrical consumption of 0.85 kWh/day (7.5%).

Case (d) pilot light operation resulted in a small decrease in furnace operation and an average electrical savings for the experimental period of 0.19 kWh/day (1.7%). ANCOVA results show that this result is significant ($F_{1,43}=61.2$, $P=8.48E-10$).

ANCOVA results show that the impact of the open fireplace vent on furnace fan electrical consumption is also statistically significant ($F_{1,41}=12.5$, $P=0.0010$). Opening the vent in case (e) resulted in a small increase in furnace operation and an average electrical consumption increase for the experimental period of 0.10 kWh/day (1.0%).

Summary tables of electrical consumption can be found in Appendix F.

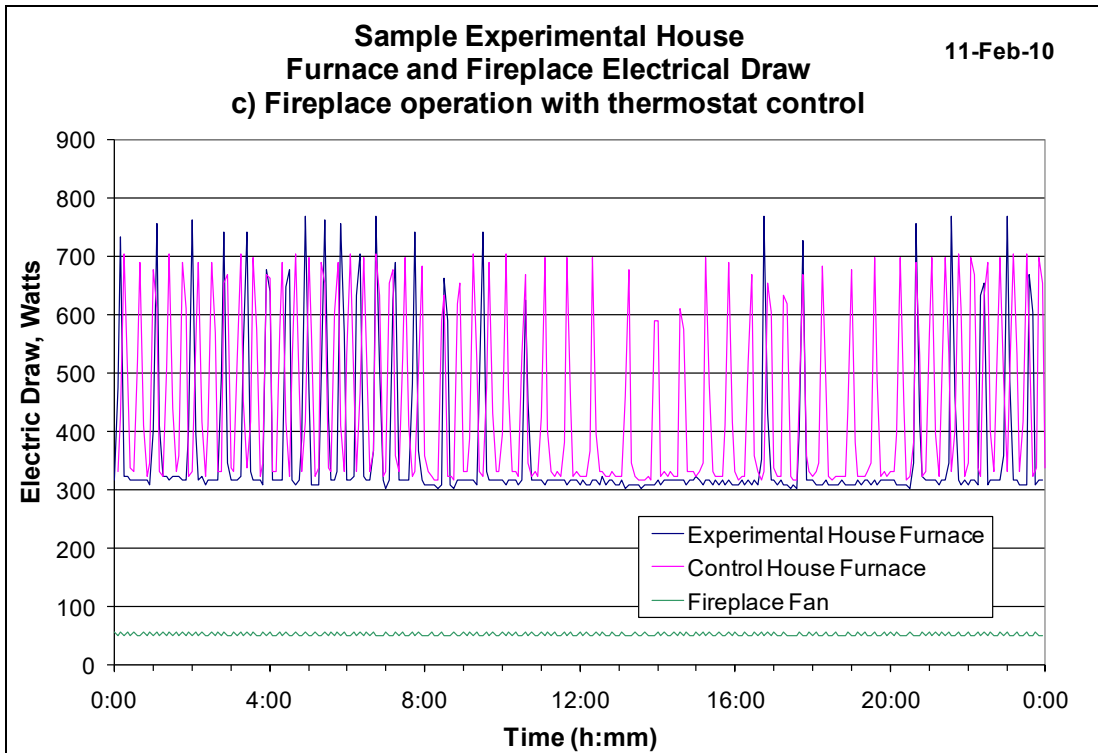


Figure 42 – Sample furnace and fireplace electrical draw in the Experimental House, Condition (c) Fireplace operation with thermostat control

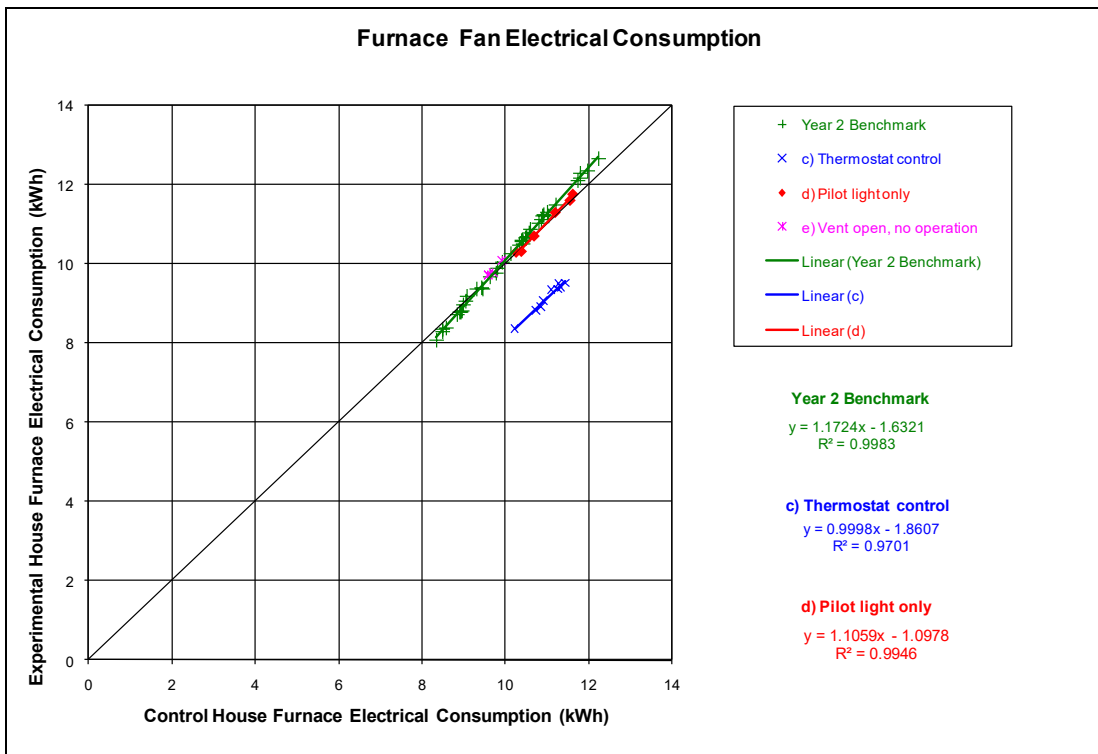


Figure 43 - Year 2 Reduction of daily furnace fan electrical consumption due to fireplace operation and pilot light operation

Total Energy Consumption for Heating

The total heating system electrical and gas consumption is plotted in Figure 44. The operation of the furnace with thermostat control (c) resulted in an increase in total heating energy consumption. During configuration (c), operation of the fireplace resulted in an average increase in consumption of 38.1 MJ/day (9.8%).

During configuration (d), pilot light operation resulted in an average increase in consumption of 18.2 MJ/day (5.0%). ANCOVA results show that the impact of the pilot light operation on total heating energy consumption is significant ($F_{1, 43}=47.9$, $P=1.67E-8$).

ANCOVA results show that the open fireplace vent does impact total heating energy consumption ($F_{1, 41}=7.76$, $P=0.0085$). During configuration (e), opening the vent resulted in an average increase in consumption of 8.5 MJ/day (3.6%). Summary tables of total energy consumption can be found in Appendix F.

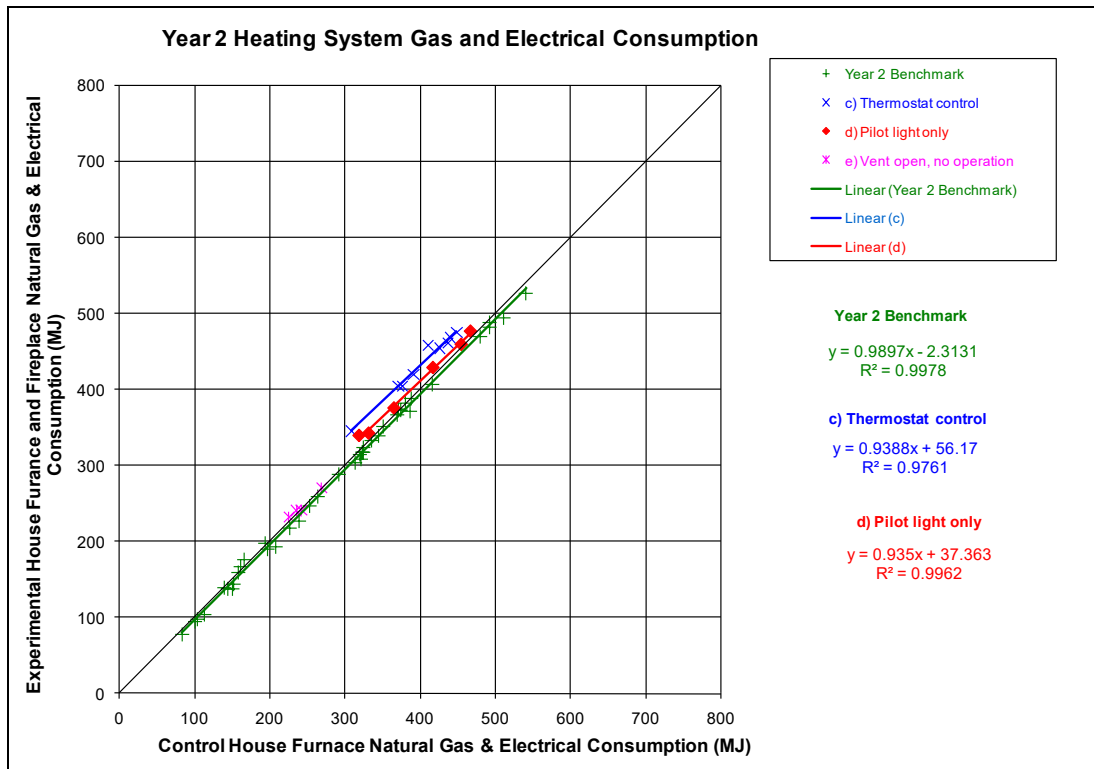


Figure 44 – Year 2 – Overall increase in total heating system gas and electrical consumption due to fireplace and pilot light operation

The total daily heating system gas and electrical consumption is presented as a bar chart in Figure 45. In this chart, the columns labeled “Bench” refer to the expected consumption of the Experimental House in benchmark condition, as adjusted using the benchmark correlations (as described in Appendix C). The columns labeled “Exp” show the measured daily Experimental House consumption from the experiment. This plot shows clearly the phenomenon of the fireplace with low efficiency offsetting furnace operation.

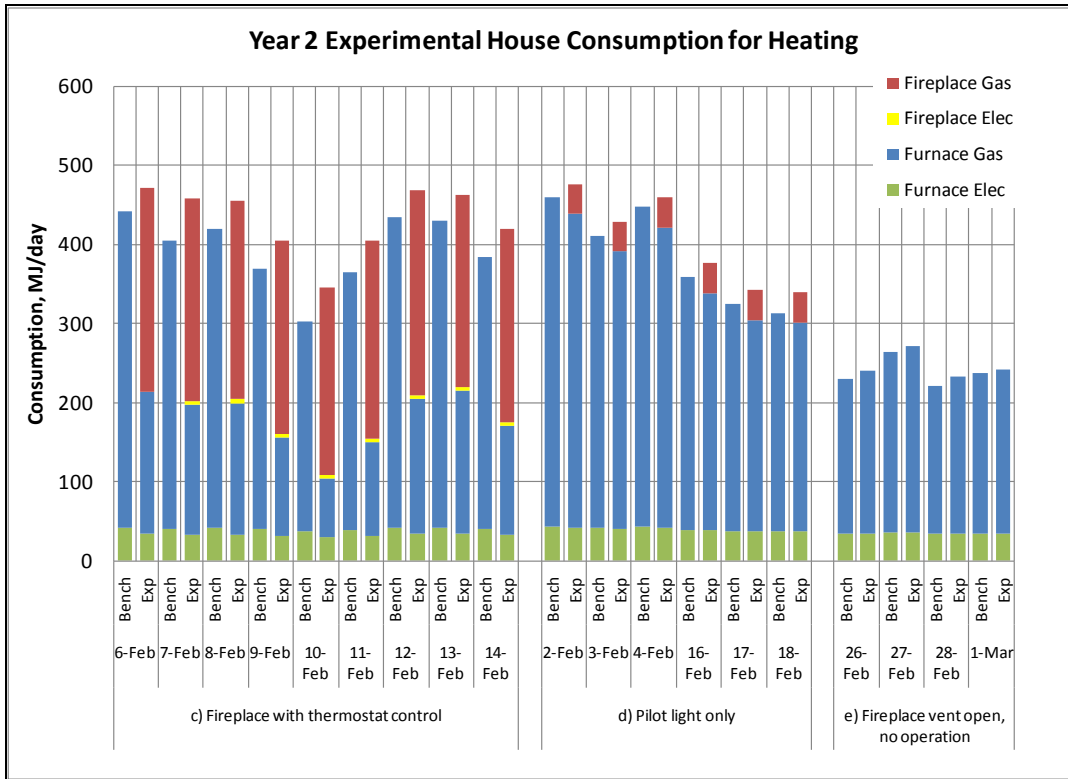


Figure 45 – Year 2 Experimental House Consumption for Heating

The increase in total heating energy consumption due to fireplace operation, however, was not as big as expected. The bar chart in Figure 46 takes into account the low efficiency of the fireplace (76.1%), and high efficiency of the furnace (94.0%) to calculate the actual total heat output to the home. On all but one day the fireplace ran with thermostat control (d), the heat output to the home with the fireplace running was less than during the benchmark configuration. Due to fireplace operation, there was on average 9.0 MJ/day (2.3%) less total heat delivered to the home.

On all days with pilot light operation (d), the heat output to the home with the pilot light on was higher than the heat output to the home in benchmark configuration, an average increase of 10.3 MJ/day (3.0%).

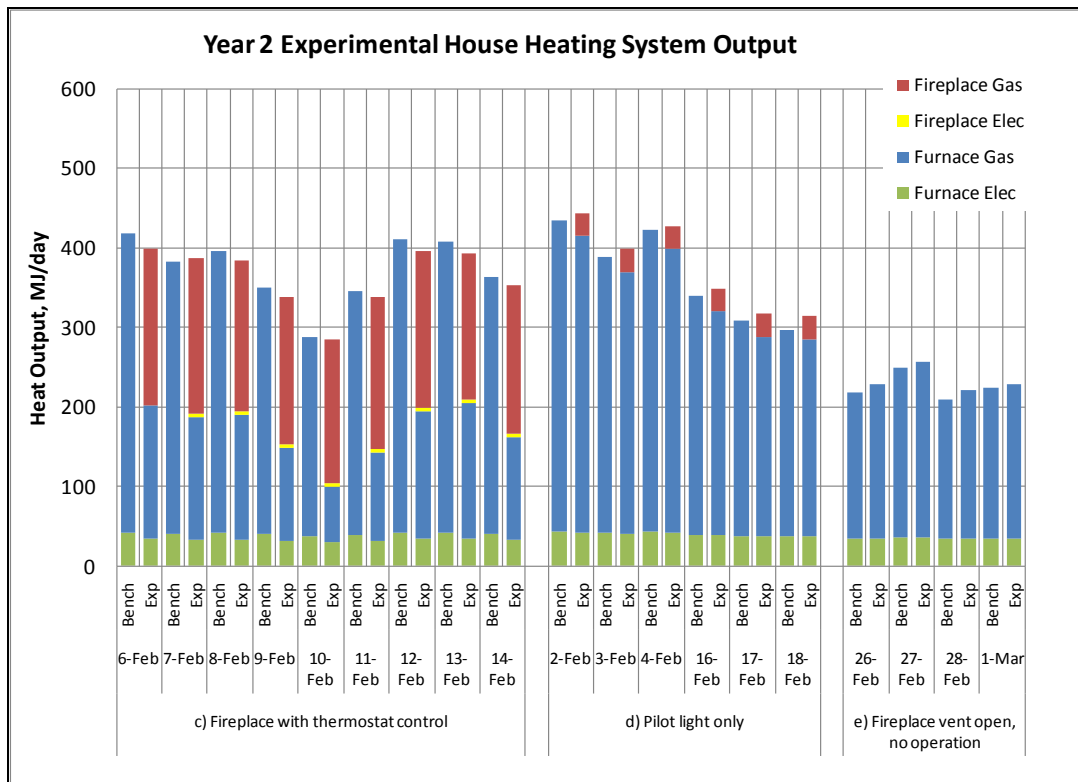


Figure 46 - Year 2 Experimental House Heating System Output

6.3 Room Temperatures

Room air temperatures were monitored throughout the Year 2 experiments, at a 4 foot height in the centre of the room. During benchmarking, temperatures on the main floor of the home were similar in the Experimental and Control houses (see Table 11 for average room air temperatures on cloudy days, vertical solar <math><15000 \text{ kJ/m}^2/\text{day}</math>). A sample of family room temperatures during benchmarking is presented in Figure 47. The house central thermostat maintained the main floor temperature between ~ 20 and $\sim 21^\circ\text{C}$. Temperatures on the second floor of the home were generally slightly lower in the Experimental House than the Control House during Year 2 benchmarking (on average 0.3 to 0.6°C cooler). A sample of master bedroom temperatures during benchmarking is presented in Figure 49. While temperatures in this room follow similar trends in both houses, the Experimental House air temperature is cooler. This difference could be due to slight differences in the two houses that could include: thermocouple position, air distribution, etc. The temperature in the master bedroom on cloudy days during benchmarking was on average 0.5°C cooler than the family room temperature (as shown on a sample day in Figure 50).

During fireplace operation with thermostat control (c), temperatures in the vicinity of the fireplace were warmer, while second floor rooms were measurably colder. On the main floor, air in the family room on cloudy days was on average 1.6°C warmer in the Experimental House than the Control House. One sample day of family room temperatures during fireplace operation by thermostat is shown in Figure 48. The fireplace thermostat maintained the room at a higher temperature throughout the day. Other temperatures on the main floor were also affected. The dining room on the main floor was similar in temperature in both houses, while the both the living room and powder room were slightly cooler in the Experimental House (0.5°C , and 1.0°C respectively).

On the second floor of the home, the fireplace operation by thermostat (c) resulted in colder temperatures on average, between 1.3°C (the second floor bathroom) and 2.4°C (master bedroom ensuite) cooler than the Control House. Sample temperatures from one experiment day in the master bedroom are shown in Figure 51. Due to the heating of the family room, and the cooling of the master bedroom, the master bedroom was on average 3.4°C cooler than the family room on cloudy days during fireplace operation by thermostat.

A small effect was seen from pilot light operation (d). On the second floor, room temperatures were slightly colder (0.2 to 0.3°C) than the temperature difference seen during benchmarking, and on the main floor, the family room was slightly warmer (0.3°C) (see Table 11).

Table 11 - Average room air temperature during Year 2 (cloudy days only, vertical solar gains < 15000 kJ/m²/day)

	Bedroom 2, °C			Bedroom 3, °C			Bedroom 4, °C		
	Exp	Cont	Difference	Exp	Cont	Difference	Exp	Cont	Difference
Y2 Benchmark	20.1	20.5	-0.4	19.8	20.1	-0.4	19.7	20.0	-0.4
c) Thermostat control	19.2	20.6	-1.4	18.7	20.2	-1.5	18.8	20.1	-1.4
d) Pilot light	19.9	20.5	-0.6	19.6	20.1	-0.6	19.4	20.0	-0.6

	Bathroom, °C			Master Bedroom, °C			Ensuite, °C		
	Exp	Cont	Difference	Exp	Cont	Difference	Exp	Cont	Difference
Y2 Benchmark	20.4	20.7	-0.3	20.2	20.8	-0.6	20.5	21.1	-0.6
c) Thermostat control	19.5	20.8	-1.3	18.9	21.0	-2.1	19.0	21.4	-2.4
d) Pilot light	20.2	20.7	-0.5	20.1	21.0	-0.8	20.4	21.3	-0.9

	Laundry, °C			Stairwell Top, °C			Stairwell Landing, °C		
	Exp	Cont	Difference	Exp	Cont	Difference	Exp	Cont	Difference
Y2 Benchmark	20.6	21.0	-0.4	20.5	20.8	-0.4	20.6	20.9	-0.3
c) Thermostat control	19.7	21.2	-1.5	19.9	21.0	-1.1	19.9	21.0	-1.1
d) Pilot light	20.5	21.1	-0.6	20.4	20.9	-0.5	20.5	20.9	-0.5

	Living room, °C			Powder room, °C			Dining room, °C		
	Exp	Cont	Difference	Exp	Cont	Difference	Exp	Cont	Difference
Y2 Benchmark	20.7	20.8	-0.1	21.3	21.5	-0.2	20.8	20.9	-0.1
c) Thermostat control	20.3	20.8	-0.5	20.5	21.5	-1.0	20.6	20.9	-0.2
d) Pilot light	20.6	20.8	-0.2	21.3	21.5	-0.2	20.8	20.9	-0.1

	Family room, °C		
	Exp	Cont	Difference
Y2 Benchmark	20.7	20.8	-0.1
c) Thermostat control	22.3	20.7	1.6
d) Pilot light	20.9	20.6	0.2

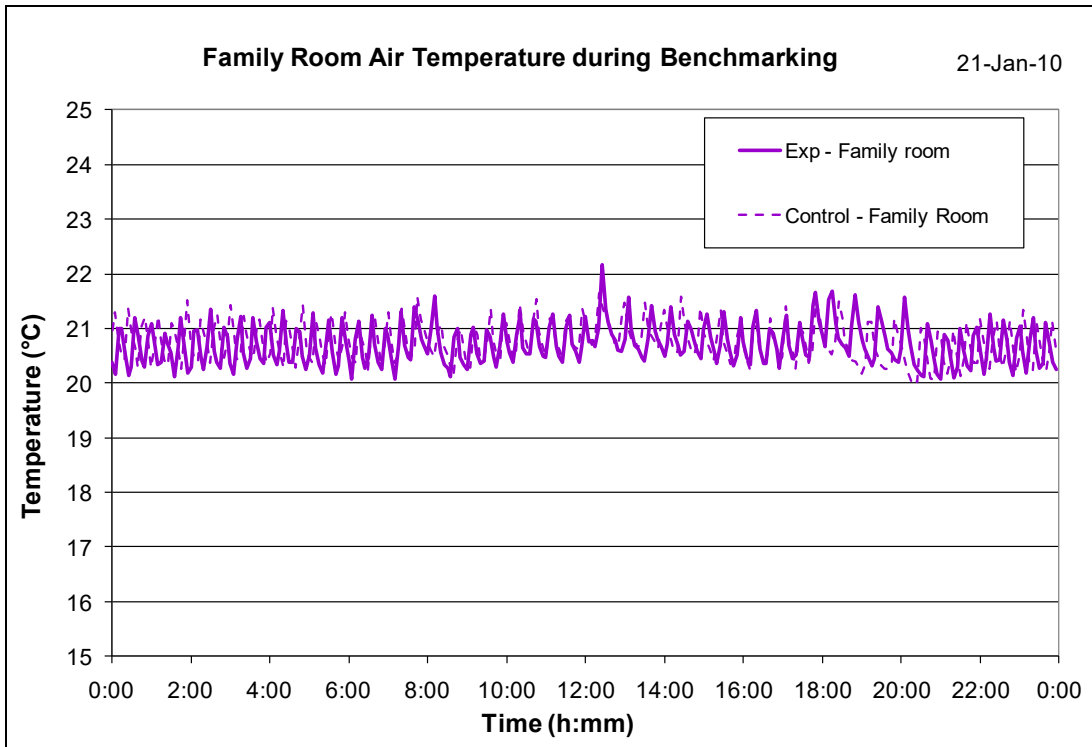


Figure 47 - Sample family room air temperatures during benchmarking

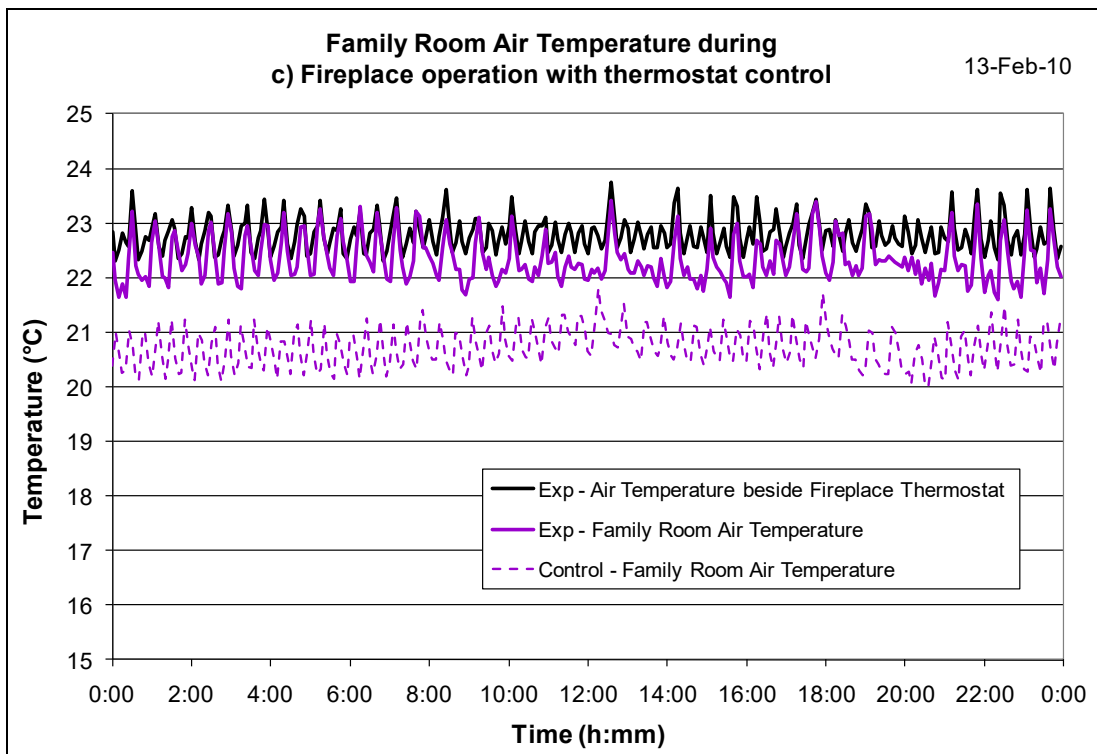


Figure 48 - Sample family room air temperatures during c) fireplace operation with thermostat control

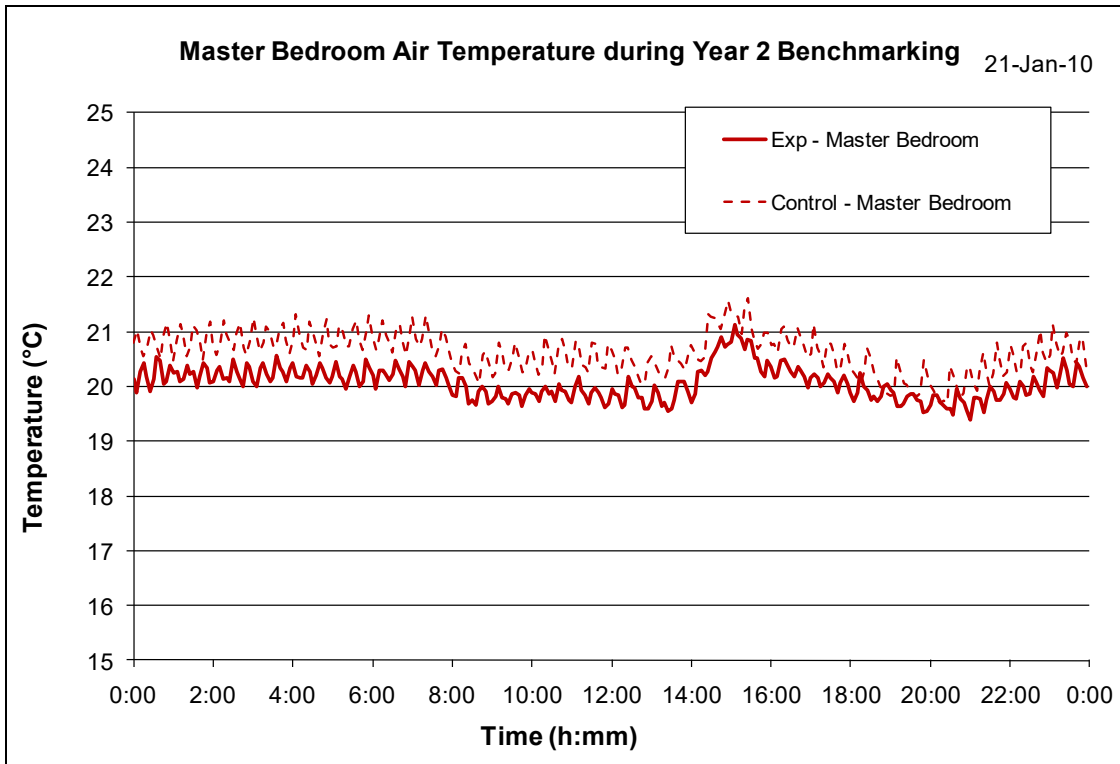


Figure 49 - Sample master bedroom air temperatures during Year 2 benchmarking

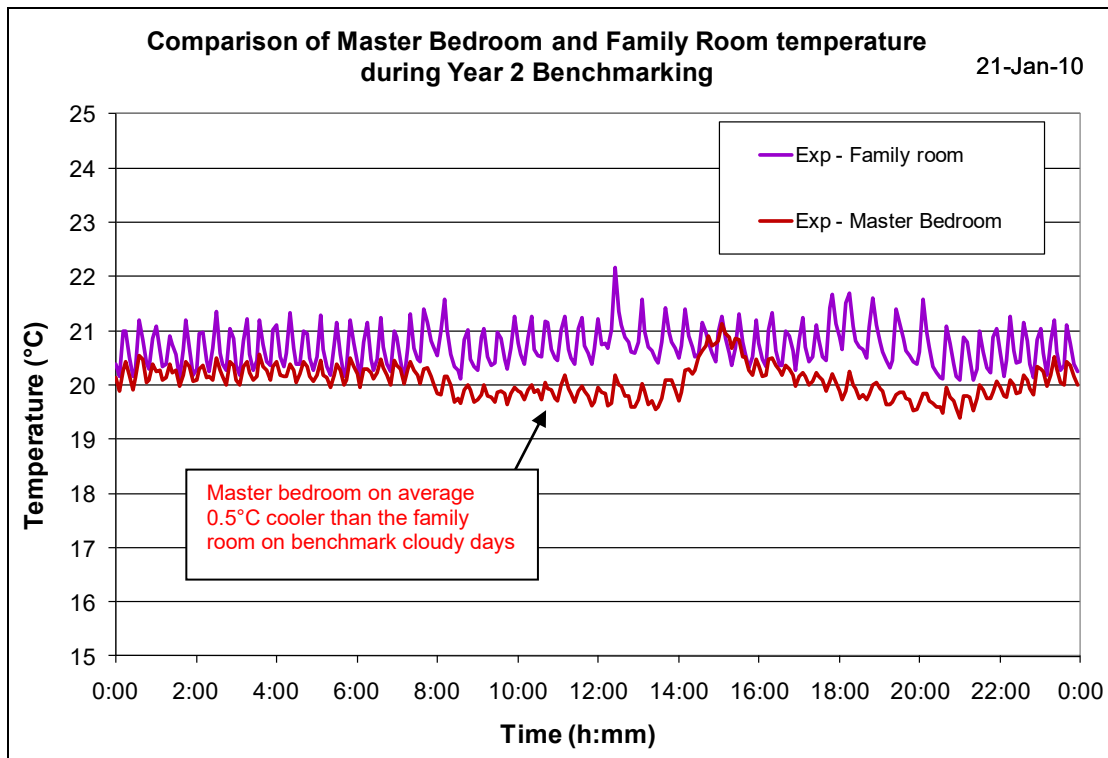


Figure 50 - Comparison of Experimental House master bedroom and family room temperature on a sample day during Year 2 Benchmarking

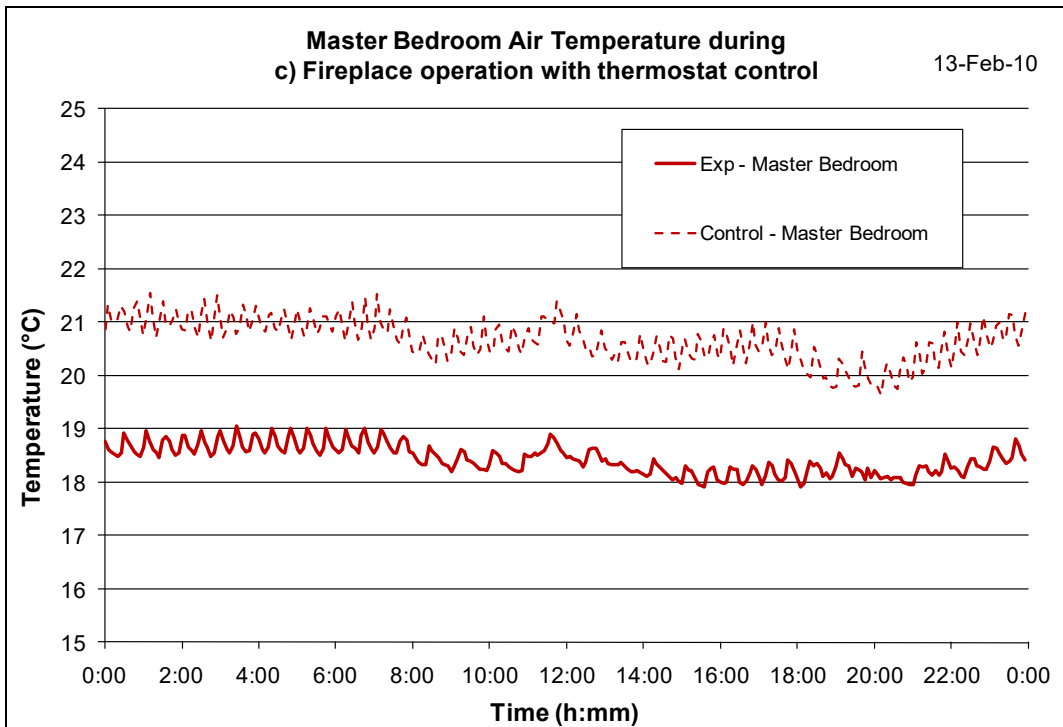


Figure 51 - Sample bedroom air temperatures during c) fireplace operation with thermostat control

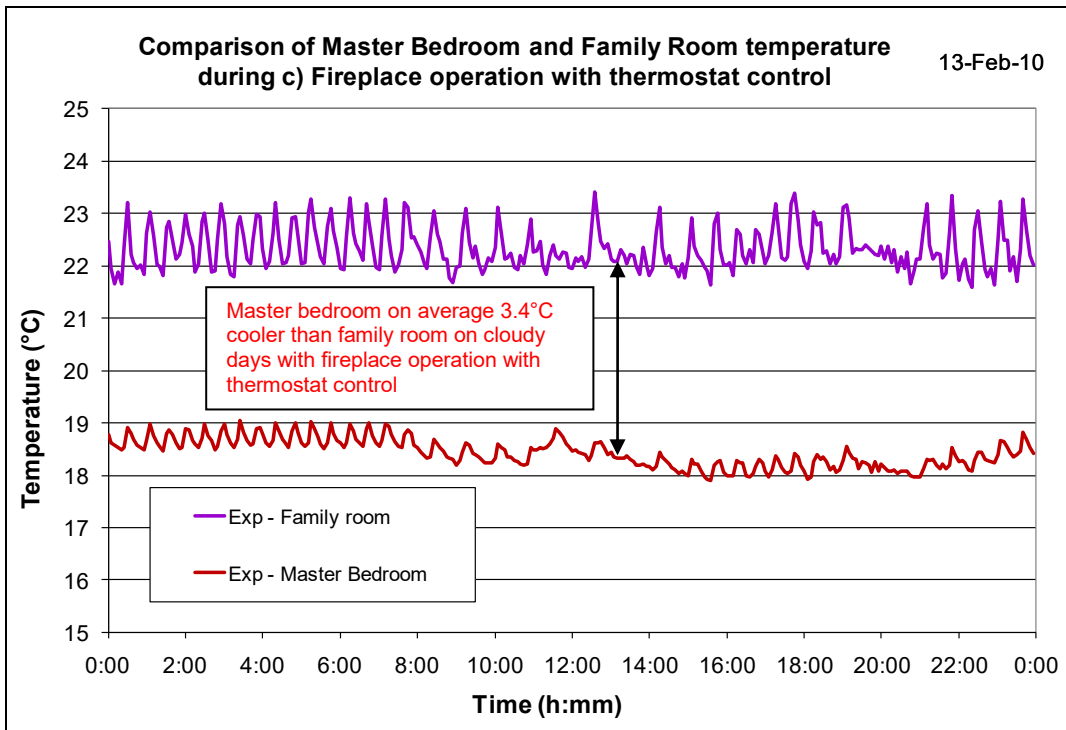


Figure 52 - Comparison of Experimental House master bedroom and family room temperature on a sample day during c) fireplace operation with thermostat control

Temperatures can also be expressed as probability distributions and cumulative frequency curves (as described in Section 0). The air temperature probability distribution for the master bedroom during benchmarking, operation by thermostat (c), and pilot light (d) is given in Figure 53. In the Control House, the probability curves are similar for the benchmark and pilot light study – both peak around 20.8°C. The Control House probability curve for the fireplace thermostat study peaks on a slightly higher temperature (~21.0°C). While all three Control House cases have identical configuration, there were a number of days with high solar gains during the fireplace thermostat control period. This caused overheating in this room, as is evident from the higher probability of temperatures occurring at 23°C and 24°C. The benchmark and pilot light curves (d) for the Experimental House peak at lower temperatures (~20.1°C) – as was expected from the chart of average data. During the period of the pilot light operation (d), the temperatures in the Control House were slightly higher than the Benchmark, while in the Experimental House, the temperatures were slightly lower than the Benchmark for the same period. This is evidence of the pilot light impacting the Experimental House second floor temperature. The temperature probability distribution in the Experimental House is much cooler than all other probability distribution curves. This again shows that the master bedroom temperature was greatly reduced by thermostat controlled fireplace operation.

To eliminate the impact of days with high solar gains, the same data was analyzed using only temperature data from days with vertical solar gains below 15000 kJ/m²/day – referred to in this analysis as “cloudy days”. The resulting temperature probability distribution for cloudy days is shown in Figure 54. The curves from cloudy day analysis closely resemble those of the full data. However, by eliminating days with high solar gains, the Control House curve during (c) thermostat control is shifted to slightly lower temperatures and closely resembles the Control House benchmark curve. Thus, the three Control House curves become more similar, and we can more confidently compare the three Experimental House curves.

Cumulative frequency curves for the same master bedroom data are plotted in Figure 55 (all data) and Figure 56 (cloudy data). The effect of analyzing the data in terms of days with low solar gains is highlighted by these two graphs. In the cloudy data graph, the Control House curves are again closer together, and so the Experimental House curves can be more directly compared. Again, the pilot light curve in the Control House is slightly warmer than the benchmark curve, while the opposite is true in the Experimental House – showing a cooling impact of the pilot light on master bedroom air temperature. In the Experimental House on cloudy days, the operation of the fireplace by thermostat (c) caused the master bedroom air temperature to be below 19°C ~70.5% of the time. Whereas, during the benchmark and pilot light experiment, the master bedroom air temperature was never below 19°C.

Cumulative frequency and probability distribution curves for all the rooms in the home during days with low solar gains in Year 2 are provided in Appendix G.

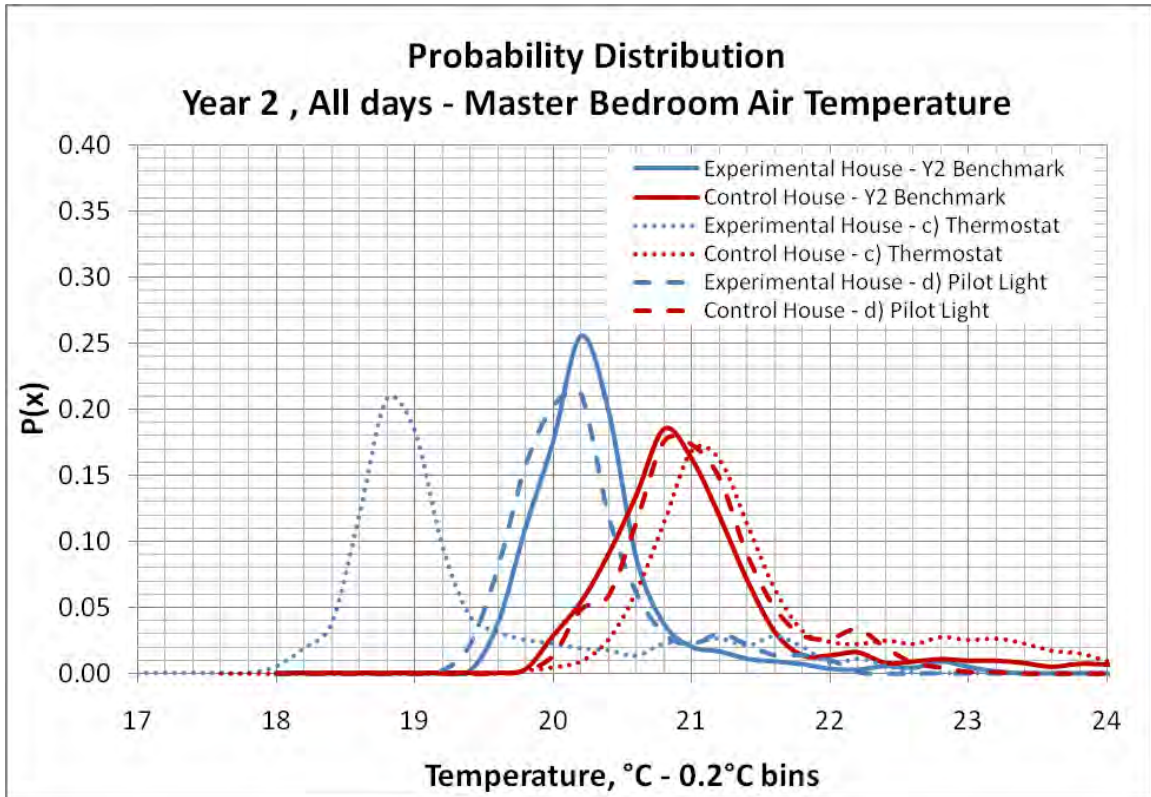


Figure 53 - Probability Distribution of master bedroom air temperature, Year 2

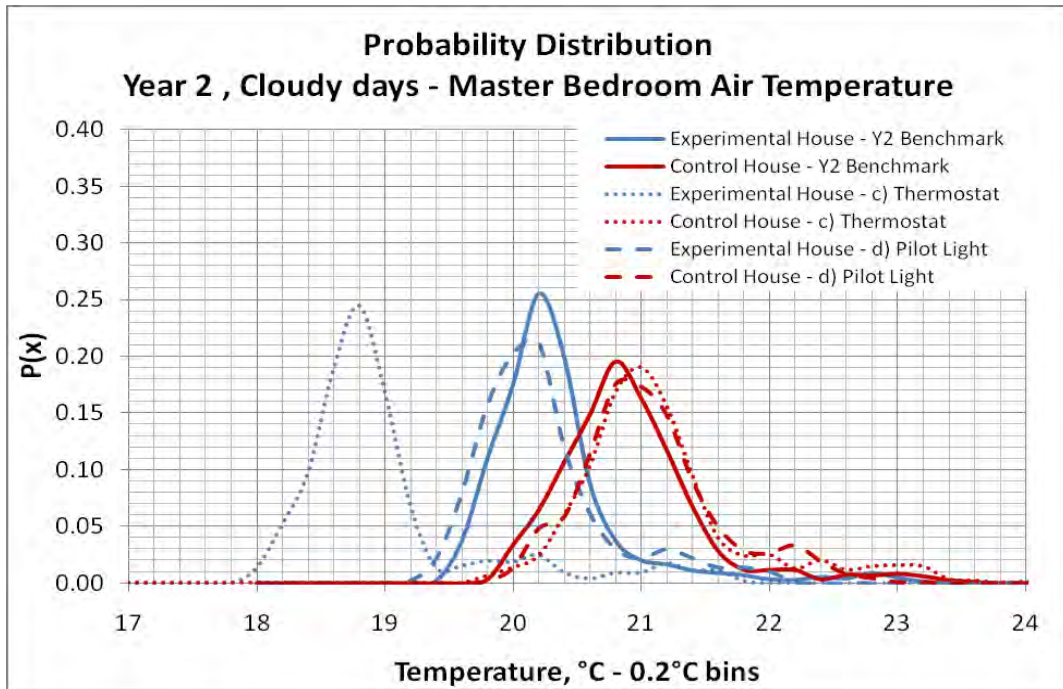


Figure 54 - Probability Distribution of master bedroom air temperature – cloudy days only, Year 2

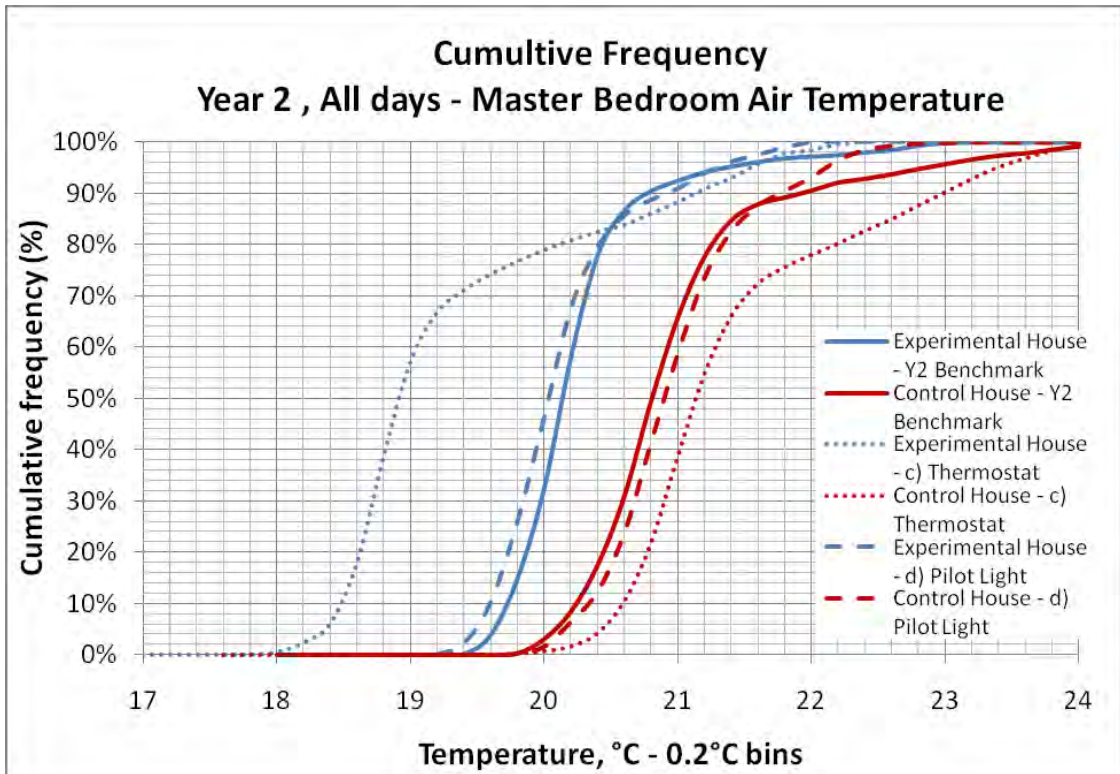


Figure 55 - Cumulative Frequency of master bedroom air temperature, Year 2

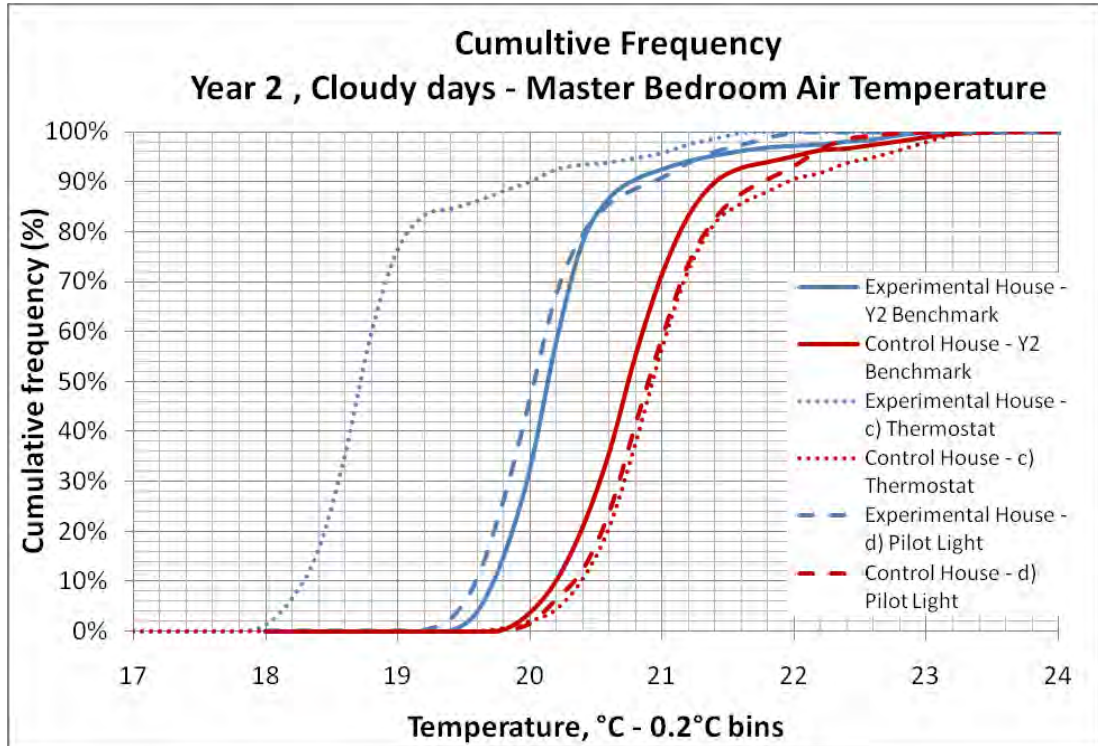


Figure 56 - Cumulative Frequency of master bedroom air temperature – cloudy days, Year 2

7 Summary and Discussion

7.1 Year 1

In year 1, the fireplace was operated in the evening from 18:00 to 24:00 each day. The impact of the fireplace was examined both with continuous air circulation provided by the furnace fan, and without continuous air circulation. Results showed no significant difference in the impact of fireplace operation on gas consumption trends due to these two modes of furnace operation. Over the experiment period in Year 1 (with and without continuous circulation), the fireplace natural gas consumed on average 144 MJ/day natural gas, decreasing furnace consumption by 106 MJ/day (39.4%), for an average increase in natural gas consumption of 38 MJ/day (16.6%).

The main difference between the experiments with and without continuous air circulation was the impact on furnace fan electrical consumption. This in turn affected total heating consumption. Without continuous fan operation, the furnace consumed on average 4.12 kWh/day, while the house would be expected to consume on average 10.06 kWh/day with continuous circulation for the experiment period. This 59% reduction in fan motor consumption alone would be expected to impact house heating load, since reduced fan motor operation would release less heat to the supply airstream. As a result, the furnace gas consumption would be expected to increase – an effect seen during the fan controller experiment (Gusdorf, 2005) and ECM motor project at CCHT (Gusdorf, 2003). The reduced air circulation would also be expected to impact air quality in the home (as seen during the fan cyclor experiment) – this was outside the scope of the fireplace project.

Generally the total energy delivered to the home from the furnace and fireplace was slightly higher than with the benchmark system. Over the duration of the experiment, the energy output of the system was 8.2 MJ/day (3.5%) higher with continuous air circulation, and 2.0 MJ (1.6%) higher without continuous air circulation. On the warmer days of the experiment, the heat delivered was up to 12% higher due to fireplace operation. This is likely an indication of overheating from the fireplace on warm days.

The family room temperature during fireplace operation increased noticeably due to the fireplace operation, as would be expected. The effect was more pronounced without continuous circulation, when the air temperature was above 25°C 10% of the time, and reached a maximum of 26.8°C, 4.9°C above the maximum temperature of the Control House family room. It is likely that without continuous circulation, the hot air from the fireplace is not circulated as readily to the home, and heats the family room to higher temperature. With continuous circulation, the family room temperature exceeded 25°C only 5% of the time.

On evenings when the fireplace was operated, temperatures on the second floor of the home dipped by up to 2°C in the bedrooms furthest away from the fireplace location. As a result, these bedrooms were as much as 8°C cooler than the family room. The temperature drop was less pronounced in the bedroom above the fireplace, where temperatures dipped by as much as 0.6°C.

Despite these daily dips in room air temperature, surface temperature effects at the three target locations (Bedroom 2 closet, bathroom cupboard, and living room corner) were minimal. A decrease in minimum temperature during the fireplace experiment was detected in the Bedroom 2 closet, in the order of 0.5°C. The lowest temperature reached at this location was 12.8°C, equivalent to the dewpoint of air at 21°C with 59% humidity. Effects at the other locations were within thermocouple measurement error. While there

were some fluctuations in surface temperature recorded during the experiment, small reductions in temperature due to the furnace shutting off during the 6 hours of fireplace operation were compensated by regular furnace operation throughout the remaining 18 hours of the day to hold the house setpoint at 21°C. A lower house setpoint temperature or daily house thermostat setback in combination with fireplace operation would reduce furnace on time, and could potentially lead to lower surface temperatures.

7.2 Year 2

In Year 2, the fireplace was operated on thermostat control – with the setpoint set 2°C above the setpoint of the central house thermostat. Due to the proximity of the fireplace to the central thermostat, operating the fireplace resulted in a large reduction in furnace operation. During the experiment, the fireplace consumed on average 249 MJ/day, and reduced furnace natural gas consumption by 208 MJ/day (59.3%) for an overall increase in natural gas consumption of 41 MJ/day (11.9%). Furnace electrical consumption was also reduced by 2.13 kWh/day (18.9%), due to decreased furnace operation, while the fireplace fan consumed an additional 1.28 kWh/day. The overall impact of the fireplace with thermostat control on total heating energy consumption (natural gas and electrical) was an increase of 38 MJ/day (9.8%).

Total heating system energy output was lower with fireplace operation than without. The calculated heat energy output, based on measured efficiencies, was 9.0 MJ/day (2.3%) lower with fireplace operation.

This reduction in the amount of the heat in the home may have contributed to the reduction in air temperatures on the second floor of the home. Average temperatures on the second floor of the home on days with low solar gains were as much as 1.8°C cooler (master bedroom and ensuite) due to operation of the fireplace with thermostat control. In the master bedroom, cloudy day air temperature was below 19°C 70.5% of the time, while temperatures during benchmarking were never below 19°C. The cooling of the master bedroom and the heating of the family room resulted in an average temperature difference of 3.4°C between rooms.

Only one fireplace thermostat setting was examined in the project. A lower fireplace thermostat setting would likely reduce fireplace operation, increasing furnace cycling and circulating heat more readily to other rooms of the home (with high speed air circulation during heating). During warmer weather, the effect could be even more pronounced – the fireplace may be able to satisfy the requirements of the house thermostat, eliminating cycling of the furnace. Higher air circulation speeds at standby could be explored to improve the distribution of heat to rooms on the second floor of the house.

The operation of the pilot light alone also impacted furnace operation. The pilot light consumed on average 38 MJ/day natural gas, and resulted in an average reduction in furnace gas consumption of 19 MJ/day (5.6%) during the experiment period, for a total gas consumption increase of 19 MJ/day (5.8%). The total impact on heating energy (electrical and gas) consumption was an increase of 18 MJ/day (5.0%).

A small difference in house temperature due to pilot light operation was also seen: a decrease of ~0.2°C in second floor rooms, and an increase of ~0.3°C in the family room (where the fireplace was located).

In this series of fireplace experiments, operation of a home with fireplace was compared to the operation of a home without fireplace. With a fireplace installed and not operating, the fireplace vent would be uncovered. The impact of having a vent uncovered was

briefly examined on four days of the experiment. These days had low heating loads ~250 MJ/day – lower than the pilot light and fireplace with thermostat control experiment days. A small increase in energy consumption was detected (3.6% increase), but more data needs to be collected over a range of different energy conditions in order to gain a better understanding of this effect.

7.3 Recommendations for future work

While measured surface temperatures during the first year indicated little drop in temperature due to fireplace operation, other house thermostat setpoints or operating strategies could result in lower temperatures. Future work could examine the operation of a fireplace in conjunction with a house thermostat setback and the impact on surface temperatures in bedrooms on the second floor.

The fireplace efficiency testing (Appendix J) showed that the operation of the circulation fan built into the fireplace did not contribute to steady state efficiency. Thus, the fireplace could be operated during a power outage with the same output. Without electricity, no furnace fan would operate to circulate the fireplace heat to other areas of the home. A future experiment could examine the impact of such operation on room temperatures, to determine under what conditions and for what duration a fireplace could be used as backup heat during a power outage.

8 References

Gusdorf, J. et al. 2005. Modified Air Circulation and Ventilation Practice to Achieve Energy Savings and Fuel Switching. Natural Resources Canada. pp. 50. Available online at: <http://www.nrc-cnrc.gc.ca/obj/irc/doc/pubs/nrcc47712/nrcc47712.pdf> [accessed March 31, 2010]

Gudorf J. et al. 2003. Final Report on the Project to Measure the Effects of ECM Furnace Motors on Gas Use at the CCHT Research Facility. Natural Resources Canada. Available Online <http://www.nrc-cnrc.gc.ca/obj/irc/doc/pubs/nrcc38500/nrcc38500.pdf> [accessed March 31, 2010]

Natural Resources Canada, 2007. 2007 Survey of Household Energy Use. Online at: <http://oee.nrcan.gc.ca/publications/statistics/sheu-summary07/trends.cfm?attr=0> [accessed March 31, 2010]

Natural Resources Canada, 2009. Buying an Energy-efficient Gas Fireplace: Energy Efficiency Considerations. Online at: <http://oee.nrcan.gc.ca/residential/personal/buying-gas-fireplace.cfm?attr=4> [accessed March 31, 2010]

Appendix A. CCHT Research Houses

Located on the National Research Council's campus in Ottawa, the Canadian Centre for Housing Technology is co-sponsored by the National Research Council, Canada Mortgage and Housing Corporation, and two branches within Natural Resources Canada – the CANMET Energy Technology Centre and the Program on Energy Research & Development.

The Centre consists of two Research Houses (a Reference House and a Test House) and a display-and-demonstration building called the InfoCentre. All three buildings were designed and built by Minto Developments Inc., Canada's largest production builder of R-2000 homes.

The Reference and Test Houses are side-by-side and identical in orientation, size and construction. Both are built to R-2000 specifications and Healthy Housing principles, to establish a "best practices" example of current construction. Their design is Minto's popular Sierra model, and feature approximately 200 m² of liveable area, and a two-car garage that is fully inside the house's footprint. Monitoring rooms have been located inside the garage, to minimize the interference of computer equipment with the house's energy system.

The Reference House serves as a control unit, while the Test House can be modified according to the research requirements. Features such as windows, heating systems, ductwork, and controls can be altered or replaced, allowing for an assessment of their effect on house performance.

Both houses use automated controls to simulate human occupancy and sophisticated computer equipment for data gathering (see Appendix B). Construction and operating costs, energy consumption, construction waste, comfort conditions, and indoor air quality are fully documented for both houses.

Appendix B. Simulated Occupancy

Monitoring the energy performance of actual houses for a full year has often been considered the most credible way of assessing the energy efficiency of a house design and its energy efficient components. In reality, the results of such experiments were always difficult to interpret, especially if the house had been occupied. From many such attempts, it was found that the occupant lifestyle had as much or more influence on the energy consumption of the house than any individual energy efficient component – thus reducing the credibility of the information provided by the monitoring. If the house were left unoccupied, the mode of operation of the house and its resulting energy budget would not be realistic. The interaction of internal heat gains from energy using appliances and occupant heat gain would be missing from the energy balance.

Sometimes, monitoring results were compared to computer simulations to try to detect whether the energy efficient devices had an impact on the overall energy consumption of the house. Yet predicting the exact performance of a house in a given year in a given climate is probably the most difficult challenge that a computer model can have. For example, models can't simulate people behaviour realistically. Thus, comparisons of measured and modeled results usually end up informing us more about shortcomings in the model than actual performance differences due to energy efficient measures.

The Canadian Center for Housing Technology has solved these problems in assessing energy efficient equipment and components. The twin-house research facility features a "simulated occupancy system". Each house features a standard set of major appliances typically found in North American homes. The simulated occupancy system, based on home automation technology, simulates human activity by operating major appliances (stove, dishwashers, washer and dryer), lights, water valves, fans, and a host of other sources simulating typical heat gains. The schedule is typical of activities that would take place in a home with a family of two adults and two children. Electrical consumption is typical for a family of four and hot water draws are set in accordance with ASHRAE standards for sizing hot water heaters. The heat given off by humans is simulated by two 60 W (2 adults) and two 40 W (2 children) incandescent bulbs at various locations in the house. The schedule can be easily modified to accommodate particular assessment requirements.

Table B-1 CCHT Simulated Occupancy Schedule

Note: Water draws shown here are for hot water only, in litres.

Overnight				
Device	Water Utility	Draw	Time	Duration
Bedroom 2 humans		66.4 W	0:00	6 hrs 45 min
Master bedroom humans		99.6 W	0:00	6 hrs 45 min
Morning				
Device	Water Utility	Draw	Time	Duration
2nd floor lights		410 W	6:45	60.0 min
	1. Master bedroom shower	36 L	6:50	10.2 min
Family room humans		166 W	7:00	60.0 min
Main floor lights		200 W	7:00	60.0 min
Kitchen products		450 W	7:30	10.2 min
Kitchen fan		80 W	7:30	10.2 min
Kitchen stove (intermittent)		1600 W	7:30	20.0 min
	2. Kitchen tap	13 L	7:45	3.0 min
Afternoon				
Device	Water Utility	Draw	Time	Duration
Kitchen fan		80 W	12:00	15.0 min
Kitchen stove (intermittent)		1600 W	12:00	15.0 min
Family room humans		166 W	12:00	30.0 min
Kitchen products		450 W	12:00	10.2 min
Main floor lights		200 W	12:00	15.0 min
	3. Kitchen tap	13 L	12:30	3.0 min
Evening				
Device	Water Utility	Draw	Time	Duration
	4 & 5. Clothes washer (46L)	400 W	17:00	60.0 min
Main floor lights		200 W	17:00	2 hrs 30 min
Kitchen fan		80 W	17:30	3.6 min
Kitchen stove (intermittent)		1600 W	17:30	30.0 min
Family room humans		166 W	17:30	2 hrs 30 min
Kitchen products		450 W	17:30	10.2 min
Dining room products		225 W	18:00	2 hrs
2nd floor lights		410 W	18:00	5 hrs
	6. Kitchen tap	27 L	18:30	6.0 min
	7 & 8. Dishwasher	650 W	19:00	60.0 min
Dryer		2250 W	19:00	25.2 min
Living room humans		166 W	19:00	2 hrs
Bedroom 2 humans		66 W	21:00	3 hrs
	9. Main bathroom bath	41 L	21:05	4.8 min
	10. Master bedroom shower	55 L	22:30	15 min
Master Bedroom Humans		100 W	23:00	60 min

Appendix C. Savings Calculation Method

The technique used to calculate the savings using the side-by-side method is described graphically below. Each red cross on this graphic represents the consumption data for a single day of the experiment. For a given day, the Control House consumes a certain amount of energy. Given the amount consumed by the Control House and the benchmark trend line, we can calculate how much energy the Experimental House would consume in benchmark configuration (shown by the dashed blue line). These consumption values are listed in the Tables in Appendix E and F under the heading "Expected from Benchmark". The measured energy consumption of the Experimental House during the experiment (shown by the dashed red line) is then subtracted from the expected Experimental House consumption in the benchmark configuration for that same day. This is equivalent to the vertical distance between the experiment data point and the Benchmark trend.

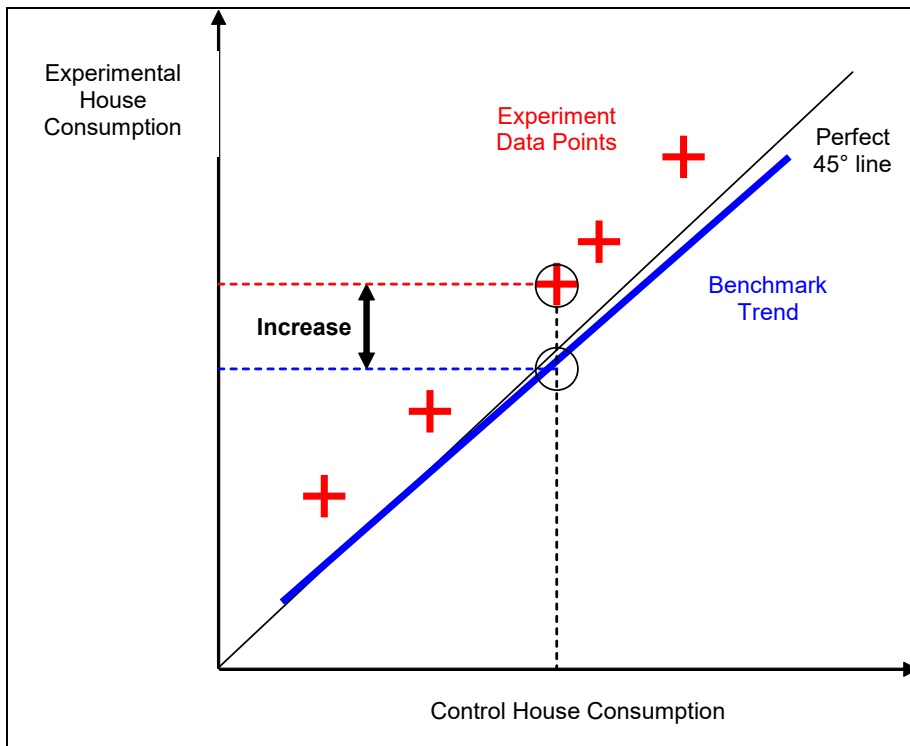
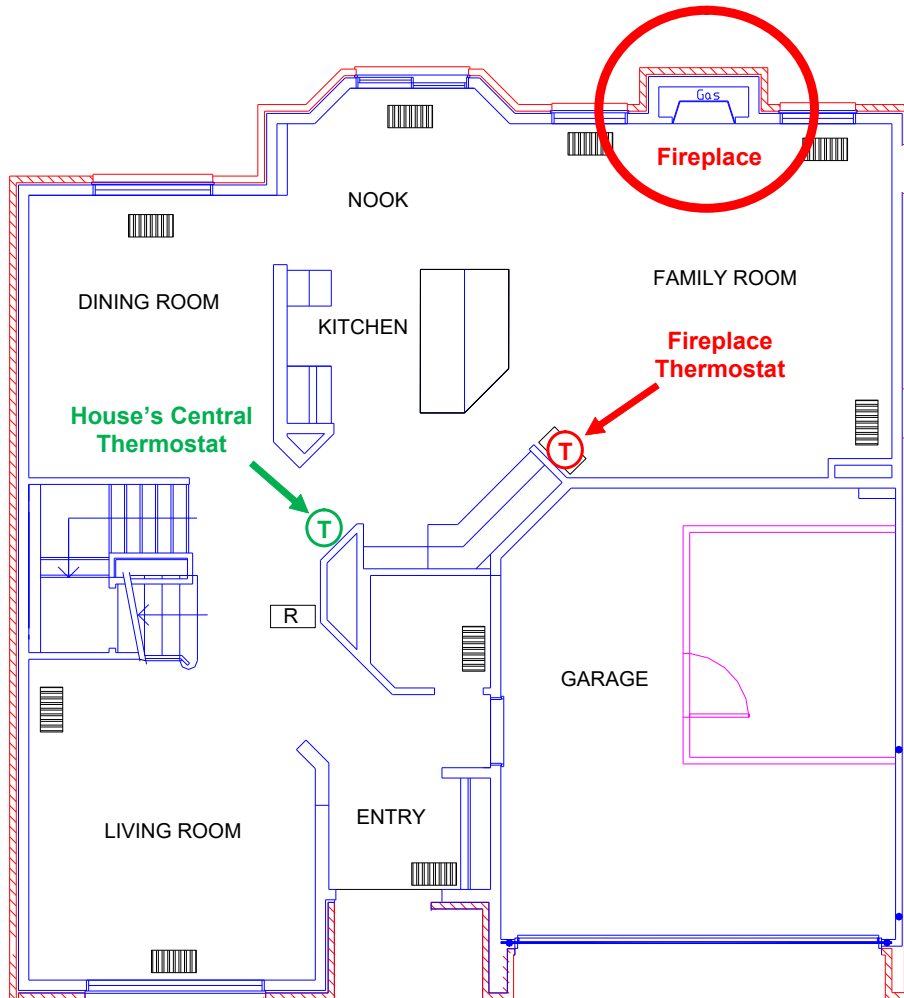



Figure C-1 Graphic Representation of the Savings Calculation Method


The benchmark trend line is used in place of the benchmark data in order to minimize random errors. On any given, some scatter is expected in the results both for the Control House and the Experimental House. The scatter in the Benchmark data appears to be random error. One possible cause is that the houses' heating systems cannot be synchronized. When one house may be at the end of a heating cycle at midnight on one day, and the other house may be at the beginning, resulting in small and opposite errors on both the first and second days when this occurs.

Appendix D. Floor Plans of the CCHT Twin Houses



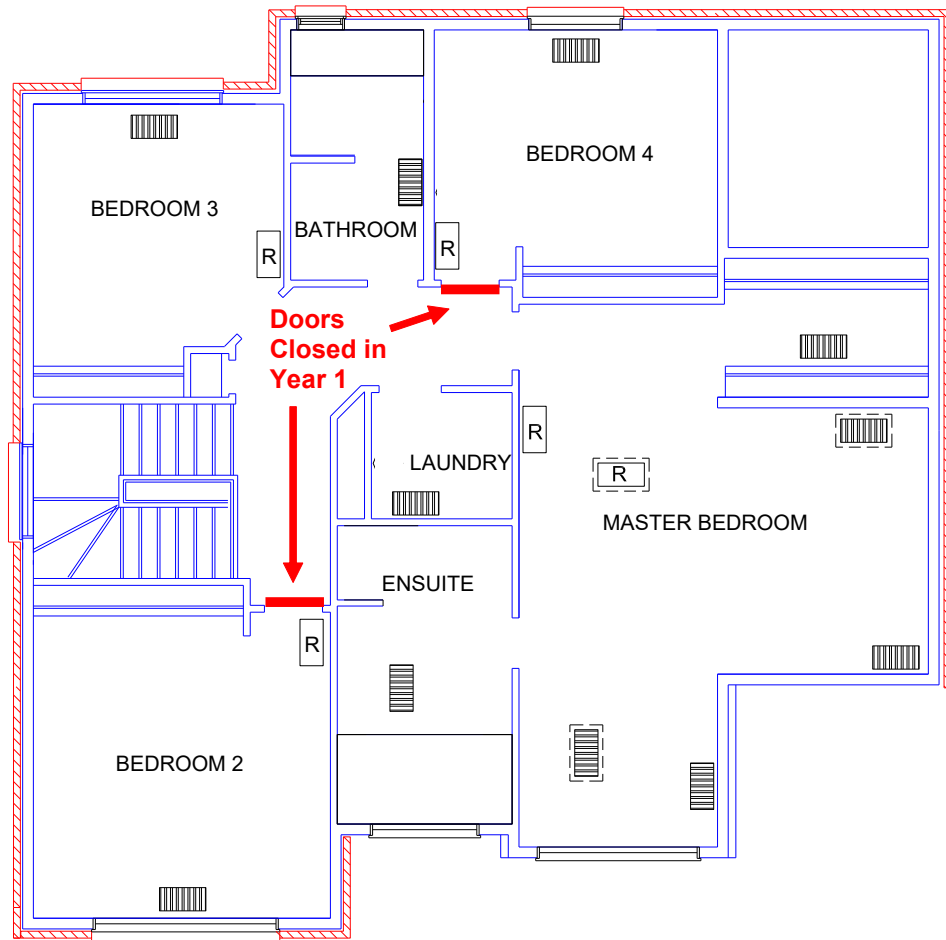
CCHT Research House - FIRST FLOOR

 Supply Register

 Thermostat

 Return

Figure D-1. Floor plan - CCHT Research House first floor



CCHT Research House - SECOND FLOOR






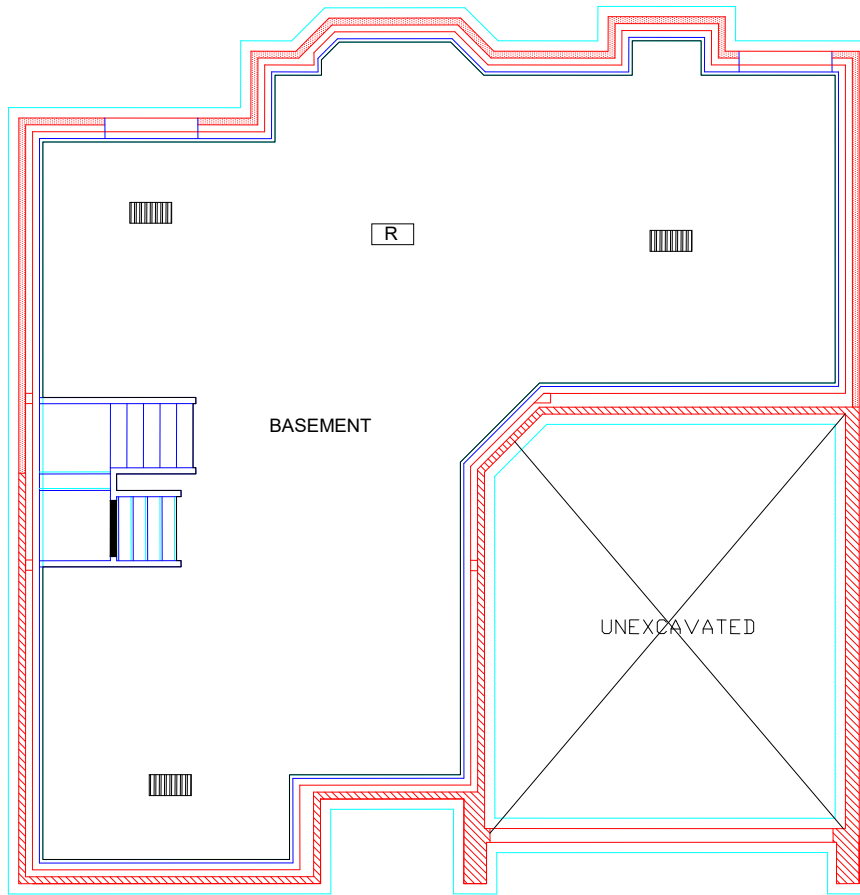
-  Supply Register - below floor
-  Supply Register
-  Thermostat
-  Return
-  Return - below floor

Figure D-2. Floor plan - CCHT Research House second floor



CCHT Research House - BASEMENT

-  Register
-  Return

Figure D-3. Floor plan - CCHT Research House basement

Appendix E. Year 1 Summary Tables of Consumption Data

Table E-1. Year 1 Natural Gas Consumption, MJ

Date	Fireplace, MJ	Furnace Gas, MJ				Total Gas, MJ			
		Measured	Expected from Benchmark	Difference	Difference %	Measured	Expected from Benchmark	Difference	Difference %
a) Operation from 18:00 – 24:00 Continuous Circulation									
19-Dec-08	143.66	290.28	405.86	-115.58	-28.5%	433.94	405.86	28.08	6.9%
20-Dec-08	143.66	413.19	519.11	-105.92	-20.4%	556.85	519.11	37.74	7.3%
21-Dec-08	145.77	328.05	432.38	-104.34	-24.1%	473.82	432.38	41.44	9.6%
22-Dec-08	143.66	402.09	516.31	-114.21	-22.1%	545.76	516.31	29.45	5.7%
23-Dec-08	143.66	287.43	396.45	-109.02	-27.5%	431.09	396.45	34.64	8.7%
24-Dec-08	145.77	104.31	208.69	-104.38	-50.0%	250.09	208.69	41.40	19.8%
25-Dec-08	143.66	298.52	399.86	-101.34	-25.3%	442.18	399.86	42.32	10.6%
26-Dec-08	144.72	272.38	378.89	-106.51	-28.1%	417.09	378.89	38.21	10.1%
6-Mar-09	145.77	59.95	152.09	-92.15	-60.6%	205.72	152.09	53.63	35.3%
7-Mar-09	143.66	28.73	122.83	-94.10	-76.6%	172.39	122.83	49.57	40.4%
8-Mar-09	145.77	102.94	205.03	-102.09	-49.8%	248.71	205.03	43.69	21.3%
9-Mar-09	143.66	152.96	263.56	-110.60	-42.0%	296.62	263.56	33.06	12.5%
10-Mar-09	145.77	122.96	228.18	-105.23	-46.1%	268.73	228.18	40.55	17.8%
b) Operation from 18:00 – 24:00 <u>No</u> Continuous Circulation									
28-Dec-08	144.72	184.28	283.31	-99.03	-35.0%	329.00	283.31	45.69	16.1%
29-Dec-08	145.77	177.09	289.31	-112.22	-38.8%	322.87	289.31	33.56	11.6%
30-Dec-08	144.72	312.89	420.67	-107.79	-25.6%	457.60	420.67	36.93	8.8%
31-Dec-08	143.66	350.02	472.28	-122.27	-25.9%	493.68	472.28	21.40	4.5%
12-Mar-09	144.72	205.77	322.09	-116.31	-36.1%	350.49	322.09	28.40	8.8%
13-Mar-09	144.72	134.79	247.73	-112.94	-45.6%	279.51	247.73	31.78	12.8%
14-Mar-09	144.72	76.16	171.49	-95.32	-55.6%	220.88	171.49	49.39	28.8%

15-Mar-09	133.10	51.55	144.71	-93.16	-64.4%	184.65	144.71	39.93	27.6%
Average	144.06	207.44	313.37	-105.93	-39.4%	351.51	313.37	38.14	15.5%
a) Average - continuous circulation	144.56	203.30	325.33	-105.04	-38.6%	364.85	325.33	39.52	15.8%
b) Average - no cont. circulation	143.27	193.02	293.95	-107.38	-40.9%	329.83	293.95	35.89	14.9%

Table E-2. Year 1 Electrical Consumption, kWh

Date	Fireplace, kWh	Furnace Elec, kWh				Total Elec, kWh			
		Measured	Expected from Benchmark*	Difference	Difference %	Measured	Expected from Benchmark*	Difference	Difference %
a) Operation from 18:00 – 24:00 Continuous Circulation									
19-Dec-08	0.259	10.45	11.67	-1.21	-10.4%	10.71	11.67	-0.95	-8.2%
20-Dec-08	0.259	11.55	12.61	-1.06	-8.4%	11.81	12.61	-0.80	-6.3%
21-Dec-08	0.259	10.81	11.86	-1.05	-8.8%	11.07	11.86	-0.79	-6.6%
22-Dec-08	0.259	11.63	12.75	-1.12	-8.8%	11.89	12.75	-0.86	-6.8%
23-Dec-08	0.259	10.47	11.63	-1.17	-10.0%	10.73	11.63	-0.91	-7.8%
24-Dec-08	0.259	8.66	9.87	-1.20	-12.2%	8.92	9.87	-0.95	-9.6%
25-Dec-08	0.259	10.64	11.72	-1.08	-9.2%	10.90	11.72	-0.82	-7.0%
26-Dec-08	0.259	10.32	11.47	-1.15	-10.0%	10.58	11.47	-0.89	-7.7%
6-Mar-09	0.259	8.25	9.32	-1.07	-11.5%	8.51	9.32	-0.81	-8.7%
7-Mar-09	0.259	7.58	8.72	-1.14	-13.0%	7.84	8.72	-0.88	-10.1%
8-Mar-09	0.259	8.73	9.84	-1.11	-11.2%	8.99	9.84	-0.85	-8.6%
9-Mar-09	0.259	9.31	10.44	-1.12	-10.8%	9.57	10.44	-0.86	-8.3%
10-Mar-09	0.259	8.95	10.06	-1.10	-11.0%	9.21	10.06	-0.85	-8.4%
b) Operation from 18:00 – 24:00 <u>No</u> Continuous Circulation									
28-Dec-08	0.259	3.62	5.51	-1.90	-34.4%	3.88	5.51	-1.64	-29.7%
29-Dec-08	0.259	3.41	5.54	-2.13	-38.4%	3.67	5.54	-1.87	-33.7%
30-Dec-08	0.259	5.66	7.61	-1.95	-25.6%	5.92	7.61	-1.69	-22.2%
31-Dec-08	0.259	6.36	8.42	-2.06	-24.5%	6.62	8.42	-1.80	-21.4%
12-Mar-09	0.259	4.01	5.95	-1.94	-32.6%	4.27	5.95	-1.68	-28.3%
13-Mar-09	0.259	2.69	4.71	-2.02	-42.9%	2.95	4.71	-1.76	-37.4%
14-Mar-09	0.259	1.65	3.47	-1.82	-52.4%	1.91	3.47	-1.56	-45.0%
15-Mar-09	0.259	3.50	5.36	-1.86	-34.7%	3.76	5.36	-1.60	-29.8%

Average	0.26	7.54	8.98	-1.44	-20.0%	7.80	8.98	-1.18	-16.7%
a) Average - continuous circulation	0.26	9.80	10.92	-1.12	-10.4%	10.06	10.92	-0.86	-8.0%
b) Average - no cont. circulation	0.26	3.86	5.82	-1.96	-35.7%	4.12	5.82	-1.70	-30.9%

*Note: the expected benchmark furnace fan consumption with no continuous circulation is based on an extrapolation of the benchmark line.

Table E-3. Year 1 Total Heating System Consumption (Electrical and Gas), MJ

Date	Fireplace, MJ	Furnace, MJ				Total, MJ			
		Measured	Expected from Benchmark*	Difference	Difference %	Measured	Expected from Benchmark	Difference	Difference %
a) Operation from 18:00 – 24:00 Continuous Circulation									
19-Dec-08	144.59	327.92	447.87	-119.95	-26.8%	472.51	447.87	24.64	5.5%
20-Dec-08	144.59	454.76	564.50	-109.74	-19.4%	599.35	564.50	34.85	6.2%
21-Dec-08	146.71	366.97	475.08	-108.11	-22.8%	513.68	475.08	38.59	8.1%
22-Dec-08	144.59	443.96	562.24	-118.27	-21.0%	588.56	562.24	26.32	4.7%
23-Dec-08	144.59	325.11	438.34	-113.22	-25.8%	469.71	438.34	31.37	7.2%
24-Dec-08	146.71	135.49	244.20	-108.71	-44.5%	282.20	244.20	38.00	15.6%
25-Dec-08	144.59	336.83	442.06	-105.24	-23.8%	481.42	442.06	39.36	8.9%
26-Dec-08	145.65	309.52	420.17	-110.65	-26.3%	455.17	420.17	35.00	8.3%
6-Mar-09	146.71	89.64	185.63	-95.98	-51.7%	236.35	185.63	50.72	27.3%
7-Mar-09	144.59	56.03	154.20	-98.17	-63.7%	200.62	154.20	46.43	30.1%
8-Mar-09	146.71	134.38	240.44	-106.06	-44.1%	281.09	240.44	40.64	16.9%
9-Mar-09	144.59	186.49	301.13	-114.64	-38.1%	331.08	301.13	29.95	9.9%
10-Mar-09	146.71	155.19	264.39	-109.20	-41.3%	301.89	264.39	37.51	14.2%
b) Operation from 18:00 – 24:00 <u>No</u> Continuous Circulation									
28-Dec-08	145.65	197.30	302.97	-105.67	-34.9%	342.95	302.97	39.98	13.2%
29-Dec-08	146.71	189.38	309.08	-119.70	-38.7%	336.09	309.08	27.01	8.7%
30-Dec-08	145.65	333.27	447.94	-114.67	-25.6%	478.92	447.94	30.98	6.9%
31-Dec-08	144.59	372.93	502.48	-129.56	-25.8%	517.52	502.48	15.04	3.0%
12-Mar-09	145.65	220.21	343.34	-123.13	-35.9%	365.86	343.34	22.52	6.6%
13-Mar-09	145.65	144.48	264.50	-120.01	-45.4%	290.13	264.50	25.64	9.7%
14-Mar-09	145.65	82.11	183.77	-101.66	-55.3%	227.76	183.77	44.00	23.9%
15-Mar-09	134.03	64.15	163.85	-99.71	-60.9%	198.18	163.85	34.33	20.9%

Average	145.00	234.58	345.63	-111.05	-36.8%	379.57	345.63	33.95	12.2%
a) Average - continuous circulation	145.49	255.56	364.63	-109.07	-34.6%	401.05	364.63	36.41	12.5%
b) Average - no cont. circulation	144.20	200.48	314.74	-114.26	-40.3%	344.68	314.74	29.94	11.6%

Table E-4. Year 1 Total Heating System Energy Output, MJ

Energy output calculation assumes:

- Fireplace gas efficiency: 76.1% (assume measured steady state efficiency)
- Furnace gas efficiency: 94.0%
- Electrical efficiency: 100%

Date	Fireplace, MJ	Furnace, MJ				Total, MJ			
		Measured	Expected from Benchmark*	Difference	Difference %	Measured	Expected from Benchmark	Difference	Difference %
a) Operation from 18:00 – 24:00 Continuous Circulation									
19-Dec-08	110.26	310.50	423.51	-113.01	-26.7%	420.76	423.51	-2.75	-0.6%
20-Dec-08	110.26	429.97	533.34	-103.37	-19.4%	540.22	533.34	6.88	1.3%
21-Dec-08	111.87	347.29	449.13	-101.85	-22.7%	459.15	449.13	10.02	2.2%
22-Dec-08	110.26	419.84	531.24	-111.40	-21.0%	530.10	531.24	-1.14	-0.2%
23-Dec-08	110.26	307.87	414.54	-106.67	-25.7%	418.13	414.54	3.58	0.9%
24-Dec-08	111.87	129.23	231.68	-102.45	-44.2%	241.10	231.68	9.41	4.1%
25-Dec-08	110.26	318.91	418.06	-99.15	-23.7%	429.17	418.06	11.11	2.7%
26-Dec-08	111.06	293.18	397.43	-104.25	-26.2%	404.24	397.43	6.81	1.7%
6-Mar-09	111.87	86.05	176.51	-90.46	-51.3%	197.91	176.51	21.40	12.1%
7-Mar-09	110.26	54.31	146.85	-92.54	-63.0%	164.57	146.85	17.72	12.1%
8-Mar-09	111.87	128.20	228.15	-99.94	-43.8%	240.07	228.15	11.92	5.2%
9-Mar-09	110.26	177.31	285.32	-108.01	-37.9%	287.57	285.32	2.25	0.8%
10-Mar-09	111.87	147.81	250.70	-102.89	-41.0%	259.68	250.70	8.98	3.6%
b) Operation from 18:00 – 24:00 <u>No</u> Continuous Circulation									
28-Dec-08	111.06	186.24	286.15	-99.91	-34.9%	297.31	286.15	11.15	3.9%
29-Dec-08	111.87	178.75	291.90	-113.15	-38.8%	290.62	291.90	-1.28	-0.4%
30-Dec-08	111.06	314.50	422.84	-108.35	-25.6%	425.56	422.84	2.72	0.6%
31-Dec-08	110.26	351.93	474.27	-122.35	-25.8%	462.19	474.27	-12.09	-2.5%
12-Mar-09	111.06	207.87	324.19	-116.33	-35.9%	318.93	324.19	-5.26	-1.6%

13-Mar-09	111.06	136.40	249.83	-113.44	-45.4%	247.46	249.83	-2.38	-1.0%
14-Mar-09	111.06	77.54	173.70	-96.16	-55.4%	188.60	173.70	14.90	8.6%
15-Mar-09	102.22	61.06	155.32	-94.27	-60.7%	163.28	155.32	7.96	5.1%
Average	110.57	222.13	326.89	-104.76	-36.6%	332.70	326.89	5.81	2.8%
a) Average - continuous circulation	110.94	242.34	345.11	-102.77	-34.4%	353.28	345.11	8.17	3.5%
b) Average - no cont. circulation	109.96	189.28	297.28	-107.99	-40.3%	299.24	297.28	1.96	1.6%

Appendix F. Year 2 Summary Tables of Consumption Data

Table F-1. Year 2 Natural Gas Consumption, MJ

Date	Fireplace, MJ	Furnace Gas, MJ				Total Gas, MJ			
		Measured	Expected from Benchmark*	Difference	Difference %	Measured	Expected from Benchmark*	Difference	Difference %
c) Fireplace with thermostat control									
06-Feb-10	257.75	179.05	399.20	-220.15	-55.1%	436.79	399.20	37.60	9.4%
07-Feb-10	256.69	163.89	363.34	-199.45	-54.9%	420.58	363.34	57.24	15.8%
08-Feb-10	250.35	165.95	377.73	-211.78	-56.1%	416.30	377.73	38.57	10.2%
09-Feb-10	244.01	124.01	329.87	-205.85	-62.4%	368.03	329.87	38.16	11.6%
10-Feb-10	236.62	74.05	265.95	-191.90	-72.2%	310.67	265.95	44.72	16.8%
11-Feb-10	250.35	118.31	325.45	-207.14	-63.6%	368.66	325.45	43.21	13.3%
12-Feb-10	258.80	171.23	391.87	-220.64	-56.3%	430.03	391.87	38.17	9.7%
13-Feb-10	241.90	181.27	388.91	-207.64	-53.4%	423.17	388.91	34.26	8.8%
14-Feb-10	245.07	137.96	344.52	-206.57	-60.0%	383.03	344.52	38.50	11.2%
d) Pilot light only									
02-Feb-10	38.03	396.34	416.76	-20.42	-4.9%	434.37	416.76	17.60	4.2%
03-Feb-10	38.03	350.33	369.00	-18.67	-5.1%	388.36	369.00	19.36	5.2%
04-Feb-10	38.03	379.65	404.86	-25.21	-6.2%	417.68	404.86	12.81	3.2%
16-Feb-10	38.03	299.47	319.63	-20.16	-6.3%	337.50	319.63	17.87	5.6%
17-Feb-10	39.08	266.83	287.46	-20.63	-7.2%	305.91	287.46	18.45	6.4%
18-Feb-10	39.08	263.93	275.30	-11.37	-4.1%	303.01	275.30	27.71	10.1%
e) Fireplace vent open, no operation									
26-Feb-10	0.00	205.67	195.73	9.93	5.1%	205.67	195.73	9.93	5.1%
27-Feb-10	0.00	234.67	227.75	6.92	3.0%	234.67	227.75	6.92	3.0%

28-Feb-10	0.00	197.59	186.28	11.31	6.1%	197.59	186.28	11.31	6.1%
01-Mar-10	0.00	206.41	201.97	4.44	2.2%	206.41	201.97	4.44	2.2%
c) Average - Thermostat Control	249.06	146.19	354.09	-207.90	-59.3%	395.25	354.09	41.16	11.9%
d) Average - Pilot light	38.38	326.09	345.50	-19.41	-5.6%	364.47	345.50	18.97	5.8%
e) Average - Vent open	0.00	211.08	202.93	8.15	4.1%	211.08	202.93	8.15	4.1%

Table F-2. Year 2 Electrical Consumption, kWh

Date	Fireplace, kWh	Furnace Electrical, kWh				Total Electrical, kWh			
		Measured	Expected from Benchmark*	Difference	Difference %	Measured	Expected from Benchmark*	Difference	Difference %
c) Fireplace with thermostat control									
06-Feb-10	1.27	9.52	11.78	-2.26	-19.2%	10.79	11.78	-0.99	-8.4%
07-Feb-10	1.28	9.36	11.38	-2.03	-17.8%	10.63	11.38	-0.75	-6.6%
08-Feb-10	1.28	9.37	11.56	-2.18	-18.9%	10.65	11.56	-0.91	-7.8%
09-Feb-10	1.28	8.93	11.08	-2.16	-19.5%	10.21	11.08	-0.88	-7.9%
10-Feb-10	1.28	8.36	10.35	-1.99	-19.2%	9.64	10.35	-0.71	-6.9%
11-Feb-10	1.28	8.83	10.95	-2.13	-19.4%	10.10	10.95	-0.85	-7.8%
12-Feb-10	1.28	9.41	11.66	-2.25	-19.3%	10.69	11.66	-0.97	-8.3%
13-Feb-10	1.28	9.50	11.59	-2.09	-18.0%	10.78	11.59	-0.81	-7.0%
14-Feb-10	1.29	9.07	11.15	-2.08	-18.7%	10.35	11.15	-0.80	-7.1%
d) Pilot light only									
02-Feb-10	0.00	11.77	11.98	-0.21	-1.7%	11.77	11.98	-0.21	-1.7%
03-Feb-10	0.00	11.31	11.49	-0.18	-1.5%	11.31	11.49	-0.18	-1.5%
04-Feb-10	0.00	11.61	11.90	-0.28	-2.4%	11.61	11.90	-0.28	-2.4%
16-Feb-10	0.00	10.72	10.90	-0.18	-1.7%	10.72	10.90	-0.18	-1.7%
17-Feb-10	0.00	10.33	10.55	-0.22	-2.1%	10.33	10.55	-0.22	-2.1%
18-Feb-10	0.00	10.31	10.40	-0.10	-0.9%	10.31	10.40	-0.10	-0.9%

e) Fireplace vent open, no operation									
26-Feb-10	0.00	9.72	9.61	0.11	1.1%	9.72	9.61	0.11	1.1%
27-Feb-10	0.00	10.10	10.00	0.10	1.0%	10.10	10.00	0.10	1.0%
28-Feb-10	0.00	9.73	9.60	0.14	1.4%	9.73	9.60	0.14	1.4%
01-Mar-10	0.00	9.79	9.75	0.04	0.4%	9.79	9.75	0.04	0.4%
c) Average - Thermostat Control	1.28	9.15	11.28	-2.13	-18.9%	10.43	11.28	-0.85	-7.5%
d) Average - Pilot light	0.00	11.01	11.20	-0.19	-1.7%	11.01	11.20	-0.19	-1.7%
e) Average - Vent open	0.00	9.84	9.74	0.10	1.0%	9.84	9.74	0.10	1.0%

Table F-3. Year 2 Total Heating System Consumption (Electrical and Gas), MJ

Date	Fireplace, MJ	Furnace, MJ				Total, MJ			
		Measured	Expected from Benchmark*	Difference	Difference %	Measured	Expected from Benchmark*	Difference	Difference %
c) Fireplace with thermostat control									
06-Feb-10	0.00	0.00	386.12	-386.12	-100.0%	0.00	386.12	-386.12	-100.0%
07-Feb-10	262.33	213.32	441.64	-228.32	-51.7%	475.65	441.64	34.01	7.7%
08-Feb-10	261.28	197.57	404.36	-206.79	-51.1%	458.86	404.36	54.49	13.5%
09-Feb-10	254.95	199.70	419.37	-219.67	-52.4%	454.65	419.37	35.28	8.4%
10-Feb-10	248.62	156.15	369.79	-213.64	-57.8%	404.77	369.79	34.98	9.5%
11-Feb-10	241.22	104.15	303.26	-199.11	-65.7%	345.37	303.26	42.11	13.9%
12-Feb-10	254.95	150.09	364.94	-214.86	-58.9%	405.04	364.94	40.09	11.0%
13-Feb-10	263.41	205.09	433.89	-228.80	-52.7%	468.51	433.89	34.61	8.0%
14-Feb-10	246.51	215.47	430.70	-215.23	-50.0%	461.98	430.70	31.28	7.3%
d) Pilot light only									
02-Feb-10	38.03	438.71	459.90	-21.19	-4.6%	476.74	459.90	16.84	3.7%
03-Feb-10	38.03	391.05	410.37	-19.32	-4.7%	429.08	410.37	18.71	4.6%

04-Feb-10	38.03	421.46	447.69	-26.23	-5.9%	459.49	447.69	11.80	2.6%
16-Feb-10	38.03	338.05	358.93	-20.88	-5.8%	376.08	358.93	17.15	4.8%
17-Feb-10	39.08	304.01	325.50	-21.48	-6.6%	343.10	325.50	17.60	5.4%
18-Feb-10	39.08	301.03	312.83	-11.80	-3.8%	340.12	312.83	27.29	8.7%
e) Fireplace vent open, no operation									
26-Feb-10	0.00	240.66	230.40	10.26	4.5%	240.66	230.40	10.26	4.5%
27-Feb-10	0.00	271.03	263.76	7.26	2.8%	271.03	263.76	7.26	2.8%
28-Feb-10	0.00	232.62	220.83	11.79	5.3%	232.62	220.83	11.79	5.3%
01-Mar-10	0.00	241.66	237.08	4.58	1.9%	241.66	237.08	4.58	1.9%
c) Average - Thermostat Control	253.66	179.13	394.74	-215.62	-55.1%	432.79	394.74	38.05	9.8%
d) Average - Pilot light	38.38	365.72	385.87	-20.15	-5.2%	404.10	385.87	18.23	5.0%
e) Average - Vent open	0.00	246.49	238.02	8.47	3.6%	246.49	238.02	8.47	3.6%

Table F-4. Year 2 Total Heating System Energy Output, MJ

Energy output calculation assumes:

- Fireplace gas efficiency: 76.1% (assume measured steady state efficiency)
- Furnace gas efficiency: 94.0%
- Electrical efficiency: 100%

Date	Fireplace, MJ	Furnace, MJ				Total, MJ			
		Measured	Expected from Benchmark*	Difference	Difference %	Measured	Expected from Benchmark*	Difference	Difference %
c) Fireplace with thermostat control									
06-Feb-10	200.73	202.57	417.66	-215.09	-51.5%	403.30	417.66	-14.36	-3.4%
07-Feb-10	199.94	187.74	382.52	-194.78	-50.9%	387.67	382.52	5.15	1.3%
08-Feb-10	195.12	189.74	396.67	-206.94	-52.2%	384.86	396.67	-11.82	-3.0%

09-Feb-10	190.30	148.71	349.98	-201.27	-57.5%	339.01	349.98	-10.97	-3.1%
10-Feb-10	184.67	99.71	287.25	-187.55	-65.3%	284.37	287.25	-2.88	-1.0%
11-Feb-10	195.11	142.99	345.35	-202.37	-58.6%	338.10	345.35	-7.25	-2.1%
12-Feb-10	201.56	194.82	410.33	-215.51	-52.5%	396.38	410.33	-13.95	-3.4%
13-Feb-10	188.69	204.60	407.29	-202.69	-49.8%	393.29	407.29	-14.00	-3.4%
14-Feb-10	191.13	162.33	363.99	-201.67	-55.4%	353.46	363.99	-10.54	-2.9%
d) Pilot light only									
02-Feb-10	28.94	414.93	434.87	-19.94	-4.6%	443.87	434.87	9.00	2.1%
03-Feb-10	28.94	370.03	388.21	-18.18	-4.7%	398.97	388.21	10.76	2.8%
04-Feb-10	28.94	398.68	423.40	-24.72	-5.8%	427.62	423.40	4.22	1.0%
16-Feb-10	28.94	320.08	339.69	-19.61	-5.8%	349.02	339.69	9.33	2.7%
17-Feb-10	29.74	288.00	308.18	-20.18	-6.5%	317.75	308.18	9.57	3.1%
18-Feb-10	29.74	285.20	296.23	-11.04	-3.7%	314.94	296.23	18.71	6.3%
e) Fireplace vent open, no operation									
26-Feb-10	0.00	228.32	218.60	9.72	4.4%	228.32	218.60	9.72	4.4%
27-Feb-10	0.00	256.95	250.07	6.87	2.7%	256.95	250.07	6.87	2.7%
28-Feb-10	0.00	220.77	209.65	11.12	5.3%	220.77	209.65	11.12	5.3%
01-Mar-10	0.00	229.28	224.95	4.33	1.9%	229.28	224.95	4.33	1.9%
c) Average - Thermostat Control	194.14	170.36	373.45	-203.09	-54.9%	364.49	373.45	-8.96	-2.3%
d) Average - Pilot light	29.21	346.15	365.10	-18.94	-5.2%	375.36	365.10	10.26	3.0%
e) Average - Vent open	0.00	233.83	225.82	8.01	3.6%	233.83	225.82	8.01	3.6%

Appendix G. Year 2 Room Temperatures, cloudy days

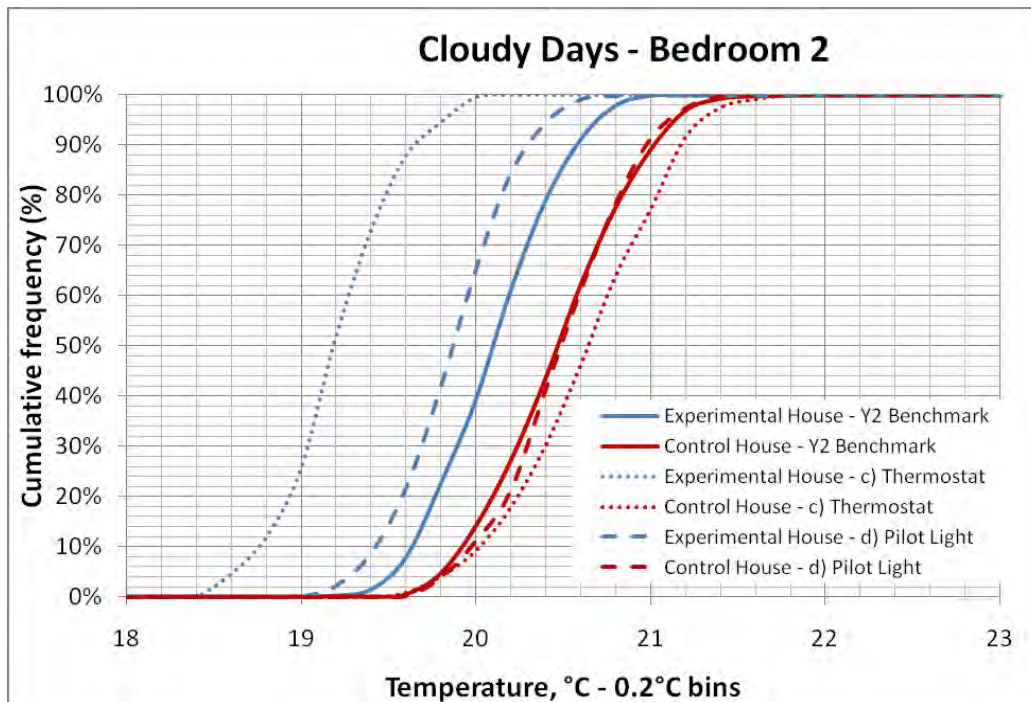


Figure G-1. Cumulative Frequency Diagram, Year 2 cloudy days - Bedroom 2

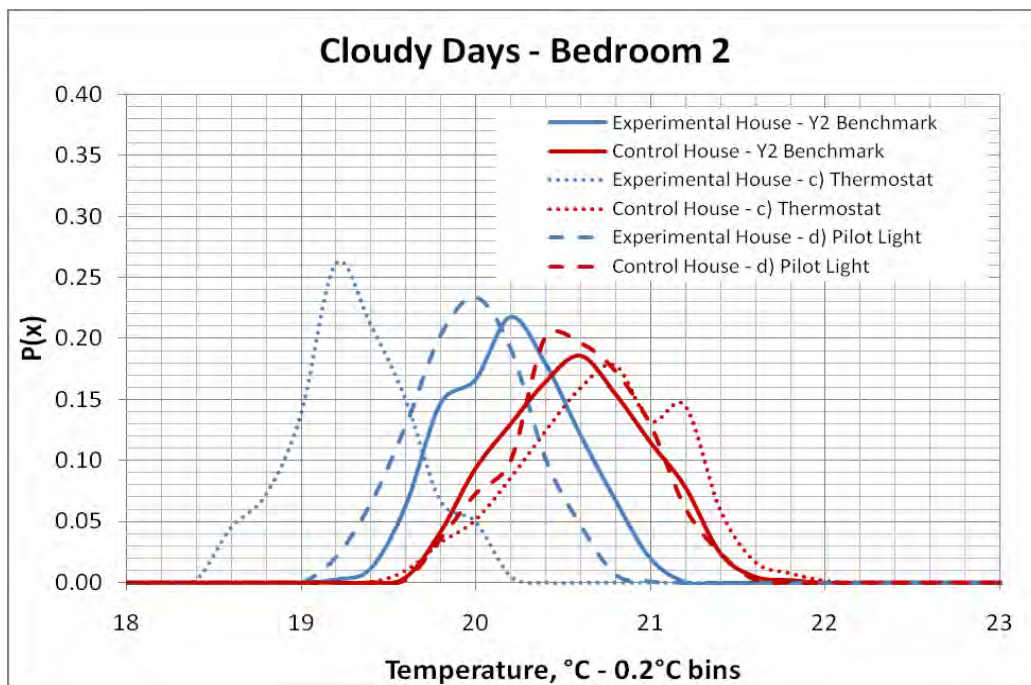


Figure G-2. Probability Distribution, Year 2 cloudy days - Bedroom 2

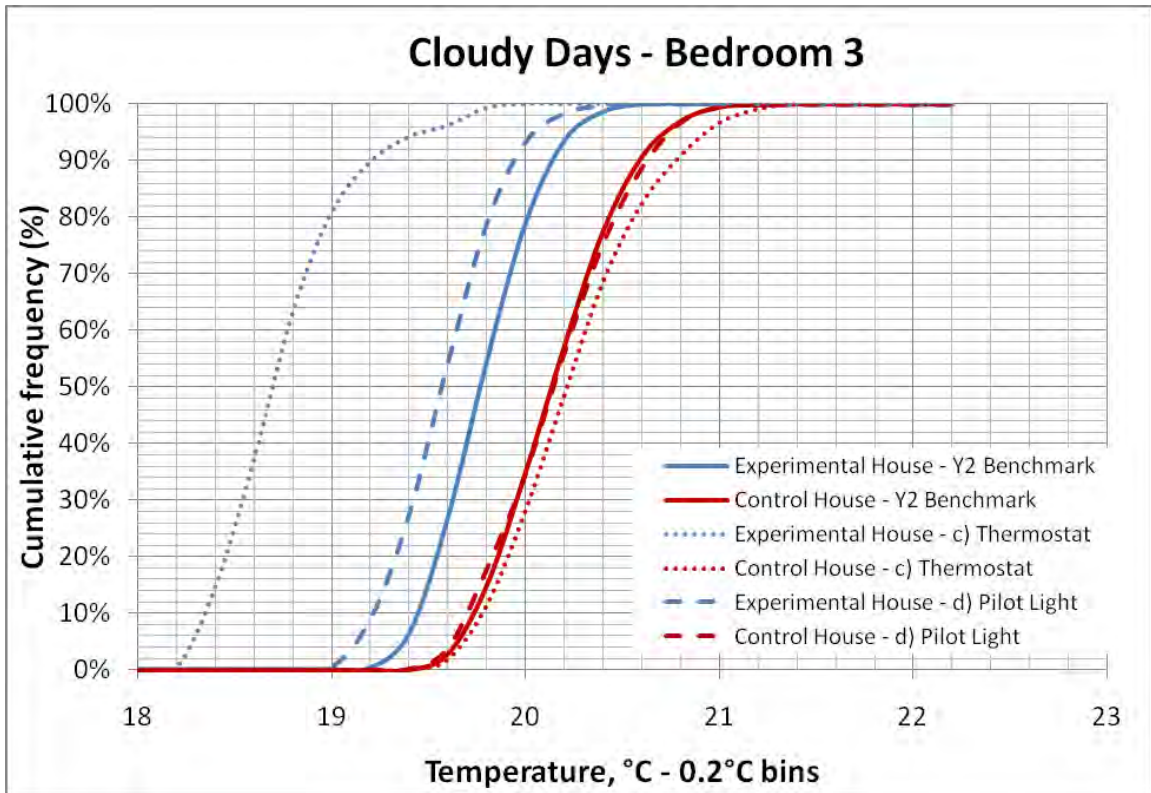


Figure G-3. Cumulative frequency diagram, Year 2 cloudy days - Bedroom 3

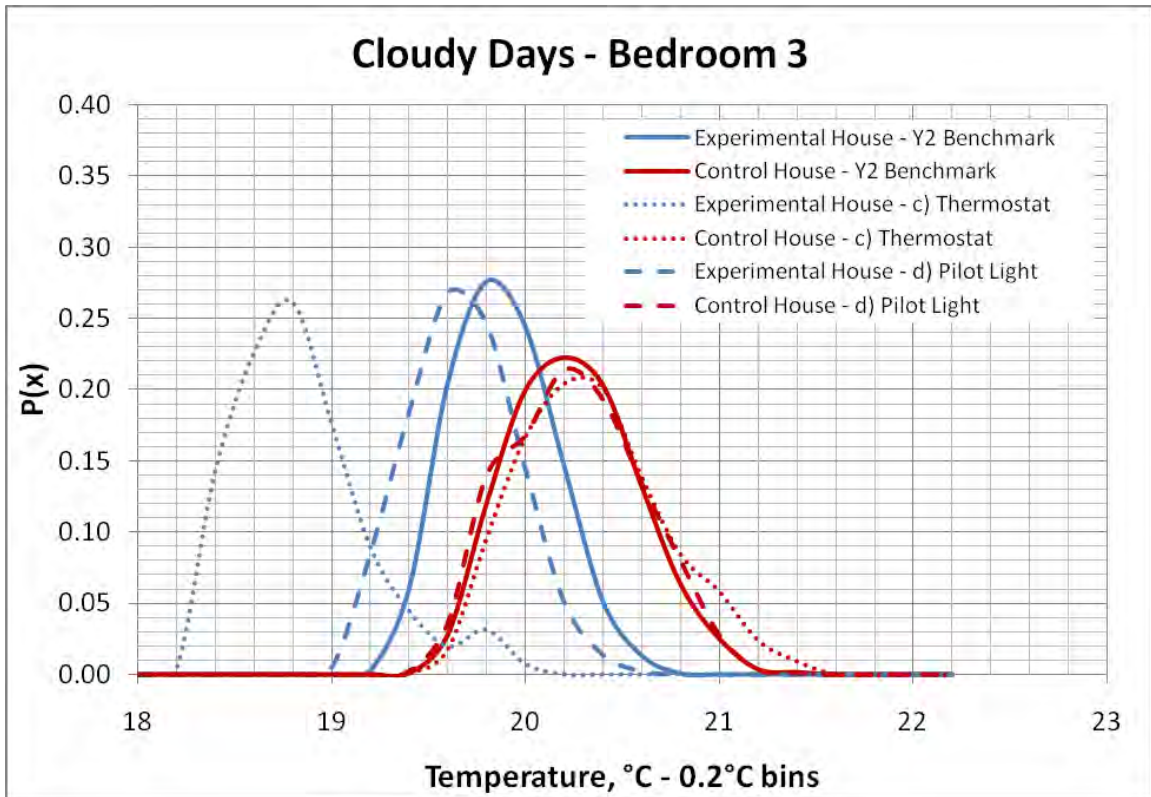


Figure G-4. Probability Distribution, Year 2 cloudy days - Bedroom 3

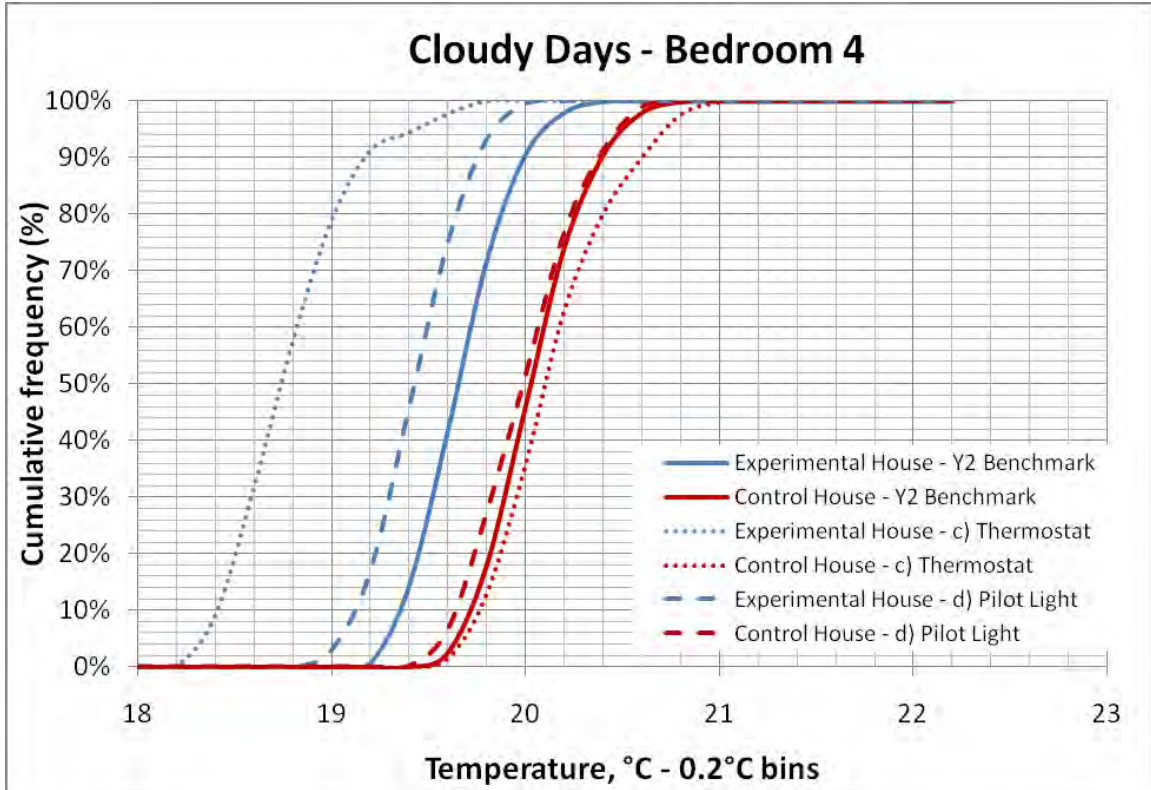


Figure G-5. Cumulative frequency diagram, Year 2 cloudy days - Bedroom 4

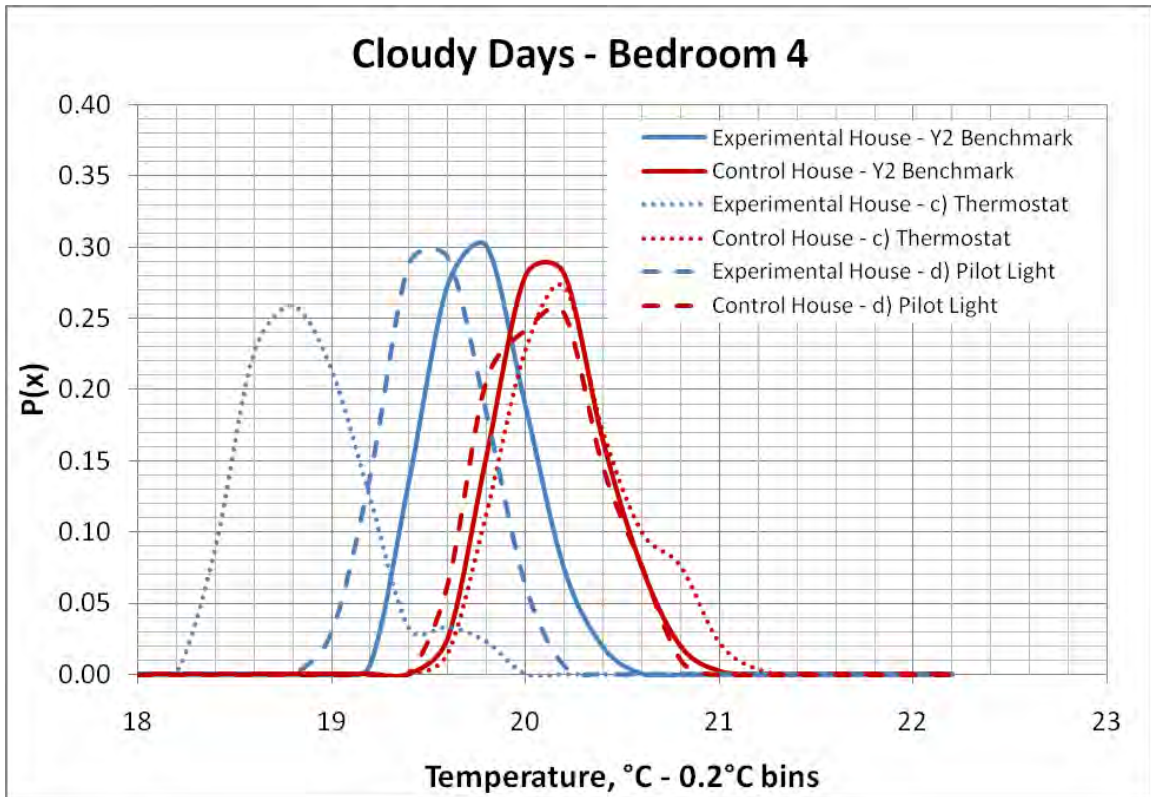


Figure G-6. Probability Distribution, Year 2 cloudy days - Bedroom 4

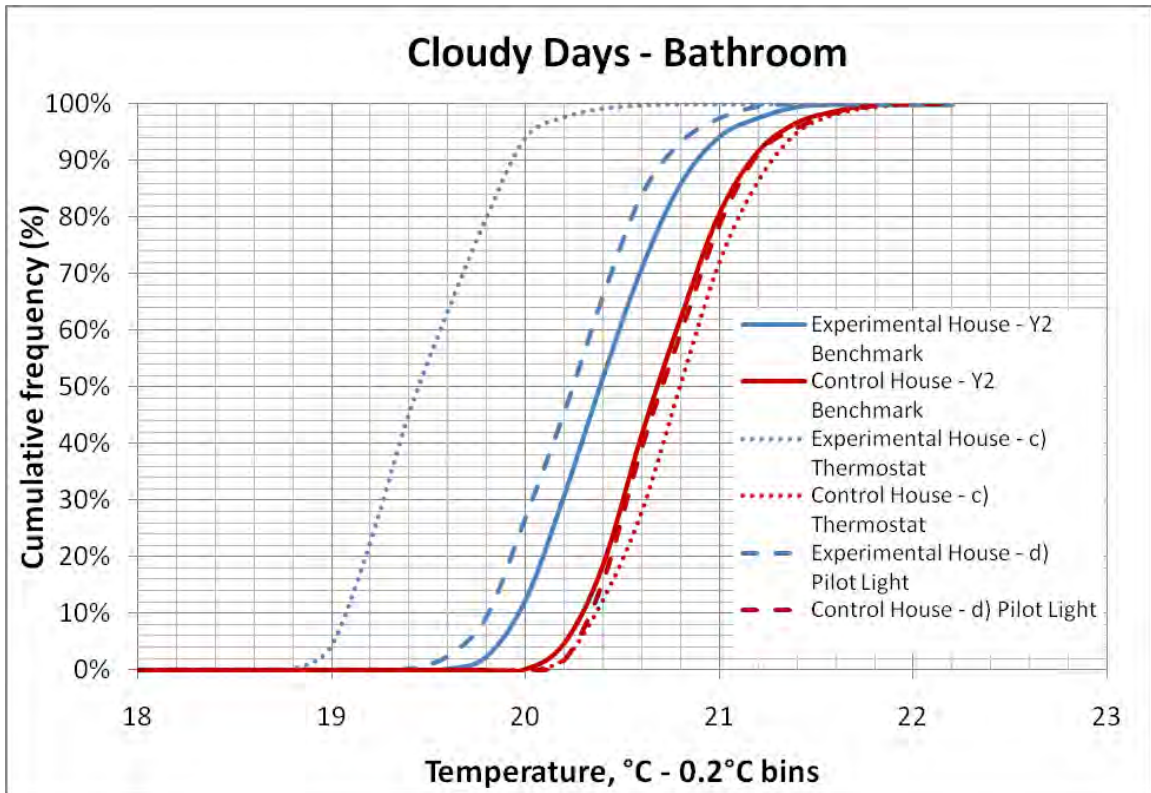


Figure G-7. Cumulative frequency diagram, Year 2 cloudy days – Second floor bathroom

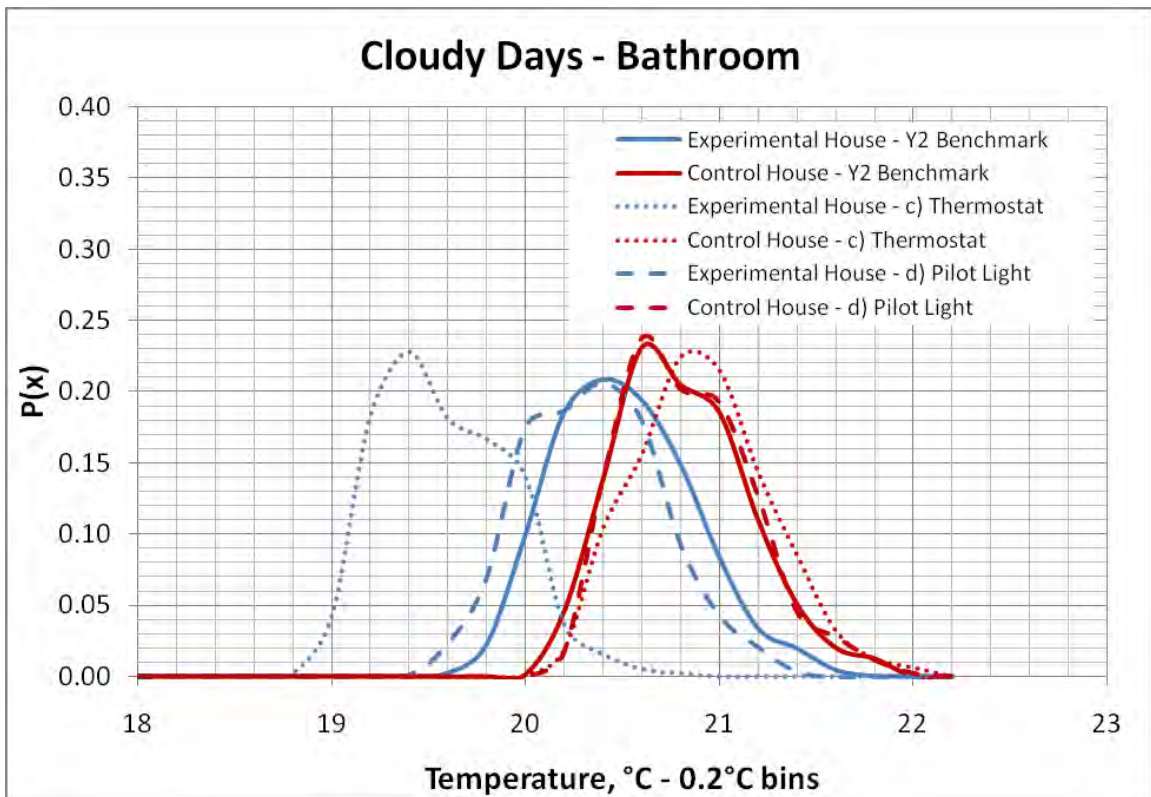


Figure G-8. Probability distribution, Year 2 cloudy days – Second floor bathroom

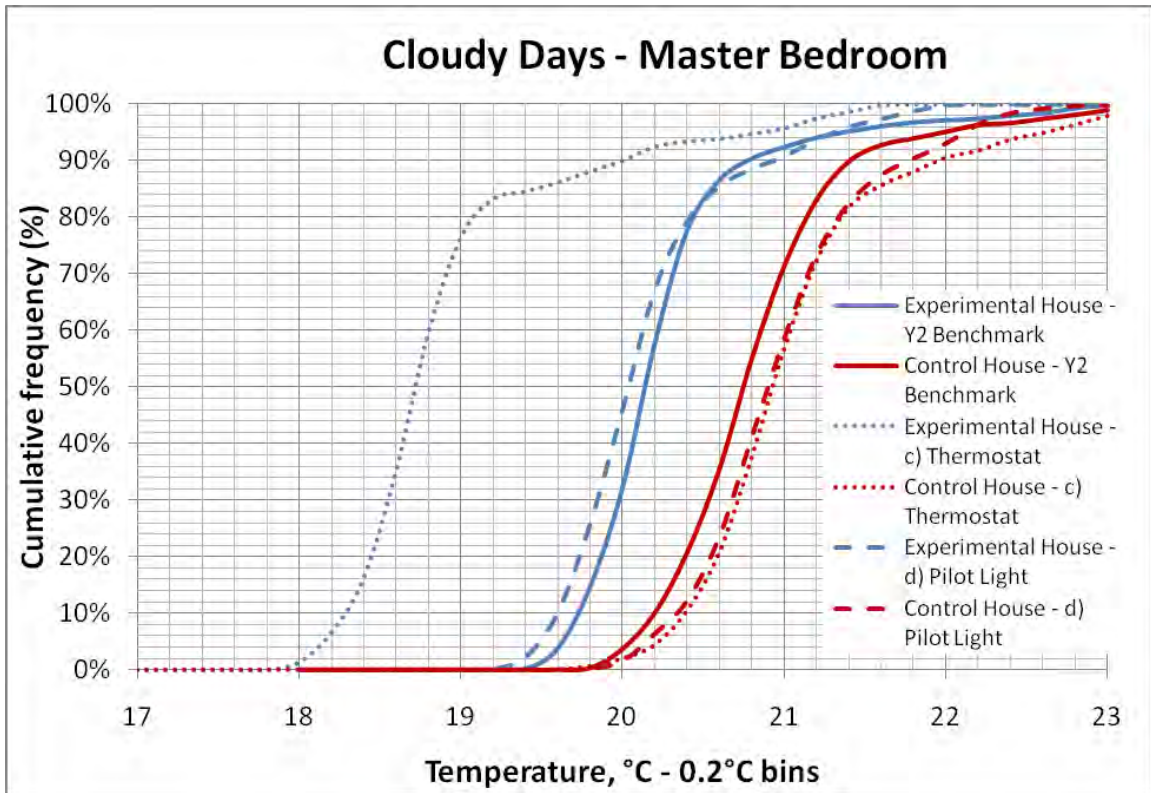


Figure G-9. Cumulative frequency diagram, Year 2 cloudy days – Master bedroom

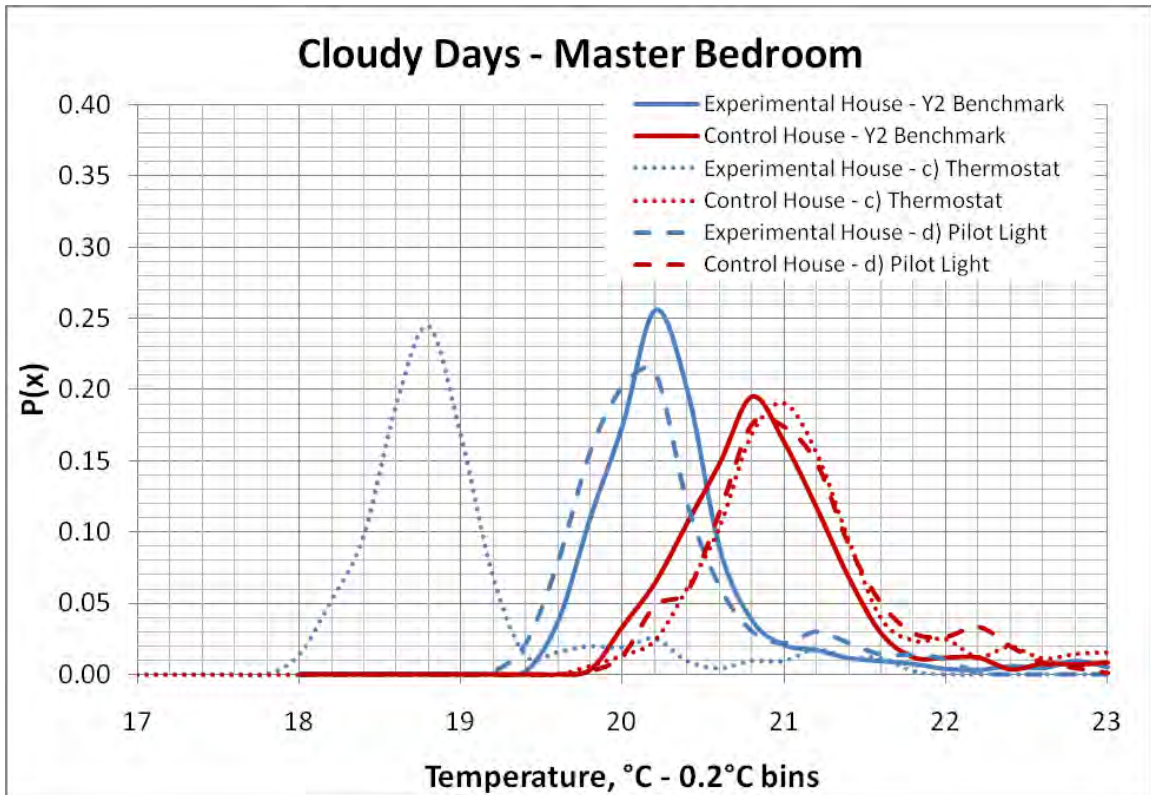


Figure G-10. Probability distribution, Year 2 cloudy days – Master bedroom

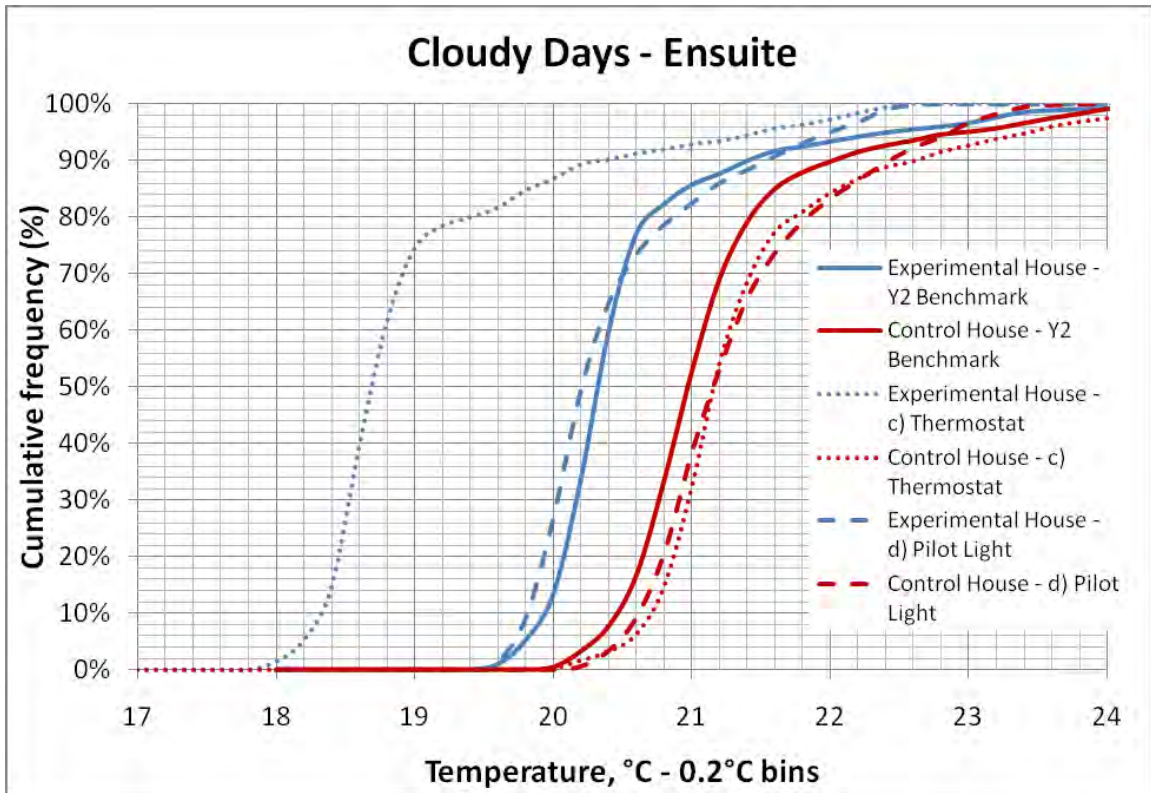


Figure G-11. Cumulative frequency diagram, Year 2 cloudy days – Ensuite

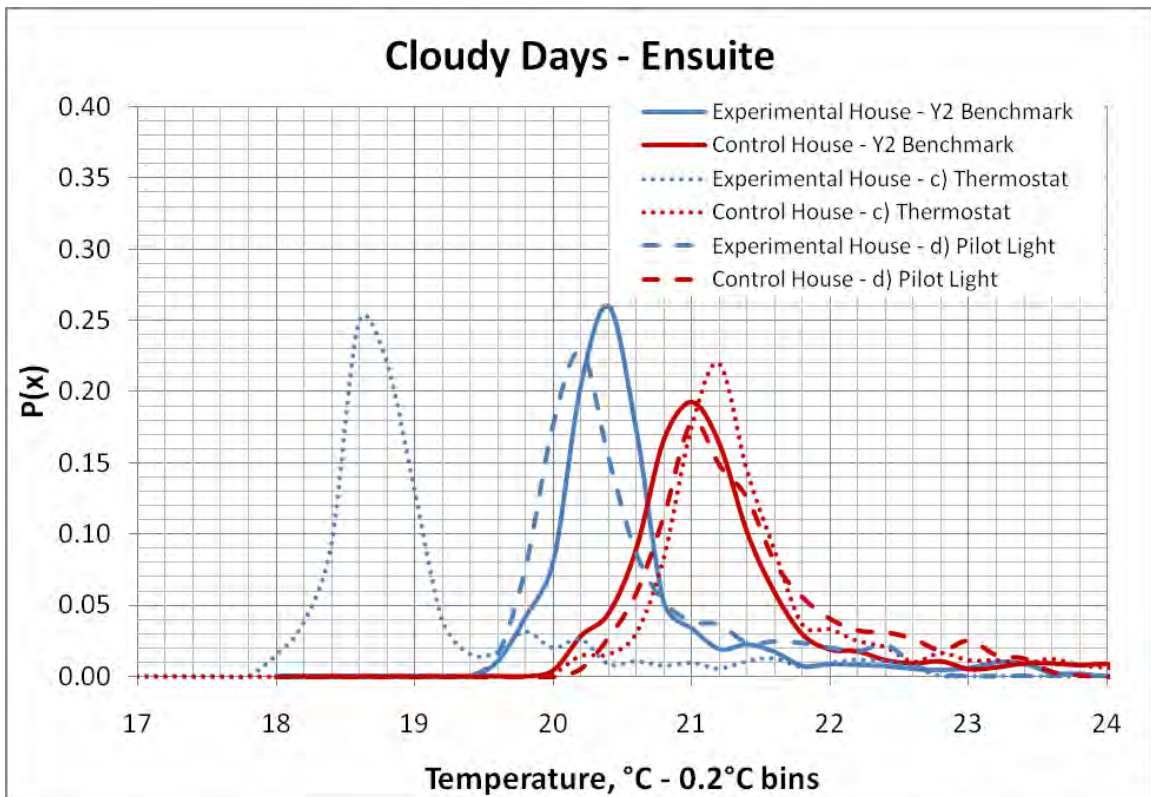


Figure G-12. Probability distribution, Year 2 cloudy days – Ensuite

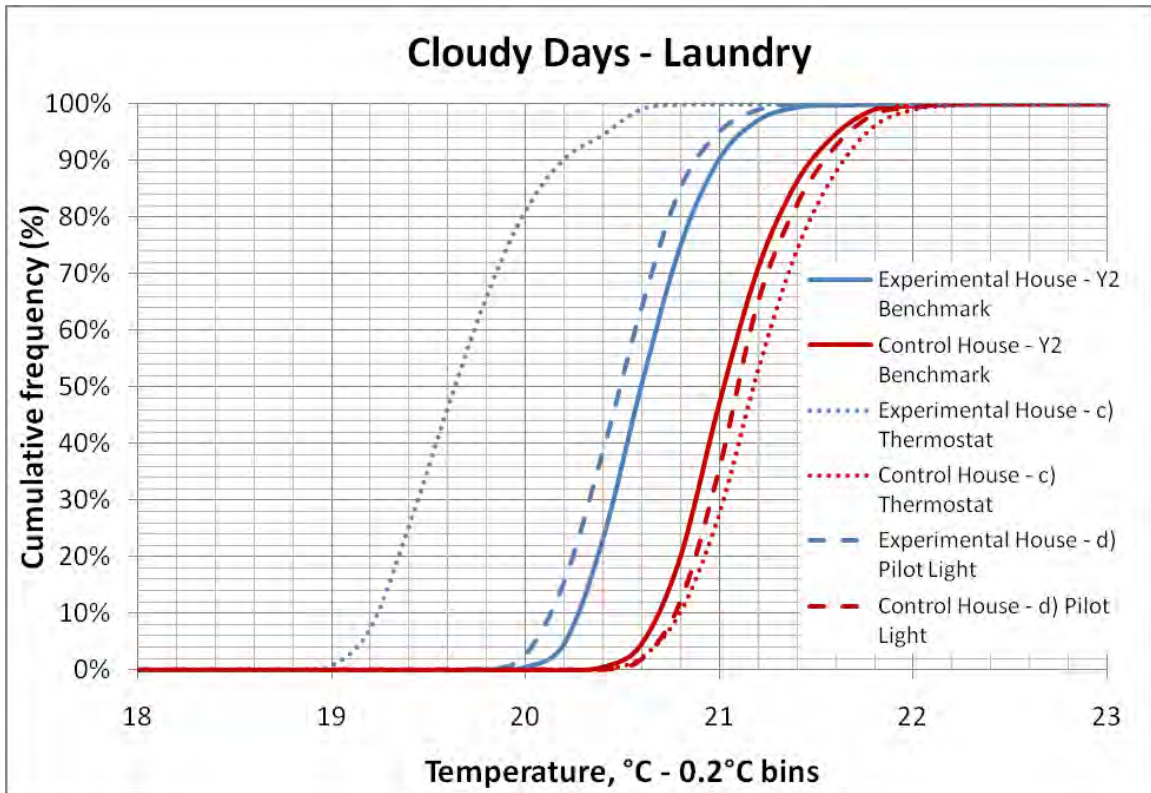


Figure G-13. Cumulative frequency diagram, Year 2 cloudy days – Laundry room

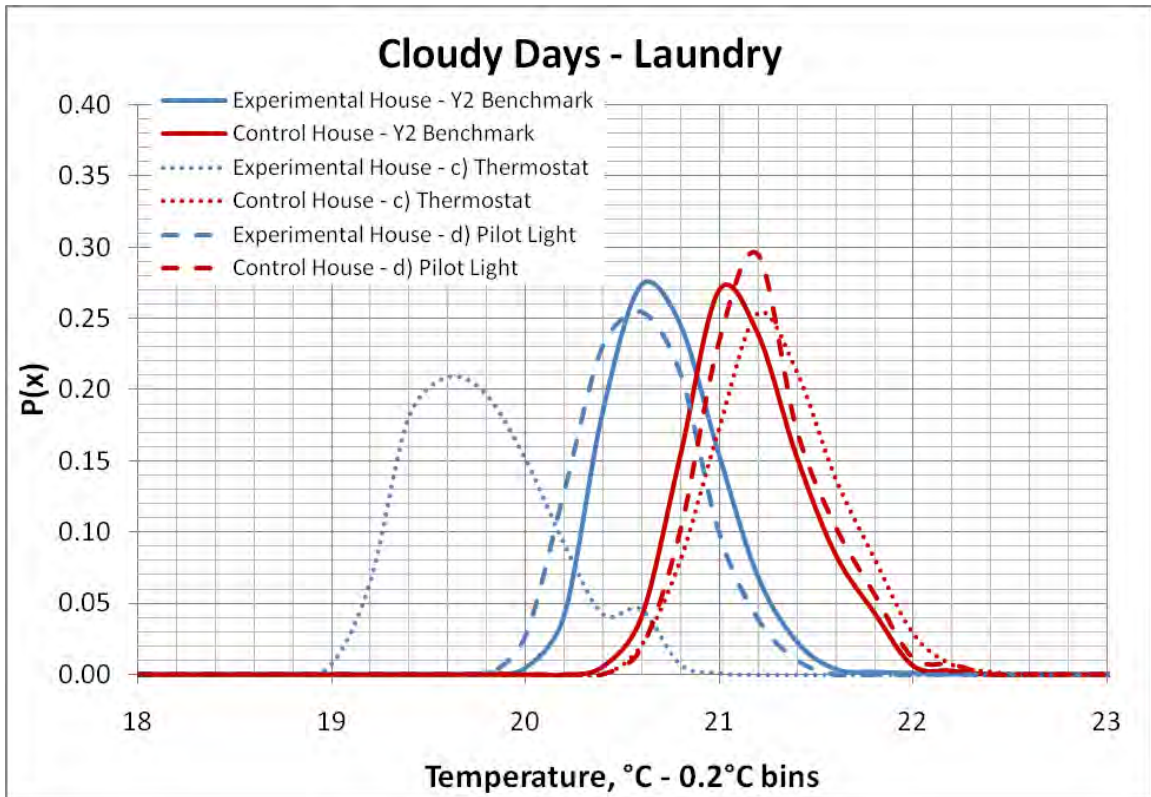


Figure G-14. Probability distribution, Year 2 cloudy days – Laundry room

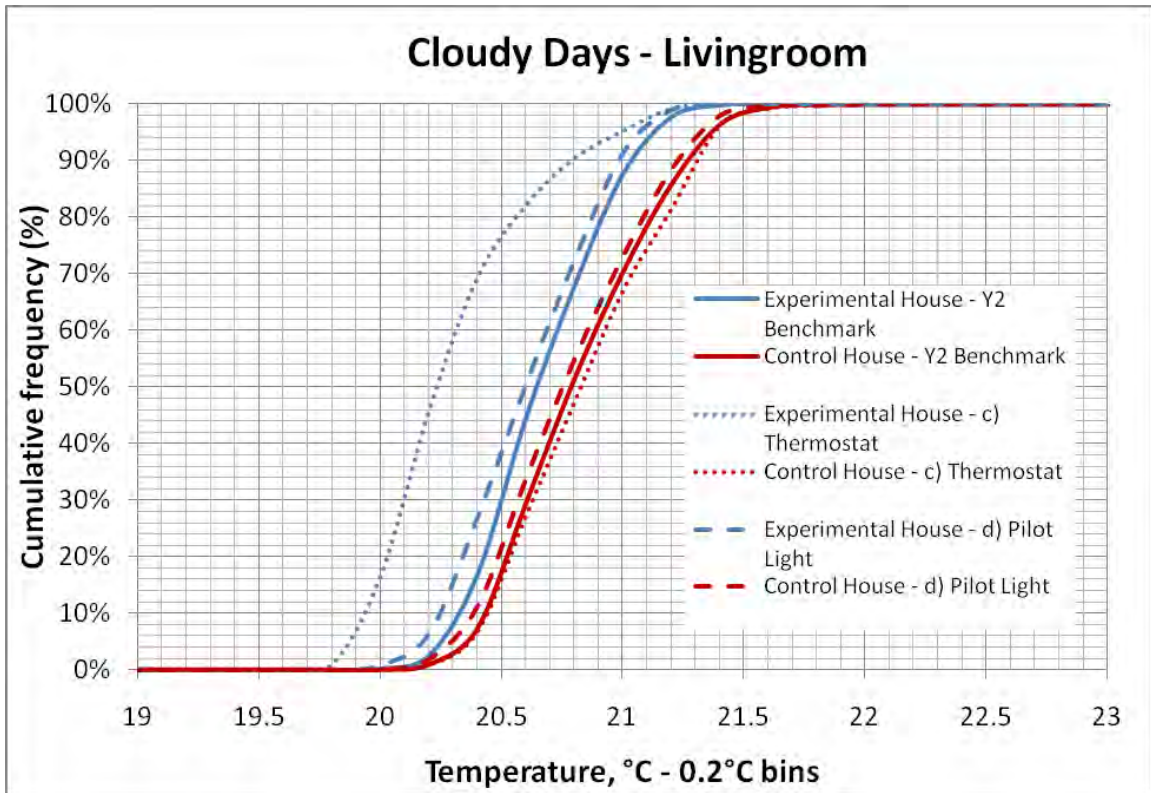


Figure G-15. Cumulative frequency diagram, Year 2 cloudy days – Living room

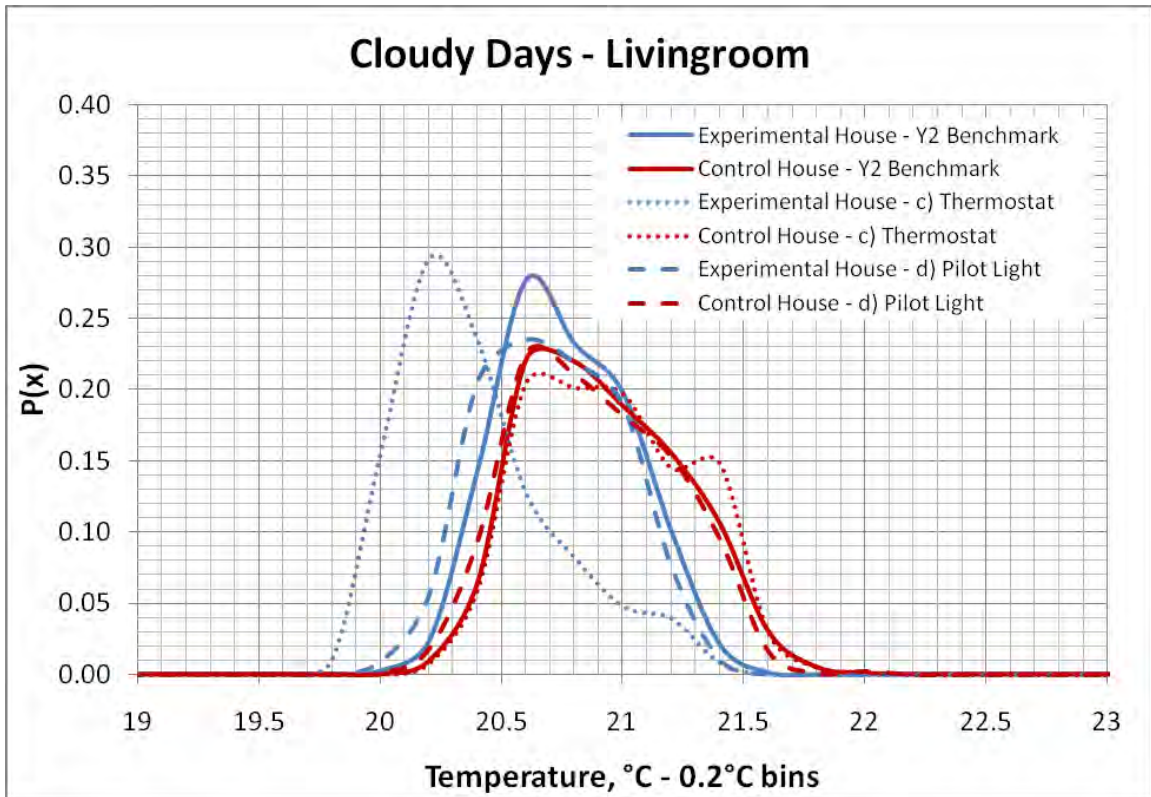


Figure G-16. Probability distribution, Year 2 cloudy days – Living room

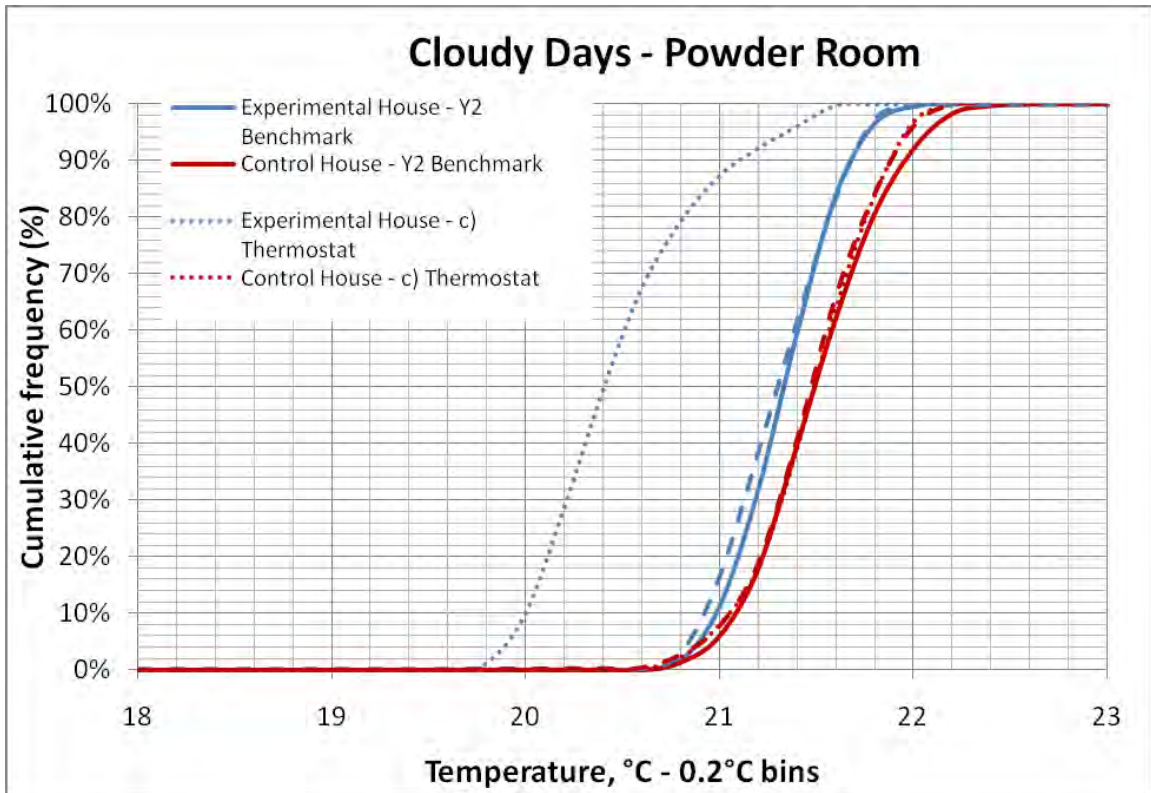


Figure G-17. Cumulative frequency diagram, Year 2 cloudy days – Powder room

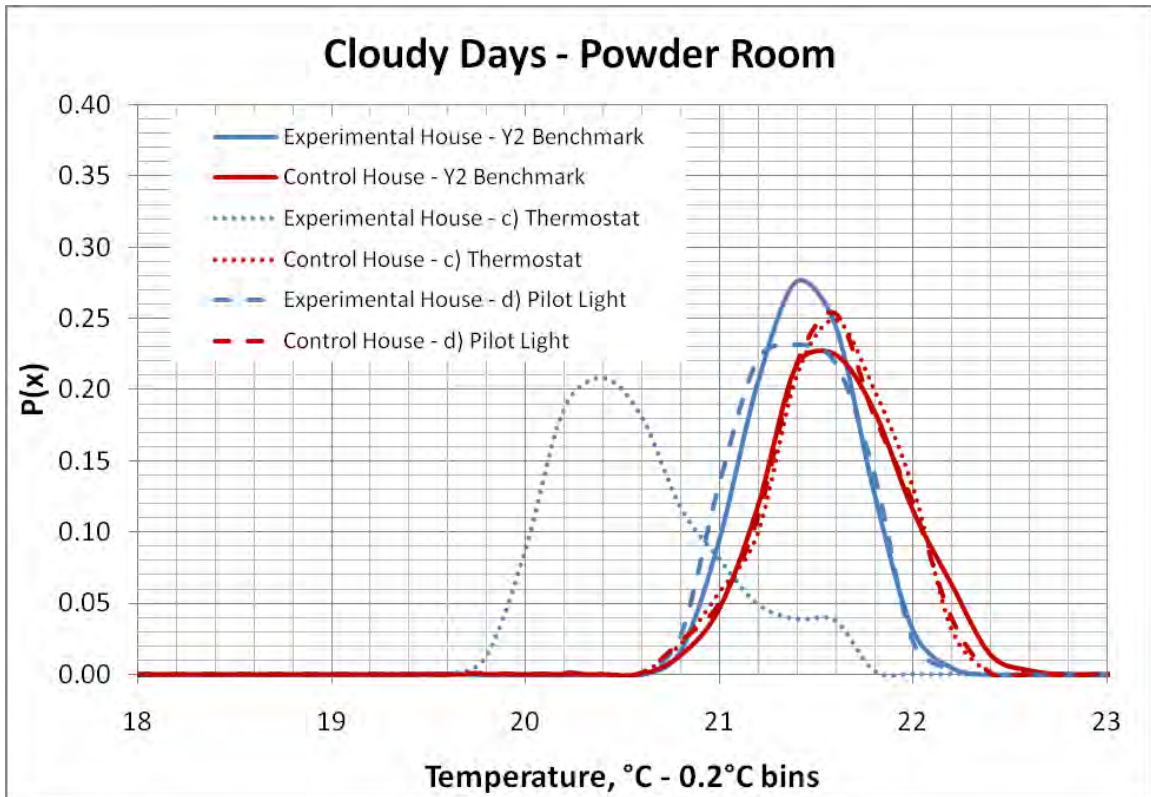


Figure G-18. Probability distribution, Year 2 cloudy days – Powder room

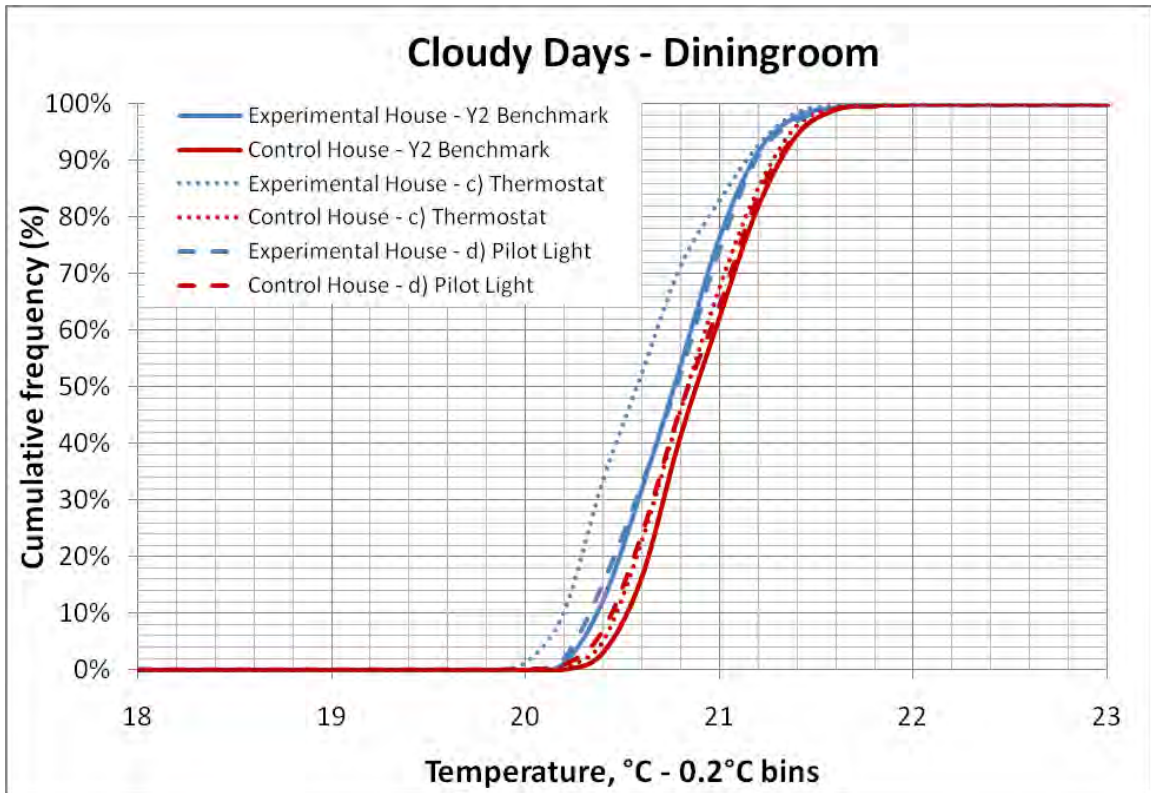


Figure G-19. Cumulative frequency diagram, Year 2 cloudy days – Dining room

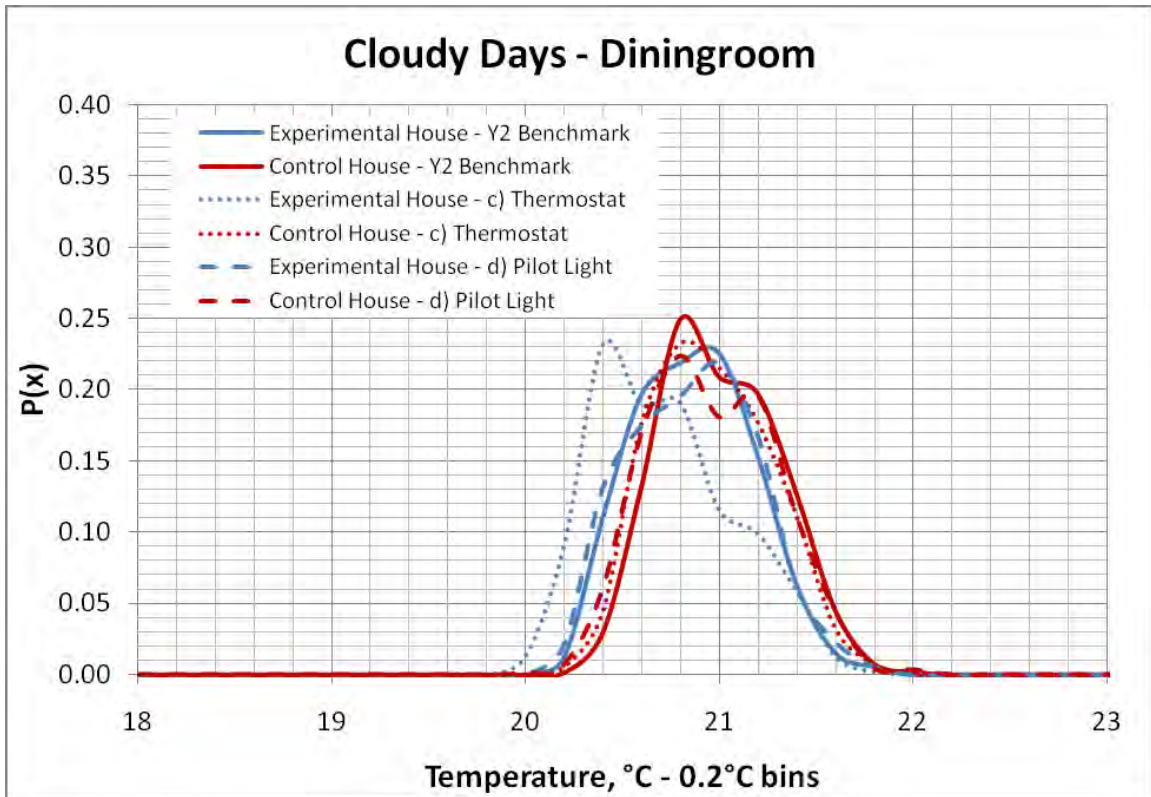


Figure G-20. Probability distribution, Year 2 cloudy days – Dining room

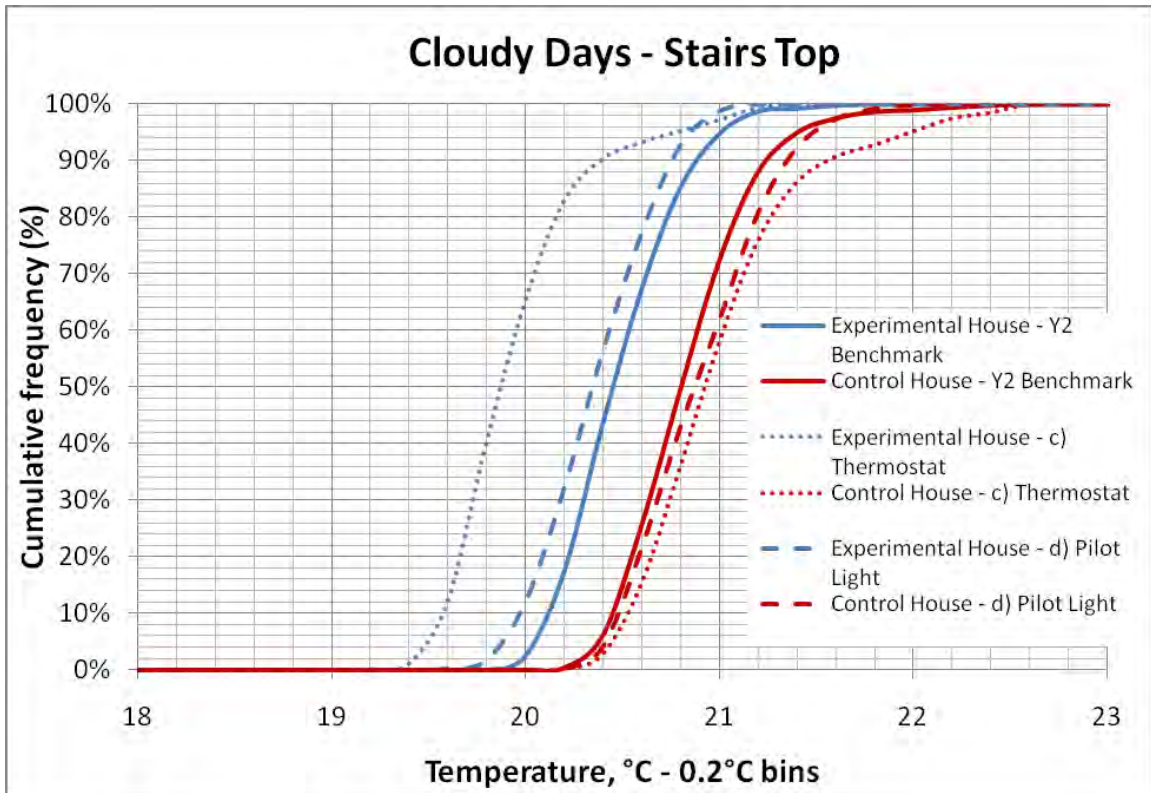


Figure G-21. Cumulative frequency diagram, Year 2 cloudy days – Top landing of stairs

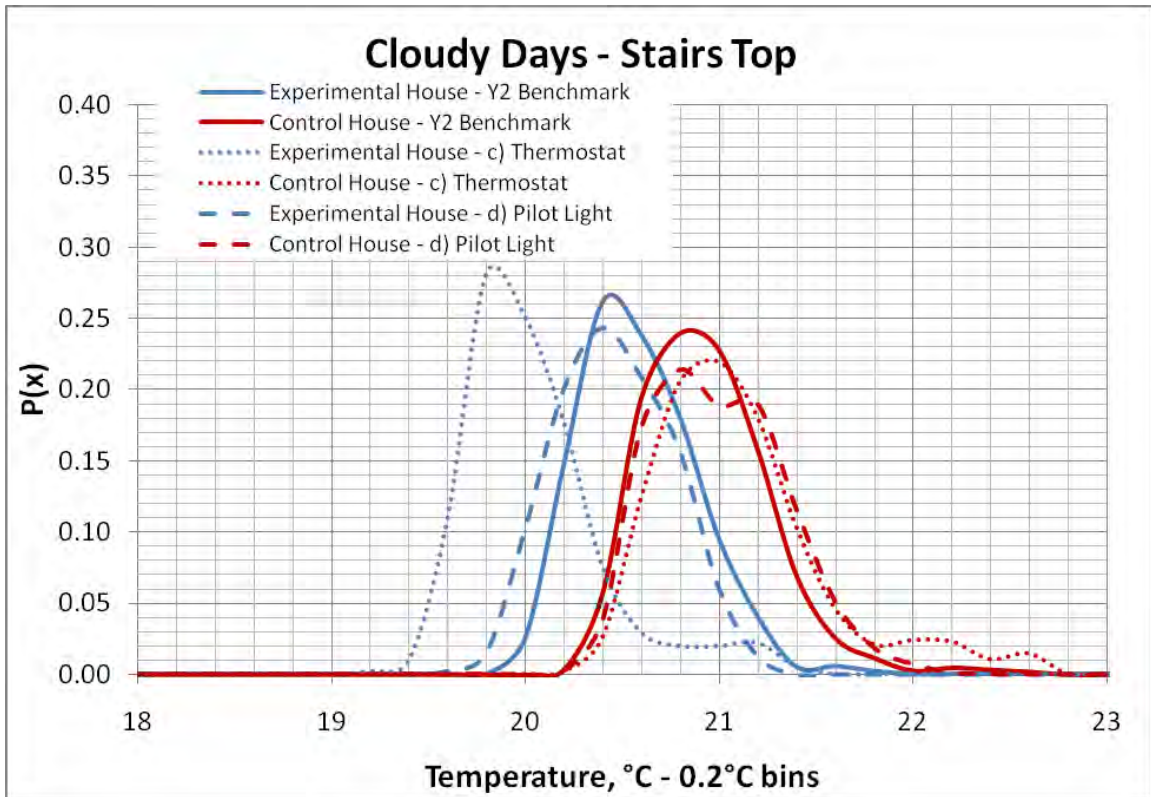


Figure G-22. Probability distribution, Year 2 cloudy days – Top landing of stairs

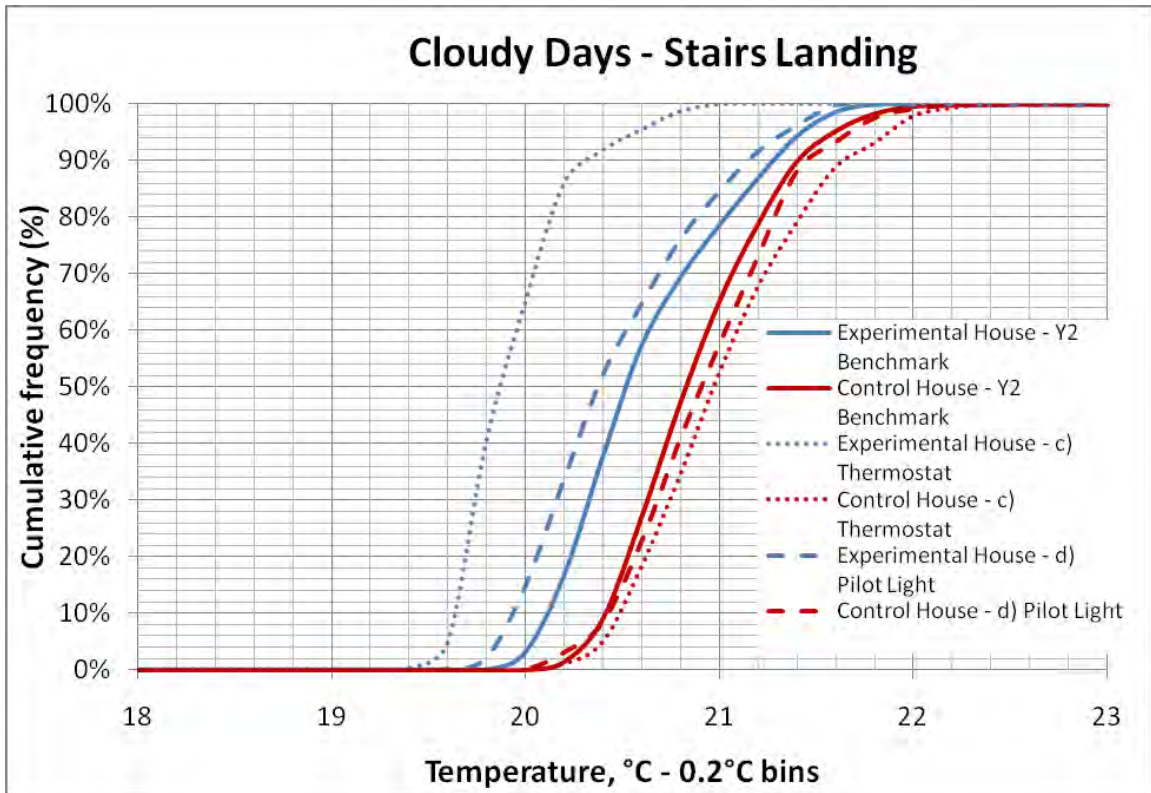


Figure G-23. Cumulative frequency diagram, Year 2 cloudy days – Middle landing of stairs

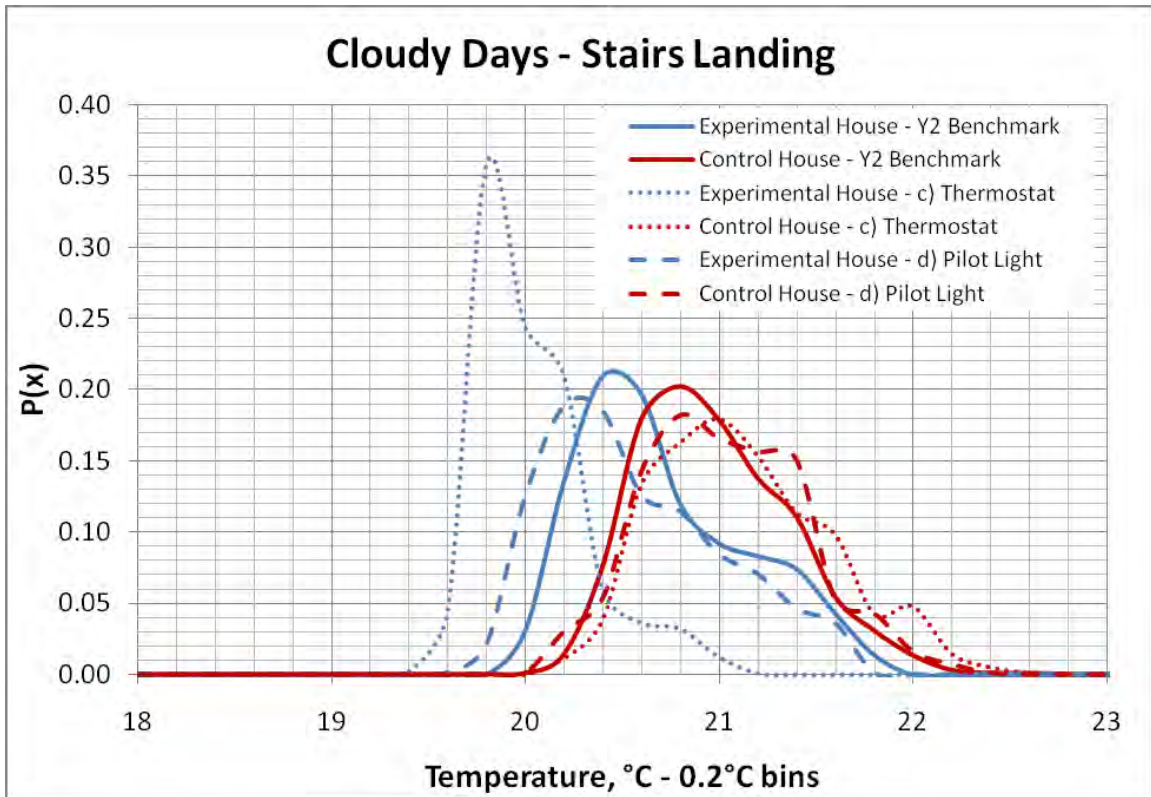


Figure G-24. Probability distribution, Year 2 cloudy days – Middle landing of stairs

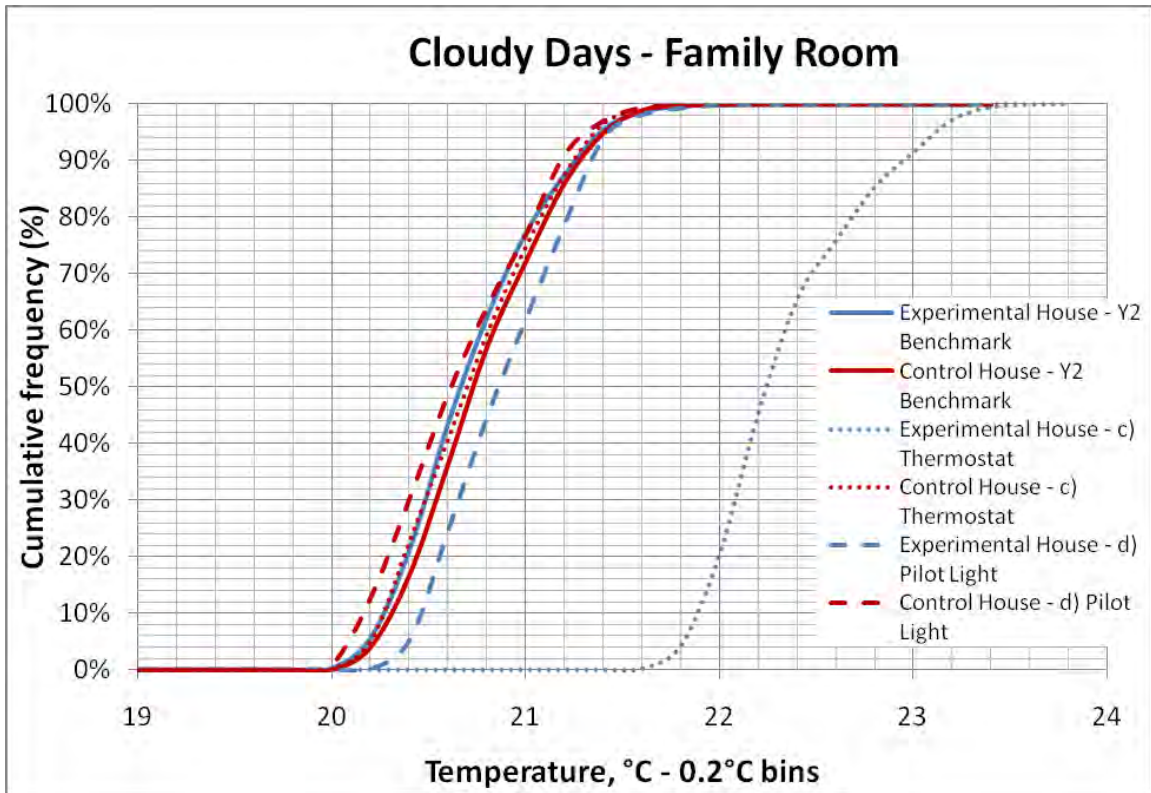


Figure G-25. Cumulative frequency diagram, Year 2 cloudy days – Family room

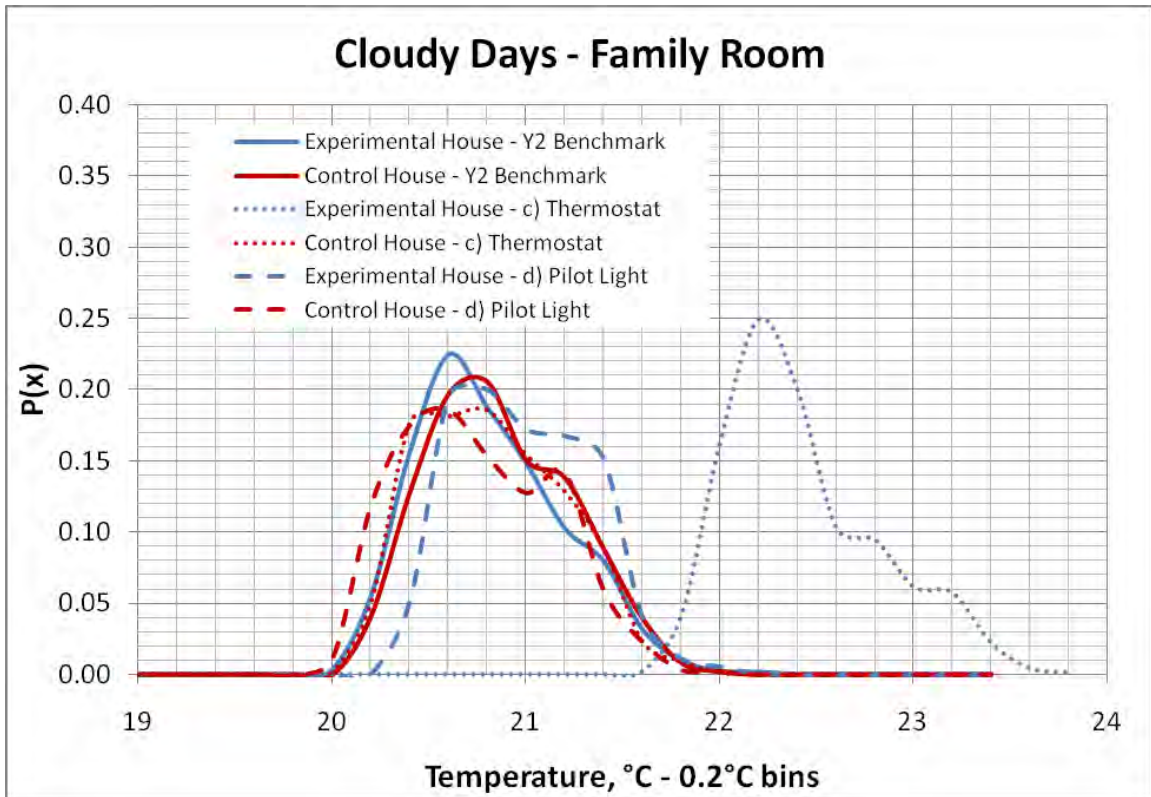


Figure G-26. Probability distribution, Year 2 cloudy days – Family room

Appendix H. Year 1 Surface Temperature Cumulative Frequency and Probability Distribution Diagrams

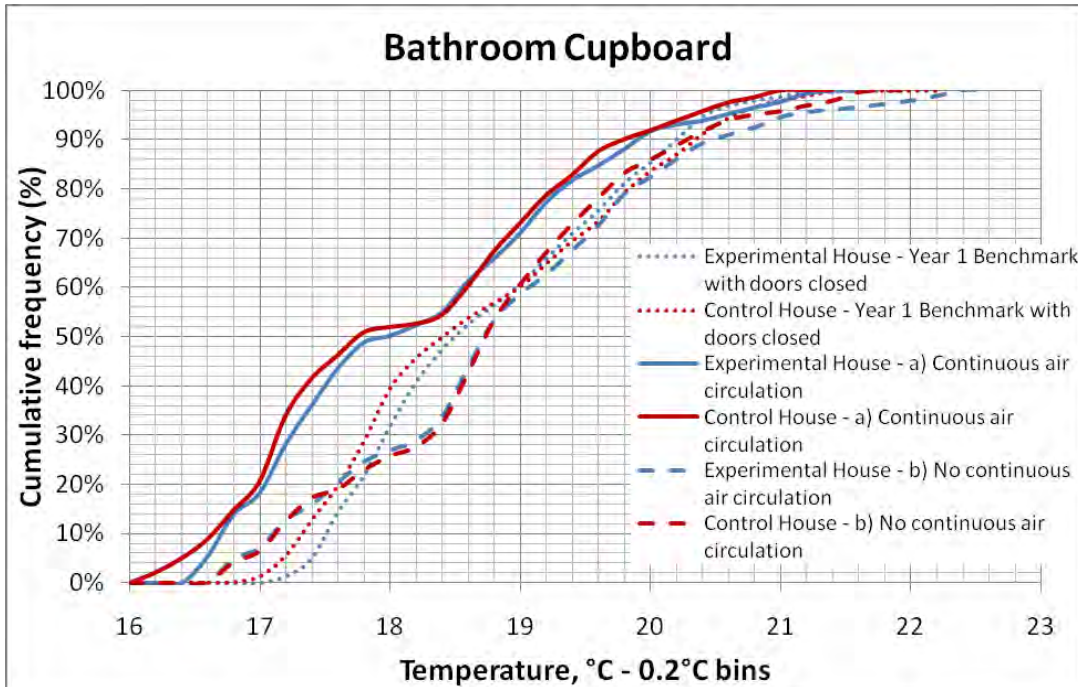


Figure H-1. Cumulative frequency diagram, Year 1 – Bathroom cupboard surface

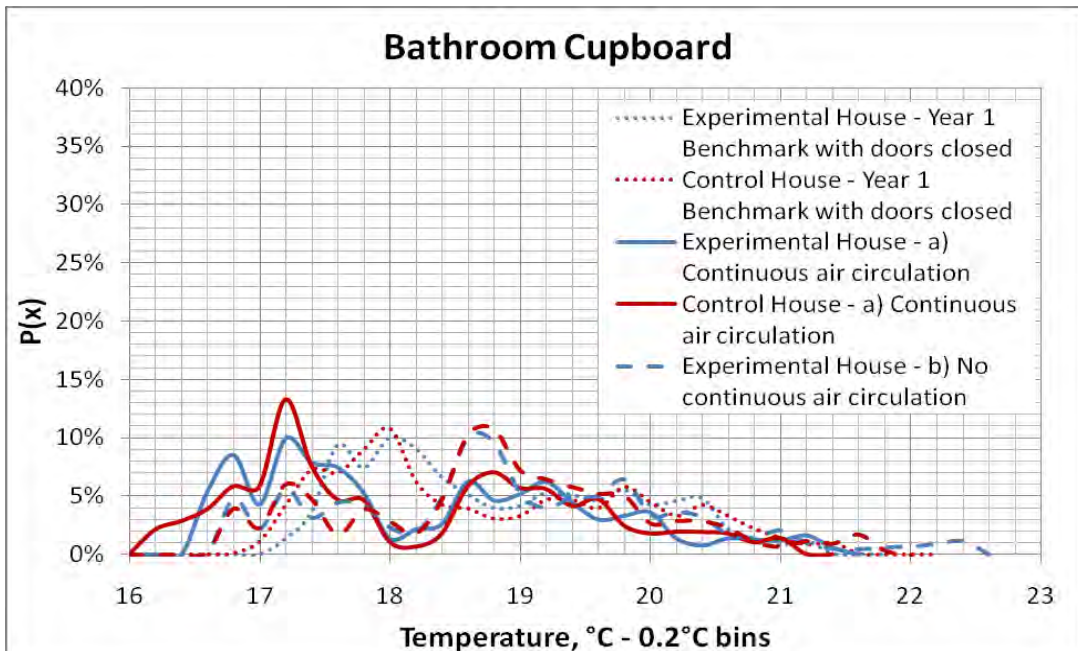


Figure H-2. Probability distribution, Year 1 – Bathroom cupboard surface

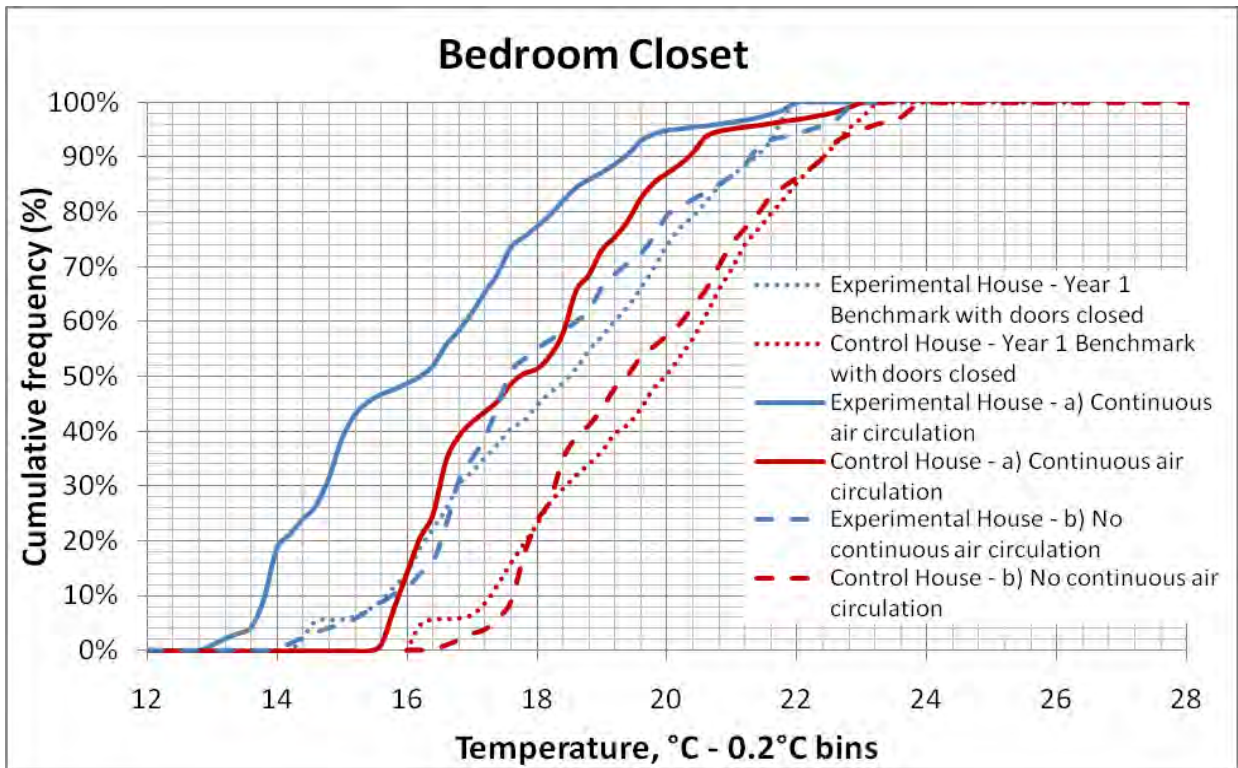


Figure H-3. Cumulative frequency diagram, Year 1 – Bedroom closet surface

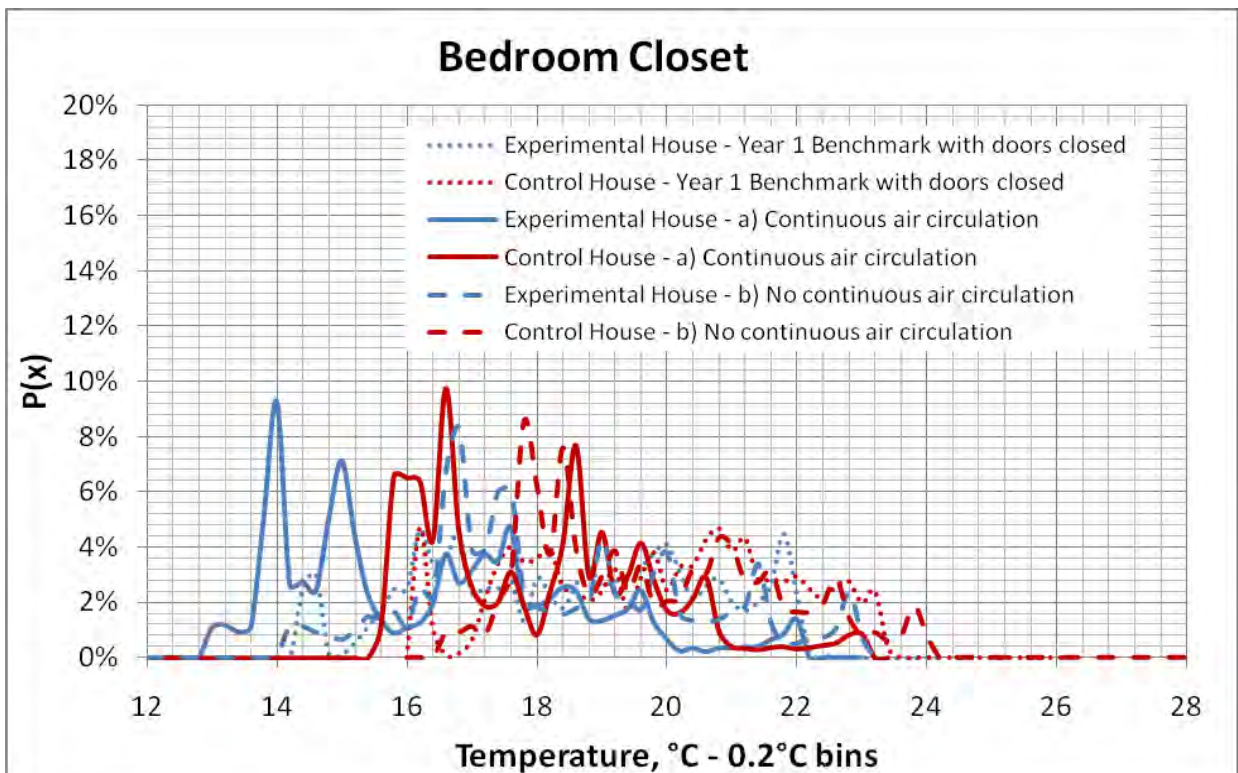


Figure H-4. Probability distribution, Year 1 – Bedroom closet surface

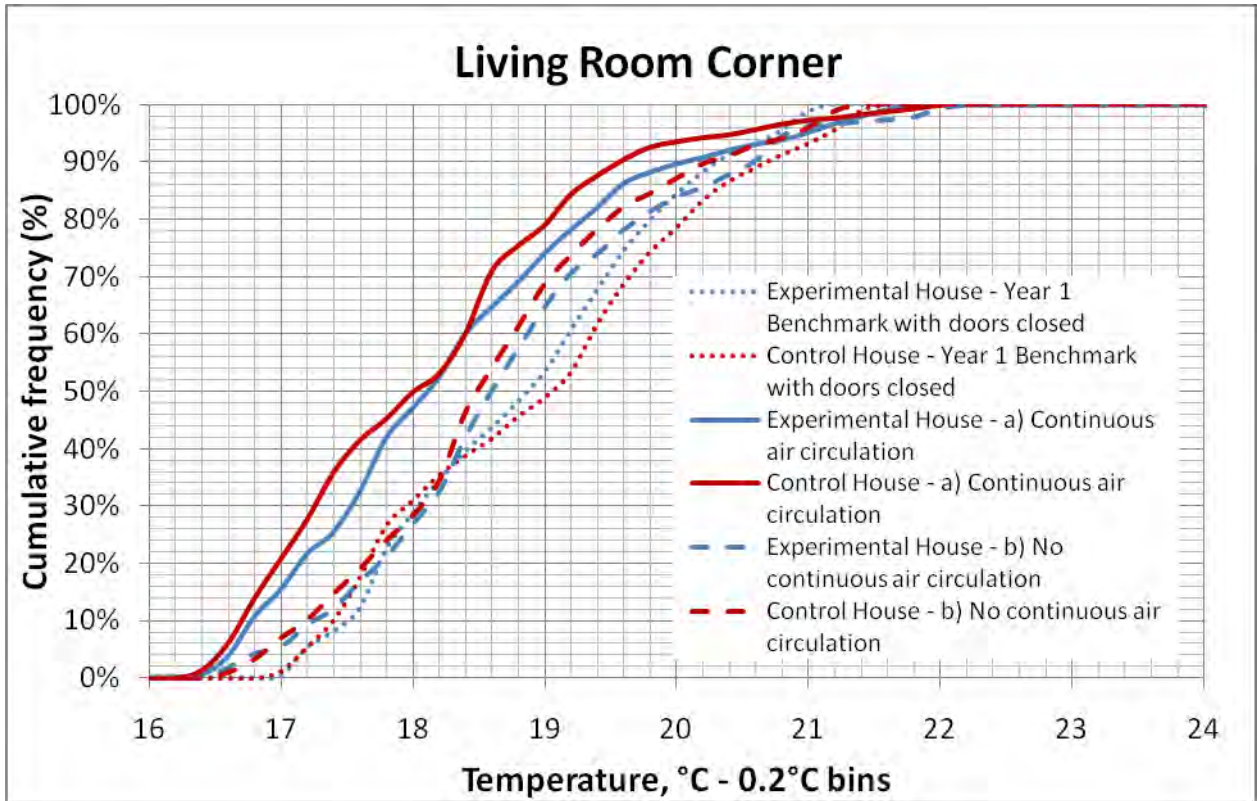


Figure H-5. Cumulative frequency diagram, Year 1 – Living room corner surface

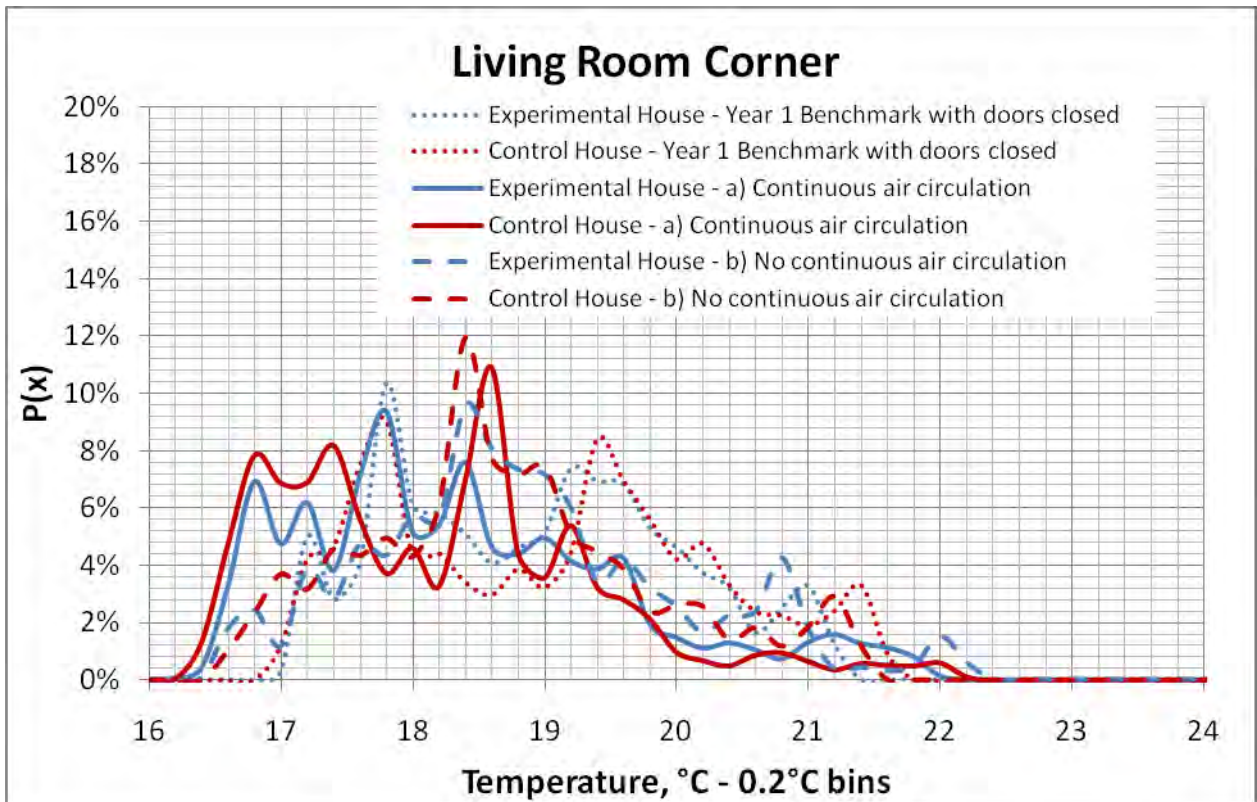


Figure H-6. Probability distribution, Year 1 – Living room corner surface

Appendix I. Analysis of Covariance (ANCOVA) Results

The software VassarStats was used to perform the ANCOVA.
 (<http://faculty.vassar.edu/~lowry/VassarStats.html>)

Table I-1. ANCOVA of Furnace Gas Consumption from:

- a) Year 1 – Fireplace operation from 18:00 – 24:00 with continuous air circulation
- b) Year 1 – Fireplace operation from 18:00 – 24:00 with no continuous air circulation

One-Way ANCOVA: Results Page

ANCOVA Results (k=2)

Source	SS	df	MS	F	P
adjusted means	68.42	1	68.42	1.72	0.206
adjusted error	716.92	18	39.83		
adjusted total	785.34	19			

Test for Homogeneity of Regressions

Source	SS	df	MS	F	P
between regressions	93.73	1	93.73	2.71	0.117
remainder	623.20	18	34.62		

Means	CV	DV	
	Observed	Observed	Adjusted
1	337.00	220.29	208.87
2	304.44	186.57	205.13
3	0.00	0.00	0.00
4	0.00	0.00	0.00
5	0.00	0.00	0.00
6	0.00	0.00	0.00
7	0.00	0.00	0.00
8	0.00	0.00	0.00
9	0.00	0.00	0.00
10	0.00	0.00	0.00

Table I-2. ANCOVA of Total Gas Consumption from:

- a) Year 1 – Fireplace operation from 18:00 – 24:00 with continuous air circulation
- b) Year 1 – Fireplace operation from 18:00 – 24:00 with no continuous air circulation

One-Way ANCOVA: Results Page

ANCOVA Results (k=2)

Source	SS	df	MS	F	P
adjusted means	119.89	1	119.89	3.20	0.091
adjusted error	675.26	18	37.51		
adjusted total	795.15	19			

Test for Homogeneity of Regressions

Source	SS	df	MS	F	P
between regressions	19.33	1	19.33	0.53	0.476
remainder	655.93	18	36.44		

Means	CV	DV	
	Observed	Observed	Adjusted
1	1	337.00	364.85
2	2	304.44	329.83
3	0.00	0.00	0.00
4	0.00	0.00	0.00
5	0.00	0.00	0.00
6	0.00	0.00	0.00
7	0.00	0.00	0.00
8	0.00	0.00	0.00
9	0.00	0.00	0.00
10	0.00	0.00	0.00

Table I-3. ANCOVA of Total Heating Gas and Electrical Consumption from:

- a) Year 1 – Fireplace operation from 18:00 – 24:00 with continuous air circulation
- b) Year 1 – Fireplace operation from 18:00 – 24:00 with no continuous air circulation

One-Way ANCOVA: Results Page

ANCOVA Results (k=2)

Source	SS	df	MS	F	P
adjusted means	348.19	1	348.19	8.80	0.008
adjusted error	712.57	18	39.59		
adjusted total	###	19			

Test for Homogeneity of Regressions

Source	SS	df	MS	F	P
between regressions	23.84	1	23.84	0.62	0.44
remainder	688.73	18	38.26		

Means	CV	DV	
	Observed	Observed	Adjusted
1	376.62	401.05	382.83
2	324.83	344.68	374.29
3	0.00	0.00	0.00
4	0.00	0.00	0.00
5	0.00	0.00	0.00
6	0.00	0.00	0.00
7	0.00	0.00	0.00
8	0.00	0.00	0.00
9	0.00	0.00	0.00
10	0.00	0.00	0.00

Table I-4. ANCOVA of Furnace Gas Consumption from:

Year 2 Benchmark
 d) Year 2 – Pilot light only

One-Way ANCOVA: Results Page

ANCOVA Results (k=2)

Source	SS	df	MS	F	P
adjusted means	1775.227	1	1775.227	56.43336	2.35E-09
adjusted error	1352.653	43	31.45705		
adjusted total	3127.881	44			

Test for Homogeneity of Regressions

Source	SS	df	MS	F	P
between regressions	40.76244	1	40.76244	1.336075	0.254109
remainder	1311.891	43	30.50909		

Means	CV	DV	
	Observed	Observed	Adjusted
1	251.0501	245.3776	258.4177
2	352.8074	326.0909	239.1568
3	---	---	---
4	---	---	---
5	---	---	---
6	---	---	---
7	---	---	---
8	---	---	---
9	---	---	---
10	---	---	---

Table I-5. ANCOVA of Total Gas Consumption from:

Year 2 Benchmark
 d) Year 2 – Pilot light only

One-Way ANCOVA: Results Page

ANCOVA Results (k=2)

Source	SS	df	MS	F	P
adjusted means	1753.499	1	1753.499	55.11306	3.15E-09
adjusted error	1368.105	43	31.8164		
adjusted total	3121.604	44			

Test for Homogeneity of Regressions

Source	SS	df	MS	F	P
between regressions	54.39139	1	54.39139	1.780319	0.189134
remainder	1313.714	43	30.55148		

Means	CV	DV	
	Observed	Observed	Adjusted
1	251.0501	245.3776	258.4147
2	352.8074	364.4711	277.5574
3	---	---	---
4	---	---	---
5	---	---	---
6	---	---	---
7	---	---	---
8	---	---	---
9	---	---	---
10	---	---	---

Table I-6. ANCOVA of Furnace Electrical Consumption from:

Year 2 Benchmark
 d) Year 2 – Pilot light only

One-Way ANCOVA: Results Page

ANCOVA Results (k=2)

Source	SS	df	MS	F	P
adjusted means	0.1779	1	0.1779	61.18463	8.48E-10
adjusted error	0.125026	43	0.002908		
adjusted total	0.302926	44			

Test for Homogeneity of Regressions

Source	SS	df	MS	F	P
between regressions	0.007203	1	0.007203	2.628915	0.112244
remainder	0.117823	43	0.00274		

Means	CV	DV	
	Observed	Observed	Adjusted
1	10.11638	10.22882	10.35544
2	10.9461	11.0079	10.16373
3	---	---	---
4	---	---	---
5	---	---	---
6	---	---	---
7	---	---	---
8	---	---	---
9	---	---	---
10	---	---	---

Table I-7. ANCOVA of Total Heating Gas and Electrical Consumption from:
 Year 2 Benchmark
 d) Year 2 – Pilot light only

One-Way ANCOVA: Results Page

ANCOVA Results (k=2)

Source	SS	df	MS	F	P
adjusted means	1622.53	1	1622.53	47.91246	1.67E-08
adjusted error	1456.172	43	33.86447		
adjusted total	3078.702	44			

Test for Homogeneity of Regressions

Source	SS	df	MS	F	P
between regressions	57.96454	1	57.96454	1.782622	0.188853
remainder	1398.208	43	32.51646		

Means	CV	DV	
	Observed	Observed	Adjusted
1	287.4691	282.2013	295.6997
2	392.2134	404.0996	314.1103
3	---	---	---
4	---	---	---
5	---	---	---
6	---	---	---
7	---	---	---
8	---	---	---
9	---	---	---
10	---	---	---

Table I-8. ANCOVA of Furnace Gas Consumption from:

Year 2 Benchmark

e) Year 2 – Fireplace vent open, no operation

One-Way ANCOVA: Results Page

ANCOVA Results (k=2)

Source	SS	df	MS	F	P
adjusted means	238.3242	1	238.3242	7.630482	0.008551
adjusted error	1280.56	41	31.23318		
adjusted total	1518.885	42			

Test for Homogeneity of Regressions

Source	SS	df	MS	F	P
between regressions	9.034601	1	9.034601	0.291318	0.592297
remainder	1271.526	41	31.01282		

Means	CV	DV	
	Observed	Observed	Adjusted
1	251.0501	245.3776	241.5196
2	207.9133	211.0823	249.6623
3	---	---	---
4	---	---	---
5	---	---	---
6	---	---	---
7	---	---	---
8	---	---	---
9	---	---	---
10	---	---	---

Table I-9. ANCOVA of Furnace Electrical Consumption from:

Year 2 Benchmark

e) Year 2 – Fireplace vent open, no operation

One-Way ANCOVA: Results Page

ANCOVA Results (k=2)

Source	SS	df	MS	F	P
adjusted means	0.033938	1	0.033938	12.52792	0.0010
adjusted error	0.111107	41	0.002709		
adjusted total	0.145008	42			

Test for Homogeneity of Regressions

Source	SS	df	MS	F	P
between regressions	0.000311	1	0.000311	0.1152	0.736033
remainder	0.110759	41	0.002701		

Means	CV	DV	
	Observed	Observed	Adjusted
1	10.11638	10.22882	10.18427
2	9.6984	9.8361	10.28156
3	---	---	---
4	---	---	---
5	---	---	---
6	---	---	---
7	---	---	---
8	---	---	---
9	---	---	---
10	---	---	---

Table I-10. ANCOVA of Total Heating System Gas and Electrical Consumption from:
 Year 2 Benchmark
 e) Year 2 – Fireplace vent open, no operation

One-Way ANCOVA: Results Page

ANCOVA Results (k=2)

Source	SS	df	MS	F	P
adjusted means	257.6349	1	257.6349	7.757	0.008
adjusted error	1361.742	41	33.21322		
adjusted total	1619.377	42			

Test for Homogeneity of Regressions

Source	SS	df	MS	F	P
between regressions	9.461902	1	9.461902	0.286877	0.595123
remainder	1352.28	41	32.98244		

Means	CV	DV	
	Observed	Observed	Adjusted
1	287.4691	282.2013	278.1854
2	242.8276	246.4923	286.6519
3	---	---	---
4	---	---	---
5	---	---	---
6	---	---	---
7	---	---	---
8	---	---	---
9	---	---	---
10	---	---	---

Appendix J. Fireplace Efficiency Testing

Steady state flue loss efficiency measurements were made on a direct vent, natural draft, gas-fired fireplace, August 27th 2009. This product is no longer sold.

The rated heat input was: 20,000 Btu/h at maximum and 14,000 Btu/h at minimum.

Testing was conducted by Martin Thomas and Frank Szadkowski of IES Lab. Measurements were made at nominally 100%, and 70% of the rated heat input. Measurements were made with a Horiba PG250 multi-component gas analyzer set with the following scale ranges:

Carbon Dioxide (CO₂) = 0 to 20 %

Oxygen (O₂) = 0 to 25 %

Carbon Monoxide (CO) = 0 to 1000 ppm

Total Nitrogen Oxides (NO_x) = 0 to 250 ppm

In this installation, flue gas, combustion air and ambient air temperature measurements were made with "T" type thermocouples, and all the above data was logged at 5 second intervals on a Campbell Scientific CR23X Data Logger. Gas consumption was recorded manually by timing a suitable number of revolutions of the 0.5 ft³ dial.

The Steady State Flue Loss Efficiency was determined by using the FLOSS spreadsheet and by using the measurements made above, in conjunction with the gas composition data provided by Enbridge for the period of the testing (see next page).

Summary of Test Results:

Mode	Heat Input (Btu/h)	% of Rated Maximum	Flue CO ₂ (%)	Flue CO (ppm)	Flue O ₂ (%)	Flue NO _x (ppm)	Flue Temp. (°C)	Combustion Air Temp. (°C)	Ambient. Air Temp. (°C)	Efficiency (%)
Pilot Only	1,321	6.6	0.84	7	19.63	5.2	63.6	24.8	13.5	*
Low Input	13,280	66.4	4.50	177	13.33	15.1	224.0	47.0	13.6	74.5
High Input	18,650	93.3	6.65	125	9.80	33.5	278.0	55.9	13.6	75.7
High Input, Fan Low	18,650	93.3	6.11	119	10.65	34.0	264	51.9	13.65	75.5
High Input, Fan High	18,650	93.3	6.03	123	10.91	31.8	255.1	54.3	13.62	76.1

* Because of the very low CO₂ Concentration, this result should not be used.

Fan Speed	Power Consumed (W)	Power Consumed (Btu/h)
Off	0	0
Low	33.5	114.3
High	48	163.8

Discussion:

Because the model is no longer sold, the fireplace is not listed on the OEE's directory of Fireplace Efficiencies (FE) at:

<http://oee.nrcan.gc.ca/residential/business/manufacturers/search/fireplace-search.cfm?attr=4>

However, the FE is typically much lower than the steady state efficiency and it could be as low as 40%.

The operation of the circulating air fan built into the fireplace had little or no effect on the steady state efficiency, i.e. The fan appeared to consume more energy than any additional energy it put into the room.

M.Thomas, IES Lab., 12/04/2010