**Canadian Centre
for Housing Technology**

**Centre canadien des
technologies résidentielles**

**The Effects of Thermostat Setting on Seasonal Energy
Consumption at the CCHT Research Facility**

Manning M.; Swinton, M.C.; Szadkowski, F.; Gusdorf J.; Ruest K.

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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.

Acknowledgements

Executive Summary

Temporarily adjusting the temperature setting on the thermostat at night or while residents are away from home offers an attractive solution to energy savings. During the winter heating season of 2002-2003, the Canadian Centre for Housing Technology (CCHT) ran a series of trials to determine actual energy savings from thermostat setback, and to examine the resultant house temperatures and recovery times. As a follow-up to these winter experiments, a set of summer trials were performed to determine the effect of thermostat setting on air conditioning performance. This document examines the results.

Three different winter setback settings were examined and compared to the benchmark (22°C): 18°C night setback, 18°C day and night setback, and 16°C day and night setback. For all settings, thermostat setback resulted in energy savings in the CCHT Test house. Savings increased with lower thermostat setback temperature – the 16°C day and night setback showed the highest savings of all the 3 trials – estimated to be about 13% over the heating season. Also, the percentage of daily energy savings increased with furnace on-time – the highest savings occurring on the coldest and cloudiest days. The time taken for the Test House to recover following thermostat setback was directly related to the minimum temperature that the main floor reached during the setback period. The longest air temperature recovery period for this set of winter setback experiments was less than 2 hours. Recorded drywall surface temperatures (measured in the middle of insulated stud spaces) during setback would not be expected to cause condensation problems in the Test House, even during the 16°C temperature setback. However, window frame temperatures could lead to condensation issues, even in the benchmark condition.

The thermostat was set at 22ºC during summer benchmarking. Two different summer settings were tested: 25°C daytime setforward, and 24°C higher temperature setting. Daytime thermostat setforward proved to be a less effective summer energy saving method than simply raising the thermostat temperature setting. The seasonal savings for the setforward strategy is estimated to be 11% based on experimental results and a calculation technique to obtain seasonal savings. The percentage of energy savings from setforward increased with higher outdoor temperature and larger solar gains (sunny days). On cloudy days, these savings were reduced significantly. The largest concern with setforward is the long recovery period. Following the setforward, it took as long as 7 hours for the Test House to regain its original cooler air temperature – the same length of time as the setforward period itself. The higher thermostat setting, on the other hand, produced large electrical savings, about 23%, throughout the full range of outdoor conditions. Despite the higher setting being one degree lower than the setforward temperature, these savings were always higher than those of the setforward experiment. Higher temperature setting did come with one disadvantage: It resulted with an increase in overall Test House humidity – due to less time spent in air conditioning mode removing moisture from the air.

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1 Introduction

In the winter of 2002-2003, a series of thermostat experiments were conducted at the Canadian Centre for Housing Technology (CCHT)[1] side-by-side testing facility. The purpose of these experiments is to examine the effects of different thermostat setback strategies on overall household energy consumption during the winter heating season. Due to the success of these trials, two follow-up experiments were performed in the summer of 2003 to determine the effects of thermostat setting on Air Conditioning performance.   The results of winter and summer experiments are outlined herein.

1.1 CCHT Research Facility

Figure 1 - CCHT Twin Research House Facility

The Twin Research House facility at the CCHT was built in 1998. It consists of two identical 2-storey houses built to R-2000 standards by a local Ottawa builder. Features of these houses include: low-emissivity argon-filled windows and a simulated occupancy system. Other specifications are listed in

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[1] The Canadian Centre for Housing Technology is jointly operated by the National Research Council, Natural Resources Canada, and Canada Mortgage and Housing Corporation.

the following table. For more information about this facility please see reference 1 and the CCHT website at http://www.ccht-cctr.gc.ca.

Table 1 - CCHT Research House Specifications

CCHT Research House specifications	
Floor Area (not including basement)	223 m^2 (2400 ft^2)
Heat load at -25°C	12.9 kW (46.4 MJ/h or 44,000 Btu/h)
Wall Insulation	RSI 3.5
Attic Insulation	RSI 8.6
Airtightness	1.5 ach @ 50 Pa

The Twin House facility is unique in the way that it provides a side-by-side comparison. Both houses experience the same weather conditions, as well as the same interior conditions – as regulated by the Simulated Occupancy System. By changing a single aspect of one house, the effects of the change can be seen on a day-by-day basis. At the end of each experiment, the houses are returned to their original identical state.

1.2 Thermostat Setback and Setforward

House temperatures are typically set by the occupants to ensure their personal comfort. When occupants are not at home, or are asleep, the house temperature requirements are different. For this reason, many homeowners "set back" the thermostat (reducing the set temperature) during nights as well as during the workday by means of a conventional thermostat or with the aid of a programmable model. This is intended as a simple way to reduce overall household energy consumption during the winter heating season while still ensuring occupant comfort. In summer, a similar strategy can be employed by "setting forward" (increasing the set temperature) during the workday, reducing the load on the air conditioning system during peak hours.

There are 3 main reasons for testing thermostat setback/setforward at CCHT. First, the Twin Research House facility is well suited to performing this experiment effectively and inexpensively. The facility is equipped with thermostats, furnaces, energy meters, thermocouples and continuous data acquisition. The only change required was the reprogramming of the thermostat. Second, the unique nature of the CCHT Twin House Facility allows not only the examination of energy savings, but also an overview of house performance. Thus, other important factors that affect occupant comfort can be examined. These include: house recovery time from setback and setforward, house surface temperatures during winter setback, solar effects, and summer house humidity: giving a complete picture of thermostat setback/setforward in a typical R-2000 home. Last, quantifying the energy savings from thermostat setting will serve as a good example showing that adjusting the thermostat setting is an inexpensive and effective way to conserve energy.

2 Methodology

2.1 Experimental Conditions

A unique feature of the CCHT test facility is the ability to make a side-by-side comparison of the energy and thermal performance of the two houses. However, the houses cannot be perfectly identical. For this reason, it is important to establish a benchmark during which the houses operate under identical conditions. In both the winter and summer benchmarking condition, thermostats were set to 22°C for 24 hours/day. Results from the benchmarking set performance lines of comparison in winter and summer operation against which the thermostat control experiments can be compared. Setback periods were chosen based on the pre-programmed options of the thermostat.   Three separate setback trials were conducted during the winter heating season. These are outlined in the following table.

Table 2 - Winter Thermostat Experiments

Trial Name	Thermostat Setting (°C)	Setback Period	Complete 24h days	Range of Dates	Range of Outdoor T (°C)
22°C Winter Benchmark	22	---------------	28	11-Oct-02 to 15-Jan-03	15 to -22
18°C Nighttime Setback	18	23:00 – 6:00	13	22-Nov-02 to 22-Jan-03	4 to -27
18°C Day and Night Setback	18	23:00 – 6:00 9:00 – 16:00	16	24-Dec-02 to 19-Jan-03	1 to -23
16°C Day and Night Setback	16	23:00 – 6:00 9:00 – 16:00	7	25-Jan-03 to 02-Feb-03	3 to -27

In the summer season, a single set-forward experiment was conducted, along with a "higher temperature setting" case.

Table 3 - Summer Thermostat Experiments

Trial Name	Thermostat Setting (°C)	Setforward Period	Complete 24h days	Range of Dates	Range of Outdoor T (°C)
22°C Summer Benchmark	22	---------------	27	26-Jun-03 to 12-Sep-03	7.9 to 34.7
25°C Daytime Setforward	25	9:00 – 16:00	20	15-Jul-03 to 30-Sep-03	5.3 to 30.8
24°C Thermostat Setting	24	---------------	14	21-Jul-03 to 03-Sep-03	8.9 to 28.7

All data was monitored to ensure that the data collection system and simulated occupancy were performing properly. The space heating and space cooling performance of the Test House with the setback and Setforward cases was then compared to the benchmark performance.

2.2 Mechanical Equipment Setup

Heating system

For the purpose of this experiment, a medium-efficiency furnace with a standard (PSC) motor was operated in both houses. The rated output of this furnace is 19.78 kW (67,500 Btu/h). The furnace fan provided constant low-speed circulation of air when not in high-speed heating mode. A heat recovery ventilator (HRV) also operated in constant circulation mode throughout the experiment.

Air Conditioning System

The air conditioning system consists of a high efficiency 12 SEER unit with 2-ton capacity. The mid-efficiency furnace fan with PSC motor circulated the air at low-speed during continuous circulation and at high-speed during cooling. An HRV operated in constant circulation mode throughout the experiments.

Heating Controls

The programmable thermostat (pictured in Figure 2) controlled the house temperature. This particular thermostat offered a preset daytime setback from 9:00 to 16:00 Monday to Friday, and a daily nighttime setback from 23:00 to 6:00. These preset time periods were used for this project.

Figure 2 – Programmable Thermostat

2.3 Energy Consumption Measurements

Gas Consumption

Two modified gas meters with a pulse output connected to the main data acquisition system (DAS) monitored gas consumption of the furnace at a rate of 1 pulse per 0.05 ft^3. The total gas consumption data was collected at 5-minute intervals.

Electrical Consumption

Two electric pulse-meters measured furnace and air conditioning electrical consumption at 1 pulse = 0.0006 kWh. This data was collected at 5-minute intervals by the DAS. Total daily furnace consumption and daily air-conditioning consumption were calculated from the 5-minute readings and this information was used in the analysis.

Furnace On-time Measurement

Furnace fan "on-time" was measured, indicating the total amount of time the furnace fan circulation motor ran at high speed (heating or cooling mode), as opposed to circulation speed. On-time data was collected by another data acquisition system in place to monitor transient performance of mechanical equipment at much shorter time intervals – 10 seconds. Total daily on-time was calculated from this data and was used in the analysis.

2.4 Temperature Measurements

In addition to the energy consumption measurements, the overall effect of thermostat setback on the house and occupants needs to be understood. During both summer and winter trials, house floor temperatures (basement, main floor, 2nd floor) were examined. Window and drywall surface temperatures were

examined during winter experiments only, in order to determine condensation risks.

It must be noted that temperature measurements were recorded hourly. They are an average of temperature measurements taken throughout the hour at 5 minute intervals. As a result, detailed information on short-term temperature fluctuations resulting in maximums (peaks) and minimums (valleys) are lost in the averaging process.

Five days were chosen for temperature analysis in each of the thermostat trials. Five consecutive days were not available in all cases. Days were instead chosen to include the coldest possible outdoor temperature in winter or the hottest possible outdoor temperature in summer: when temperature effects would be most prominent.

Table 4- Dates for House Temperature Analysis

Winter Trial	Dates	Minimum Outdoor Temperature
Winter Benchmarking (22°C)	Jan 10, 11, 12, 13, 15	-21.81°C
18°C Setback (day and night)	Jan 6, 7, 17, 18, 19	-23.13°C
16°C Setback (day and night)	Jan 25, 26, 27, 28, 29	-26.86°C

Summer Trial	Dates	Maximum Outdoor Temperature
Summer Benchmarking (22°C)	Jun 26, 27, 28, 29, 30	34.41°C
25°C Setforward (day)	Aug 6, 7, 8, 9, 10	29.61°C
24°C Setting	Jul 22, 23, 24, 25, 26	28.11°C

House Temperatures

Changes in basement, main floor and 2nd floor temperatures were tracked in both houses to help understand the overall effect of thermostat setback. These temperatures were measured at mid-wall height. The thermostat itself is located in the hallway of the main floor, beside the main floor thermocouple.

Drywall Surface Temperature

The main concern in examining drywall surface temperatures is to ensure that temperatures do not approach the dew point of surrounding air, leading to condensation problems.

The following graph shows the dew point temperatures for air and is referred to throughout the surface temperature analysis. Air at 22°C and 30% humidity will condense on a surface with a temperature below 3.7°C.
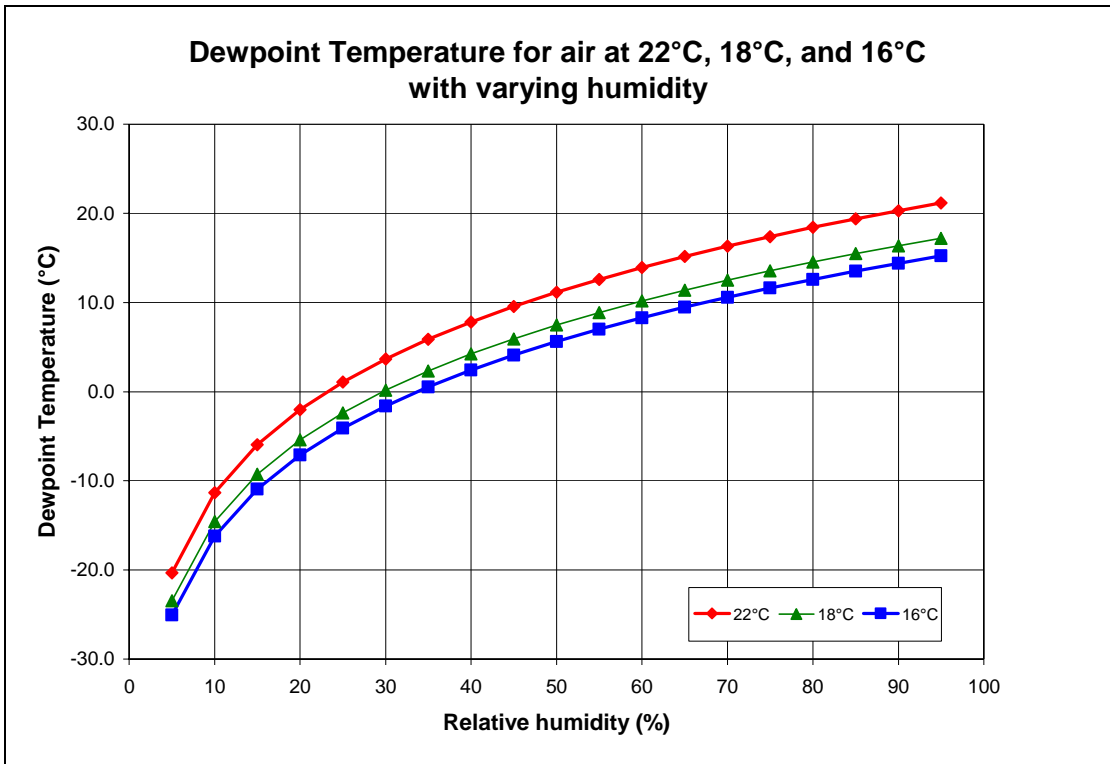
Figure 3 - Dew point Temperature for 22°C, 18°C and 16°C air with varying humidity

(Source – derived from psychometric relationships published in ASHRAE Handbook of Fundamentals, ref 2)

Drywall surface temperatures were measured in the following locations:

- Living room – First Floor South facing
- Nook – First Floor North facing
- Dining room – First Floor West facing
- Family room – First Floor East facing
- Bedroom 2 – Second Floor South facing
- Bedroom 2 – Second Floor West facing
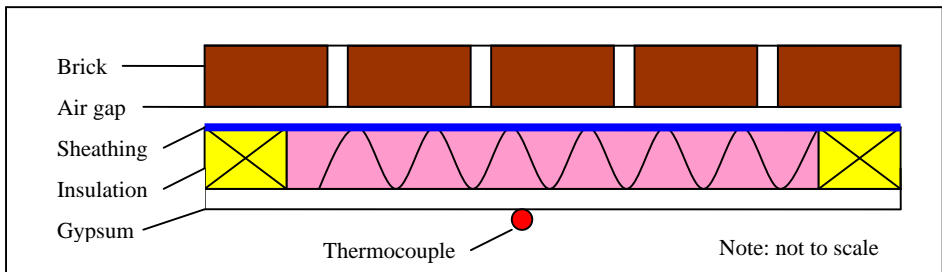
Figure 4 - Wall cross-section showing thermocouple location

Window Surface Temperature

Window temperature measurement is similarly important. If the window surface or frame temperature drops below the dew point of the ambient air, condensation (or ice) will form and may cause water damage to the surrounding wall. All windows in the CCHT houses are argon filled double-pane, with a low-E coating.

Window surface temperatures were measured at 5 different locations in each window (as shown in Figure 5). Three different windows were examined:

- Bedroom 2 – second floor south facing
- Living room – first floor north facing
- Dining room – first floor south facing
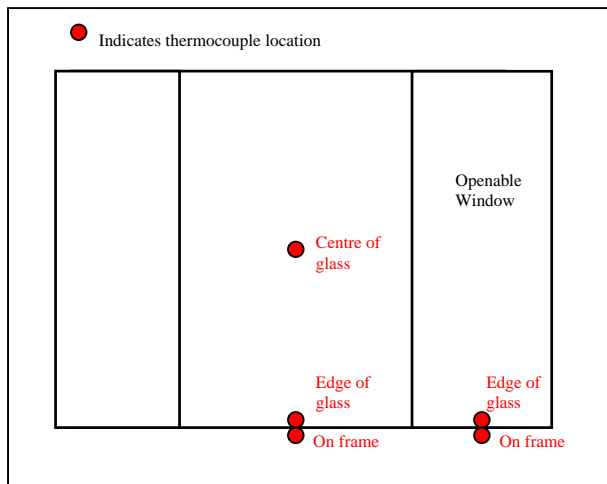
Figure 5 - Thermocouple Location on Window Inner Surface

2.5 Recovery Time Calculation

The main floor thermocouple, located beside the thermostat, was used as the basis for recovery time calculations. The temperature of this thermocouple is captured at 5-minute intervals by the main data acquisition system. This gives a better resolution for calculating recovery time than other thermocouples in the house, whose temperatures are recorded hourly.

The benchmark condition was examined to determine the relationship between the daily average main floor temperature of the Reference house and the Test house.   A graph outlining this relationship can be found in Appendix D.

This main floor temperature correlation was then used to determine the expected average main floor

temperature of the Test house for any given day during the setback and setforward trials. This "expected average" was set as the threshold temperature for determining recovery time. Recovery time was calculated from the point the thermostat automatically reset to 22°C to the time the house reached the threshold temperature. See Figure 24 for a sample graph showing recovery time.

2.6 Humidity Measurements

Humidity is an important factor in determining occupant comfort. During the winter setback experiments, the houses experienced very low humidity (around 10% RH) due to the fact that there were no real occupants, and no humidifiers were run.

In the summer, water is removed from the air in the form of condensation on the indoor air conditioner coil. During the summer trials, this condensation was collected and measured by means of a tipping scale with pulse output at a resolution of 0.011 L/pulse.

The relative humidity of each floor is recorded hourly by the main DAS. Relative humidity measurements in conjunction with hourly temperature measurements were used to calculate the humidity ratio of air (grams vapor per kg air) for each floor of the house. The three humidity ratios – for basement, main floor and 2nd floor – were then averaged to generate an average house humidity ratio. This allowed the moisture content of the Test and Reference House to be compared.

2.7 Weather Measurements

Outdoor temperature and humidity were measured and recorded every 5 minutes by means of a thermocouple and humidity sensor mounted on the exterior of the Reference House.
During the summer experiments, solar radiation incident on the south wall of the Reference House was measured on a 5-minute basis by a wall-mounted pyronometer. See Figure 6 for sample data. This data was then used to separate cloudy days from sunny days during the setforward experiment. A total vertical solar radiation of 8.5 MJ/m^2/day was arbitrarily chosen to divide cloudy days from sunny days.
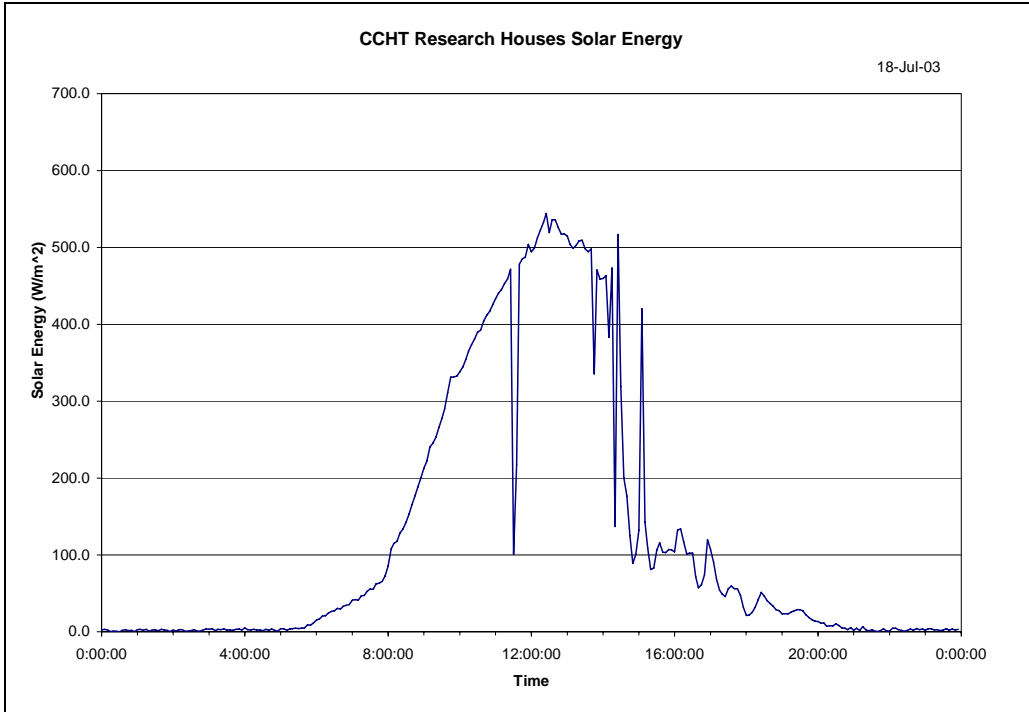
Figure 6 - Sample data from the CCHT Reference House Solar Pyranometer
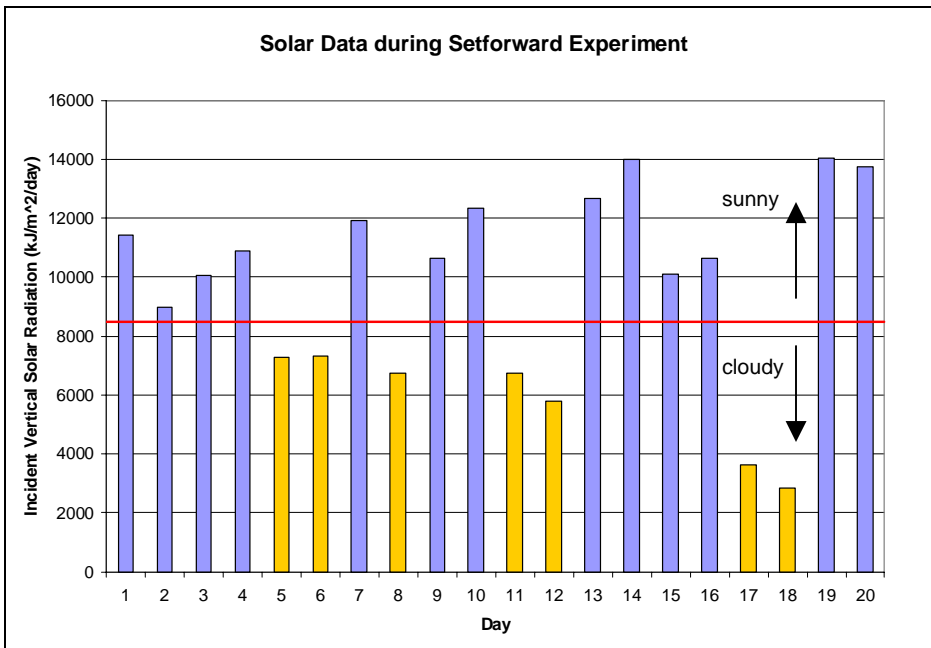
Figure 7 - Division of Summer days by Measure of Incident Solar Radiation

At the time of the winter setback experiment the pyronometer had not yet been installed. In order to see the effect of solar radiation on the thermostat experiment, the outer brick temperature of the south-facing wall of the Reference House was used to differentiate between sunny and cloudy days. On a sunny day, this

temperature can rise upwards of 20°C above the surrounding outdoor temperature. On a cloudy day, the brick temperature tracks the outdoor temperature within a few degrees. A threshold of 20°C difference between outdoor temperature and brick temperature was chosen arbitrarily to indicate sunny days, and less than a 5°C difference was chosen to indicate cloudy days.

See the following figures for a sample of brick temperature data. In this example, December 17th and 18th were classified as sunny days, and the rest were cloudy. In this way, the 18°C day and night setback data were separated into sunny, cloudy and mixed days (temperature difference between 5°C and 20°C). Not enough 16°C Day and Night Setback data were collected to separate in this manner.

It should be noted that because of the nature of the data, summer data was divided into two groups (sunny & cloudy), while winter data was divided into 3 groups (sunny, cloudy & mixed). Most winter days were either perfectly sunny or cloudy days, with only two days that could be classified as "mixed". As a result, sunny and cloudy data formed two very distinct trends (both R^2 values were larger than 0.995) with two days of "mixed" data clearly not belonging to either trend. In summer, there was more of a mix of weather with very few completely sunny days or completely cloudy days. This is shown in Figure 7, where only the 14th and 19th day on this graph could be said to be fully sunny. In essence, almost all days were "mixed". For this reason, a threshold was chosen to split the "mixed" data into two trends with R-squared values of 0.993 (cloudy) and 0.989 (sunny). As expected by the mixed summer weather, resultant summer trends show more scatter than winter trends.
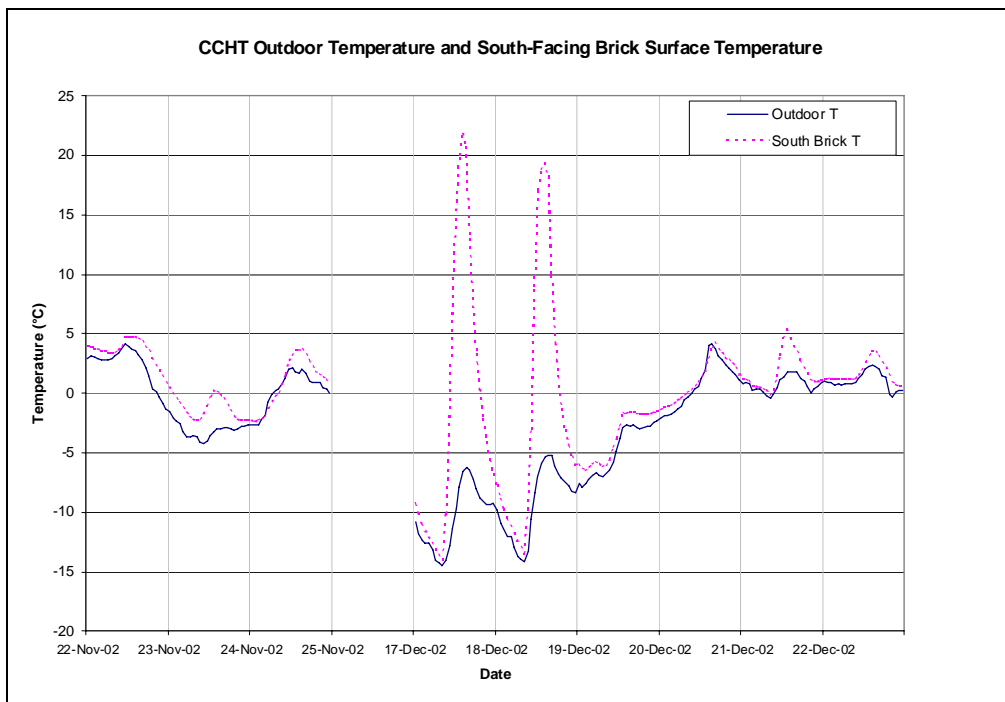
Figure 8 - CCHT Outdoor Temperature and South-Facing Brick Surface Temperature
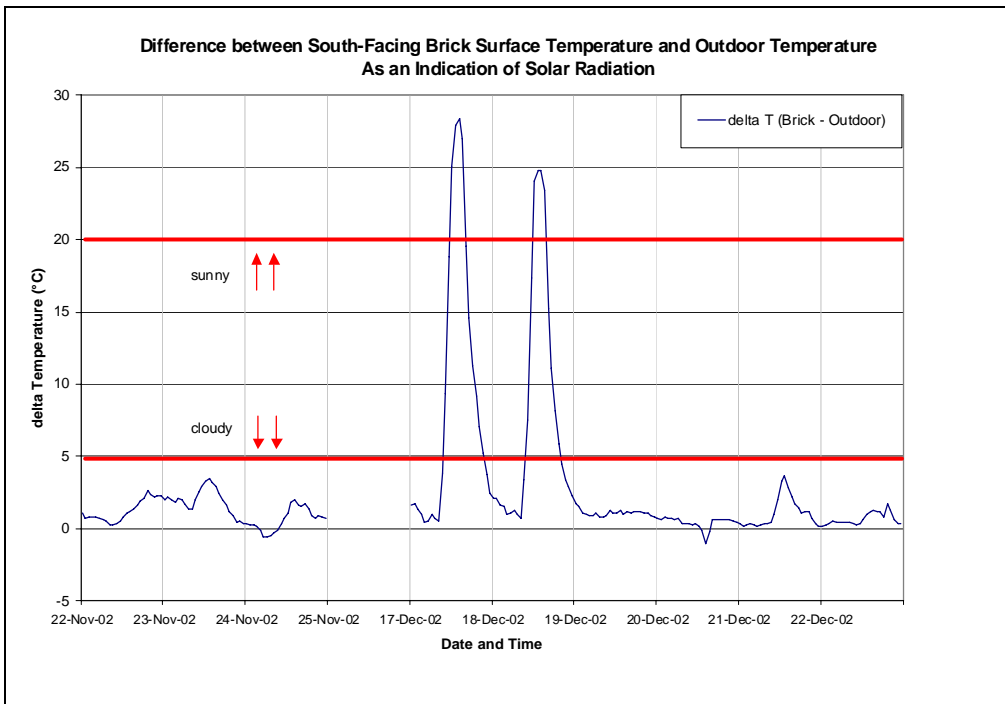
Figure 9 - Difference between South-Facing Brick Surface Temperature and Outdoor Temperature as an Indication of Solar Radiation

3 Results

3.1 Benchmarking

3.1.1 Winter Benchmark

To compare the performance of the houses, daily consumption is plotted. Each point on the consumption graph represents a day with the Reference House value as the X-coordinate, and the Test House value as the Y-coordinate. If the benchmark were "perfect", we would expect the data to form a linear trend with a slope of one and intercept of zero.

During the heating season, the mid-efficiency furnaces in the two houses performed very similarly in gas consumption (slope of 1.0437) and in on-time (slope of 1.0489). Unfortunately, differences in electrical consumption were apparent, emerging as a slope of 1.2044 on the electrical consumption graph. This is a result of differences in the power draw (Wattage) of the two motors in heating speed. These power differences are partially due to static pressure differences in the ducting causing different loads on the motors, as well as inherent differences in the motors themselves.

CCHT Research Houses - Winter 2002-2003 Benchmark
Mid-Efficiency Furnace On Time (PSC motor)

$y = 1.0489x - 17.339$
$R^2 = 0.9972$

Test House Heating On Time (min)

Reference House Heating On Time (min)
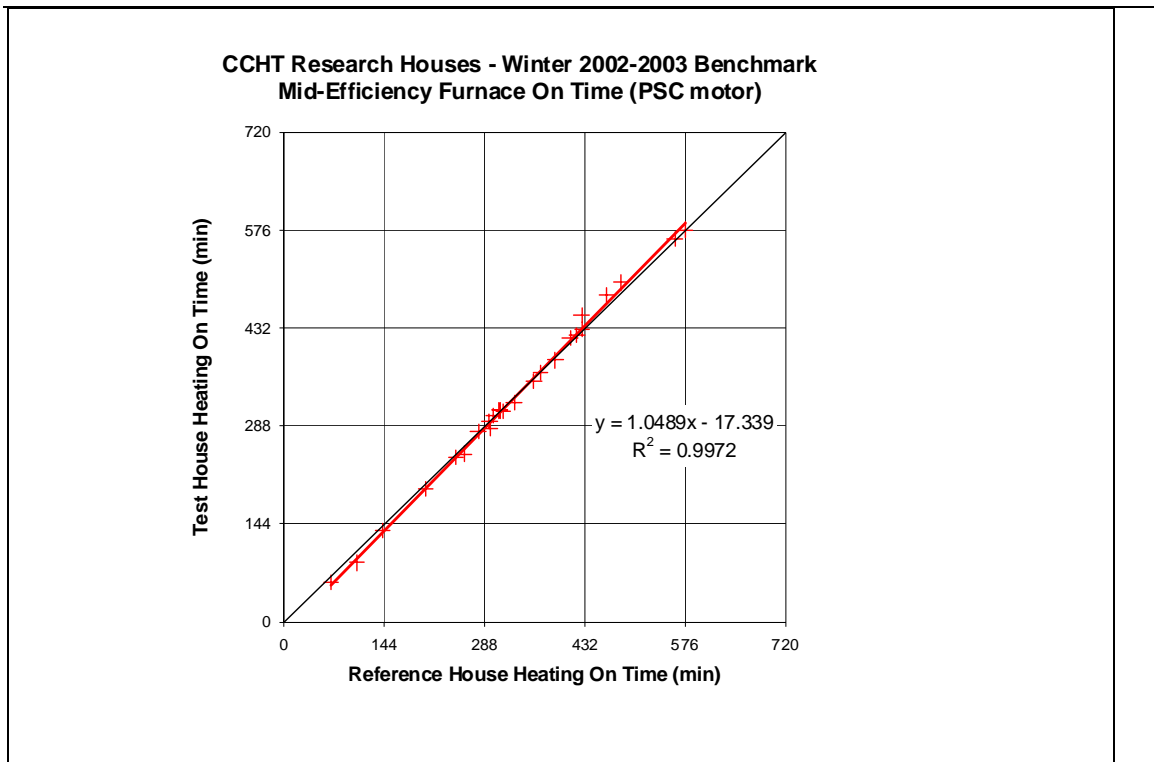
Figure 10 - Winter 2002-2003 Benchmark - Furnace On-time
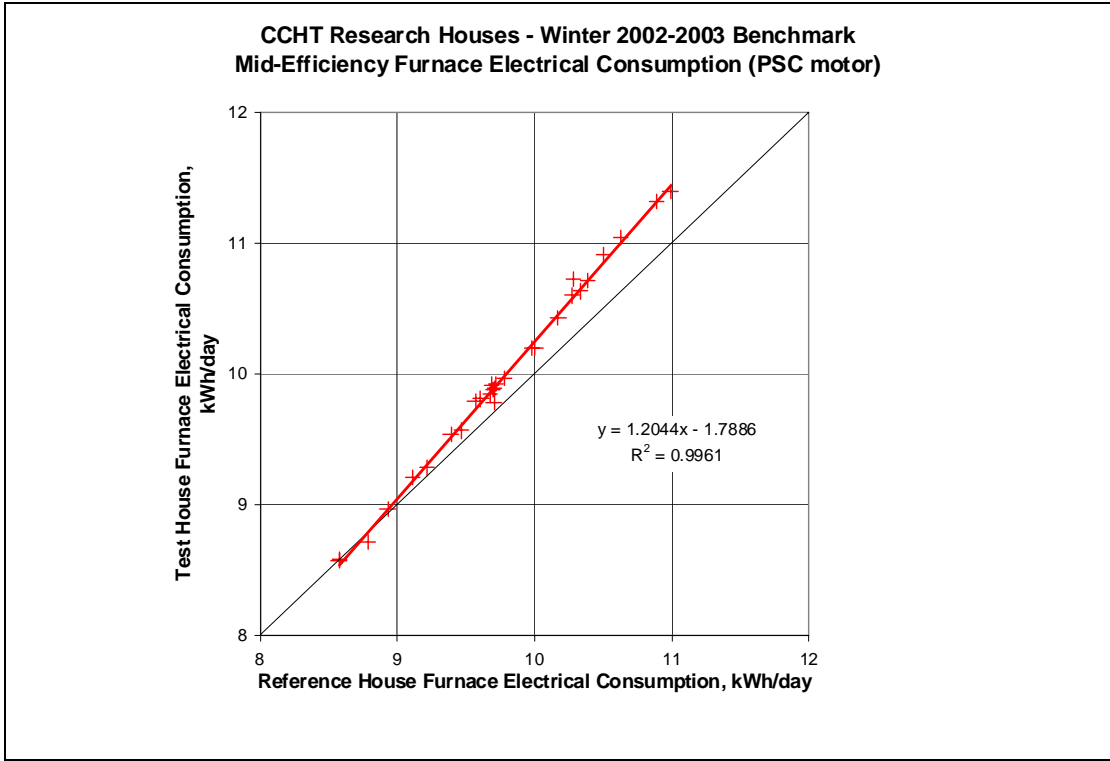
Figure 11 - Winter 2002-2003 Benchmark - Furnace Electrical Consumption
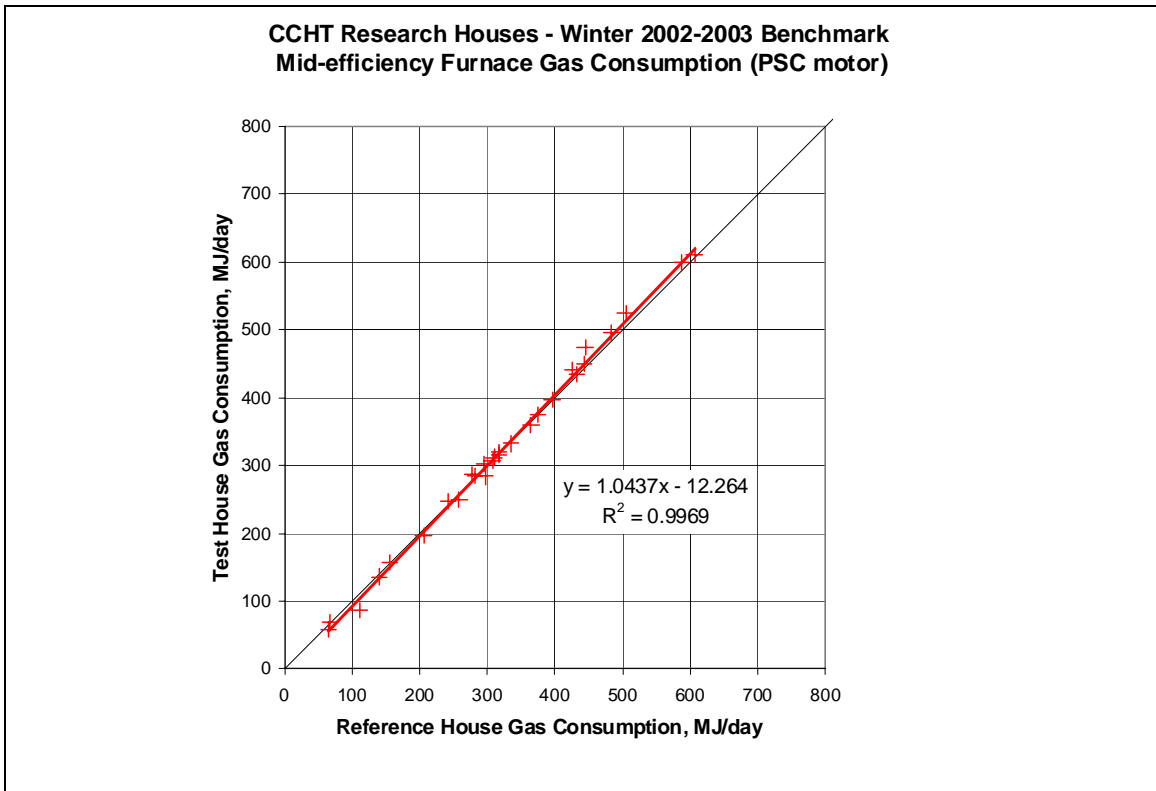
Figure 12 - Winter 2002-2003 Benchmark - Furnace Gas Consumption

3.1.2 Summer Benchmark

Similar trends are apparent in the summer benchmarking results. During the 2003 cooling season, the houses experienced similar on-times and air conditioner consumption, shown in the following graphs. However, differences in furnace fan motor performance resulted in higher Test House electrical consumption.

**CCHT Research Houses - Benchmark Summer 2003
Air Conditioner On Time**

$y = 0.9552x + 51.667$
$R^2 = 0.9888$
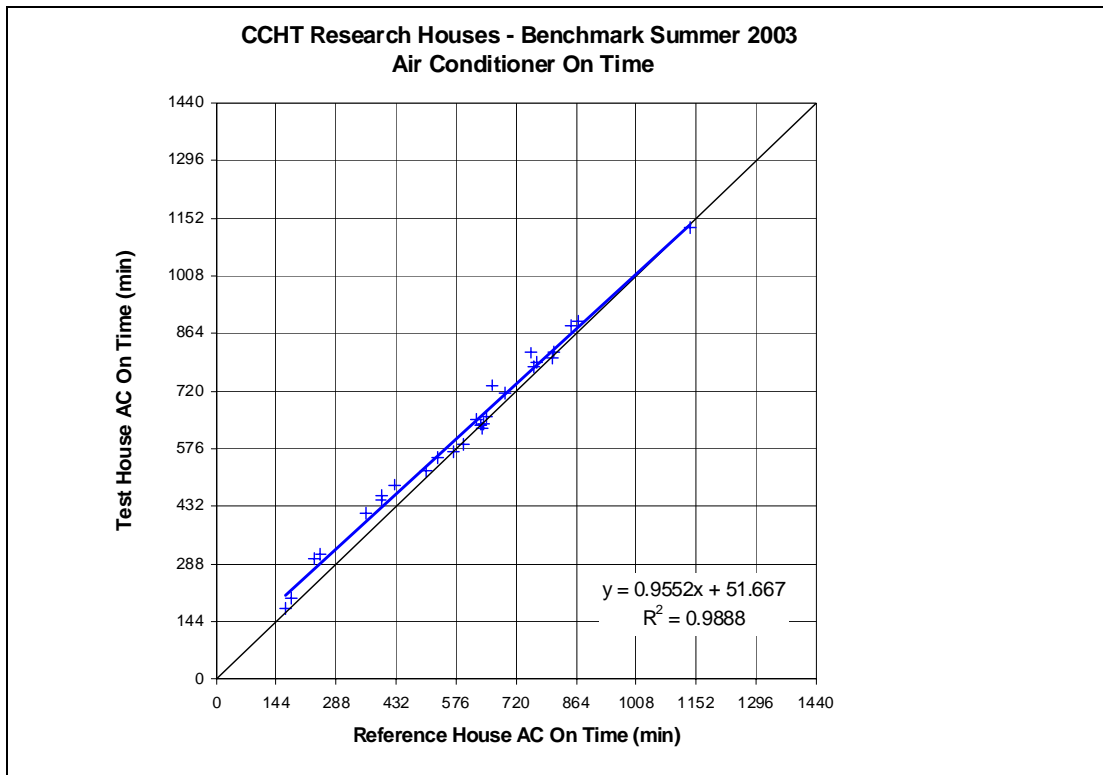
Figure 13 - Summer 2003 Benchmark - Air Conditioning On-time
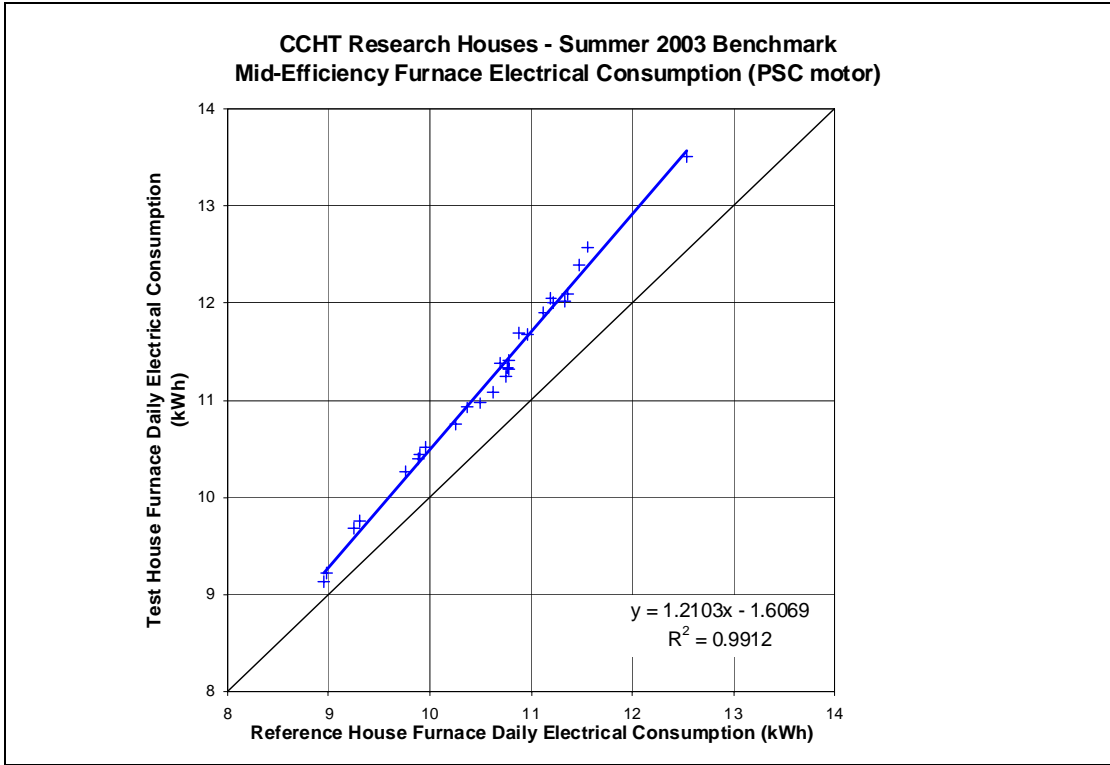
Figure 14 - Summer 2003 Benchmark - Furnace Electrical Consumption
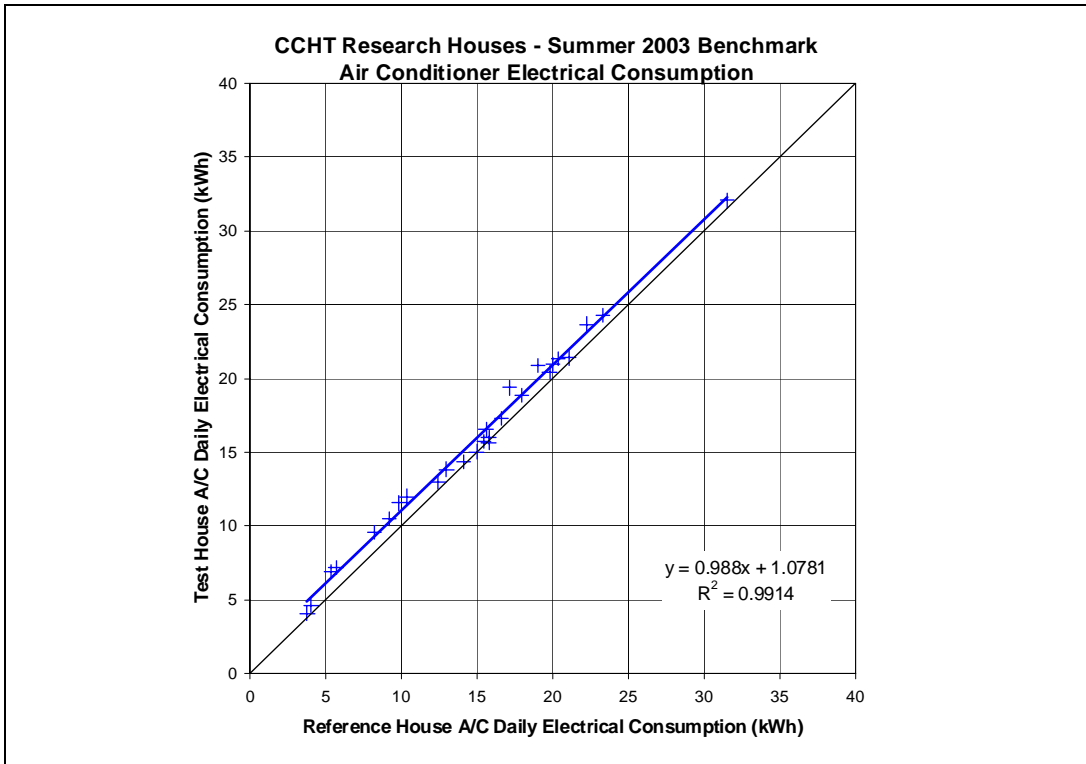
Figure 15 - Summer 2003 Benchmark - Air Conditioner Electrical Consumption

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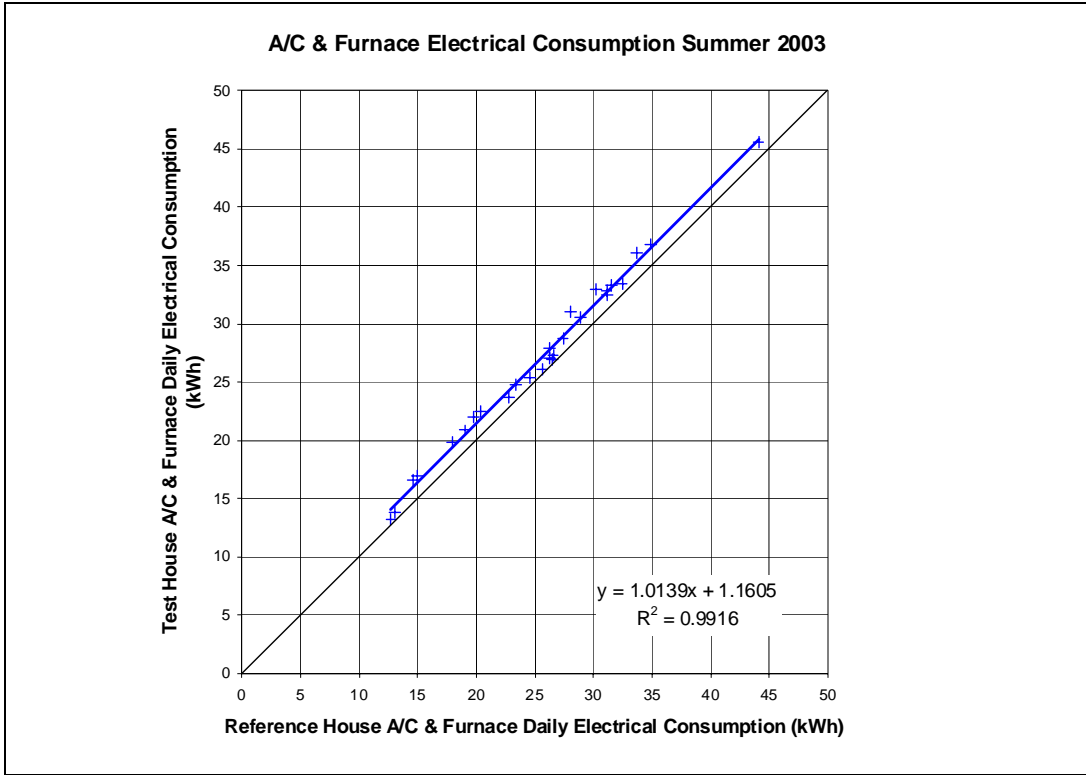
Figure 16 - Summer 2003 Benchmark - Air Conditioner and Furnace Fan Electrical Consumption

3.2 Winter Thermostat Experiment Results

3.2.1 Furnace On-Times

Furnace gas and electrical consumption are both closely related to furnace on-time. Trends in the on-time data are indicative of savings trends: the less the furnace runs in heating mode, the more the energy savings. The benchmark trend and thermostat data are plotted in Figure 17. The vertical drop from the benchmark line to the thermostat experiment trend lines indicates a reduction in on-time. As expected, thermostat setback data show that the introduction of a nighttime thermostat setback reduces furnace on-time. The following observations can be drawn from this data:

- Decrease in thermostat setback temperature results in a reduction in furnace on-time per day
- Additional setback periods (daytime and nighttime) further reduce on-time
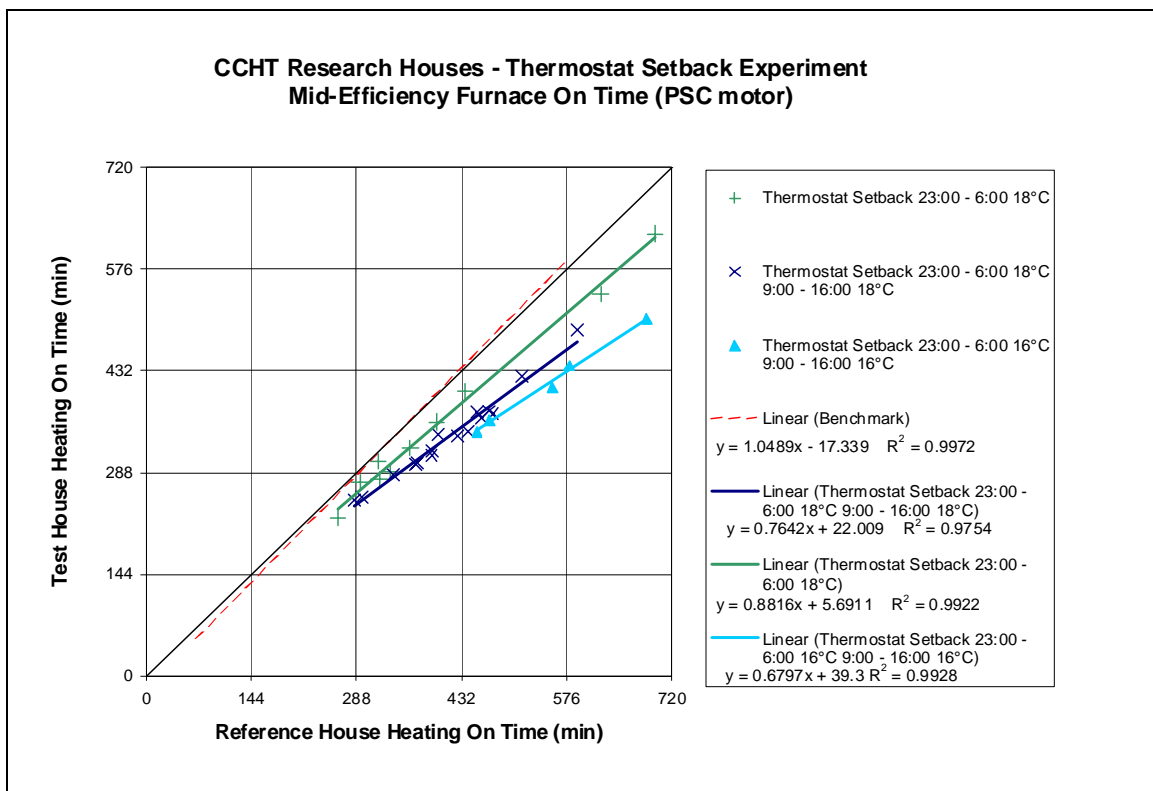
Figure 17 - Thermostat Setback Experiment - Furnace On-time

We can see from the different slopes of the setback data that as furnace on-time increases (to cope with cold weather conditions), the percentage of on-time savings increase. Therefore, we will find the greatest savings on the coldest day of the heating season. In this experiment, the coldest day of the season was

January 22nd 2003 (High -19°C, Low -27°C). On this day, the Reference House Furnace ran for 697 minutes. In benchmarking conditions we would expect the Test House furnace to run in heating mode for 714 minutes. Calculated maximum reduction in on-time for the Test House on this coldest day are summarized in the following table.

Table 5 - Maximum Calculated Reduction in On-time - from coldest day data

Setting	Calculated On-time* (min)	Calculated Reduction (min)	Reduction (%)
Winter Benchmark	714	-----	-----
18°C nighttime setback	620	94	13
18°C day and nighttime setback	555	159	22
16°C day and nighttime setback	513	201	28

*Calculated by applying the on-time correlations (Figure 17) to the Reference House coldest day data (on-time of 697 minutes)

3.2.2 Electrical Consumption

The same trends can be seen in electrical savings. The more hours the house remains at the setback temperature, the lower the setback temperature, and the cooler the conditions outside, the greater the electrical savings.
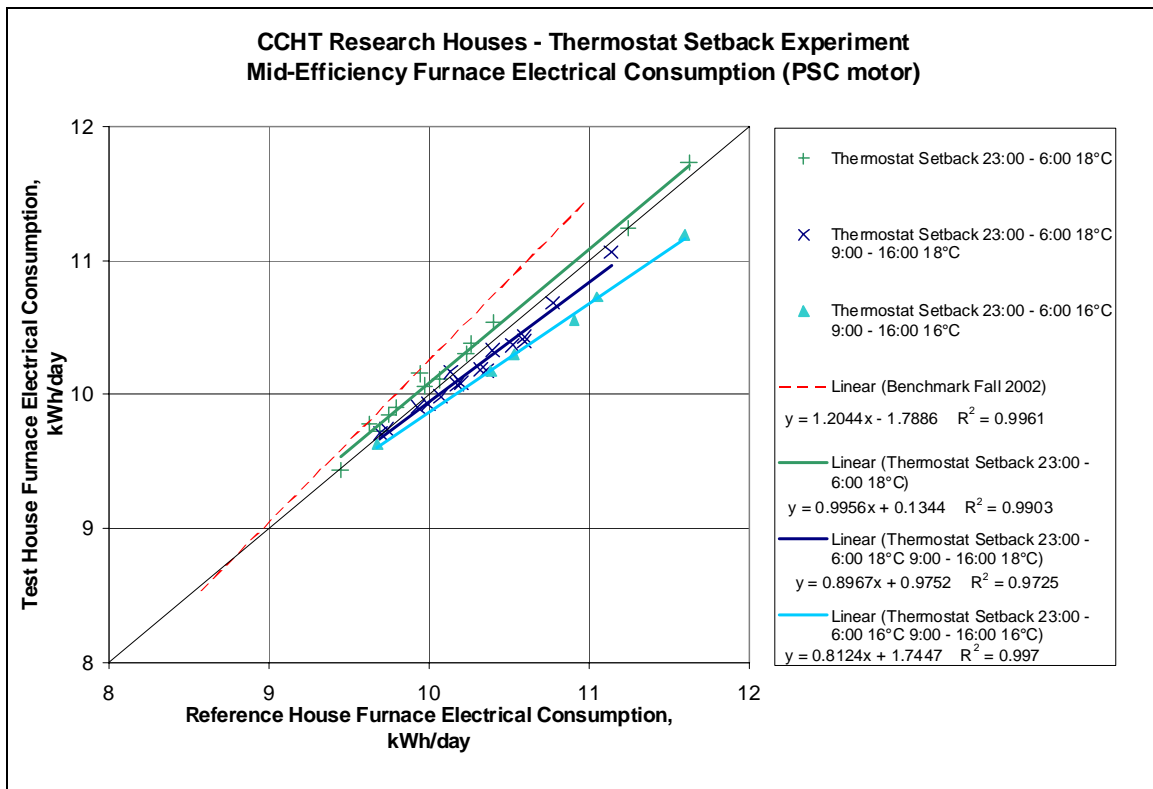
Figure 18 - Thermostat Setback Experiment - Furnace Electrical Consumption

On the coldest winter day this season, the Reference House furnace consumed 11.62 kWh of electricity. In benchmarking conditions we would expect the Test House furnace to consume 12.21 kWh. Calculated reductions in electrical consumption for the Test House in setback conditions on this coldest day are summarized in the following table.

Table 6 – Maximum Calculated Reduction in Electrical Consumption– from coldest day data

Setting	Calculated Consumption* (kWh/day)	Calculated Reduction (kWh/day)	Reduction (%)
Winter Benchmark	12.208	-----	-----
18°C nighttime setback	11.704	0.504	4.1
18°C day and nighttime setback	11.396	0.812	6.7
16°C day and nighttime setback	11.186	1.022	8.4

*Calculated by applying the electrical consumption correlations (Figure 18) to the Reference House coldest day data (electrical consumption of 11.62 kWh)

3.2.3 Gas Consumption

Gas data follow the same trends.
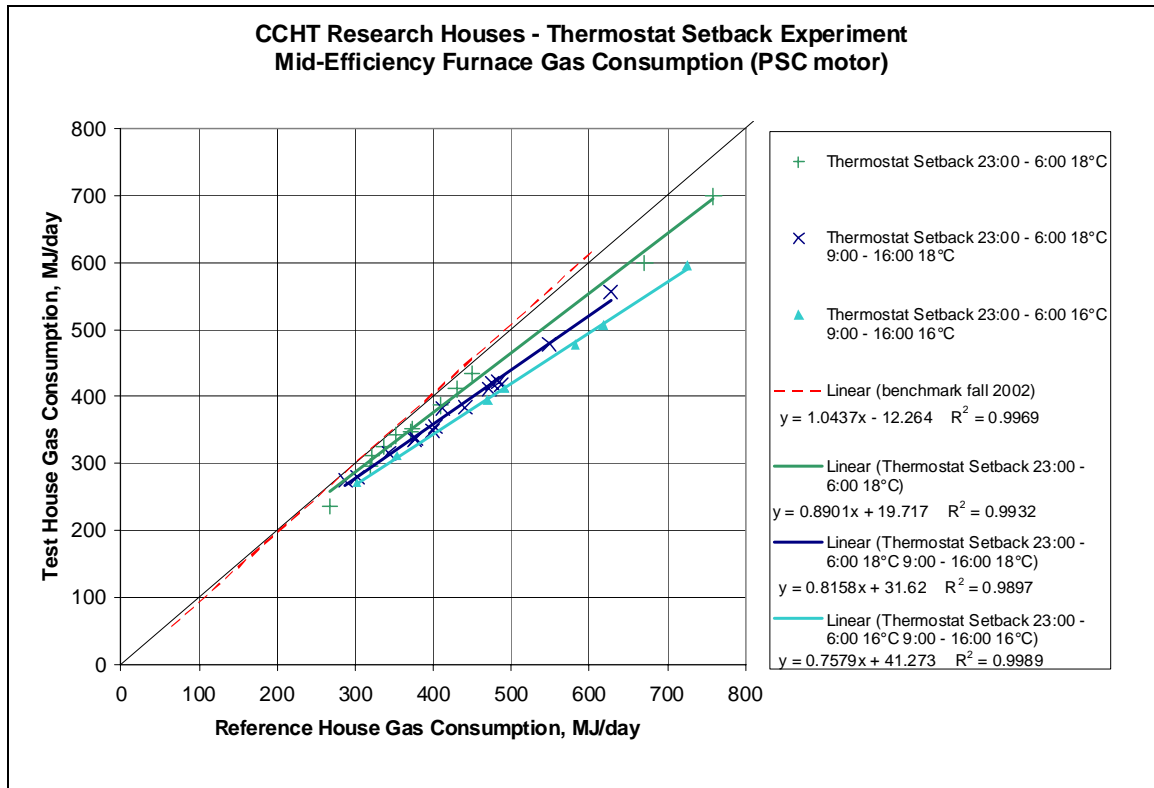
Figure 19 - Thermostat Setback Experiment - Furnace Gas Consumption

On the coldest day in the heating season (January 22nd 2003, High -19°C, Low -27°C), the Reference House Furnace consumed 759.1 MJ. In benchmarking conditions we would expect the Test House furnace

to consume 780.0 MJ. Calculated reductions in gas consumption for the Test House on this coldest day are summarized in the following table.

Table 7 - Maximum Calculated Reduction in Gas Consumption - from coldest day data

Setting	Calculated Consumption* (MJ/day)	Calculated Reduction (MJ/day)	Reduction (%)
Winter Benchmark	780.0	-----	-----
18°C nighttime setback	695.4	84.6	11
18°C day and nighttime setback	650.9	129.1	17
16°C day and nighttime setback	616.6	163.4	21

*Calculated by applying the gas consumption correlations (Figure 19) to the Reference House coldest day data (gas consumption of 759.1 MJ)

For projected savings over the entire heating season, please refer to Section 4.1.

3.2.4 Effect of Solar radiation on results

Splitting winter data into "cloudy" and "sunny" days highlights the effects of solar radiation on daytime setback savings.

On some sunny days, the added energy from solar radiation can keep the house from even reaching the setback temperature. This reduces the added savings of a daytime setback. Daytime setback is most effective on cloudy days.
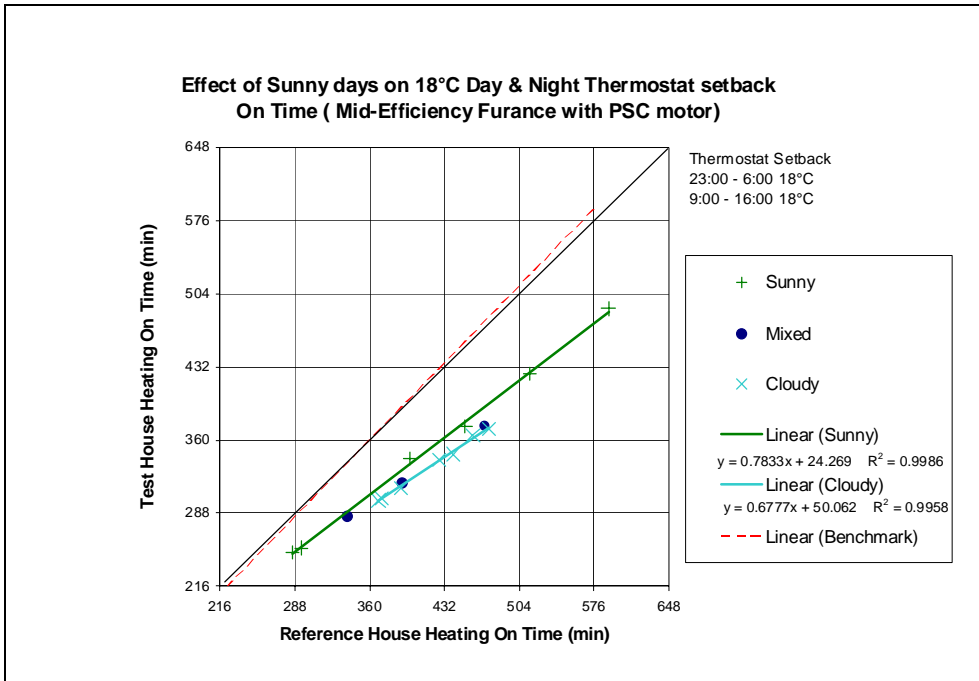
Figure 20 - Effect of Sunny days on 18°C Day & Night Thermostat Setback On-time
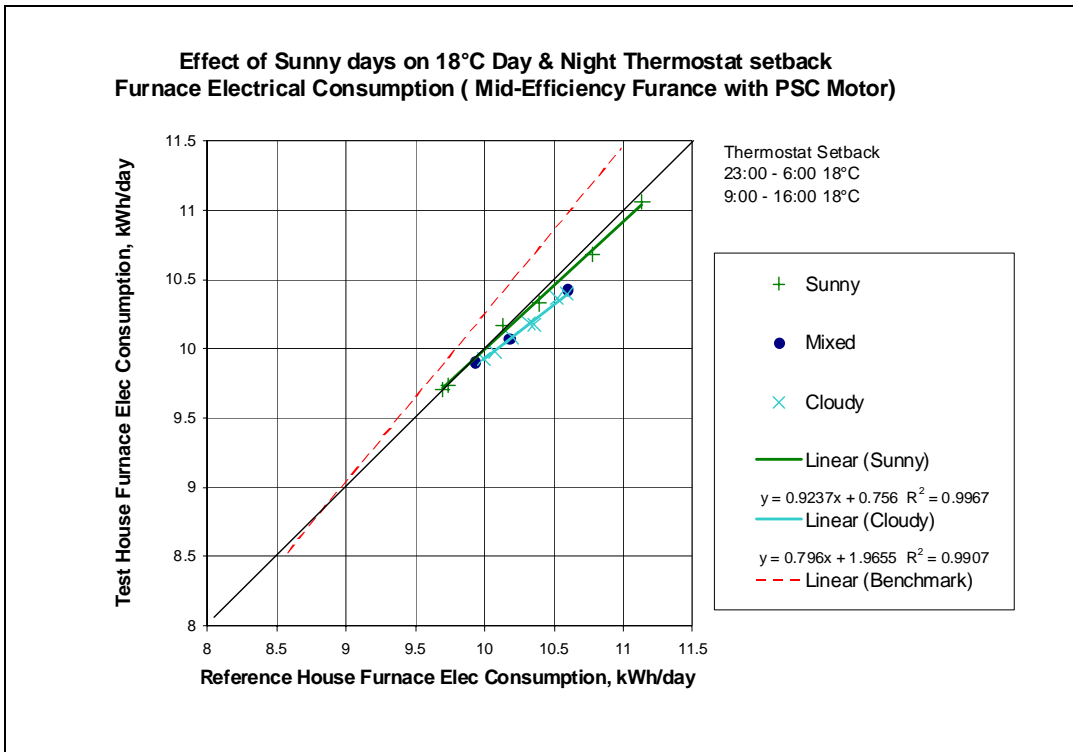
Figure 21 - Effect of Sunny days on 18°C Day & Night Thermostat Setback Furnace Electrical Consumption
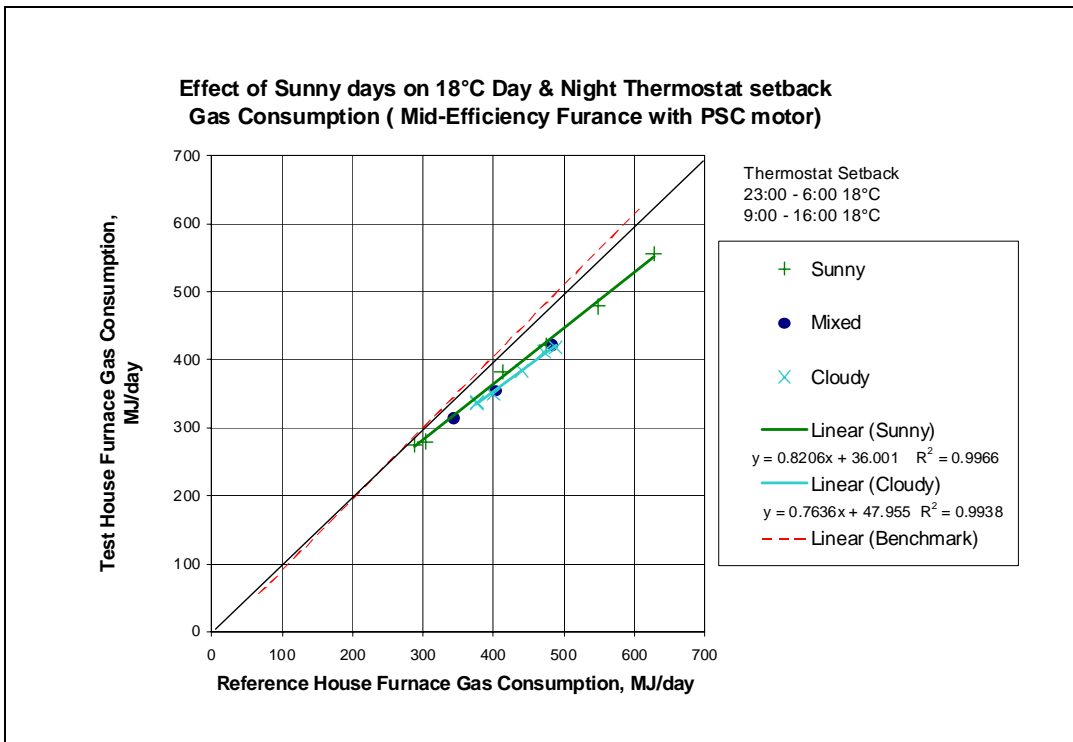
Figure 22 - Effect of Sunny days on 18°C Day & Night Thermostat Setback Furnace Gas Consumption

3.2.5 Recovery Time

Perhaps one of the most important factors in examining thermostat setback is recovery time – the amount of time taken for the house air to return to its original temperature setting. Recovery time is a function of the minimum house temperature reached during the setback, irrespective of whether the setback is day or night. This relationship is shown in Figure 23. The circled data points on this graph indicate that the furnace ran more than once to reach the threshold temperature. An example of this phenomenon is shown in Figure 25. These points are included in the R^2 value.

The lower the temperature the house is permitted to reach, the longer the recovery time. During the 18 °C setback, the main floor temperature of the Test House dropped to almost 16°C on the coldest winter days, requiring 1.5 hours to recover. At the 16°C setback setting, the house was allowed to drop to 14.5°C on the coldest days and required almost 2 hours of recovery time. Recovery time will directly affect the comfort of the occupants in the early morning hour and upon return from work. It can be expected that in less energy-efficient homes, recovery times may be longer.

Characteristics of the thermostat also come into play. The deadband is a temperature range around the setpoint used to control furnace operation. It is an important factor in the control of the house temperature, allowing the furnace to run for fewer and longer cycles. When the house cools down to the lower boundary of the deadband, heating is triggered. Once the house is heated up to the top of the deadband, the heating demand is satisfied and heating stops. The thermostat used for this experiment produced a measured average of ~21.5°C when set to 22°C, with a deadband of about 20.5°C to 22.5°C. A setting of 18°C produced a deadband of about 16.2°C to 18.2°C (see Figure 25).

This particular thermostat also has a feature called "anticipation" that is intended to prevent the house temperature from overshooting the setpoint. The anticipator, common to many programmable thermostats, comes into play during the recovery period, causing the furnace to cycle as it approaches the setpoint temperature (See Figure 27). Although anticipation improves overall temperature control, it may add significantly to recovery times from thermostat setback.

Cool surface temperatures may also be a factor in increasing recovery times. Air temperatures may temporarily reach thermostat settings, only to drop quickly because of lagging cool surfaces. More investigation of this phenomenon is needed to develop a better understanding.
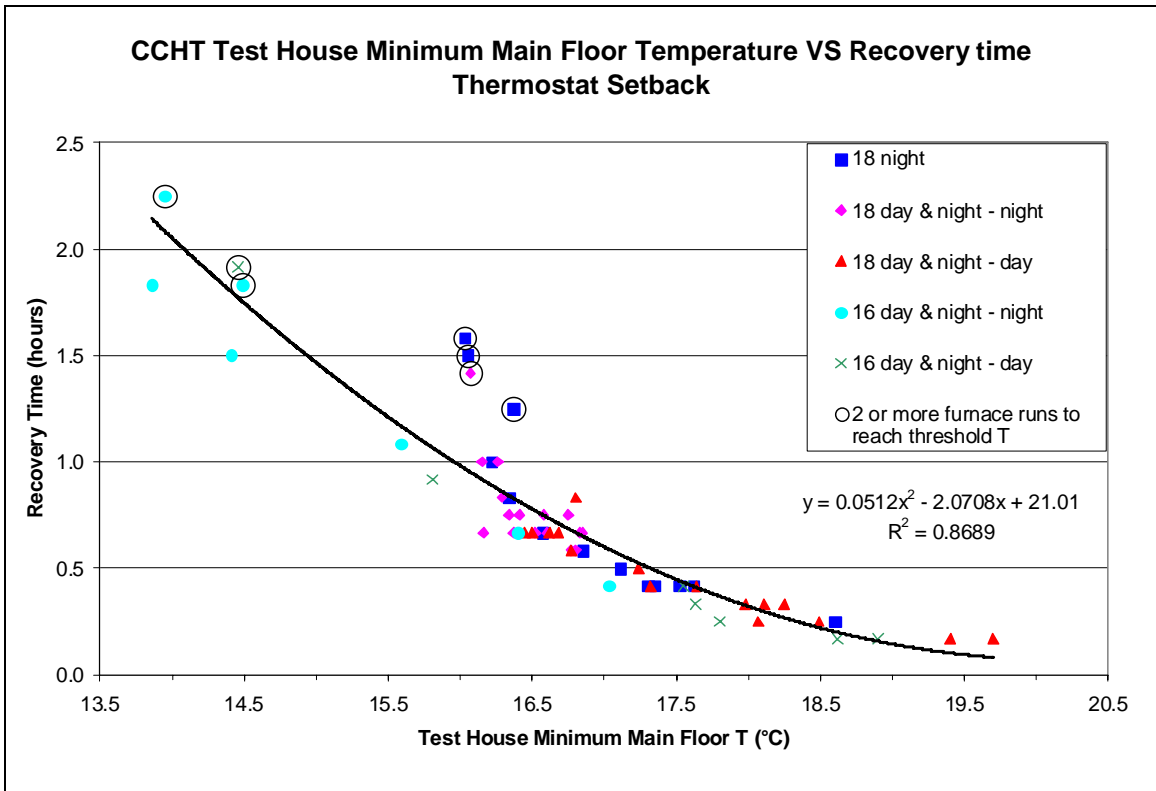
Figure 23 - Thermostat Setback Recovery Time Winter 2002-2003

$$y = 0.0512x^2 - 2.0708x + 21.01$$
$$R^2 = 0.8689$$
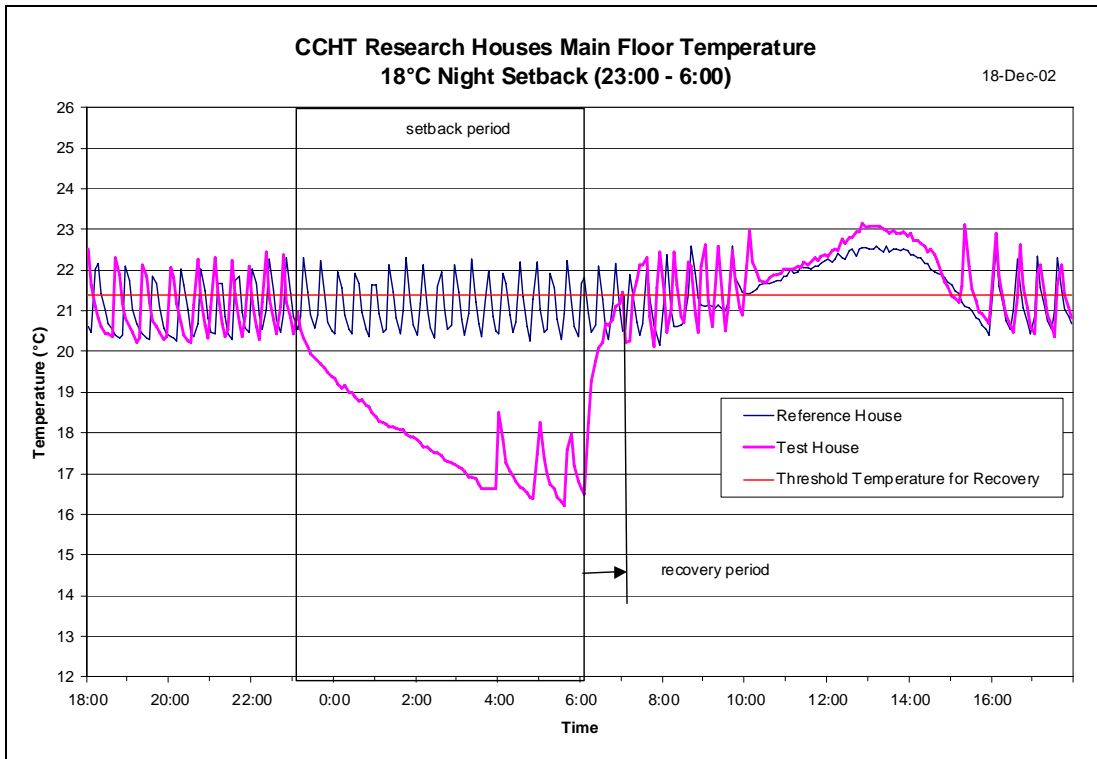
Figure 24 - Sample Recovery Time for 18°C Night Setback 18-Dec-02 (outdoor temperature: -14.4°C min, -5.0°C max, sunny day)
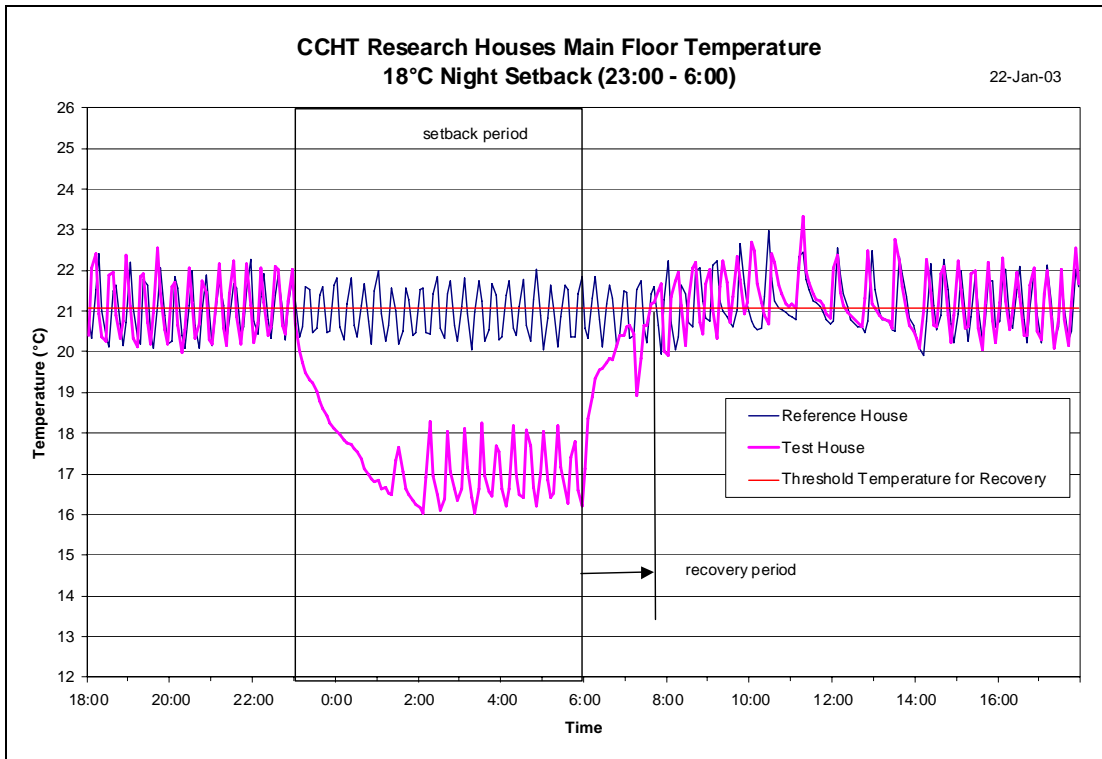
Figure 25 - Sample Recovery Time for 18°C Night Setback 22-Jan-03, showing 2 furnace runs to reach the threshold temperature for recovery (outdoor temperature: -27.5°C min, -19.2°C max)
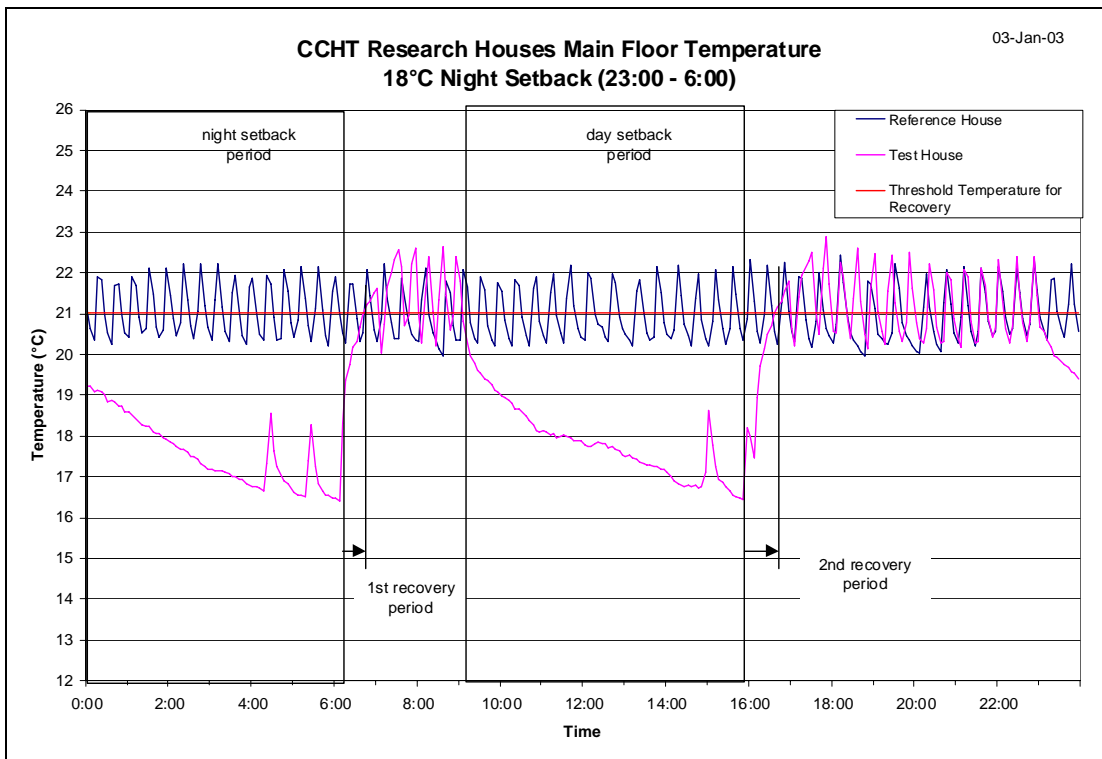
Figure 26 - Sample Recovery Time for 18°C Night and Day Setback 03-Jan-03 (outdoor temperature: -8.5°C min, -4.7°C max)
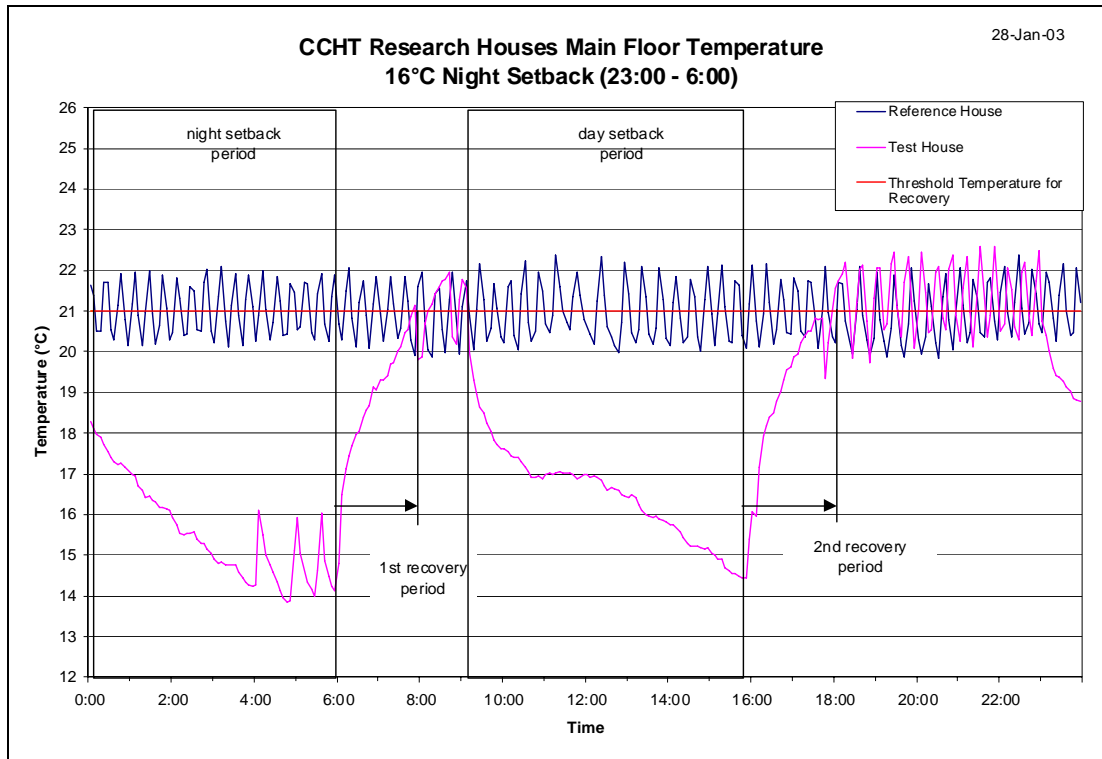
Figure 27 - Sample Recovery Time for 16°C Night and Day Setback (outdoor temperature: -27.0°C min, -14.6°C max)

3.2.6 House Temperatures

Benchmarking shows that the Test House temperature is maintained slightly above the Reference House temperature. This is likely due to small differences in the accuracy of the thermostats.

Except on sunny days, the main floor temperature in both houses remains above the second floor temperature, even throughout thermostat setback.

The effects of the setback are most prominent on the main floor: minimum temperatures follow thermostat settings closely. Differences in the second floor temperatures appear to be slightly smaller.

The most interesting effects are shown in the basement. The minimum temperatures in the two basements remain close throughout all trials, showing a 1.65°C difference during the 16°C setback (as opposed to the 5.34°C temperature difference on the main floor). Also, maximum basement temperatures are higher in the Test house than the Reference house during the setback days. This could be a result of the furnace running for an extended period of time whenever the thermostat returns to the 22°C setting, adding heat to the Test house basement. Mass effects of the concrete walls and slab, and mass of the equipment in the Test House Basement may be a contributing factor.

Table 8 - Minimum House Temperatures

	Main Floor (°C)			2nd Floor (°C)			Basement (°C)		
	Test	Ref	Difference	Test	Ref	Difference	Test	Ref	Difference
22°C Benchmark	21.69	21.27	0.42	20.01	19.57	0.44	16.68	17.02	-0.34
18°C Setback	18.06	21.1	-3.04	16.93	19.79	-2.86	14.26	15.72	-1.46
16°C Setback	15.81	21.15	-5.34	14.77	19.41	-4.64	13.67	15.32	-1.65

Table 9 - Maximum House Temperatures

	Main Floor (°C)			2nd Floor (°C)			Basement (°C)		
	Test	Ref	Difference	Test	Ref	Difference	Test	Ref	Difference
22°C Benchmark	22.81	22.53	0.28	24.35	23.39	0.96	20.24	20.03	0.21
18°C Setback	22.56	22.36	0.2	23.14	23.46	-0.32	22.21	20.09	2.12
16°C Setback	22.72	22.48	0.24	22.75	23.35	-0.6	20.96	19.8	1.16

Detailed graphs of house temperatures can be found in Appendix A.

Drywall inner surface T

Table 10 - Minimum Drywall Surface Temperatures Measured on Centre of Insulated Stud Space

	Test House			Reference House		
	Min T (°C)	Location	RH resulting in condensation	Min T (°C)	Location	RH resulting in condensation
22°C Benchmarking	18.31	Bedroom 2 – West	80% @ 22°C	18.08	Bedroom 2 - South	79% @ 22°C
18°C Setback	14.88	Family room – East	64% @ 22°C 82% @ 18°C	17.83	Bedroom 2 - West	78% @ 22°C >100% @ 18°C
16°C Setback	12.74	Family room – East	55% @ 22°C 81% @ 16°C	17.80	Bedroom 2 - South	78% @ 22°C >100% @ 16°C

The coldest drywall surface temperature measured in the Test House during these trials was 12.74°C (during the 16°C Setback experiment). For the same experiment, the coldest drywall surface temperature in the Reference House was 17.80°C. In order for this to cause condensation problems in the test house, the humidity of the air at 22°C would have to exceed 55%. In the Reference House, air humidity would have to exceed 78%.

See Appendix B for detailed graphs of the drywall temperatures. The coldest drywall temperatures in the Test house occur for the most part in the morning. At this time we would expect a bedroom, having been occupied throughout the night, to have the highest humidity levels. During sunny days, drywall temperatures on the second floor can be seen to rise above 25°C.

It should be noted that these drywall surface temperatures were measured at the centre of an insulated wall cavity, and lower surface temperatures could be expected on the wall stud framing, at the bottom plates, at corners, or in sections with poorer thermal characteristics.

During the setback trials, drywall surface temperatures were seen to rise and fall in synch with air temperature, while remaining approximately 2-degrees cooler – with the exception of sunny days, when the surface temperatures on south facing walls rose above the room air temperature (see Figure 28 to Figure 31). No distinct lag between wall and air recovery time was seen in the hourly data, a higher rate of data sampling could reveal a different result.
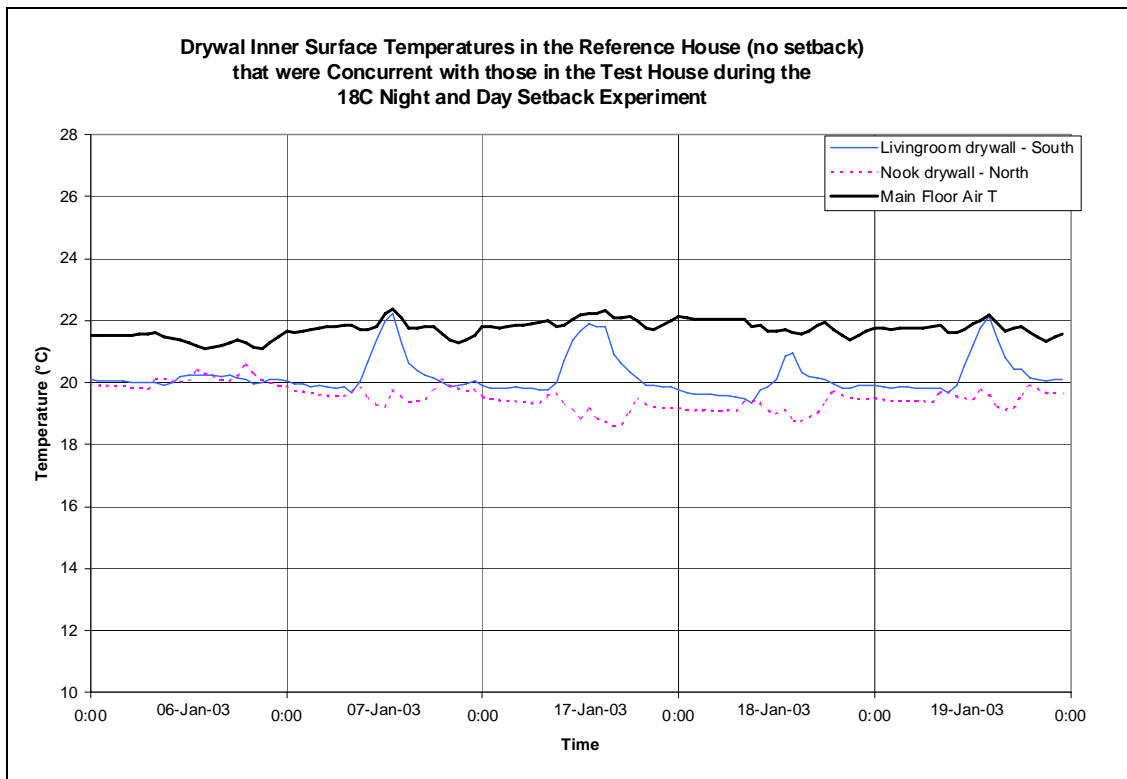
Figure 28 - Reference House Air and Drywall Surface Temperature during the 18°C Night and Day Setback Experiment
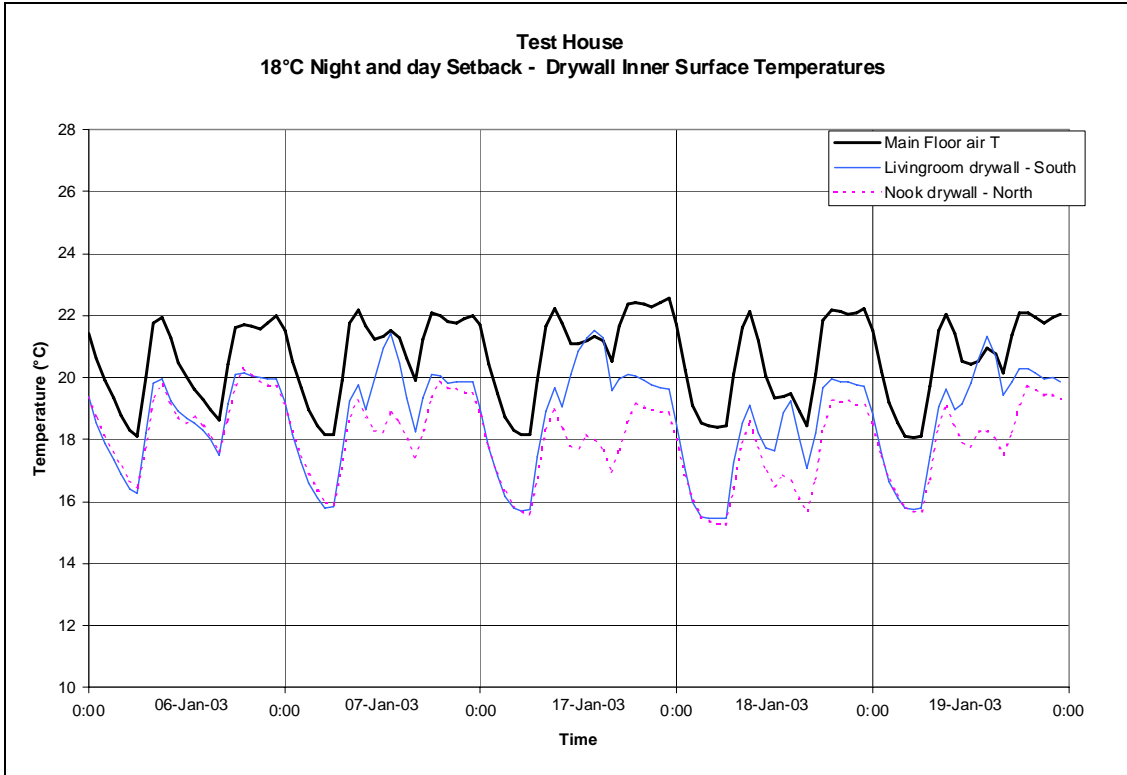
Figure 29 - Test House Air and Drywall Surface Temperature - 18°C Night and Day setback
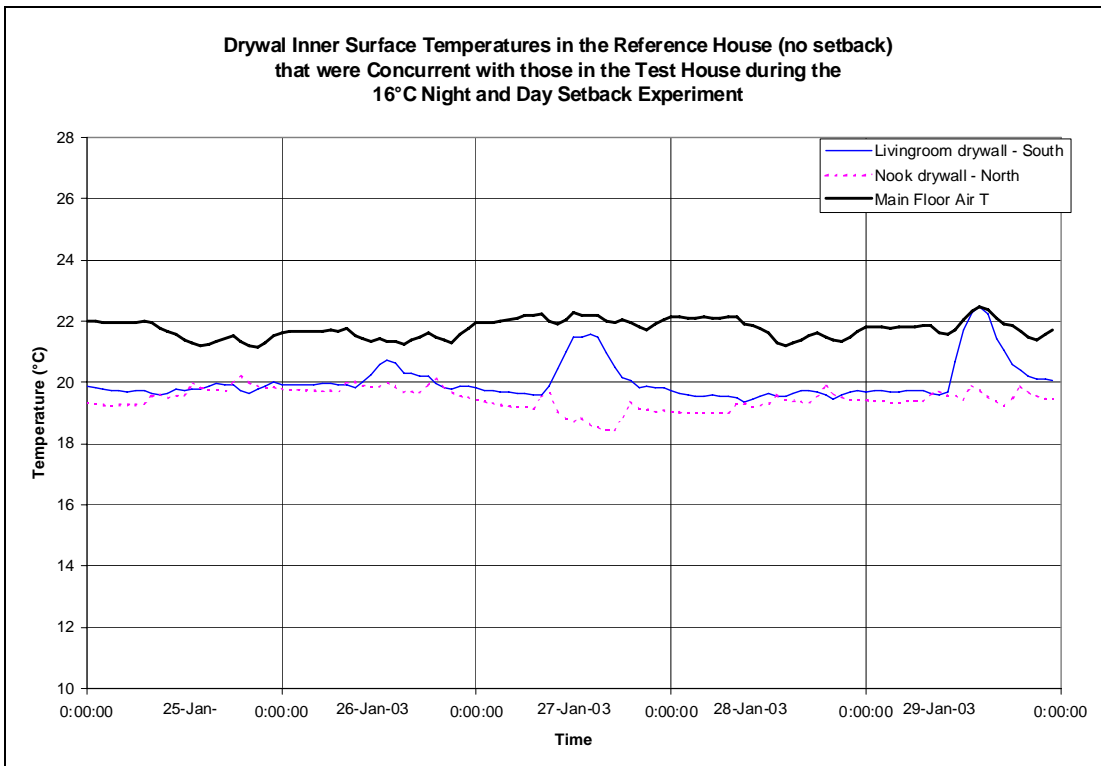
Figure 30 - Reference House Air and Drywall Surface Temperature during the 16°C Night and Day setback experiment
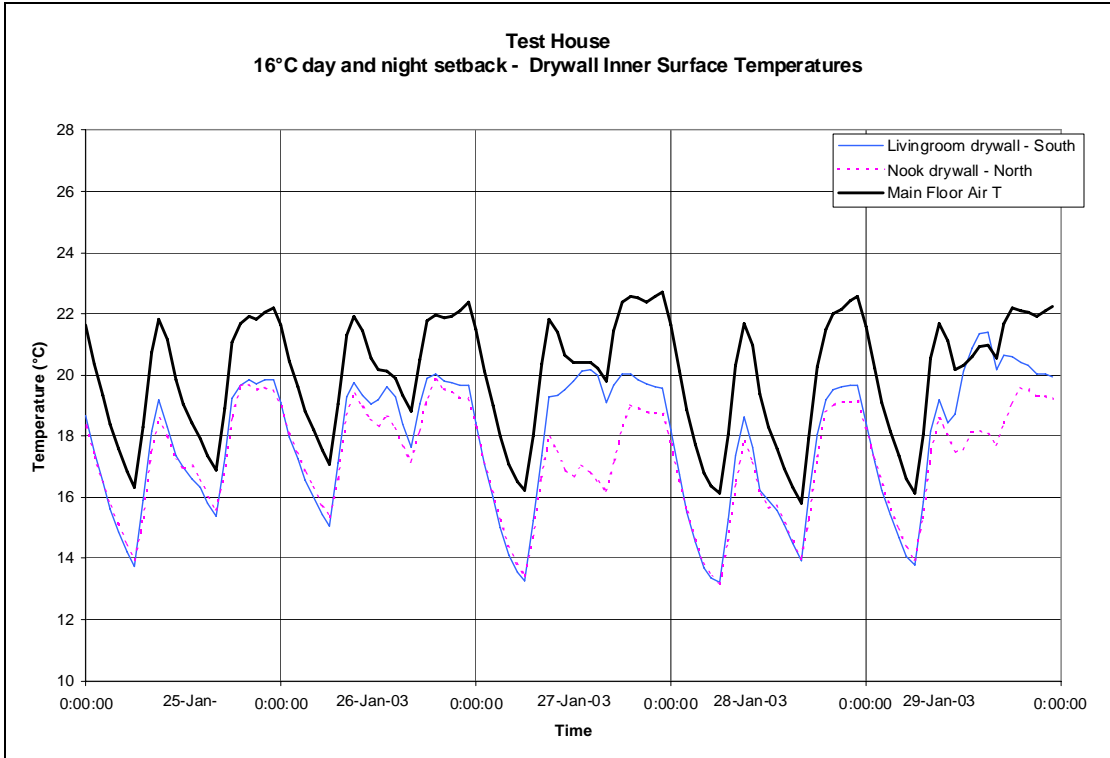
Figure 31 - Test House Air and Drywall Surface Temperature - 16°C Night and Day setback

Window Surface Temperatures

The following tables present temperatures reached on the inner surface of the Test and Reference House windows (locations are shown in Figure 5). All windows in the house are equipped with interior Venetian blinds with 2.5 cm wide, white colored slats. During the setback experiments, all blinds were kept lowered with a horizontal (open) orientation.

Table 11 - Minimum Window Temperatures - Bedroom 2 (2nd Floor South Facing)

	Test House			Reference House		
	Min T (°C)	Location	RH resulting in condensation	Min T (°C)	Location	RH resulting in condensation
22°C Benchmarking	2.23	Frame of openable	27% @ 22°C	5.28	Edge of openable	34% @ 22°C
18°C Setback	-1.24	Frame of openable	21% @ 22°C 27% @ 18°C	4.93	Edge of glass	33% @ 22°C 42% @ 18°C
16°C Setback	-3.19	Frame of openable	18% @ 22°C 27% @ 16°C	3.95	Edge of glass	31% @ 22°C 45% @ 16°C

Table 12 - Minimum Window Temperatures – Dining room (1st Floor North Facing)

	Test House			Reference House		
	Min T (°C)	Location	RH resulting in condensation	Min T (°C)	Location	RH resulting in condensation
22°C Benchmarking	1.81	Edge of glass	26% @ 22°C	4.31	Edge of glass	31% @ 22°C
18°C Setback	-1.43	Edge of glass	21% @ 22°C 27% @ 18°C	3.22	Frame of openable	29% @ 22°C 37% @ 18°C
16°C Setback	-4.99	Edge of glass	16% @ 22°C 23% @ 16°C	-0.49	Frame of openable	22% @ 22°C 33% @ 16°C

Table 13 - Minimum Window Temperatures - Living room (1st Floor South Facing)

	Test House			Reference House		
	Min T (°C)	Location	RH resulting in condensation	Min T (°C)	Location	RH resulting in condensation
22°C Benchmarking	-2.65	Frame of openable	19 % @ 22°C	1.02	Frame of openable	25% @ 22°C
18°C Setback	-4.92	Frame of openable	16% @ 22°C 21% @ 18°C	0.10	Frame of openable	23% @ 22°C 34% @ 18°C
16°C Setback	-7.81	Frame of openable	13% @ 22°C 19% @ 16°C	-0.94	Frame of openable	22% @ 22°C 32% @ 16°C

For the most part, the lowest temperatures on the interior of the window occurred at the edge of the glass or the frame. This is an expected result and is consistent with lab assessments of surface temperatures of such windows[4].

In the benchmarking phase, the Test and Reference House windows showed more variation than the drywall. For all three windows, the lowest benchmark temperatures measured in the Test House were approximately 3 degrees lower than the Reference House minimums. In both houses, the first floor Living room window reached the lowest temperatures. In the Reference House, condensation is predicted to occur with an RH above 22%. In the Test House, results from the 16-degree setback predict that condensation and ice would occur at a relative humidity above 13% @ 22°C (19% @ 16°C).

See Appendix C for a sample of window temperature graphs plotted for the Living room windows.

3.3 Summer Thermostat Experiment Results

3.3.1 Air Conditioner On-Time

On-time data is a measure of the amount of time the furnace circulation fan runs in high-speed cooling mode. Figure 32 shows that as Reference House furnace on-time increases, the vertical distance between the benchmark and setforward trend lines increases. This is an indication of increasing reductions in furnace on-time as more time is spent in cooling mode. On hotter, sunnier days, the furnace ran in cooling mode for the longest time, causing the largest reductions in AC on-time due to thermostat setforward. The spread of this data was due to solar gains (sunny VS cloudy days) as discussed in section 3.4.3.

The benefits gained from the setforward, as the house drifts to the higher temperature, is partially offset by the time the AC unit has to run to re-cool the house at the end of the setforward period. By contrast, we see larger reductions in AC on-time throughout the test period for the higher temperature setting, in Figure 32 the higher temperature correlation remains almost parallel to the benchmarking line. This setting produces an almost constant on-time reduction (~200 minutes), irrespective of outdoor temperature or solar gains.
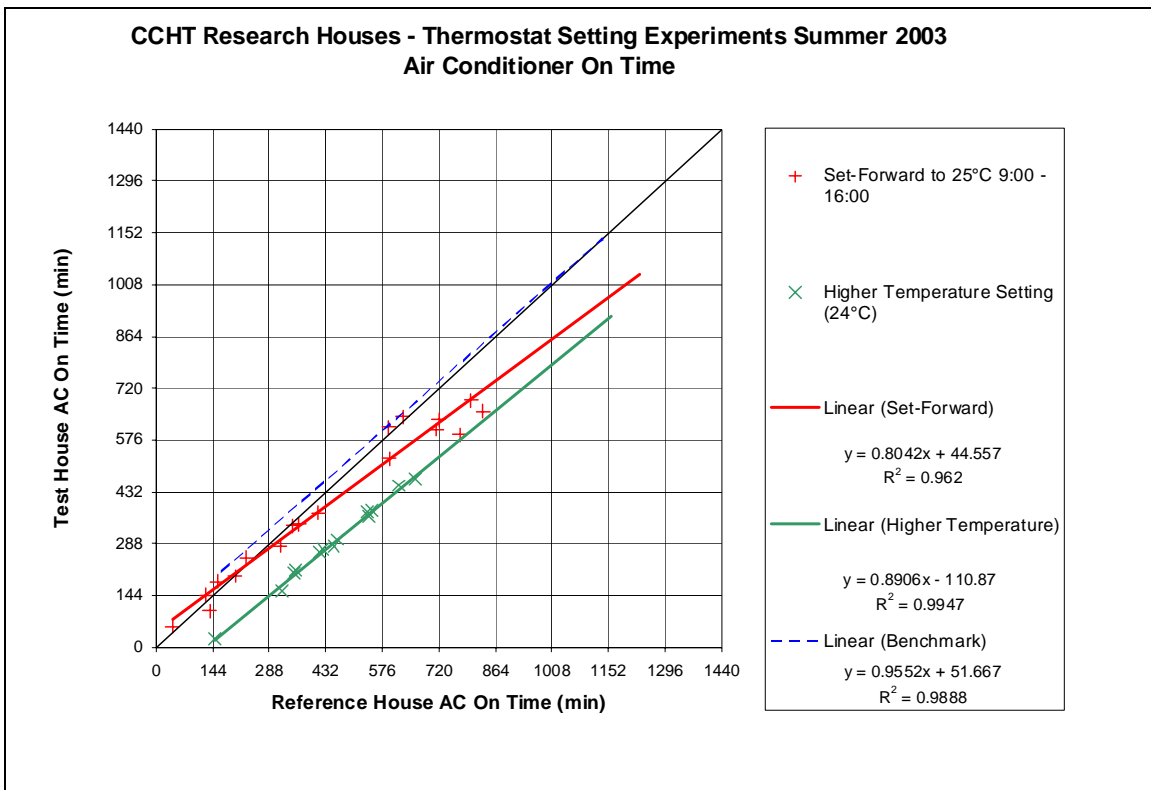

Figure 32 - Summer Thermostat Experiments - Air Conditioner On-Time

We will find the greatest on-time reductions on the hottest day of the heating season. In this experiment, the hottest day of the season was June 26th 2003 (High 34.7°C, Low 23.2°C). On this day the Reference

House air conditioning ran for 1136 minutes. In benchmarking conditions we would expect the Test House air conditioning to run for 1137 minutes. Calculated maximum reductions in on-time for the Test House on this hottest day are summarized in the following table.

Table 14 - Maximum Calculated Reduction in On-time - from Hottest Day Data

Setting	Calculated On-time* (min)	Predicted Reduction (min)	Reduction (%)
22°C Summer Benchmark	1137	-----	-----
25°C Daytime Setforward	958	179	16
24°C Higher Temperature Setting	901	236	21

*Calculated by applying the on-time correlations (Figure 32) to the Reference House coldest day data (on-time of 1136 min)

3.3.2 Electrical Consumption

The same on-time trends are reflected directly in electrical consumption. Longer on-times result in higher electrical consumption, and higher electrical savings. On the hottest day, this translates into the following reductions:

Table 15 - Maximum Calculated Reductions in Air Conditioner Electrical Consumption - from Hottest Day Data

Setting	Calculated Consumption* (kWh/day)	Calculated Reduction (kWh/day)	Reduction (%)
22°C Summer Benchmark	32.249		
25°C Daytime Setforward	26.655	5.593	17
24°C Higher Temperature Setting	25.859	6.390	20

*Calculated by applying the AC electrical consumption correlations (Figure 33) to the Reference House coldest day data (AC electrical consumption of 31.549 kWh)

Table 16 - Maximum Calculated Reductions in Furnace Fan Electrical Consumption - from Hottest Day Data

Setting	Calculated Consumption* (kWh/day)	Calculated Reduction (kWh/day)	Reduction (%)
22°C Summer Benchmark	13.565		
25°C Daytime Setforward	12.843	0.722	5.3
24°C Higher Temperature Setting	12.383	1.182	8.7

*Calculated by applying the furnace fan electrical consumption correlations (Figure 33) to the Reference House coldest day data (furnace fan electrical consumption of 12.536 kWh)

Table 17 - Maximum Predicted Reductions in A/C and Furnace Fan Electrical Consumption - from Hottest Day Data

Setting	Calculated Consumption (kWh/day)	Calculated Reduction (kWh/day)	Reduction (%)
22°C Summer Benchmark	45.814		
25°C Daytime Setforward	39.498	6.316	14
24°C Higher Temperature Setting	38.242	7.572	17

For projected electrical savings over the entire cooling season, please refer to Section 4.1.
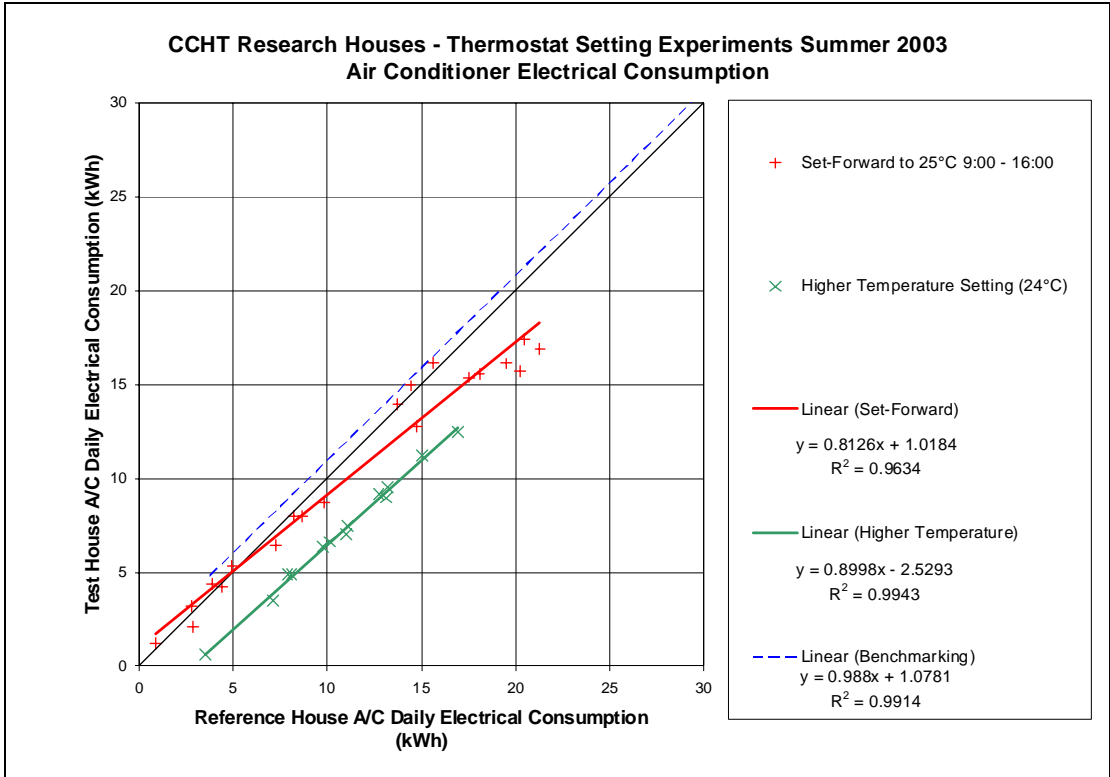
Figure 33 - Summer Thermostat Experiments - Air Conditioner Electrical Consumption
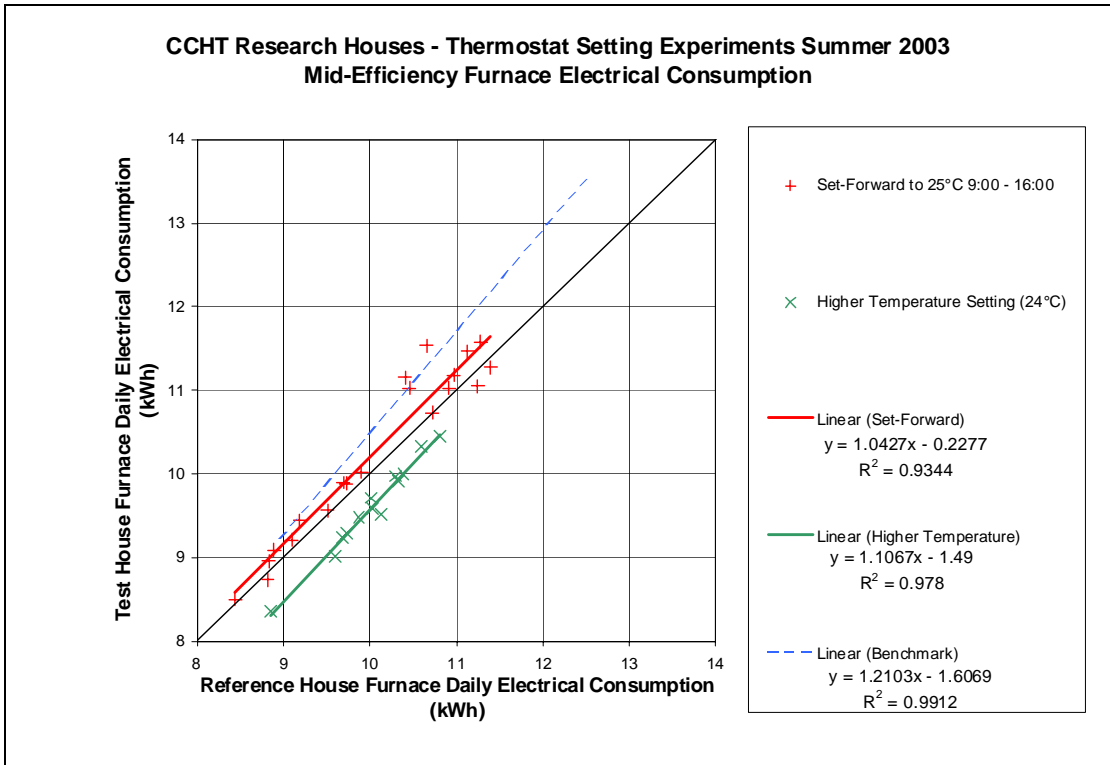
Figure 34 - Summer Thermostat Experiments - Furnace Fan Electrical Consumption
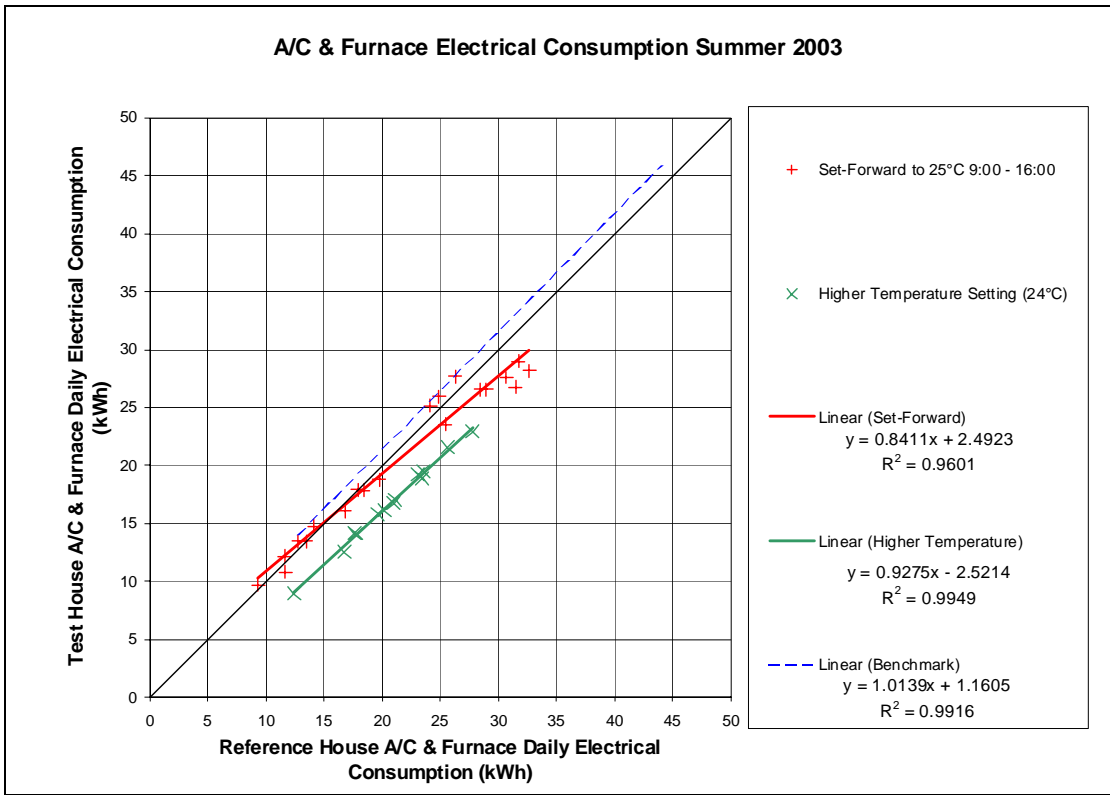
Figure 35 - Summer Thermostat Experiments – Air Conditioning and Furnace Fan Electrical Consumption

3.3.3 Effects of Solar Radiation on Setforward

The difference between sunny day and cloudy day setforward trends is even more distinct than those of the winter setback. On sunny days the Test House is allowed to float up to the 25°C setforward setting, while the Reference House fights against large solar gains to keep the house at 22°C. Savings are very slight on cloudy days, likely due to the fact that the Reference House air conditioning system did not need to run often during the setforward period to maintain the house temperature at the set point. During the cloudy days in this experiment, the Test House temperature never drifted high enough to reach the 25°C setting.
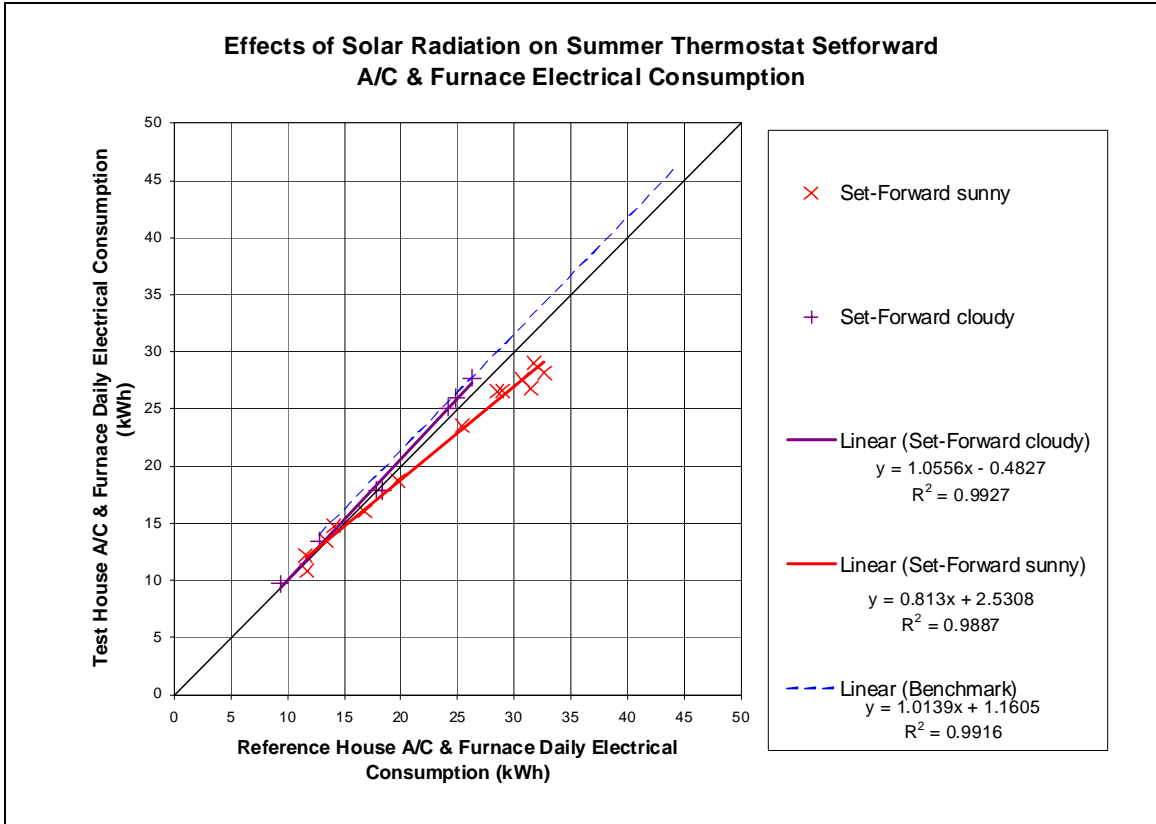
Figure 36 - Effects of Solar Radiation on Summer Thermostat Setforward

3.3.4 Setforward & House Humidity

In examining house humidity, we looked at both the condensate (as a measure of moisture removed from the air), as well as the average humidity ratio of air throughout the house. During thermostat setforward there is a scatter of condensate data around the benchmark – no clear increase or decrease in condensate collection (see Figure 37) or change in household humidity (Figure 39). By contrast, during the higher temperature setting experiment, there is a distinct drop in AC condensate collected in the Test House. This is due to the fact that the air conditioning system on-time is reduced at this higher temperature setting (see Figure 32), and therefore the air conditioner coil spends less time extracting water from the air. As expected, this drop in condensate results in an increase in overall humidity, shown in Figure 38. This increase in thermostat setting accompanied by a resultant increase in household humidity will affect occupant comfort.
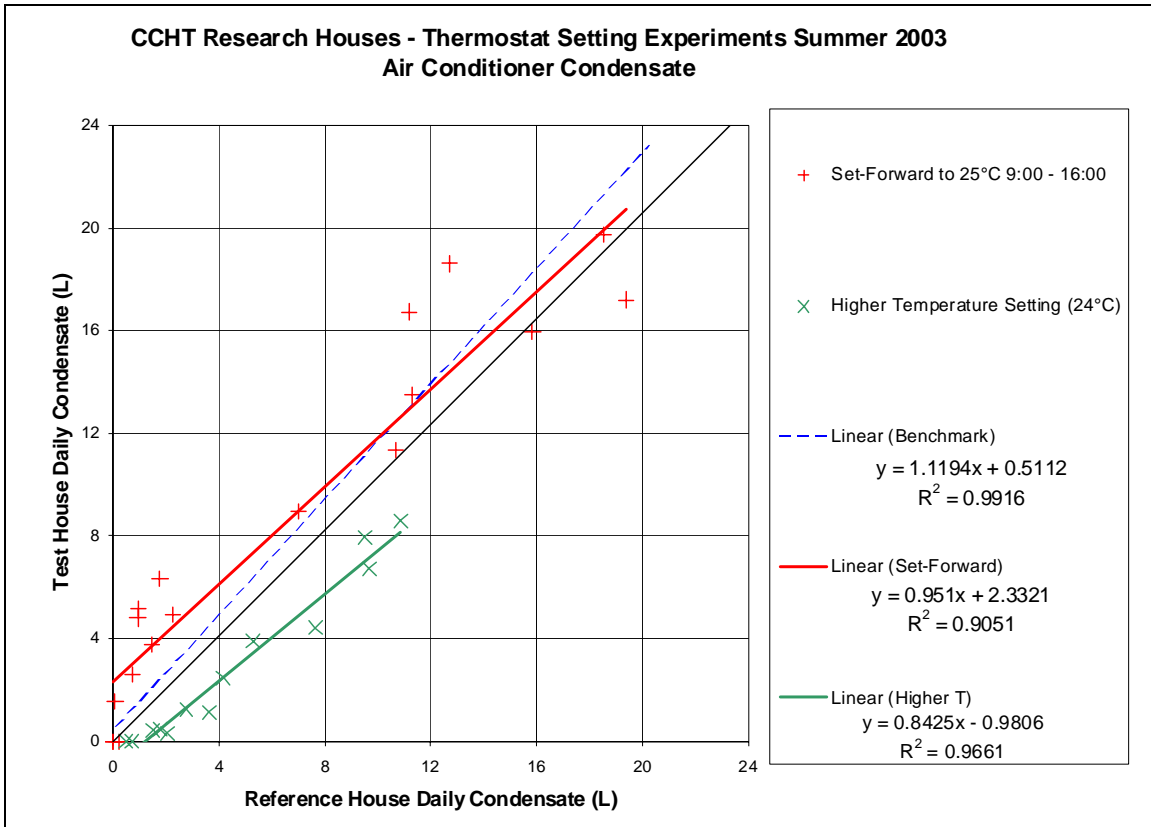
Figure 37 - Summer Setforward Experiments - Air Conditioner Condensate
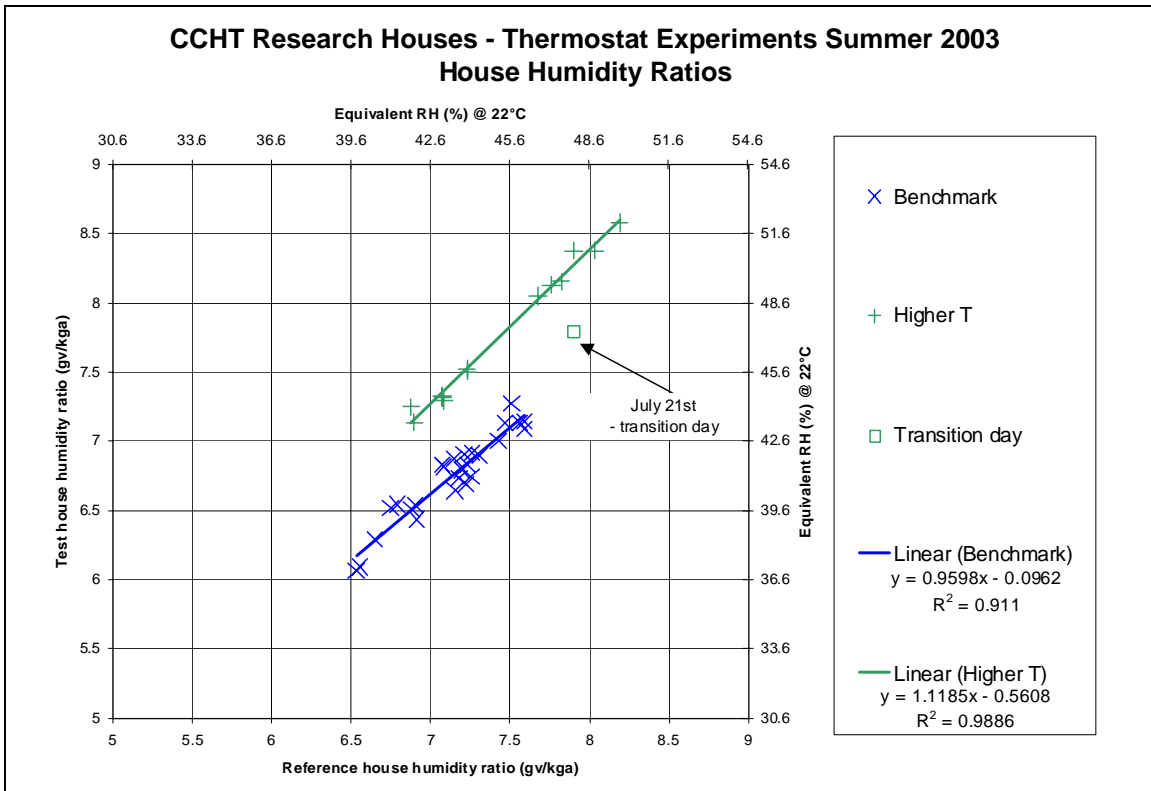
Figure 38 - House Humidity Ratios for Higher Temperature Setting
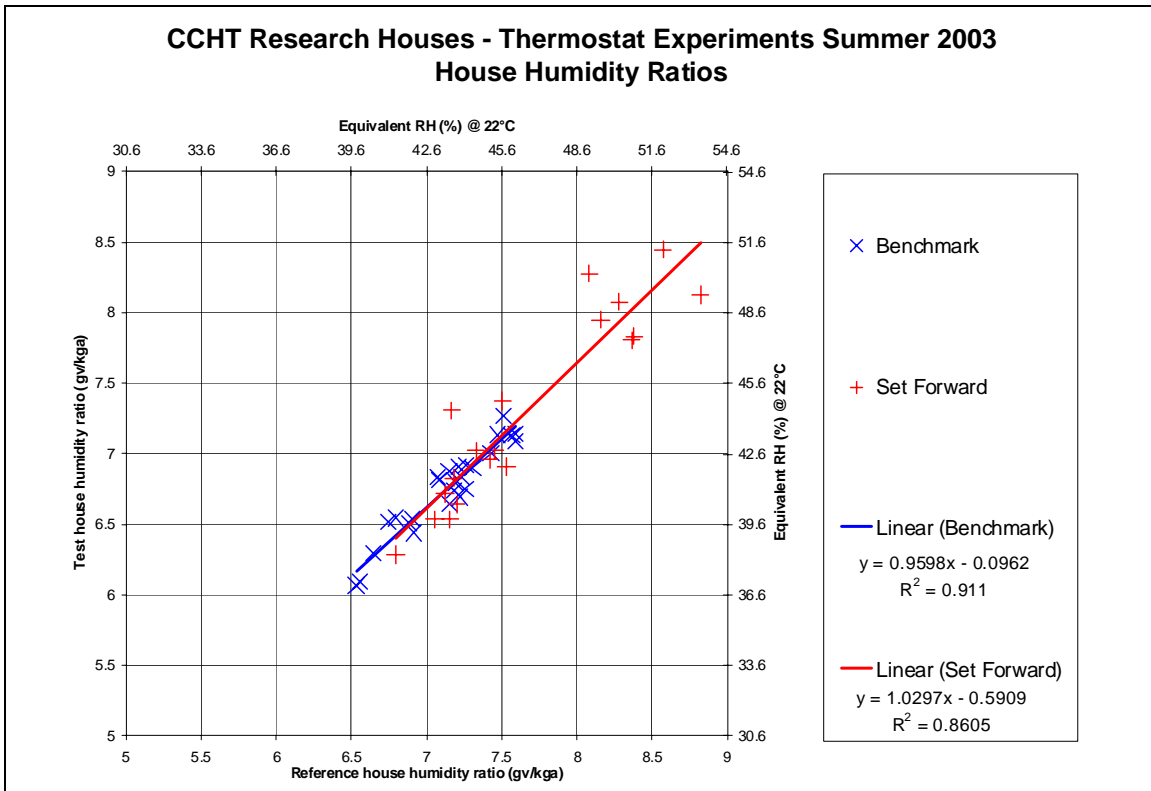
Figure 39 - House Humidity Ratios for Thermostat Setforward

3.3.5 Recovery Time

Setforward recovery time is directly related to the maximum temperature reached by the house. When the house approaches the 25°C setforward temperature on the hottest summer days, it can take over 7 hours for the house to fully recover, as shown in Figure 40.

**CCHT Test House Maximum Main Floor Temperature VS Recovery time
Thermostat Set Forward Experiment - Summer 2003**

$y = 0.4082x^2 - 17.039x + 177.77$
$R^2 = 0.9298$
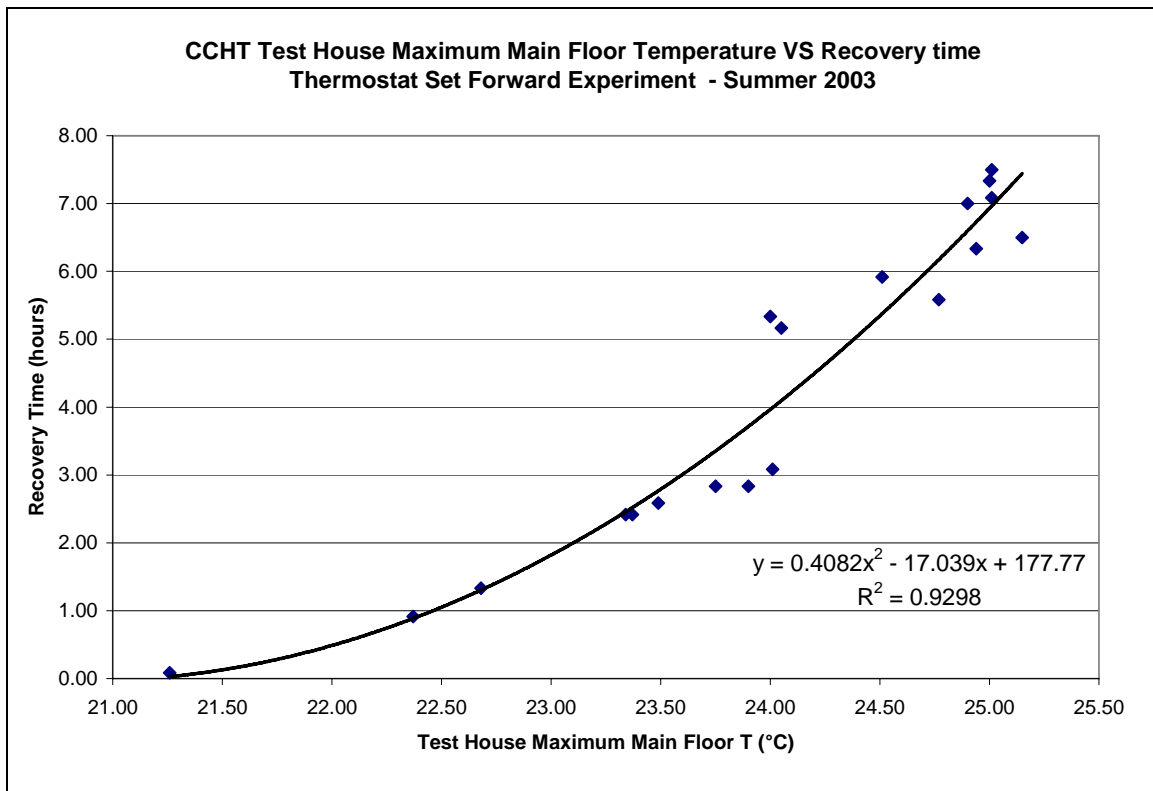
Figure 40 - Summer Setforward Recovery Time

The following figures offer a sample of recovery times from thermostat setforward. The recovery time for July 16th is shown in Figure 41. This was not a record hot day - with an outdoor temperature high of 26.6°C, nor was it an extremely sunny day – as shown by Figure 42. However, on this day the indoor temperature of the house reached close to 25°C, and took over 6 hours to recover from the setforward.

July 18th was a cooler day, with a high of 22.7°C. Solar gains on this day caused the Test house main floor temperature to rise more than a degree above the outdoor temperature, requiring over 3 hours to recover (see Figure 43 and Figure 44).
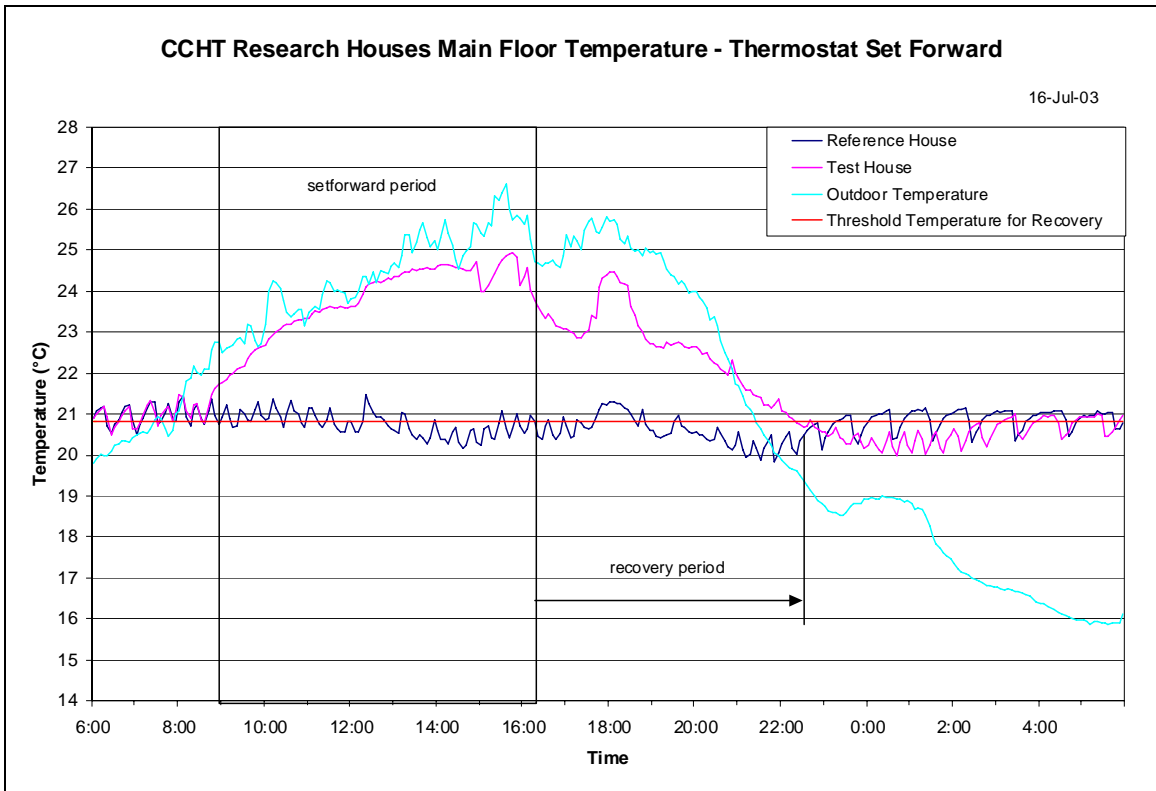
Figure 41 - Sample Recovery Period for Summer Thermostat Setforward July 16th 2003
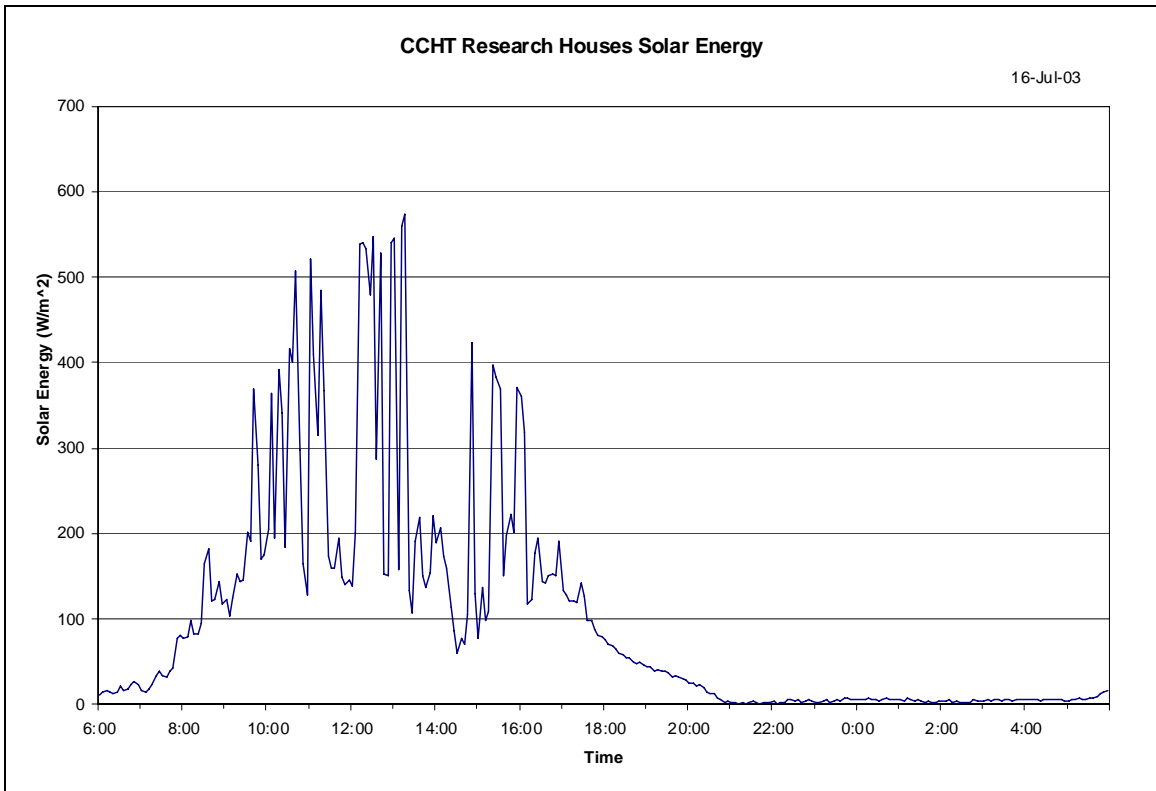
Figure 42 - Solar Radiation on South Wall July 16th 2003
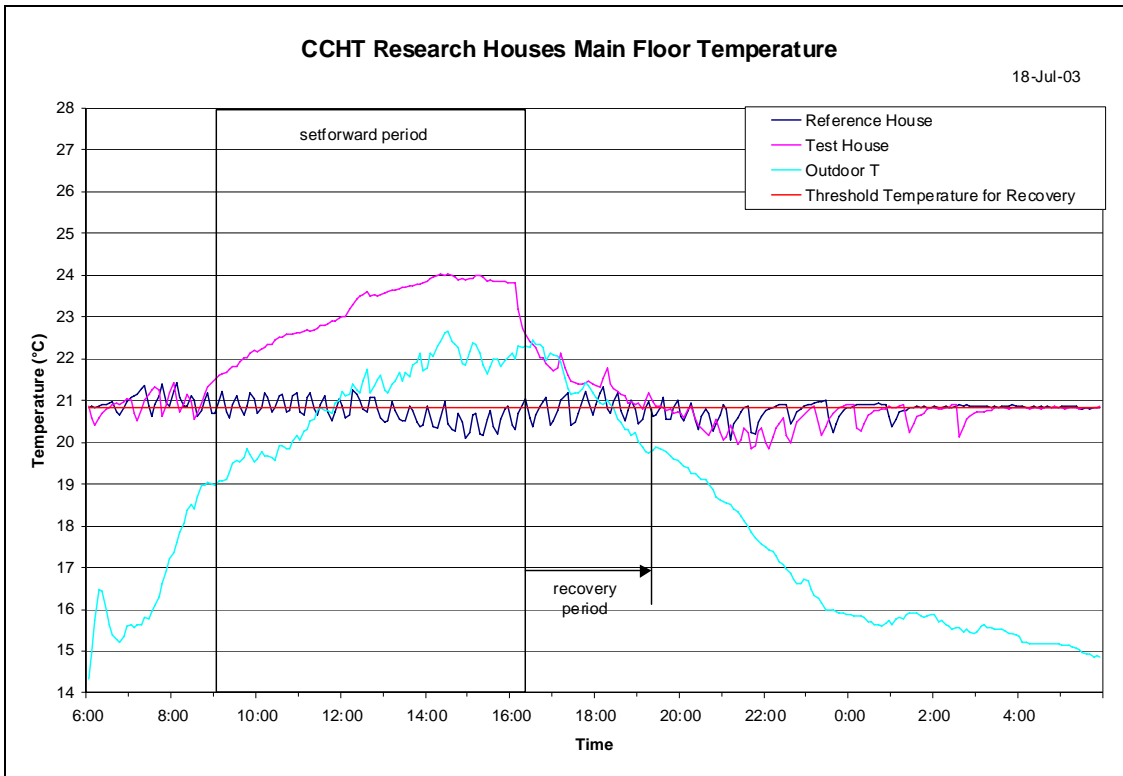
Figure 43 - Sample Recovery Period for Summer Thermostat Setforward July 18th 2003
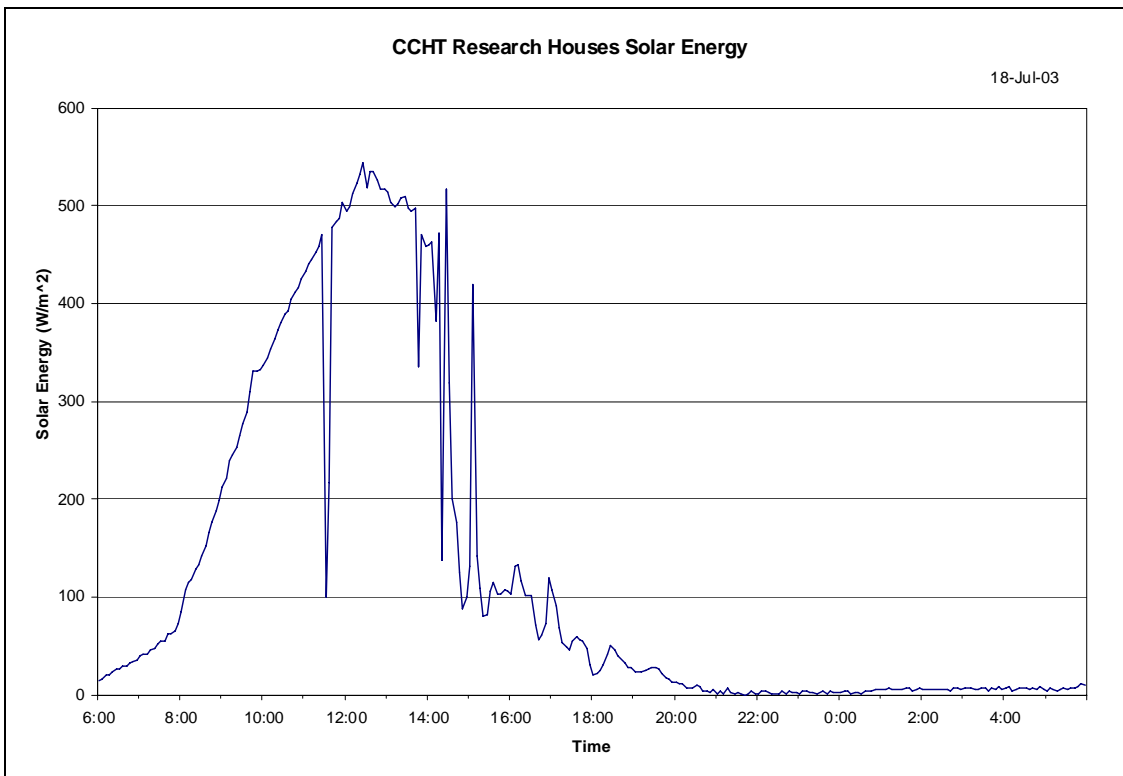
Figure 44 - Solar Radiation on South Wall July 18th 2003

3.3.6 House Temperatures

During the summer thermostat experiments, maximum temperature differences were magnified on the 2nd floor and buffered in the basement. A 2-degree thermostat setting increase translates into a 2.45-degree increase on the 2nd floor and only a 1.47-degree increase in the basement. Detailed graphs of summer house temperatures can be found in Appendix E.

Table 18 - Minimum House Temperatures – Summer 2003

|	Main Floor (°C)			2nd Floor (°C)			Basement (°C)		
	Test	**Ref**	**Difference**	**Test**	**Ref**	**Difference**	**Test**	**Ref**	**Difference**
22°C Benchmark	20.46	20.77	-0.31	22.13	21.83	0.3	17.26	17.54	-0.28
25°C Setforward	21.17	20.98	0.19	22.54	21.94	0.6	18.31	18.06	0.25
24°C Setting	22.70	20.8	1.9	23.66	21.54	2.12	18.98	17.81	1.17

Table 19 - Maximum House Temperatures – Summer 2003

	Main Floor (°C)			2nd Floor (°C)			Basement (°C)		
	Test	**Ref**	**Difference**	**Test**	**Ref**	**Difference**	**Test**	**Ref**	**Difference**
22°C Benchmark	22.07	22.34	-0.27	25.84	25.77	0.07	19.51	19.54	-0.03
25°C Setforward	24.65	21.76	2.89	27.16	23.91	3.25	21.68	19.76	1.92
24°C Setting	23.63	21.62	2.01	25.86	23.41	2.45	21.28	19.81	1.47

4 Discussion

4.1 Estimation of Electrical and Gas Savings to the Entire Heating or Cooling Season

The results from the thermostat setting experiments can be estimated for the entire heating and cooling seasons by combining experimental results of this project with one year of monitored data for the CCHT Reference House. The extrapolation method was originally developed by Mike Swinton for the CCHT Combo experiments [6], and further developed by Marianne Manning for the purpose of this report. This method involves examining the measured performance of the Reference House for a full year, Nov 2002 – Oct 2003 year (4671 heating degree days, which is very close to the published long-term degree days for Ottawa), and calculating the expected consumption of the Test House for any given technology. A 'bin technique' is used to capture the number of days in which the Reference house consumes a certain quantity of energy. The frequency of occurrence of each 'bin' is established from the monitored data for the Reference house. Then, using the linear correlations published in this report, the corresponding Test house performance is established for those consumption bins. Multiplying the frequency of occurrence (number of days) by the consumption of each house in the same conditions (MJ/day), allows us to integrate the bins into total seasonal consumption for each house. A full description can be found in reference 5.

On this basis the following savings in Test House furnace gas and electrical consumption were calculated for the entire heating season:

Table 20 – Calculated Winter Furnace Gas Consumption Savings from Thermostat Setback

Condition	Total Furnace Gas Consumption (MJ)	Predicted Savings from Benchmark (%)
22°C Winter Benchmark	66131	--
18°C Night Setback	61854	6.5
18°C Night and Day Setback	59231	10
16°C Night and Day Setback	57241	13

Table 21 – Calculated Winter Furnace Electrical Consumption Savings from Thermostat Setback

Condition	Total Furnace Electrical Consumption (kWh)	Predicted Savings from Benchmark (%)
22°C Winter Benchmark	2314	--
18°C Night Setback	2295	0.8
18°C Night and Day Setback	2270	1.9
16°C Night and Day Setback	2261	2.3

Similarly, savings can be calculated for the cooling season. We estimate the following Test House electrical savings on furnace and air conditioning consumption for the entire 2003 cooling season:

Table 22 - Calculated Summer Electrical Savings from Thermostat Setting

Condition	Total Furnace & AC Electrical Consumption (kWh)	Predicted Savings from Benchmark (%)
22°C Summer Benchmark	3099	-----------------------
25°C Day Setforward	2767	11
25°C Day Setforward – all sunny	2690	13
25°C Day Setforward – all cloudy	3010	2.9
24°C Higher Setting	2376	23

4.2 Significance of On-time Data

Throughout the winter setback experiments, on-time data showed larger percentage reductions than gas or electrical data. For example, on the coldest day we would expect a 16°C day and night setback to produce a reduction in on-time of 28%, a reduction in gas consumption of 21%, and a reduction in furnace fan electrical consumption of 8.4%.

On-time of the furnace is a measurement of the time spent by the circulation fan in high speed mode. During the heating season, the fan runs in high speed for a "furnace cool down period" (~1.6 min in length) after the burner has shut off - during this discussion this portion of the fan on time will be referred to as FAN_{CDP}. In setback mode, FAN_{CDP} is completely eliminated during the setback period until the house drifts down to the setback temperature, which for an energy efficient R-2000 house takes considerable time. As well, because the furnace can run for a stretch of up to 50 minutes in recovery mode, 5 or more furnace cycles are eliminated, again reducing FAN_{CDP}. By reducing FAN_{CDP} as well as the overall on-time of the furnace, the thermostat setback strategy produces even greater on-time savings. On this coldest day, reductions in FAN_{CDP} account for the 7% difference between percentage reductions in on-time and gas consumption.

Reductions in electrical consumption (%) are much smaller than reductions in on-time because the furnace fan is run continuously in low speed to provide circulation to the house while not in high-speed heating mode. Larger percentage reductions would be shown if the furnace fan were set to automatic – only running when there is a demand for heat. In the "auto" setting we would expect savings in the order of on-time savings, possibly larger than gas savings. Setback experiments without continuous circulation would have to be run to verify this hypothesis.

4.3 Limitations

Thermostat setback savings will be different for different houses and mechanical setups. Care should be taken in applying these results to other homes, due to certain attributes of the CCHT facility.
Some of the issues that should be kept in mind include:

- The CCHT houses are built to R-2000 standards; therefore, they hold heat better than older houses. As a result, they don't cool down as quickly during setback for example, and there is less benefit to the strategy. This was seen in warmer weather, where savings were negligible.

- During thermostat setback, lower quality windows and insulation could lead to lower surface temperatures and additional condensation problems.

- The furnaces are sidewall-vented mid-efficiency furnaces and are oversized by about 50%, based on monitored results so far. A smaller sized furnace would likely take a longer time to recover from thermostat setback. Similarly, air conditioner sizing is a factor in summer setforward recovery times.

- The houses feature a heat recovery ventilator that runs in continuous circulation mode to bring fresh air into the house while losing little heat. This is a feature of R-2000 houses due to their high airtightness, and not common in older "looser" houses where air exchange occurs without mechanical help and without heat recovery.

- The CCHT houses are unfurnished. In a furnished house, the contents could affect the time taken for the house to adapt to changes in the temperature settings, and the time required to return to the set temperature.

- The benchmark thermostat setting during the summer testing season was relatively low (22°C). If a higher thermostat setting were to be used for the benchmark condition, this would likely affect the savings predicted from the setforward results.

- The furnace fan runs continuously on low-speed to circulate air through the house, which only reflects a portion of all Canadian households. Increased stratification of house temperatures would be expected when running the fan on "auto".   The "auto" setting would also result in significantly greater percentage savings in furnace electricity. It would probably also cause slightly higher kWh savings in cooling mode, due to less motor heat.

- During the winter trials, the humidity levels were unconventionally low in the houses below 20% RH (no humidifiers were run). Condensation problems can only be predicted by dew point calculation and were not observed by humidity measurement.

- Setback recovery times would be shorter if the heating system did not cycle as temperatures approach the setpoint. The thermostat anticipator could be adjusted to prevent unnecessary cycling during recovery time. However, this would likely result in air temperatures overshooting the setpoint.

5   Conclusions and Recommendations

5.1 Winter Thermostat Setback

The winter experiments demonstrated that setting back the thermostat during the day and night saves energy in the CCHT Test House. As the setback temperature is decreased, savings increased. Also, higher savings (percentage-wise) were achieved on colder days, with longer furnace on-times.

An 18°C night and daytime setback reduced the length of time the furnace ran, resulting in furnace electrical savings of up to 6.4% and furnace gas consumption savings of up to 17% on the coldest day. A 16°C night and daytime setback saved up to 8.1% and 21% in electrical and gas consumption respectively. On warm or sunny days, the heating demand is less, and so savings were reduced. Projecting these results to the entire heating season revealed furnace gas seasonal savings of 13% with the 16°C day and night setback, and 10% with the 18°C day and night setback. Predicted furnace electrical savings were lower for the season: 2.3% and 1.9% savings for the 16°C and 18°C night and daytime setback respectively.

Recovery times from thermostat setback were all below 2 hours, on most occasions taking less than 1 hour to recover. The lower the temperature the house was allowed to reach (the lower the thermostat setback setting), the longer the recovery time. Because of this effect, the thermostat setback temperature and setback times should be chosen wisely to ensure occupant comfort in the early morning, after the nighttime setback, and during the early evening, after the daytime setback. Settings should be anticipated to allow the house ample time to reheat to a comfortable temperature before the occupants awake or return home from work.

Measured drywall surface temperatures remained above 12.7°C for the 16-degree setback, and above 17.8°C for the 18-degree setback. (It should be noted that surface temperatures were measured at the centre of an insulated wall cavity, and lower surface temperatures could be expected on the wall stud framing, at the bottom plates, at corners, or in sections with poorer thermal characteristics). Based on these measurements, no drywall condensation problems would be expected in the CCHT Test House during the setback experiments, unless humidity levels were above RH 55%. Based on current Health Canada recommendations, the Canada Mortgage and Housing Corporation suggests that relative humidity be kept between 30% and 50%, and at 30% when exterior temperatures are below -10°C. Excesses in humidity can lead to window condensation, stains on walls and ceilings, and mold, and allergic reactions. Long-term effects include: structural damage, and health problems. Humidity levels fluctuate with the activities of the house. Occupant breath and perspiration, cooking, showering, bathing, and washing can all increase humidity levels in the home.

Window Surface temperatures in both houses on the other hand were problematic. The frame of the window reached temperatures as low as -2.6°C, even under benchmark conditions, with no setback. We would expect this to lead to condensation and ice problems on the frame, unless RH levels were kept below 19% - not a comfortable level, and below the CMHC recommended 30% RH.

5.2 Summer Thermostat Experiment

Thermostat setforward savings increased with outdoor temperature and solar gains. Thermostat setforward produced savings of up to 21% in Air Conditioning electrical consumption and 5.2% in Furnace fan consumption in the Test House on the hottest sunniest day, totaling over 6.3 kWh electrical savings for that day. Unfortunately, the energy savings from setforward were offset by poor recovery time – up to 7 hours for these same hot days – the same length of time as the setforward itself. This could have a strong influence on occupant comfort during hot summer evenings.

Additionally, thermostat setforward savings were substantially reduced on cloudy days. If all days during the summer were cloudy we would expect Test House electrical savings of only 2.8% on AC and furnace electrical consumption, as opposed to 13% electrical savings for a completely sunny summer.

With current house technology, it is much easier to add heat to an indoor environment than to remove it. For this reason, the summer energy saving strategy needs to be different from the winter energy saving strategy. A 'higher temperature' thermostat setting proved to be a more effective method than employing a daytime setforward.

During the cooling experiments, the higher temperature setting produced consistently higher savings than the setforward strategy, as would be expected – furnace circulation fan and air conditioning electrical savings of 23% for the cooling season were calculated, based on monitored results. Not only did the 'higher temperature' setting produce similar savings on cool and hot days, savings were not reduced on cloudy days. The drawback to the 'higher temperature' setting is the associated increase in overall house humidity, not seen with the setforward strategy. This added humidity and temperature could change comfort levels for the occupant.

5.3 Recommendations for Further Experiments

Future experiments could be conducted to further explore the effects of thermostat setback and higher summer temperature setting. Suggested experiments include:

- Setback with no continuous furnace fan circulation (thermostat set to "auto") to explore house temperature distribution and furnace electrical savings

- Setback with humidified (30% RH) house conditions to explore condensation effects on windows
- Higher Temperature setting combined with exterior blinds to reduce summer solar gains, reducing the load on the air conditioning system and increasing energy savings
- Setback with added mass in the houses, to explore the effect of mass on recovery times and energy savings.
- Investigate different thermostats and their respective control strategies during recovery periods.

6 References

1) Swinton, M.C.; Moussa, H.; Marchand, R.G. "Commissioning twin houses for assessing the performance of energy conserving technologies," Performance of Exterior Envelopes of Whole Buildings VIII Integration of Building Envelopes (Clearwater, Florida, Dec, 2001), pp. 1-10, 2001 (NRCC-44995)

2) ASHRAE Handbook of Fundamentals, 1989.

3) Canada Mortgage and Housing Corporation, Measuring Humidity in Your Home, 1996-2003 CMHC-SCHL November 28th, 2003. Available Online at: http://www.cmhc-schl.gc.ca/en/burema/gesein/abhose/abhose_ce01.cfm

4) Elmahdy, A.H., Effects of Improved Spacer Bar Design on Window Performance. Construction Technology Update #58, Institute for Research in Construction, National Research Council Canada, September 2003. http://irc.nrc-cnrc.gc.ca/ctus/58.html

5) Manning, M.M.; Swinton, M.C. "Annual Energy Consumption Analysis of the CCHT Research Houses", Research Report, Canadian Centre for Housing Technology, IRC,/NRCC, 2005.

6) Swinton, M.C.; Moussa, H.; Entchev, E.; Szadkowski, F.; Marchand, R. Assessment of the Energy Performance of Two Gas Combo Heating Systems at the Canadian Centre for Housing Technology, pp. 18, September 14, 2000 (B-6001.1)

Appendix A – Winter House Temperatures

The following graphs show house temperatures during winter benchmarking, the 16°C setback, and the 18°C setback. Test House and Reference House data has been separated in the setback graphs for clarity.
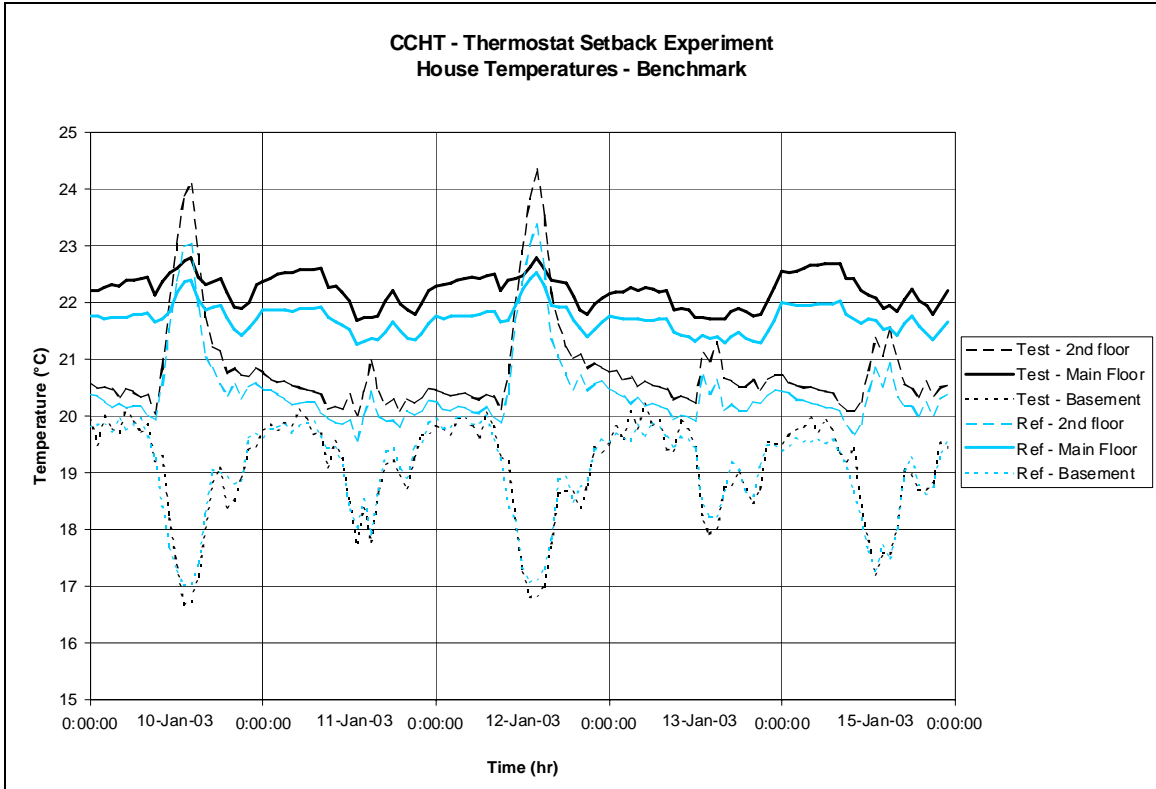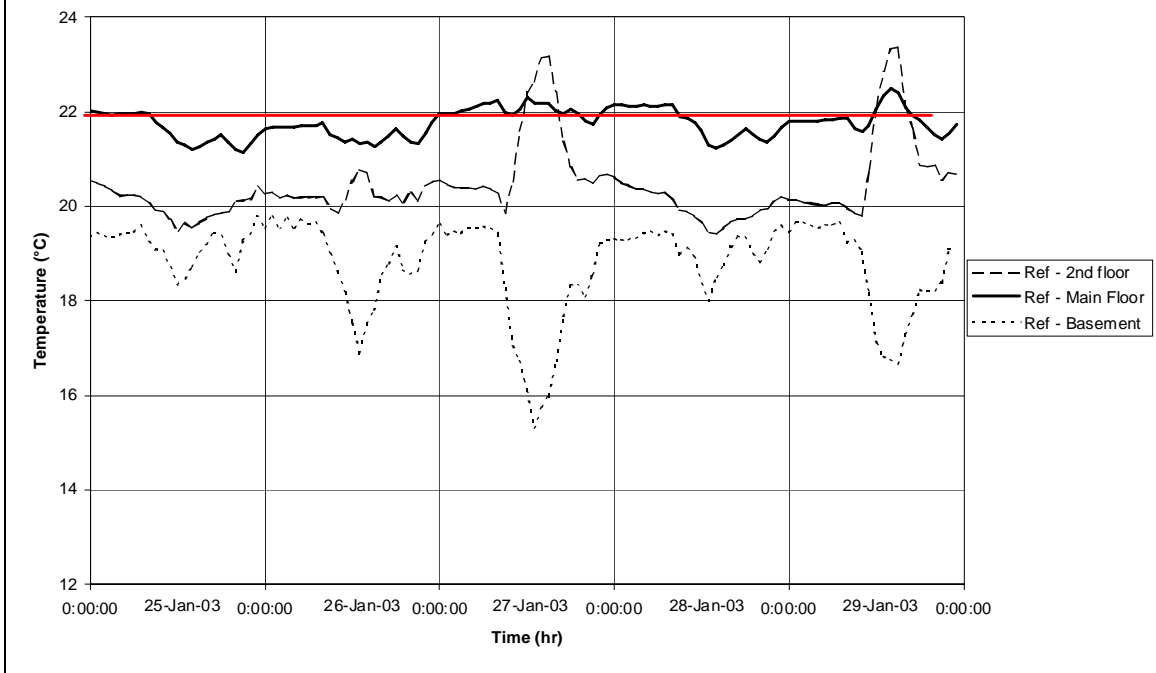
**Temperatures in the Reference House (no setback)
which were Concurrent with those in the Test House During
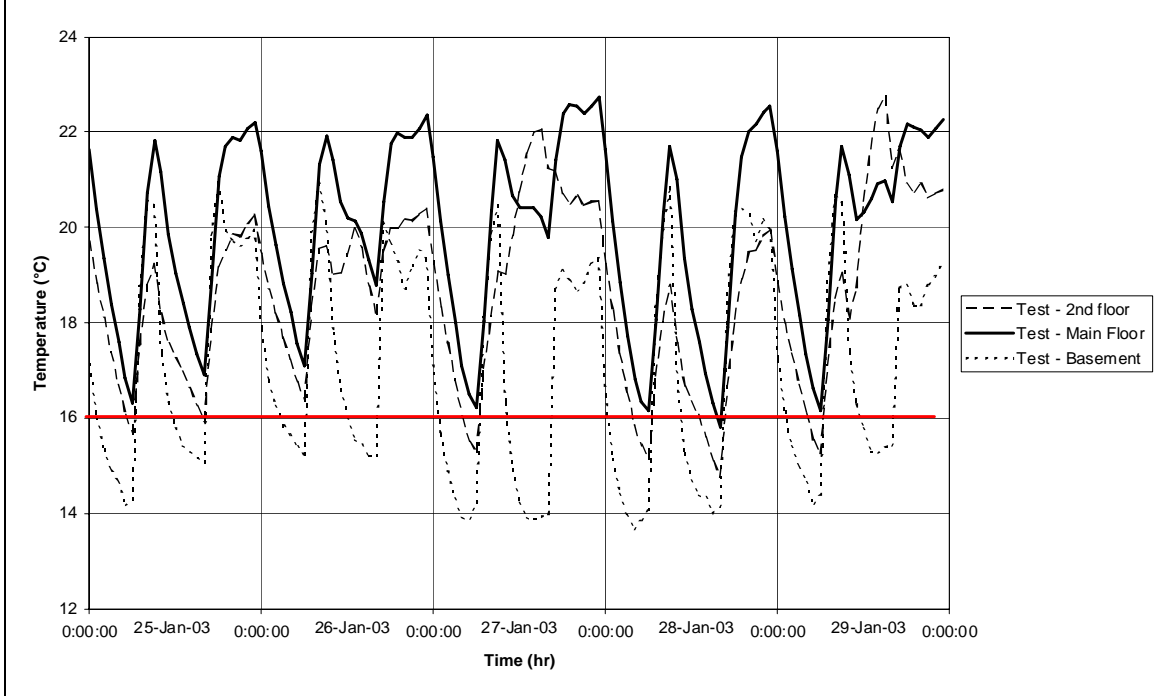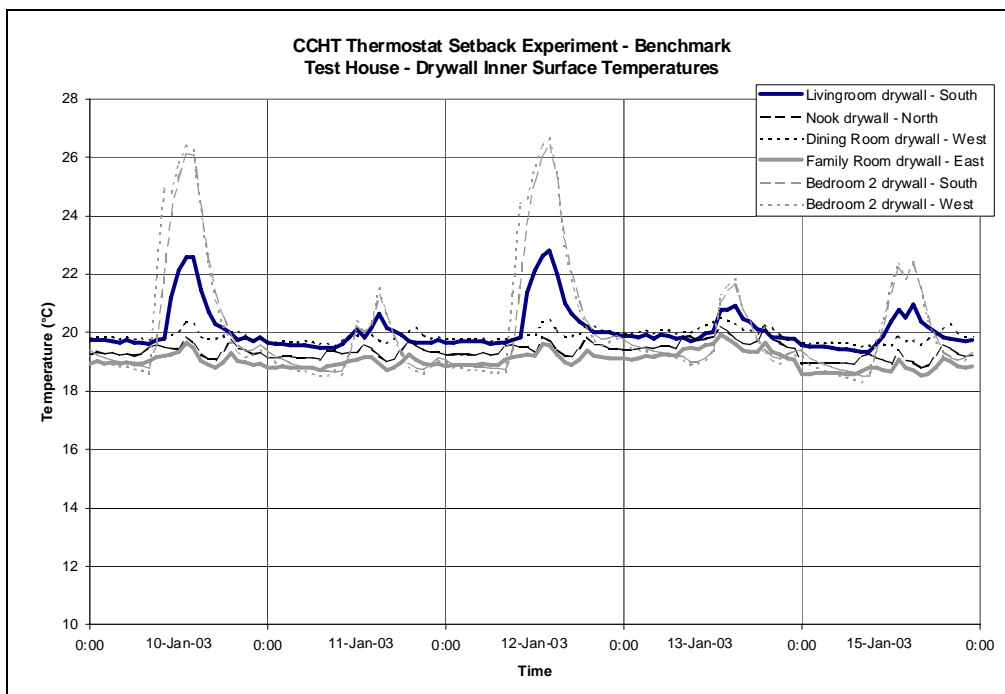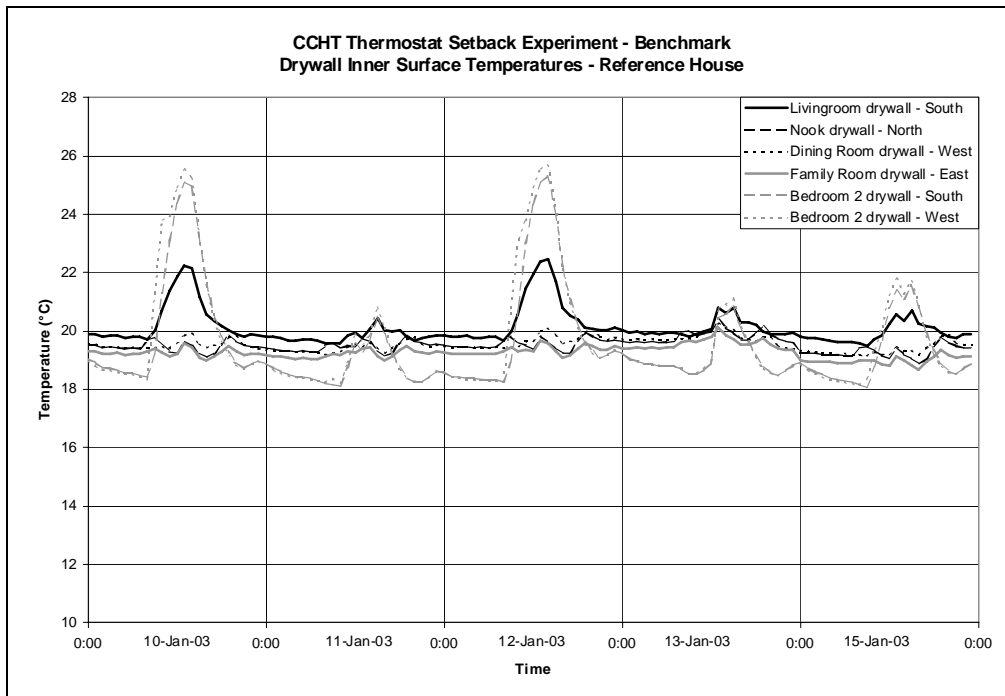the 18°C Night and Day Setback Experiment**
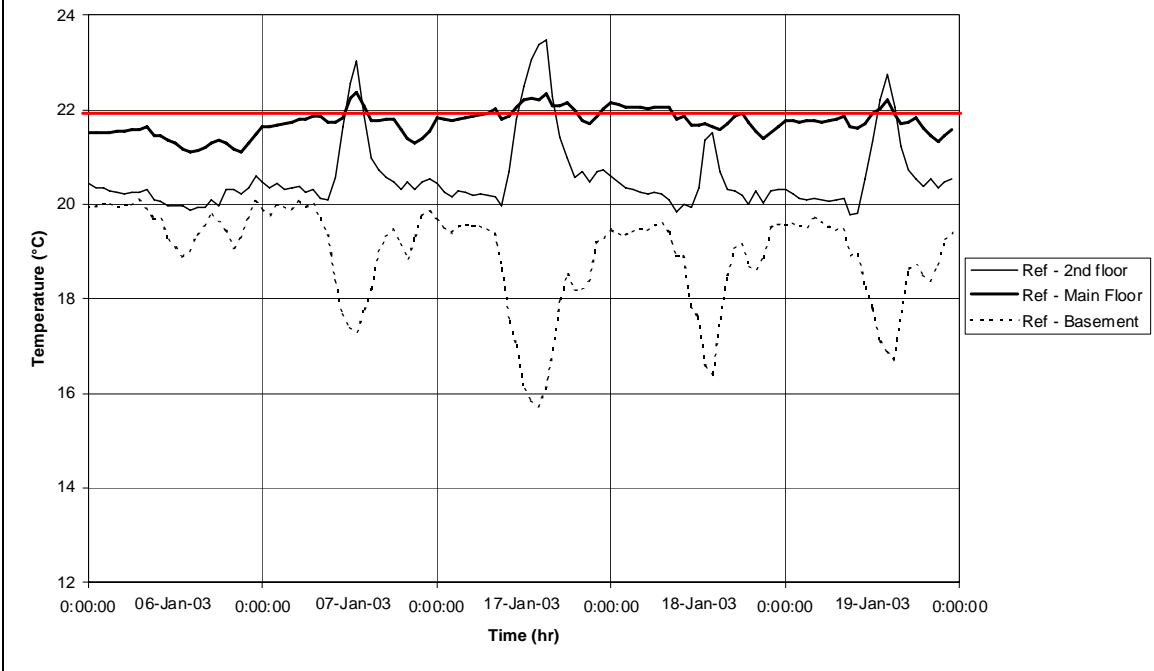
**CCHT - Thermostat Setback Experiment
Test House Temperatures for 18°C day and night setback**
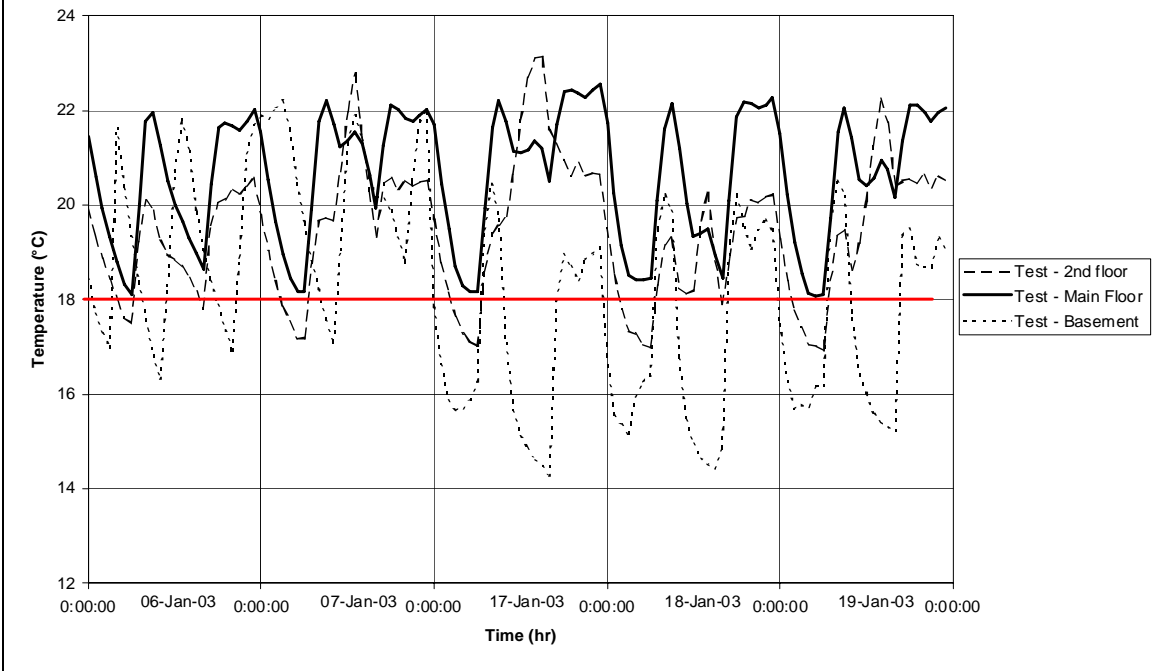
Temperatures in the Reference House (no setback)
which were Concurrent with those in the Test House During
the 16°C Night and Day Setback Experiment

CCHT - Thermostat Setback Experiment
Test House Temperatures for 16°C day and night setback
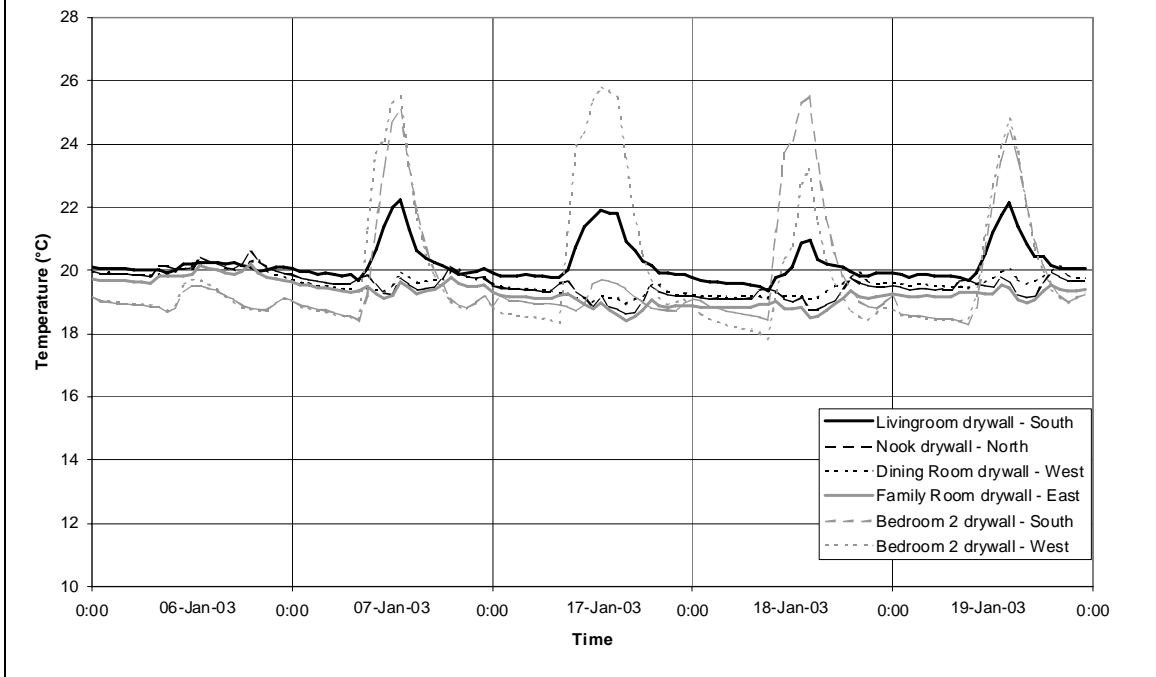
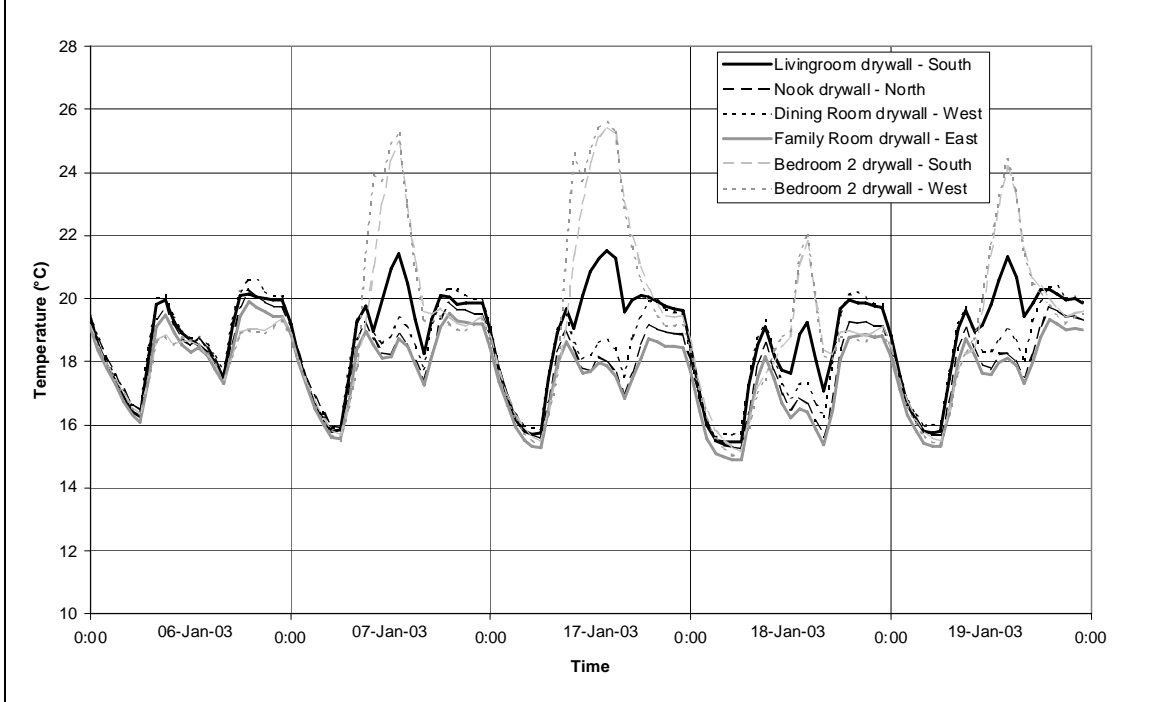# Appendix B – Winter Drywall Surface Temperatures

The following graphs show drywall temperatures during the winter thermostat setback experiments at CCHT. Second floor drywall temperatures in the south facing bedroom (Bedroom 2) are seen to rise above 25 on sunny days due to solar gains. Drywall temperatures in the main floor living room are also affected by these solar gains – although to a lesser extent, as hot air rises.
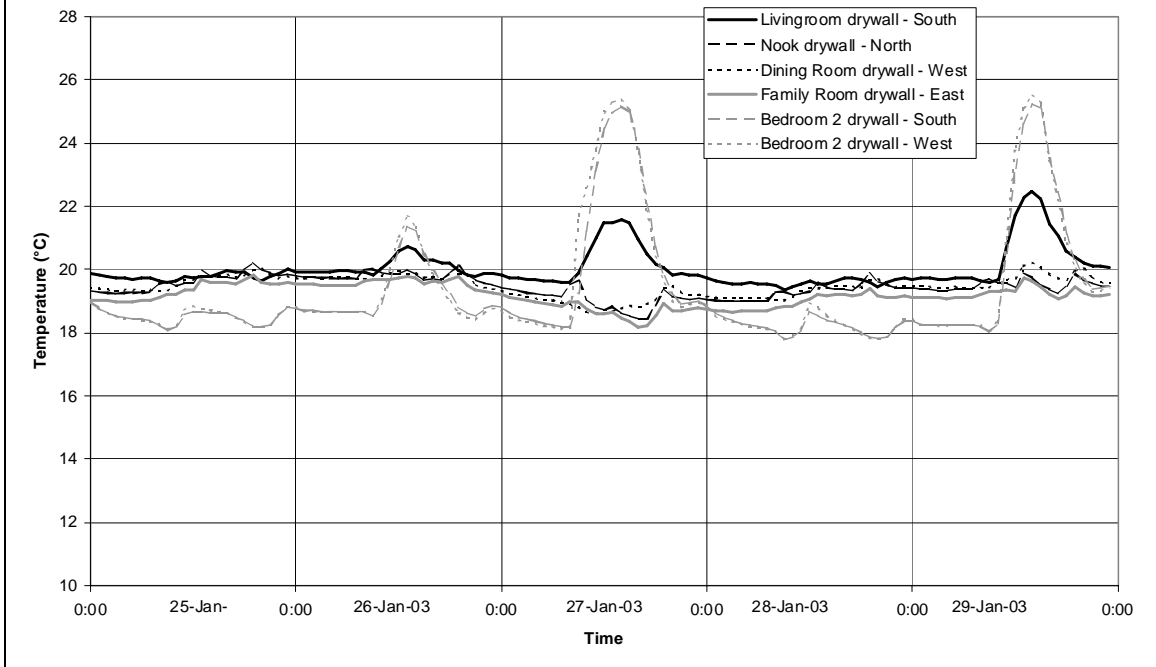
Drywall Inner Surface Temperatures in the Reference House (no setback) which were Concurrent with those in the Test House During the 18°C Night and Day Setback Experiment
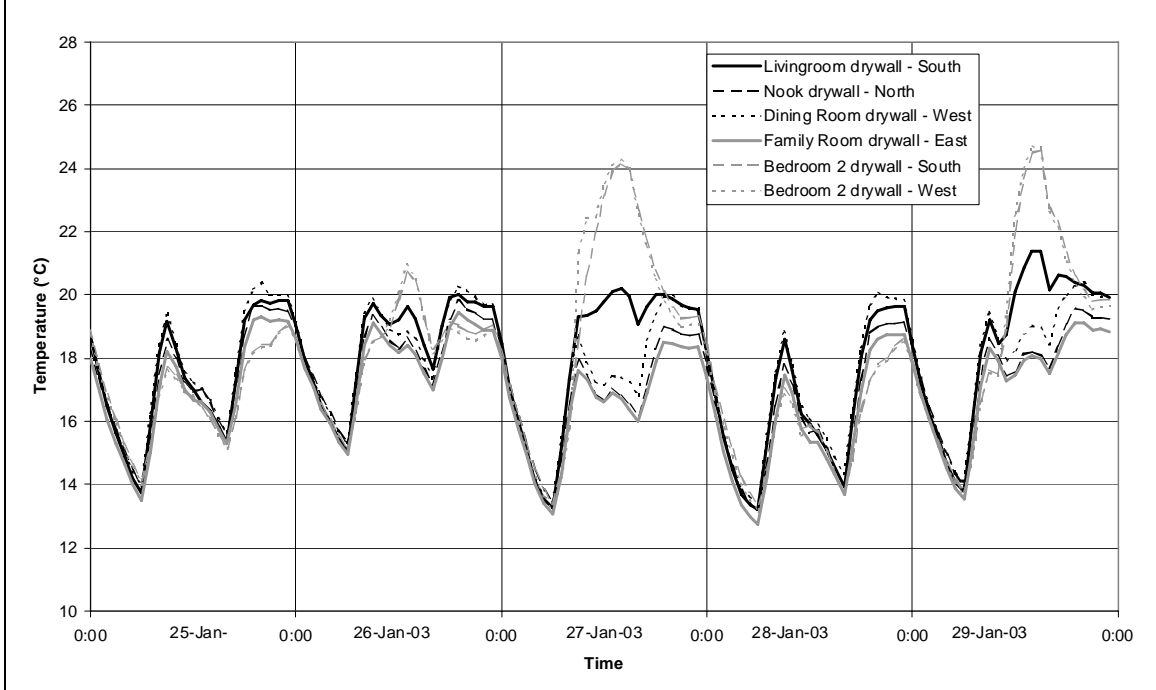
Legend:
- Livingroom drywall - South
- Nook drywall - North
- Dining Room drywall - West
- Family Room drywall - East
- Bedroom 2 drywall - South
- Bedroom 2 drywall - West

Test House
18°C Night and day Setback - Drywall Inner Surface Temperatures

Legend:
- Livingroom drywall - South
- Nook drywall - North
- Dining Room drywall - West
- Family Room drywall - East
- Bedroom 2 drywall - South
- Bedroom 2 drywall - West

Drywall Inner Surface Temperatures in the Reference House (no setback) which were Concurrent with those in the Test House During the 16°C Night and Day Setback Experiment
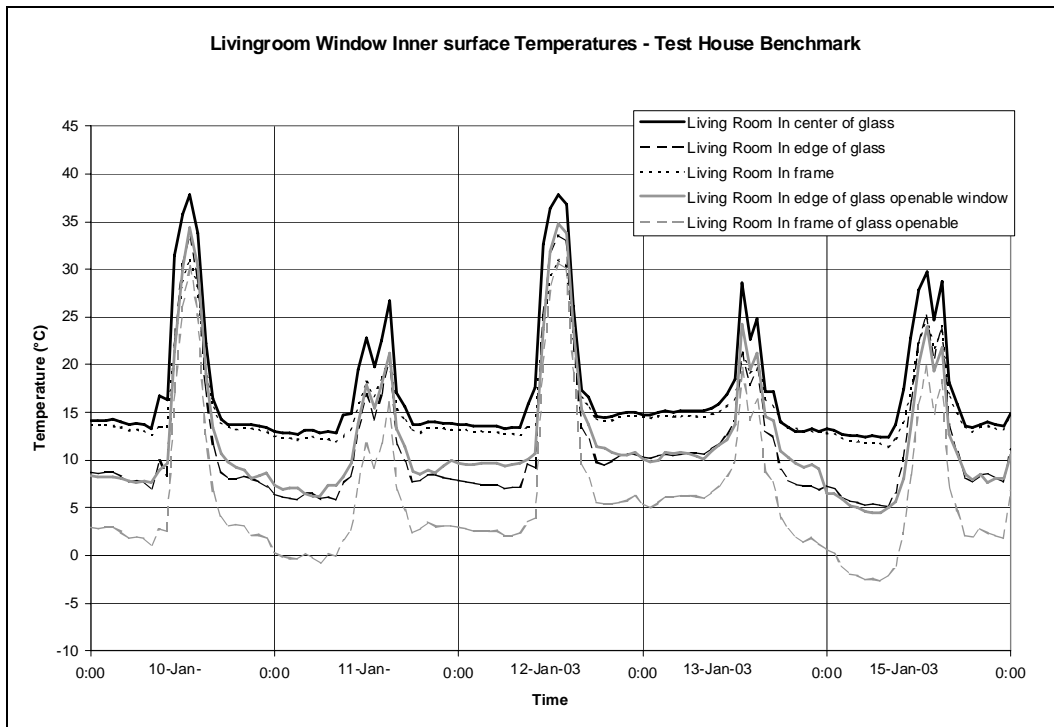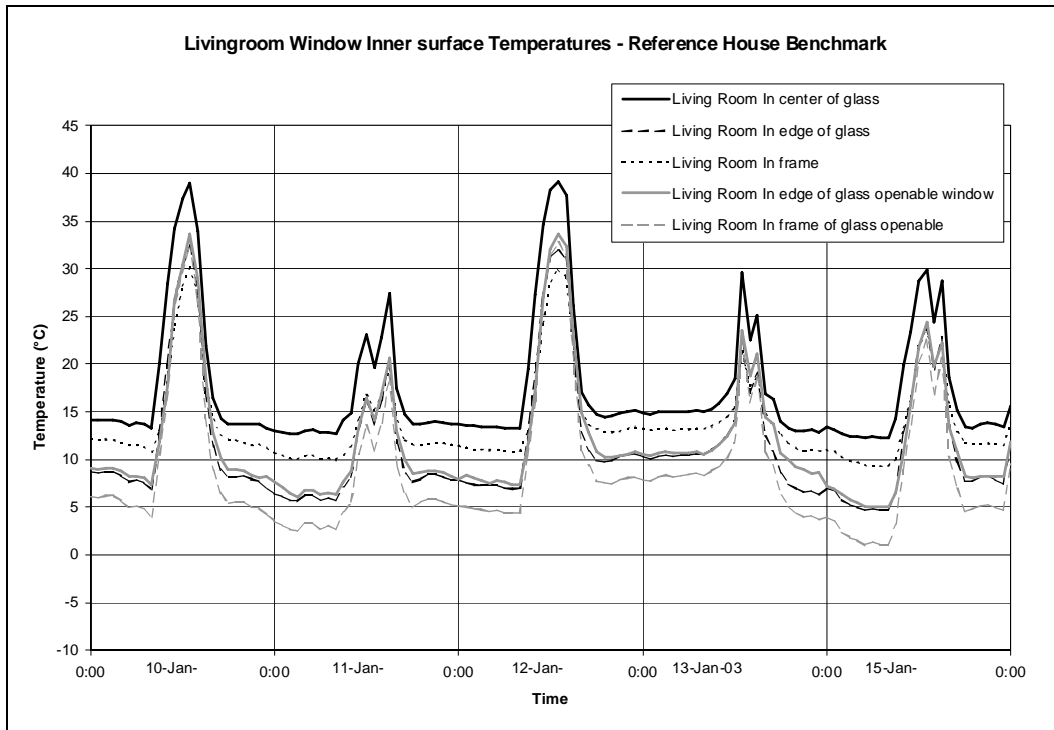
Legend:
- Livingroom drywall - South
- Nook drywall - North
- Dining Room drywall - West
- Family Room drywall - East
- Bedroom 2 drywall - South
- Bedroom 2 drywall - West

Y-axis: Temperature (°C)
X-axis: Time (25-Jan-, 26-Jan-03, 27-Jan-03, 28-Jan-03, 29-Jan-03)

Test House
16°C day and night setback - Drywall Inner Surface Temperatures

Legend:
- Livingroom drywall - South
- Nook drywall - North
- Dining Room drywall - West
- Family Room drywall - East
- Bedroom 2 drywall - South
- Bedroom 2 drywall - West

Y-axis: Temperature (°C)
X-axis: Time (25-Jan-, 26-Jan-03, 27-Jan-03, 28-Jan-03, 29-Jan-03)

# Appendix C – Winter Window Surface Temperatures

The following graphs are a sample of winter surface temperature graphs plotted for the Living room windows. Similar graphs for the Dining room and Bedroom 2 windows can be found in *Thermocouples - wall T's June 24 2003.xls*.

Livingroom Window Inner surface Temperatures - Reference House Benchmark

Legend:
- Living Room In center of glass
- Living Room In edge of glass
- Living Room In frame
- Living Room In edge of glass openable window
- Living Room In frame of glass openable

Livingroom Window Inner surface Temperatures - Test House Benchmark

Legend:
- Living Room In center of glass
- Living Room In edge of glass
- Living Room In frame
- Living Room In edge of glass openable window
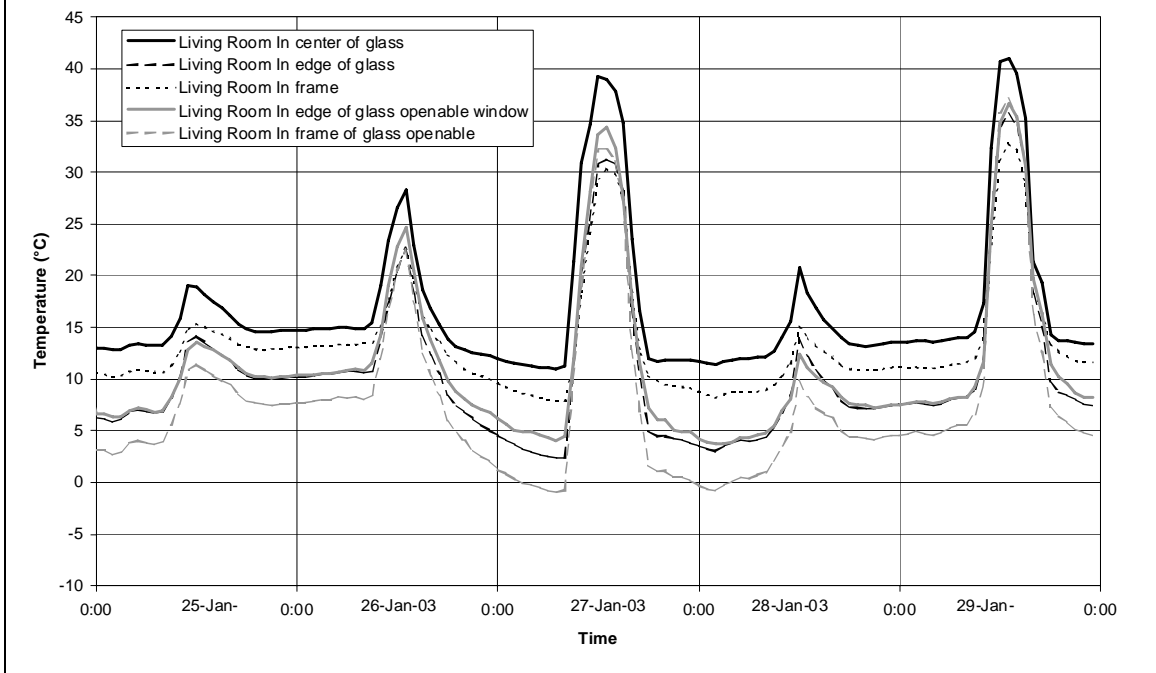- Living Room In frame of glass openable

Livingroom Window Inner surface Temperatures in the Reference House (no setback) which were Concurrent with those in the Test House During the 18°C Night and Day Setback Experiment
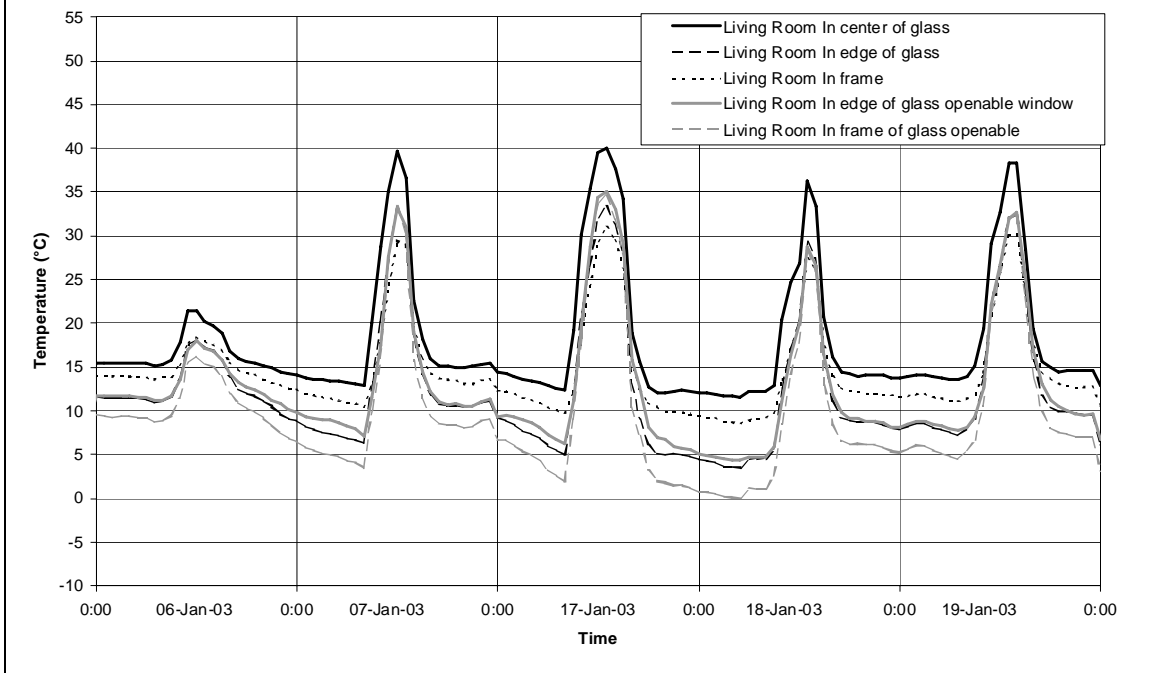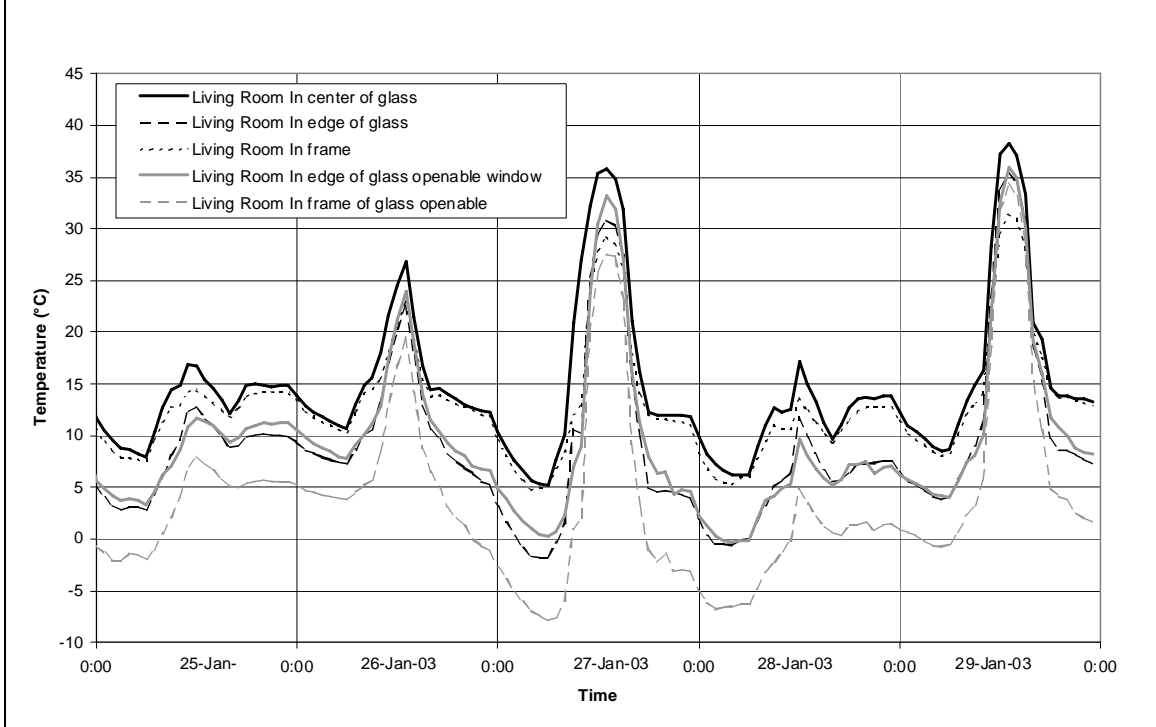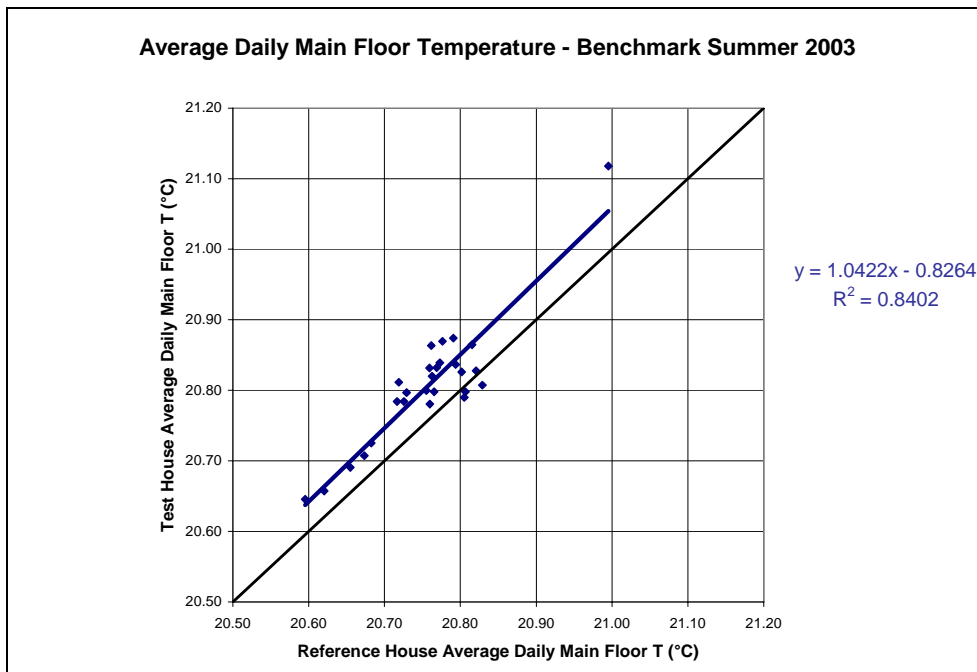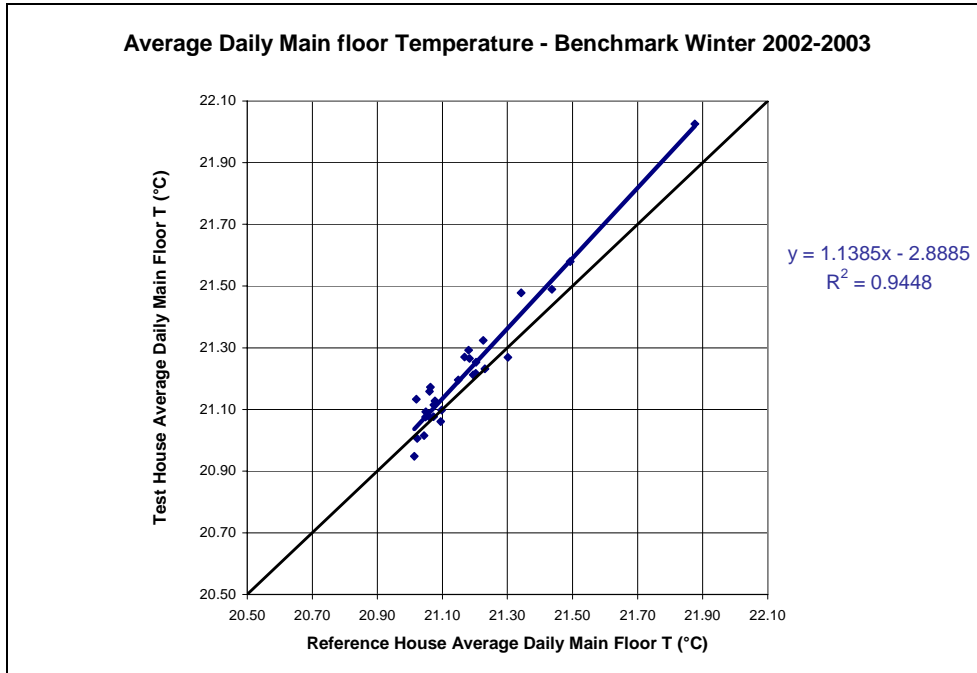

Livingroom Window Inner surface Temperatures - Test House 18°C setback
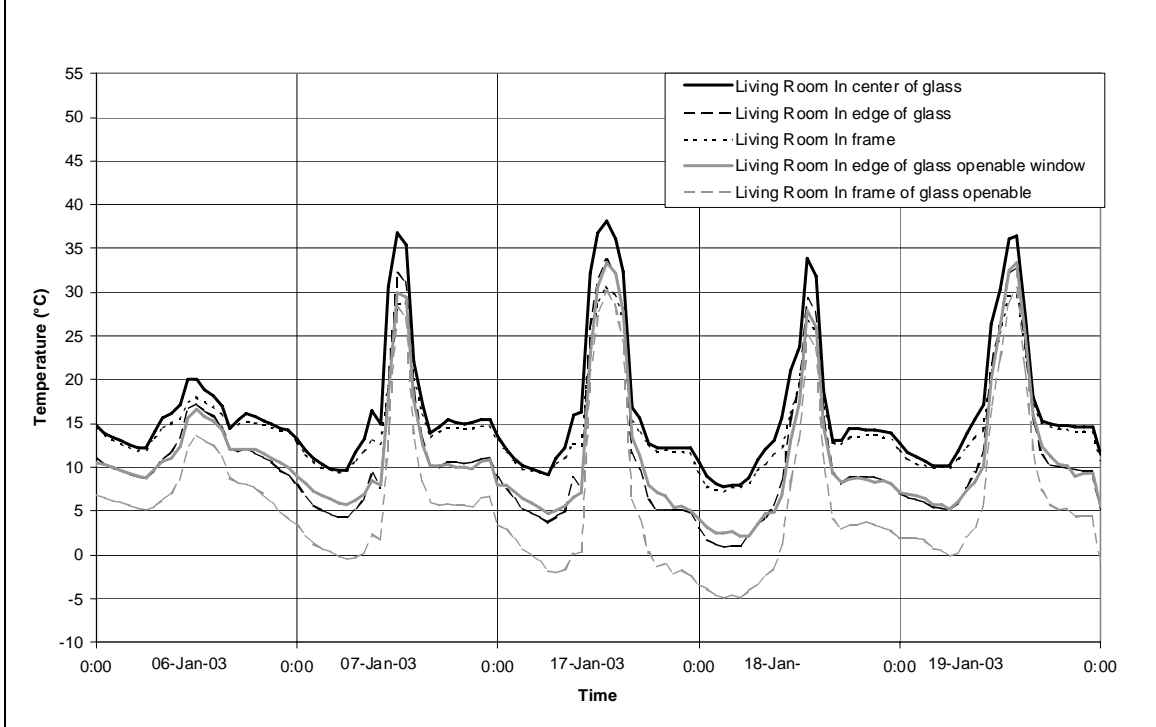
Livingroom Window Inner surface Temperatures in the Reference House (no setback) which were Concurrent with those in the Test House During the 16°C Night and Day Setback Experiment

Livingroom Window Inner surface Temperatures - Test House 16°C Setback
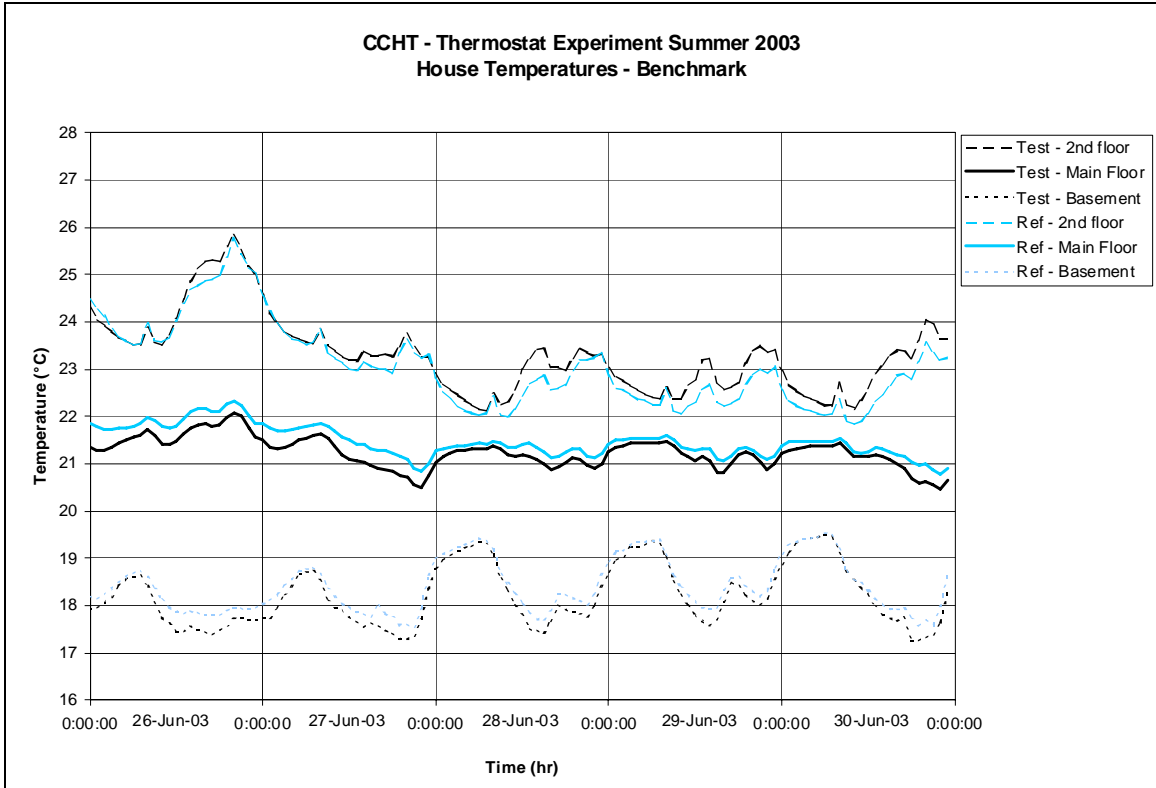
# Appendix D – Benchmark of Main Floor Temperature – for recovery threshold calculation

The following graphs were created in order to determine the threshold temperature for recovery from thermostat setback and setforward.


Average Daily Main floor Temperature - Benchmark Winter 2002-2003

$y = 1.1385x - 2.8885$
$R^2 = 0.9448$

Average Daily Main Floor Temperature - Benchmark Summer 2003

$y = 1.0422x - 0.8264$
$R^2 = 0.8402$

Appendix E – Summer House Temperatures

Temperatures in the Reference House (no higher temperature setting) which were Concurrent with those in the Test House During the 25°C Daytime Setforward Experiment
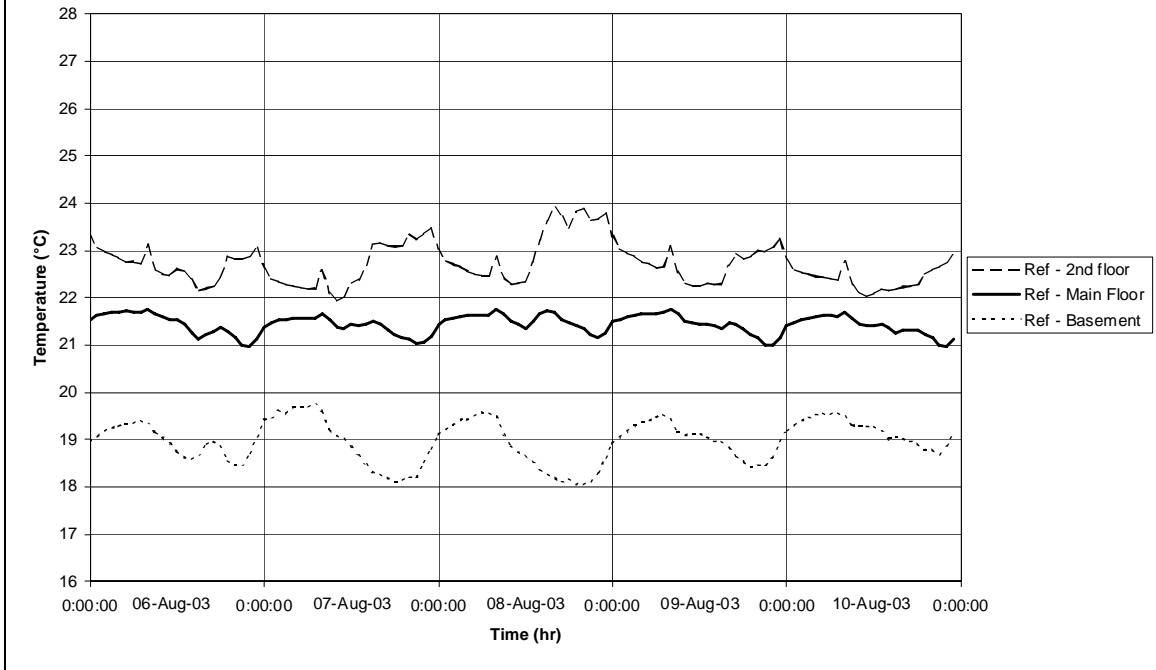
CCHT - Thermostat Experiment Summer 2003
Test House Temperatures for 25°C daytime setforward
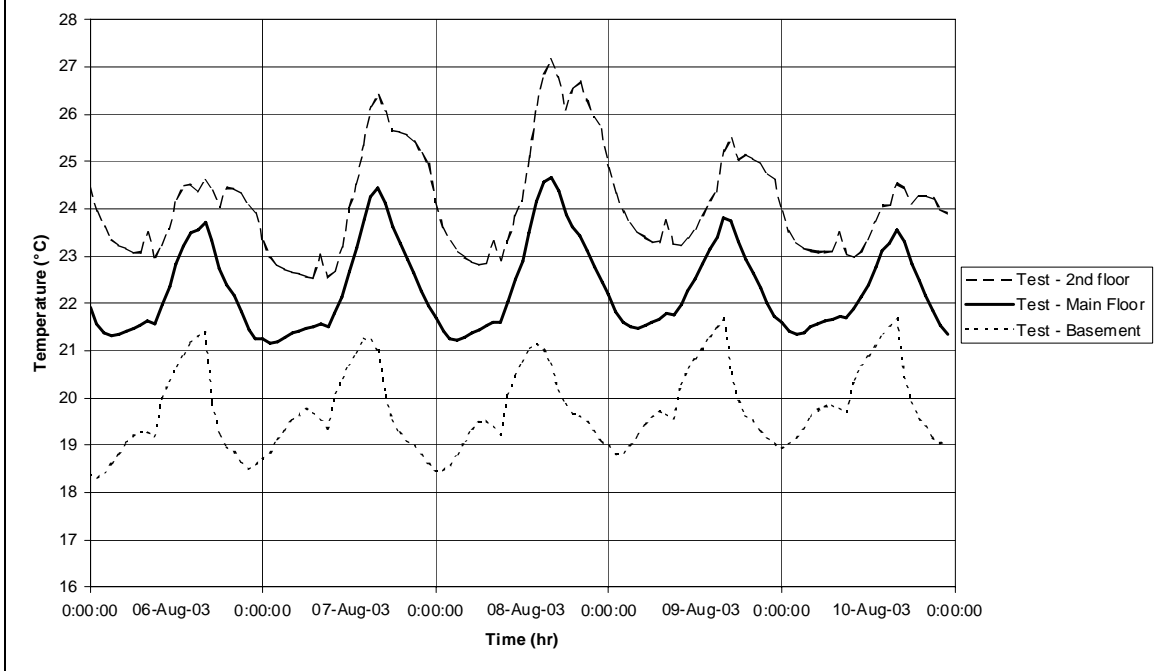
Temperatures in the Reference House (no higher temperature setting) which were Concurrent with those in the Test House During the 24°C Higher Temperature Setting Experiment
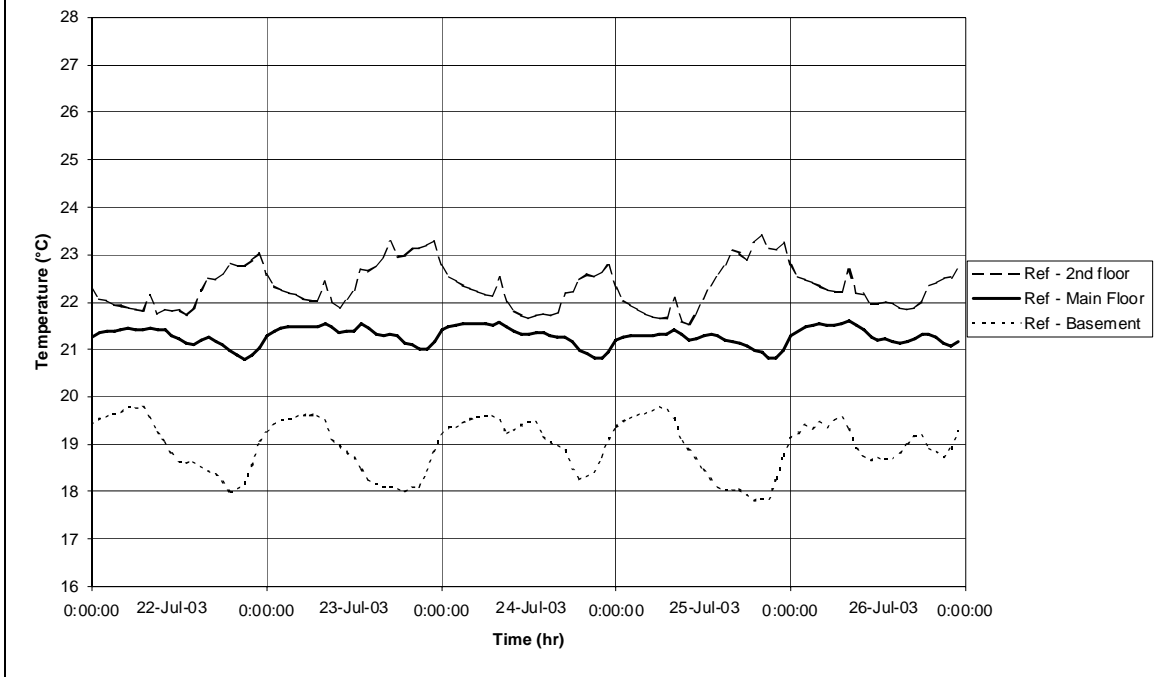
CCHT - Thermostat Experiment Summer 2003
Test House Temperatures for 24°C Higher Temperature Setting