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Canadian Centre for Housing Technology

Centre canadien des technologies résidentielles

ASSESSMENT OF REFLECTIVE INTERIOR SHADES AT THE CANADIAN CENTRE FOR HOUSING TECHNOLOGY

Contract: B-6020

Manning M.M.; Swinton, M.C.; Ruest, K.

February 9, 2007

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.

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Acknowledgements

Thanks are extended to Anil Parekh (Natural Resources Canada), Anca Galasiu and Christoph Reinhart (NRC Institute for Research in Construction), and Christopher Barry (Pilkington North America, Inc.) for their advising role throughout the project. Sylvain Harnay's help in conducting the window trials and monitoring the window temperatures was also greatly appreciated.

Project Team

Marianne Manning (NRC Institute for Research in Construction) as project manager was responsible for monitoring data collection, performing data analysis and writing this report. Mike Swinton (NRC Institute for Research in Construction), expert in side-by-side evaluation, oversaw operations throughout the experiment, monitored results, and provided important feedback throughout the analysis and report writing. Ken Ruest (Canada Mortgage and Housing Corporation) developed the shading device concept and testing methodology, and assisted with data analysis.

Acronyms

ach – air changes per hour
cfm – cubic feet per minute
HRV – Heat Recovery Ventilator

CCHT - Canadian Centre for Housing Technology
CMHC - Canada Mortgage and Housing Corporation
NRC - National Research Council Canada
NRCan - Natural Resources Canada

Executive Summary

In the summer of 2005, an innovative reflective shading device was evaluated at the Canadian Centre for Housing Technology (CCHT) twin-house facility. The shades were built from materials readily available at the hardware store: foil covered bubble wrap (two layers of bubble wrap sandwiched between two layers of aluminium foil), and screen frames. The shades were installed on the interior of the south and west facing windows of the CCHT Test House, leaving a small gap (~3 cm, 1") between the window surface and the shade.

Past evaluations of shading systems at the CCHT had revealed that opaque exterior shading was more effective than interior Venetian blinds at reducing cooling energy consumption. The reflective shading experiment was led by CMHC, hoping to identify an inexpensive interior shading option that could be used in locations where exterior shading was not a possibility, or as a temporary measure during the hottest portion of the cooling season. During the experiment, two different shading strategies were evaluated: shading 24 hours per day, and shading from 9 a.m. to 5 p.m.

Results showed that both strategies were effective at reducing the house's cooling consumption. Over their respective test periods, the 24-hour shading strategy reduced cooling consumption by 9.1%, and the 9 to 5 strategy reduced cooling consumption by 10%. The 0.9 % difference in savings was attributable to differing outdoor conditions during the trials. As would be expected, savings were highest on days with high solar gains – vertical solar gains in excess of 12000 kJ/m^2/day. On these high solar days, both shading strategies produced an average of 12% savings in cooling consumption. Extrapolation of results to the entire 2005 cooling season revealed that the 24-hour shading strategy is expected to produce approximately 9.9% seasonal savings in cooling energy consumption, while the 9 to 5 shading strategy is expected to produce slightly less: 9.0% seasonal savings.

For the 24-hour strategy, a portion of the daily savings from use of the reflective shades occurred outside the hours of 9 a.m. to 5 p.m. This was likely caused by the shade on the west-facing window shading the house from evening solar gains. The opposite held true for the 9 a.m. to 5 p.m. strategy. Daily savings from this strategy were reduced by an increase in consumption during the hours that the house operated without the shades in place, compared to the consumption of the house without reflective shades. This increase could be attributable in part to heat that was trapped between the window and the shade being radiated back into the house upon removal of the shades at 5 p.m.

Measurements revealed that the reflective shades caused window surface temperatures to approach the operating limits. The temperature at the centre of the window surpassed 68°C on the sunniest day, and the temperature differential between the edge and centre of the glass approached 30°C. These high temperatures lead to thermal stresses that could potentially damage the glazing unit. For this reason, this particular shading device cannot be recommended for use with argon-filled windows with a low-e coating on surface 3. Further studies are required to determine the effectiveness and safety of these shades when combined with other types of windows. The performance of commercially available shading systems should also be examined.

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1 Introduction

Canada Mortgage and Housing Corporation (CMHC) is interested in testing low cost/low energy solutions for minimizing cooling loads. Past experiments at the Canadian Centre for Housing Technology (CCHT) have proven the effectiveness of opaque exterior blinds at preventing solar gains and reducing air conditioner consumption. The same set of experiments also revealed the less than desirable performance of interior Venetian blinds in combination with argon filled low-e coated windows, producing only a minimal daily savings (<1%) in air conditioning cooling consumption on the sunniest of days. In many locations such as large apartment buildings, or on the upper stories of a house, it is difficult or impossible for residents to install exterior blinds. For this reason, an effective interior solution is required.

To this purpose, CMHC tested the effects of using a reflective interior blind at the CCHT twin-house facility in the summer of 2005. It was hoped that this interior blind solution could help lessen a house's peak air conditioning load during the hottest and sunniest days of summer, helping consumers to save money and utilities to manage peak demands.

2 Objective

The main objective of this project was to evaluate the effectiveness of reflective interior shades in reducing cooling load and air conditioning consumption, while monitoring the resulting window surface temperatures, to ensure that temperatures do not rise high enough to potentially damage the glazing unit.

Secondary objectives included: evaluating the effect of the shading devices on night time energy performance (cooling demand could increase due to any insulating effect from the shades) and to monitor indoor humidity (humidity could increased due to shortened air conditioning runs).

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 1). 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. A full list of the twin houses characteristics can be found in Table 1.

Table 1 - Twin House Characteristics

Feature	Details
Construction Standard	R-2000
Liveable Area	210 m^2 (2260 ft^2), 2 storeys
Insulation	Attic: RSI 8.6, Walls: RSI 3.5, Rim joists: RSI 3.5
Basement	Poured concrete, full basement Floor: Concrete slab, no insulation Walls: RSI 3.5 in a framed wall. No vapour barrier.
Garage	Two-car, recessed into the floor plan; isolated control room in the garage
Exposed floor over the garage	RSI 4.4 with heated/cooled plenum air space between insulation and sub-floor.
Windows	Area: 35.0 m^2 (377 ft^2) total, 16.2 m^2 (174 ft^2) South Facing Double glazed, high solar heat gain coating on surface 3. Insulated spacer, argon filled, with argon concentration measured to 95%.
Air Barrier System	Exterior, taped fiberboard sheathing with laminated weather resistant barrier. Taped penetrations, including windows.
Airtightness	1.5 air changes per hour @ 50 Pa (1.0 lb/ft^2)
Furnishing	Unfurnished

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 - CCHT Twin-House Facility - Test House (left) and Reference House (right)

3.2 Shading Experiments at CCHT

Past tests at the CCHT in July 2002 addressed the issue of blind placement. Galasiu et al. (2005) conducted a shading experiment at the CCHT twin-house facility to determine the effect of two types of shadings devices in July 2002 – an exterior opaque shading device, and common indoor manual aluminum Venetian blinds. Results showed that on days with clear skies, interior blinds reduced cooling loads from 9 AM to 5 PM by approximately 10-12%. However, in the evening and overnight this effect was counteracted, the house with the interior blinds requiring 5-10% more cooling energy. The resulting total daily savings from use of the interior blinds on clear days was less than 1%. By contrast, the opaque exterior blind strategy offered savings of 70-75% from 9 AM to 5 PM, and 20-25% over 24 hours.

3.3 Reflective Shading Device

The reflective shading “proof of concept” prototype was conceived by CMHC. The shades were built from materials readily available at the hardware store. The shade itself was made from a reflective insulation product: a double layer of 8 mm polyethylene bubble wrap sandwiched between 2 layers of 99.9% aluminum foil. The foil-covered bubble wrap was mounted in a typical screen frame, sized to fit the window. A one-inch gap was left at the top and bottom of the screen, between the foil and frame, to encourage air circulation between the screen and window and prevent window temperatures from exceeding safe levels, and to maintain a more uniform temperature distribution.

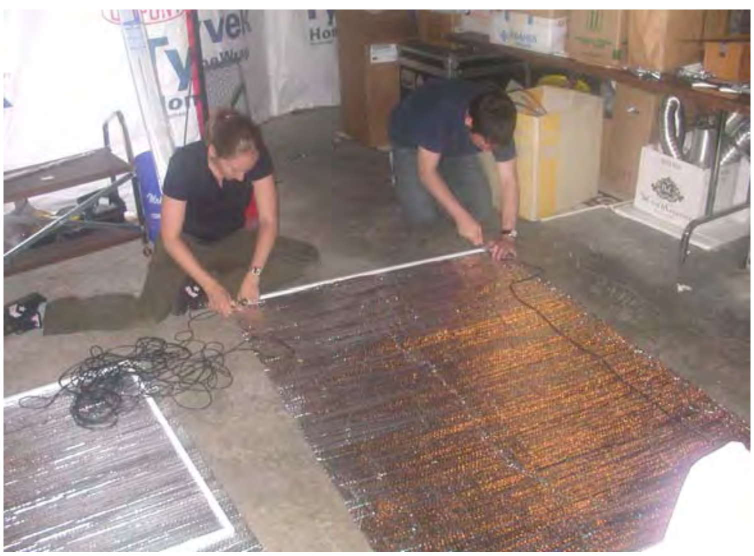


Figure 2 - Shading device construction

Figure 3 - Interior view of shaded window

4 Methodology

4.1 Installation

The shades were installed on the interior side of 9 south-facing windows, and one west-facing window of the CCHT Test House (see Figure 4). The shading devices were mounted in the normal interior side screen position (where possible), or 1-2" from the interior window surface. In total, the shades covered a south-facing window pane area of 9.4 m^2 and a west-facing window pane area of 1.3 m^2.

The experiment consisted of two different trials:

- 24-hour shading: leaving the shades in place 24 hours/day
- 9 to 5 shading: installing the shades at 9 am, and removing them at 5 pm

Because of the heat transfer characteristics of the shades (i.e. reflective surfaces, trapped air in the layers of bubbles), it was proposed that removing them overnight would allow the house to dissipate heat through the window, and some difference would be seen between the results of the two trials.

Figure 4 - Windows shaded during Experiment, west face (left) and south face (right)

4.2 Side-by-side testing procedure

Throughout the shading experiment, the houses were operated in identical configuration, differing only in respect to the shading configuration. Operating conditions are listed in Table 2.

Table 2 - Operating Conditions for the Shading Experiment

	System	Reference House	Test House
1	Air Conditioner	12 SEER unit, 2 ton	12 SEER unit, 2 ton
2	Furnace	PSC motor provides high speed cooling and low speed continuous circulation	PSC motor provides high speed cooling and low speed continuous circulation
3	Thermostat	Setpoint: 22°C, standard central location on main floor	Setpoint: 22°C, standard central location on main floor
4	Heat Recovery Ventilator (HRV)	Constant ventilation, 65 cfm 84% efficiency (nominal)	Constant ventilation, 65 cfm 84% efficiency (nominal)
5	Window Shades	No exterior shades, all interior Venetian blinds down with slats in the horizontal position (see Figure 5)	No exterior shades or Venetian blinds, Interior reflective shades installed on 1 West-facing and 9 South-facing windows
6	Simulated Occupancy	Standard Schedule	Standard Schedule
7	Humidifier	Off	Off
8	Hot Water Heater	Standard Gas 81% efficiency (measured)	Standard Gas 81% efficiency (measured)

Figure 5 - The Benchmark shading configuration - Venetian blinds in the down and horizontal position

4.3 Measurement and Instrumentation

4.3.1 Incident Solar Radiation

A vertically-mounted pyranometer on the south-facing wall of the Reference house measured global solar radiation (W/m^2), see Figure 6. Readings were taken every 5 minutes and integrated over a whole day to obtain total daily vertical solar radiation ($kJ/m^2/day$). A value of 12000 $kJ/m^2/day$ was arbitrarily chosen to divide the experiment data into days with high solar gains, and days with low solar gains.

Figure 6 - Pyranometer Location on Reference House South Façade

4.3.2 Electrical Consumption

Both air conditioner compressor and furnace circulation fan electrical consumption were measured in each house by individual electric meters with pulse output, at a resolution of 0.0006 kWh/pulse. Additional electric meters measured the electrical consumption of all other lights and appliances in the house. These meters were monitored to ensure that total house consumption remained similar in both houses.

4.3.3 Window Surface Temperatures

One set of south-facing windows on the second floor (top left on the South façade in Figure 4) were equipped with thermocouples to measure surface temperature at one exterior location and six interior locations on the window and sill (see Figure 7). The thermocouples were secured to the window and sill surface by means of a conductive epoxy (Figure 8). Surface temperature measurements were taken every 5-minutes, with an accuracy of 0.5°C.

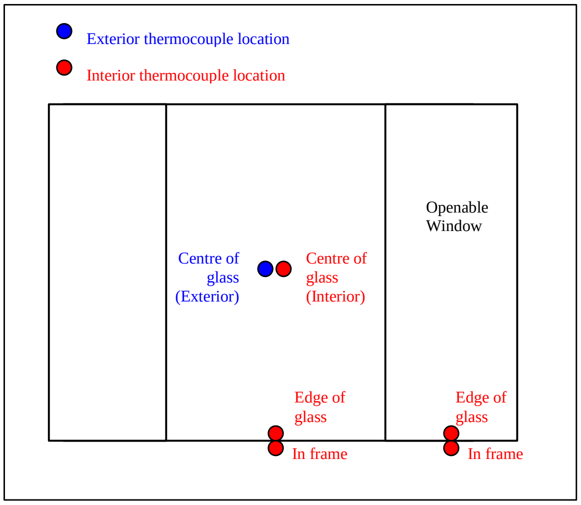


Figure 7 - Thermocouple Locations on Bedroom 2 Window

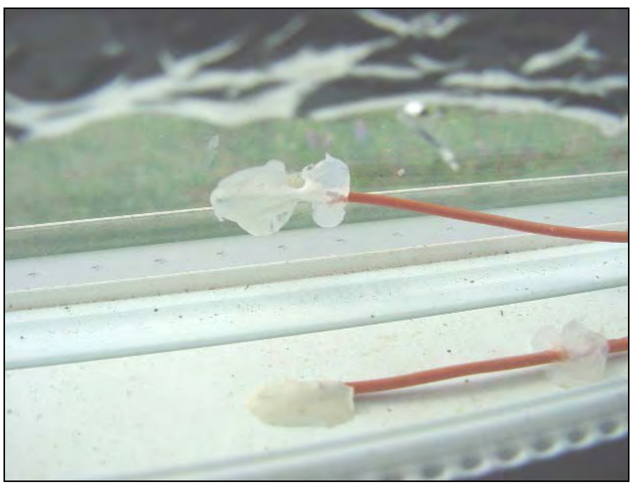


Figure 8 - Thermocouple location on edge of glass and interior frame

4.3.4 Air Temperature and Humidity

A thermocouple and humidity sensor located beside the central thermostat measured the main floor temperature and humidity of each house. A temperature and relative humidity sensor located on the north side of the Reference House measured the exterior conditions. Measurements were taken every 5-minutes, with an accuracy of 0.5°C.

4.4 Test Dates

The reflective shading experiment took place in August 2005. Table 3 lists the range of test dates and the variation in outdoor temperature during the experiment. Note that not all days in the listed date range necessarily belonged to that particular configuration. In the case of benchmarking, groups of benchmark days were spread throughout the cooling season to obtain a large range of outdoor conditions, and to ensure that the benchmark condition was maintained for the entire season.

Table 3 - Test Dates

Configuration	Date Range	Number of Days	Range of Average Daily Outdoor Temperature (°C)
Benchmark	21-Jun-05 to 21-Aug-05	17	15.7°C to 27.2°C
Reflective Shading 24h	04-Aug-05 to 25-Aug-05	11	20.2°C to 26.1°C
Reflective Shading 9:00 to 17:00	15-Aug-05 to 24-Aug-05	7	15.7°C to 22.7°C

Figure 9 shows the outdoor temperature and vertical solar radiation measurements during the shading experiments. While all shading experiment days are represented, only three of the 17 benchmark days are shown in this graph. The test period for both the 24-hour and 9 to 5 shading strategies contained a number of days with high solar gains. Outdoor temperatures during the evaluation of the 9 to 5 strategy were generally cooler than temperatures on days that the 24h shading strategy was employed.

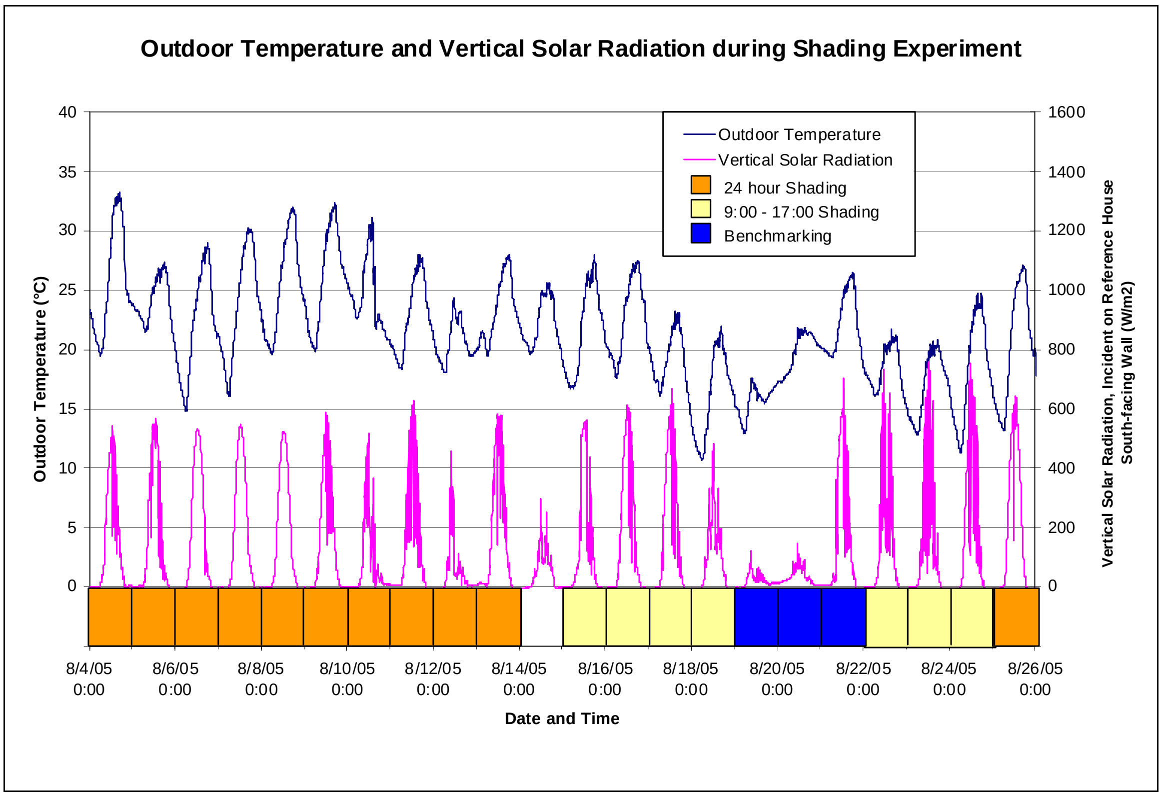


Figure 9 - Outdoor Temperature and Vertical Solar Radiation during Shading Experiment

5 Results

5.1 Cooling System Energy Consumption

Consumption data was analyzed using a side-by-side method, as described by Mike Swinton et al. in *Commissioning twin houses for assessing the performance of energy conserving technologies*. The method consists of plotting the daily consumption in the Test House against the daily consumption in the Reference House. During the benchmarking period, the houses are operated in identical configuration and a benchmark trend line is developed. Were the houses completely identical, this trend line would have a slope of 1 and intercept 0. However, the real benchmark trend line is never this perfect, since it takes into account all the small differences between the houses.

With the new technology installed in the Test House - in this case the reflective shades - the daily consumption is again plotted Test House VS Reference House. The benchmark trend and Reference House consumption can be used to determine the expected consumption for a particular day, were the Test House in benchmarking configuration (without the reflective shades). Savings can then be calculated by comparing the measured Test House consumption with reflective shades installed, to the calculated Test House consumption without reflective shades. This savings calculation method is described in more detail in Appendix B.

Cooling system electrical consumption is composed of air conditioner compressor consumption and furnace circulation fan consumption. For a breakdown of the consumption of these individual components refer to Table 4. The benchmark trendline for cooling consumption, shown in black in Figure 10, is slightly below the ideal 45° line, with a slope of 0.98 and an intercept of –0.99. This indicates that during benchmarking, the Reference House consistently consumed slightly more energy than the Test House for cooling.

The experiment points are also plotted in Figure 10: the 24 hour shading strategy plotted as diamonds, and the 9 a.m. to 5 p.m. shading strategy plotted as squares. Each experimental data set was divided into two categories based on measured daily vertical solar radiation: days with high solar gains (>12000 kJ/m^2/day) and days with low solar gains (<12000 kJ/m^2/day). Six out of 11 days of the 24-hour shading trials and three out of seven of the 9 a.m. to 5 p.m. shading strategy days fell into the high solar gain category. Both shading strategies revealed significant savings in cooling energy consumption. Savings were greatest on the days with the highest solar gains. This savings is shown graphically by the distance between the high solar gain data points (solid squares and diamonds) and the benchmark line.

A trend line is drawn through the five high solar gain 24-hour shading points in Figure 10. This trend line is almost parallel to the Benchmark line, with a slope of 1.0. The two lines are separated by approximately 4 kWh/day. This indicates that the 24-hour shading strategy would be expected to produce a constant amount of savings on days with high solar gains throughout a large range of outdoor temperature conditions.

The daily savings from the 24-hour shading strategy are listed in Table 4. The rows containing data for days with high solar gains are highlighted in yellow. Savings from the

24-hour strategy ranged from 1.10 kWh to 4.60 kWh. The average savings for the 11-day test period was 3.28 kWh/day, or 9.1% of calculated Test House consumption in benchmark configuration. Savings were highest on the days with vertical solar gains above 12000 kJ/m^2/day, averaging 4.14 kWh/day savings, or 12% of the calculated Test House benchmark consumption.

Slightly lower absolute savings in kWh were seen during the 9 a.m. to 5 p.m. shading strategy (see Table 5). This may have been due in part to the cooler outdoor temperature conditions and lower air conditioner consumption during these trials. Additionally, removing the shades from the west window at 5 pm allowed some evening solar gains to enter the house, and additional evening savings to be missed. 9 a.m. to 5 p.m. shading resulted in an average savings of 2.67 kWh/day (10%) savings over the test period. Savings were again highest on days with high solar gains, averaging 3.48 kWh/day (12%).

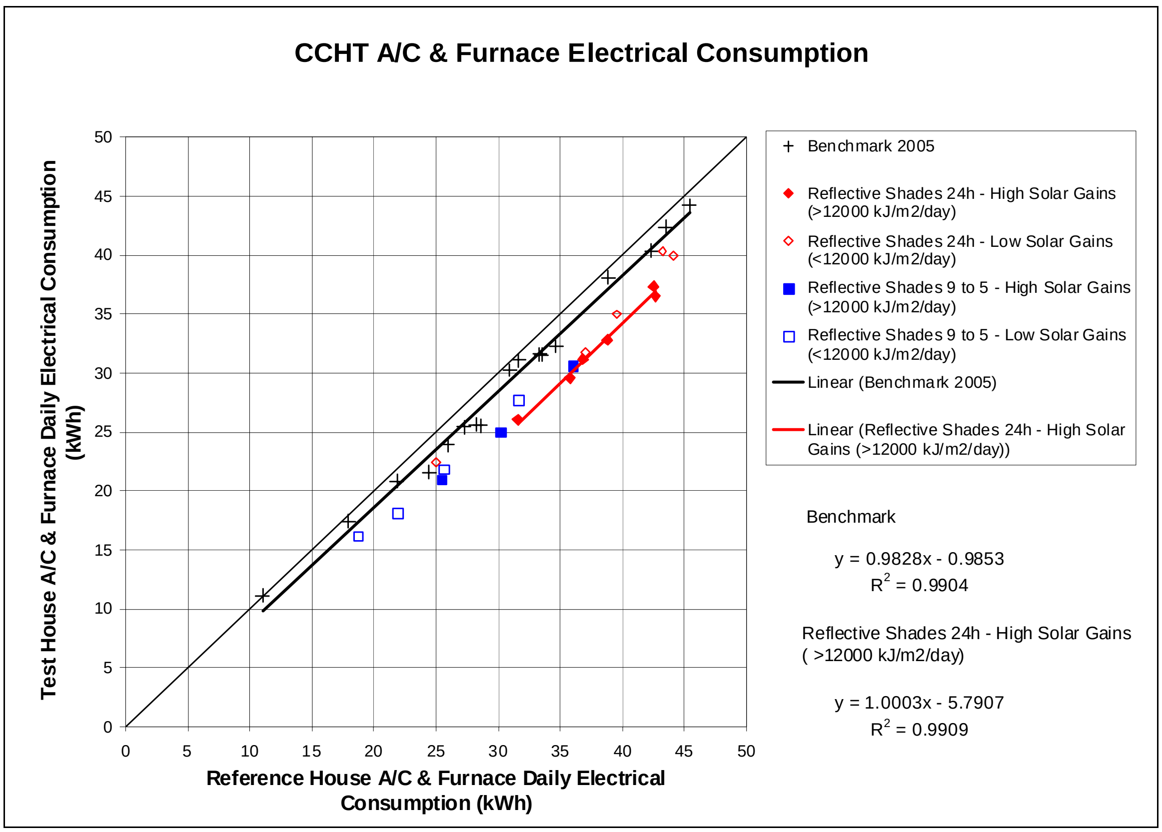


Figure 10 - Total Cooling System Electrical Consumption

Table 4 - Daily Shading Cooling Consumption Savings for 24-hour shading strategy

	Measured Air Conditioner Compressor Electrical Consumption (kWh)		Measured Furnace Fan Electrical Consumption (kWh)		Measured Total Cooling Electrical Consumption (kWh)		Calculated Total Test House Cooling Electrical Consumption with no reflective blinds (kWh)			Weather Conditions			
Date	Reference House	Test House	Reference House	Test House	Reference House	Test House	Based on the Benchmark Correlation	Savings from blind strategy (kWh)	Savings (%)	Max T (°C)	Min T (°C)	Average T (°C)	Solar Radiation Incident on South facing wall (KJ/m2/day)
04-Aug-05	28.99	27.16	14.22	13.19	43.20	40.35	41.47	1.13	2.7%	33.3	19.5	25.7	11125
05-Aug-05	28.27	23.75	14.40	12.78	42.67	36.53	40.95	4.42	11%	27.4	20	24	12665
06-Aug-05	22.64	17.99	13.16	11.60	35.79	29.59	34.19	4.60	13%	29	14.8	22	12858
07-Aug-05	25.26	20.78	13.54	12.04	38.80	32.82	37.15	4.33	12%	30.3	16.1	23.7	13132
08-Aug-05	28.38	24.63	14.12	12.72	42.50	37.34	40.78	3.44	8.4%	32	19.6	25.4	12748
09-Aug-05	29.78	26.87	14.35	13.10	44.13	39.97	42.39	2.42	5.7%	32.4	19.8	26.1	11850
10-Aug-05	25.79	22.52	13.79	12.47	39.57	34.99	37.91	2.91	7.7%	31.1	20.6	24.4	6794
11-Aug-05	23.69	19.80	13.35	11.95	37.04	31.76	35.42	3.66	10%	28	18.4	22.9	11805
12-Aug-05	13.81	12.04	11.17	10.43	24.98	22.47	23.56	1.10	4.7%	24.3	18	20.6	4141
13-Aug-05	23.58	19.36	13.26	11.80	36.84	31.16	35.22	4.05	12%	28	19.4	23.4	13544
25-Aug-05	19.25	15.09	12.30	10.94	31.55	26.04	30.02	3.98	13%	27.1	13.2	20.2	14725
Average	**24.49**	**20.91**	**13.42**	**12.09**	**37.92**	**33.00**	**36.28**	**3.28**	**9.1%**	**29.4**	**18.1**	**23.5**	**11399**
Average - Low Solar (<12000)	24.41	21.68	13.38	12.23	37.79	33.91	36.15	2.24	6.2%	29.8	19.3	23.9	9143
Average - High Solar (>12000)	24.56	20.27	13.46	11.98	38.03	32.25	36.39	4.14	12%	29.0	17.2	23.1	13279

Note: Highlighted rows indicate days with Total Vertical Solar gains in excess of 12000 kJ/m^2/day

Table 5 - Daily Shading Cooling Consumption Savings for 9 a.m. to 5 p.m. shading strategy

	Measured Air Conditioner Compressor Electrical Consumption (kWh)		Measured Furnace Fan Electrical Consumption (kWh)		Measured Total Cooling Electrical Consumption (kWh)		Calculated Total Test House Cooling Electrical Consumption with no reflective blinds (kWh)			Weather Conditions			
Date	Reference House	Test House	Reference House	Test House	Reference House	Test House	Based on the Benchmark Correlation	Savings from blind strategy (kWh)	Savings (%)	Max T (°C)	Min T (°C)	Average T (°C)	Solar Radiation Incident on South facing wall (KJ/m2/day)
15-Aug-05	19.22	16.41	12.37	11.30	31.59	27.71	30.06	2.35	7.8%	28.0	16.7	21.7	9758
16-Aug-05	22.88	18.91	13.12	11.74	35.99	30.65	34.39	3.73	11%	27.5	17.5	22.7	13843
17-Aug-05	17.89	14.03	12.30	10.98	30.20	25.01	28.69	3.68	13%	23.2	14.2	19.1	13372
18-Aug-05	8.71	6.87	9.99	9.31	18.70	16.18	17.39	1.21	7.0%	17.6	13.0	15.7	1754
22-Aug-05	14.24	11.52	11.39	10.37	25.63	21.89	24.20	2.31	9.6%	21.7	15.3	18.4	9165
23-Aug-05	11.29	8.50	10.61	9.65	21.90	18.14	20.53	2.39	12%	20.9	12.8	17.0	9719
24-Aug-05	14.20	10.87	11.24	10.11	25.44	20.98	24.02	3.03	13%	24.8	11.3	18.2	12434
Average	**15.49**	**12.44**	**11.57**	**10.49**	**27.06**	**22.94**	**25.61**	**2.67**	**10%**	**23.4**	**14.4**	**18.9**	**10006**
Average - Low Solar (<12000)	13.36	10.82	11.09	10.16	24.45	20.98	23.05	2.07	9.0%	22.1	14.4	18.2	7599
Average - High Solar (>12000)	18.32	14.61	12.22	10.94	30.54	25.55	29.03	3.48	12%	25.2	14.3	20.0	13216

Note: Highlighted rows indicate days with Total Vertical Solar gains in excess of 12000 kJ/m^2/day

5.2 Energy Savings and Time of Day

The reflective shades work to primarily reduce solar gains in the house, so theoretically most of the savings are expected to occur during the day. For this reason, the consumption data was further analyzed by daytime (9 a.m. to 5 p.m.) and night time (midnight to 9 a.m. and 5 p.m. to midnight) consumption.

As expected, the majority of savings occurred during the day for both strategies (see Figure 11 and Figure 12). On average, the 24-hour shading strategy produced daytime savings of 2.31 kWh (14% of benchmark daytime consumption). This was again highest on the days with the highest solar gains, averaging 3.16 kWh in savings (19% of benchmark daytime consumption). See Table 6 for details of nighttime and daytime savings for this strategy.

Large daytime savings were measured during the 9 a.m. to 5 p.m. shading strategy as well (Table 7). This strategy produced an average daytime savings of 2.95 kWh (24% of benchmark daytime consumption). On days with high solar gains, the savings were slightly higher at 3.52 kWh (25% of benchmark daytime consumption).

Figure 13 and Figure 14 show the nighttime savings from the two shading strategies. The nighttime consumption data revealed that 24-hour shading provided additional savings overnight on most days during the experiment. On average, overnight shading produced an additional savings of 0.9 kWh (4% of benchmark nighttime consumption). The maximum nighttime savings produced by the strategy was 2.41 kWh (10% of the benchmark nighttime consumption for that day) on August 5th. There are two factors that are likely contributing to these nighttime savings. First, during the 24-hour shading strategy the shade on the west-facing window shaded the house from evening solar gains. Second, on the majority of test days, the average outdoor temperature overnight was warmer than the indoor conditions (~21°C). On these nights, the shades may have provided added insulation, reducing heat gains to the house and increasing savings. More evidence of this effect is provided by the glass surface temperature analysis in Section 5.3. Were the nights cooler than indoor conditions, the insulating effect of the shade would adversely affect savings – decreasing the ability of heat to leave the house through the windows.

The nighttime analysis of the 9 a.m. to 5 p.m. shading data revealed a slight increase in consumption over the benchmark case. On average, an additional 0.63 kWh (a 6.1% increase from the benchmark nighttime consumption) of electricity was consumed per night. Outside the hours of 9 a.m. to 5 p.m. the house was returned to its benchmark configuration, and so cooling consumption would be expected to be the same as the benchmark cooling consumption. One possible explanation for the increase in nighttime consumption from this strategy is that each evening the heat trapped behind the blind during the day radiated from the hot window surface into the house when the shades were removed at 5 p.m.

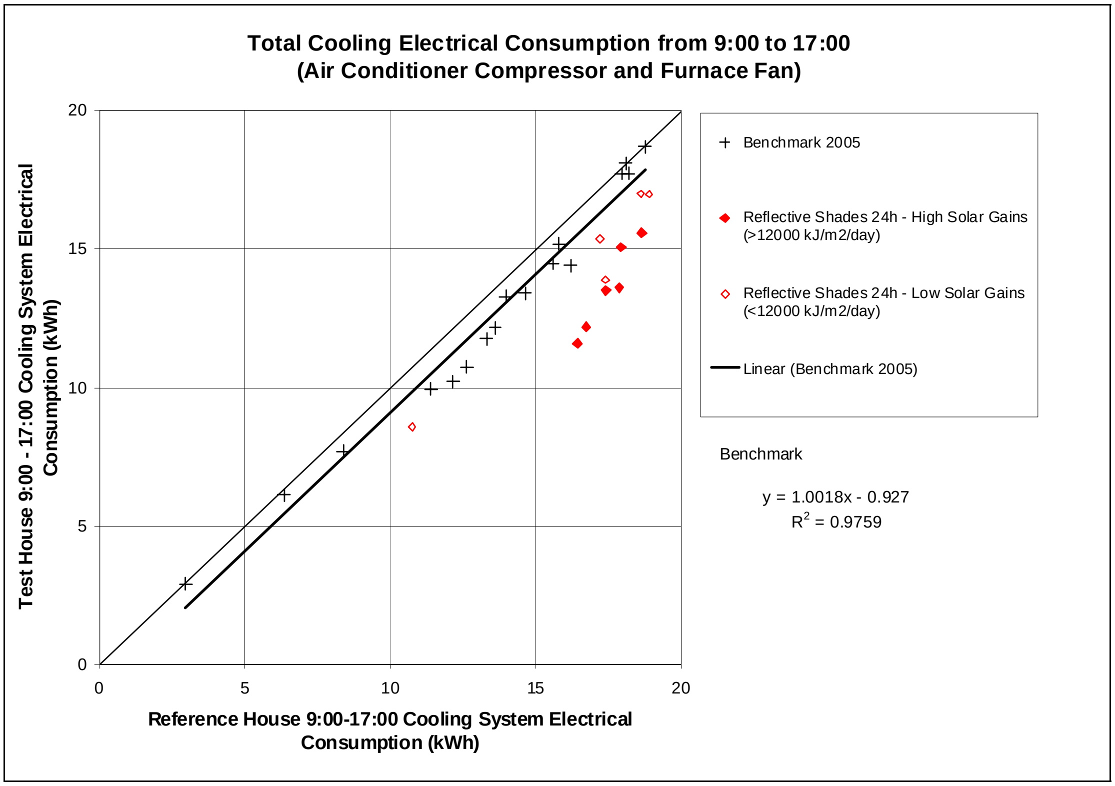


Figure 11 – Daytime Cooling Electrical Consumption (9 a.m. to 5 p.m.) for 24-hour shading strategy

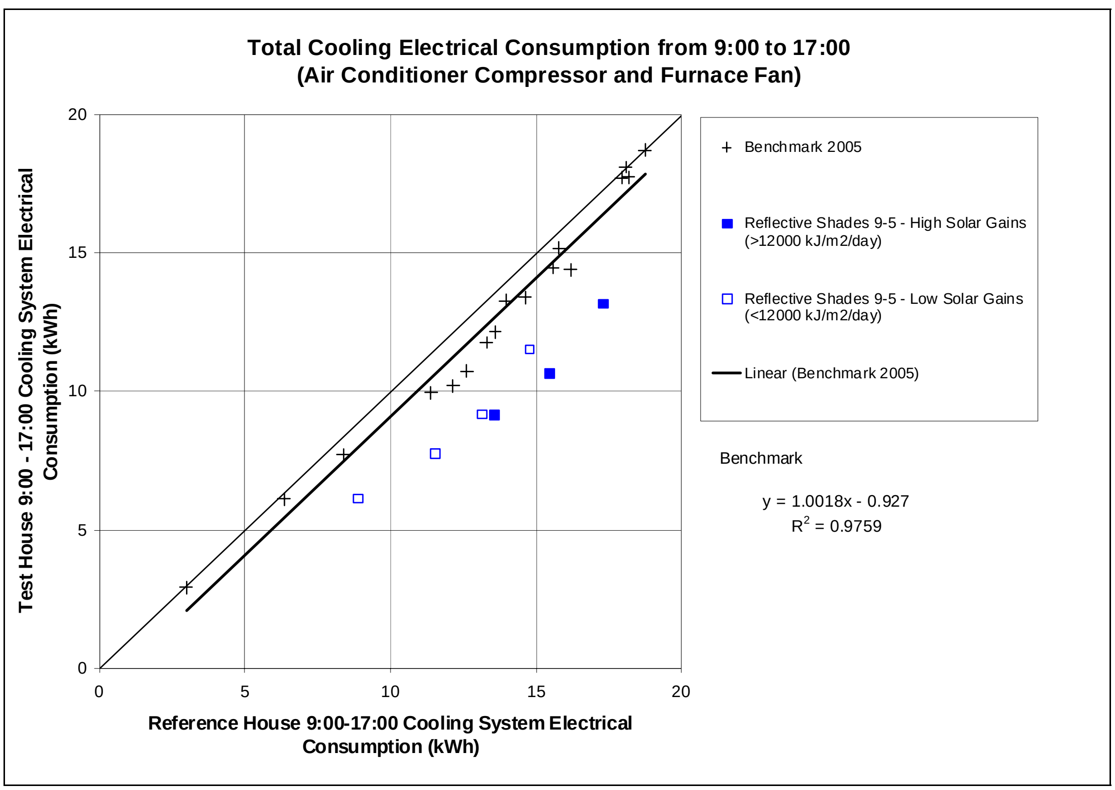


Figure 12 - Daytime Cooling Electrical Consumption (9 a.m. to 5 p.m.) for 9 to 5 shading strategy

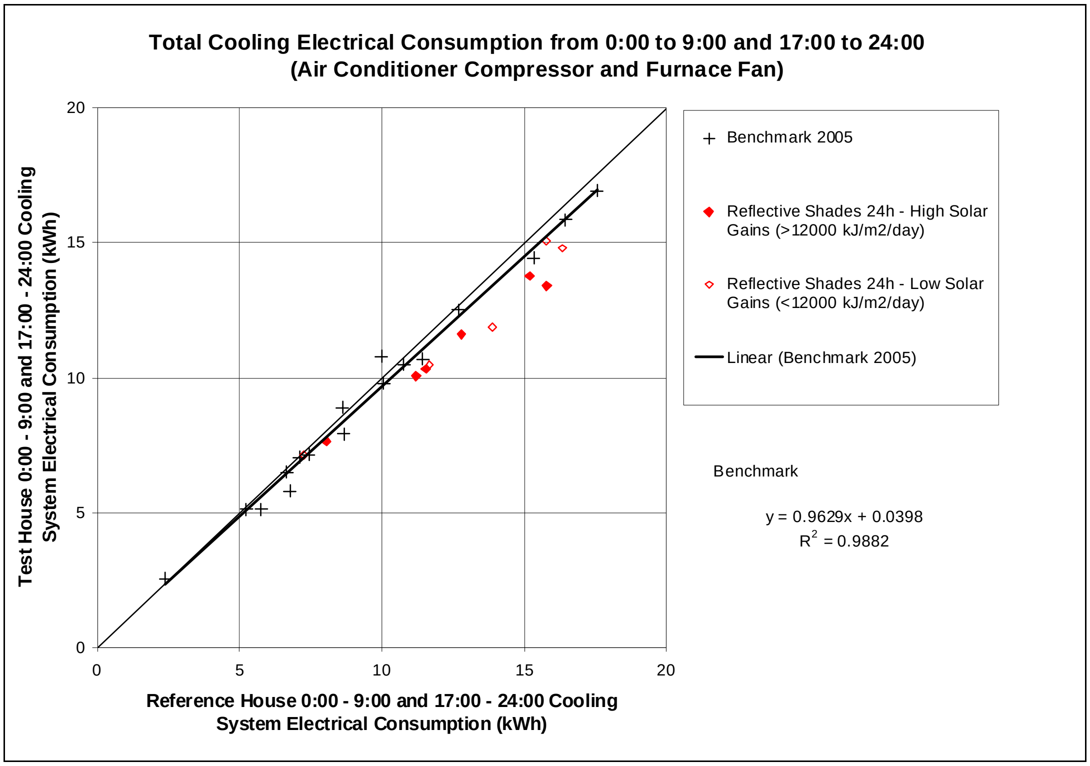


Figure 13 - Nighttime Cooling Electrical Consumption (midnight to 9 a.m. and 5 p.m. to midnight) for 24 hour shading strategy

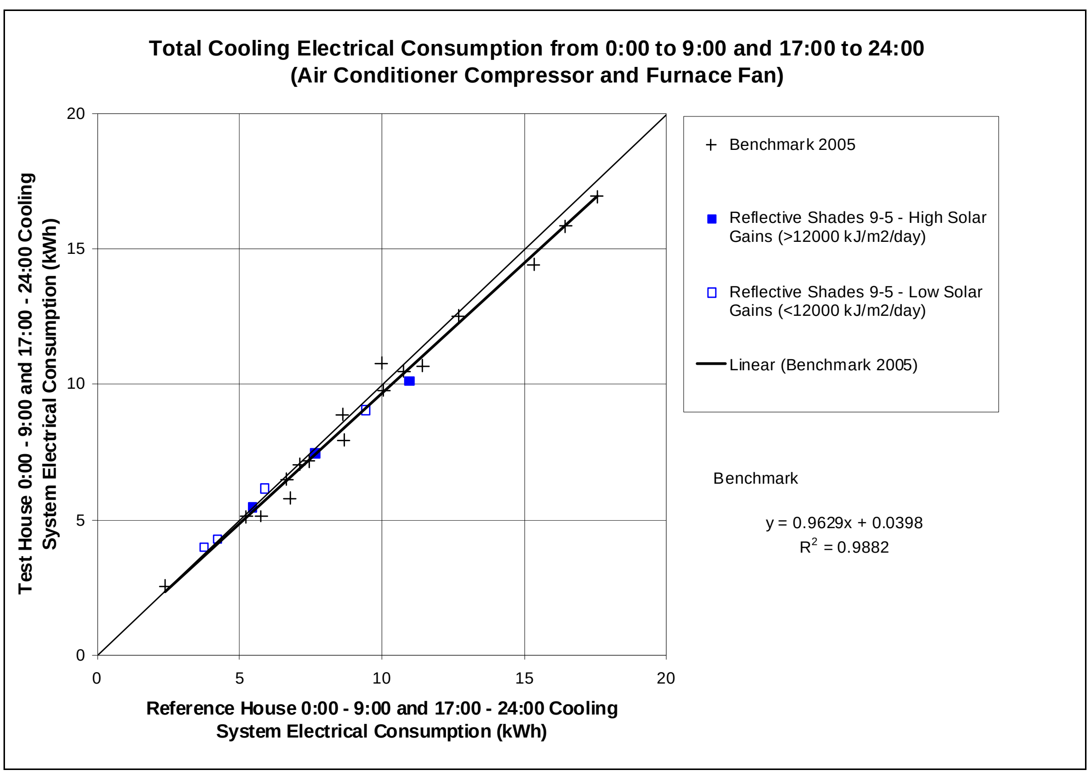


Figure 14 - Nighttime Cooling Electrical Consumption (midnight to 9 a.m. and 5 p.m. to midnight) for 9 to 5 shading strategy

Table 6 - Cooling Energy Savings by Time Period - 24 hour shading

Date	9:00 to 17:00						0:00 to 9:00 and 17:00 to 24:00					
	Reference House Measured Cooling Consumption (kWh)	Test House Measured Cooling Consumption (kWh)	Test House Calculated Cooling Consumption - based on Benchmark (kWh)	Savings (kWh)	Savings (%)	Average Outdoor Temperature (°C)	Reference House Measured Cooling Consumption (kWh)	Test House Measured Cooling Consumption (kWh)	Test House Calculated Cooling Consumption - based on Benchmark (kWh)	Savings (kWh)	Savings (%)	Average Outdoor Temperature (°C)
04-Aug-05	18.60	17.00	17.70	0.71	4.0%	29.4	24.60	23.35	23.72	0.37	1.6%	23.8
05-Aug-05	17.93	15.08	17.04	1.96	11%	25.3	24.74	21.45	23.86	2.41	10%	23.4
06-Aug-05	16.73	12.19	15.83	3.65	23%	25.1	19.06	17.40	18.17	0.77	4.2%	20.5
07-Aug-05	17.86	13.61	16.97	3.36	20%	26.5	20.94	19.21	20.05	0.84	4.2%	22.3
08-Aug-05	18.64	15.58	17.75	2.17	12%	28.3	23.86	21.76	22.97	1.21	5.3%	24.0
09-Aug-05	18.88	16.99	17.99	1.00	5.5%	29.3	25.25	22.98	24.37	1.39	5.7%	24.4
10-Aug-05	17.19	15.38	16.29	0.91	5.6%	27.3	22.38	19.61	21.50	1.89	8.8%	23.0
11-Aug-05	17.40	13.90	16.51	2.61	16%	25.3	19.64	17.86	18.75	0.88	4.7%	21.6
12-Aug-05	10.75	8.57	9.84	1.27	13%	22.6	14.23	13.90	13.33	-0.56	-4.2%	19.6
13-Aug-05	17.40	13.52	16.51	2.99	18%	25.1	19.43	17.65	18.54	0.89	4.8%	22.5
25-Aug-05	16.43	11.60	16.43	4.84	29%	23.9	15.11	14.44	14.21	-0.22	-1.6%	18.3
Average	**17.07**	**13.95**	**16.26**	**2.31**	**14%**	**24.0**	**20.84**	**19.06**	**19.95**	**0.90**	**4.0%**	**22.1**
Average - Low Solar (<12000)	16.56	14.37	15.67	1.30	8.8%	26.0	21.22	19.54	20.33	0.79	3.3%	22.5
Average - High Solar (>12000)	17.50	13.59	16.75	3.16	19%	25.7	20.53	18.65	19.64	0.98	4.5%	21.8

Table 7 - Cooling Energy Savings by Time Period - 9:00 to 17:00 Shading

Date	9:00 to 17:00						0:00 to 9:00 and 17:00 to 24:00					
	Reference House Measured Cooling Consumption (kWh)	Test House Measured Cooling Consumption (kWh)	Test House Calculated Cooling Consumption - based on Benchmark (kWh)	Savings (kWh)	Savings (%)	Average Outdoor Temperature (°C)	Reference House Measured Cooling Consumption (kWh)	Test House Measured Cooling Consumption (kWh)	Test House Calculated Cooling Consumption - based on Benchmark (kWh)	Savings (kWh)	Savings (%)	Average Outdoor Temperature (°C)
15-Aug-05	14.77	11.54	13.87	2.33	17%	24.1	16.82	16.17	15.92	-0.24	-1.5%	20.5
16-Aug-05	17.30	13.19	16.40	3.21	20%	24.8	18.70	17.47	17.80	0.34	1.9%	21.6
17-Aug-05	15.44	10.66	14.54	3.88	27%	21.0	14.76	14.35	13.85	-0.50	-3.6%	18.1
18-Aug-05	8.88	6.14	7.97	1.83	23%	16.4	9.81	10.04	8.90	-1.14	-13%	15.3
22-Aug-05	13.14	9.19	12.24	3.05	25%	19.7	12.49	12.70	11.58	-1.11	-9.6%	17.7
23-Aug-05	11.53	7.77	10.63	2.86	27%	19.0	10.36	10.38	9.46	-0.92	-9.8%	16.0
24-Aug-05	13.56	9.18	12.65	3.48	27%	21.4	11.88	11.81	10.98	-0.83	-7.6%	16.5
Average	**13.52**	**9.66**	**12.61**	**2.95**	**24%**	**20.9**	**13.55**	**13.27**	**12.64**	**-0.63**	**-6.1%**	**18.0**
Average - Low Solar (<12000)	12.08	8.66	11.18	2.52	23%	19.82	12.37	12.32	11.47	-0.85	-8.4%	17.37
Average - High Solar (>12000)	15.43	11.01	14.53	3.52	25%	22.40	15.11	14.54	14.21	-0.33	-3.1%	18.75

5.3 Approximation of Seasonal Savings

A rough correlation can be drawn between daily cooling system electrical and daily vertical solar radiation. As mentioned in the previous section, savings from shade use increase with increase in solar gains. The trends in Figure 15 are based on the assumption of a zero intercept since there was a limited amount of data at the low solar radiation end of the curve. More data is required to verify the exact correlations, however, these trends can still be used to approximate the expected savings for the 2005 cooling season.

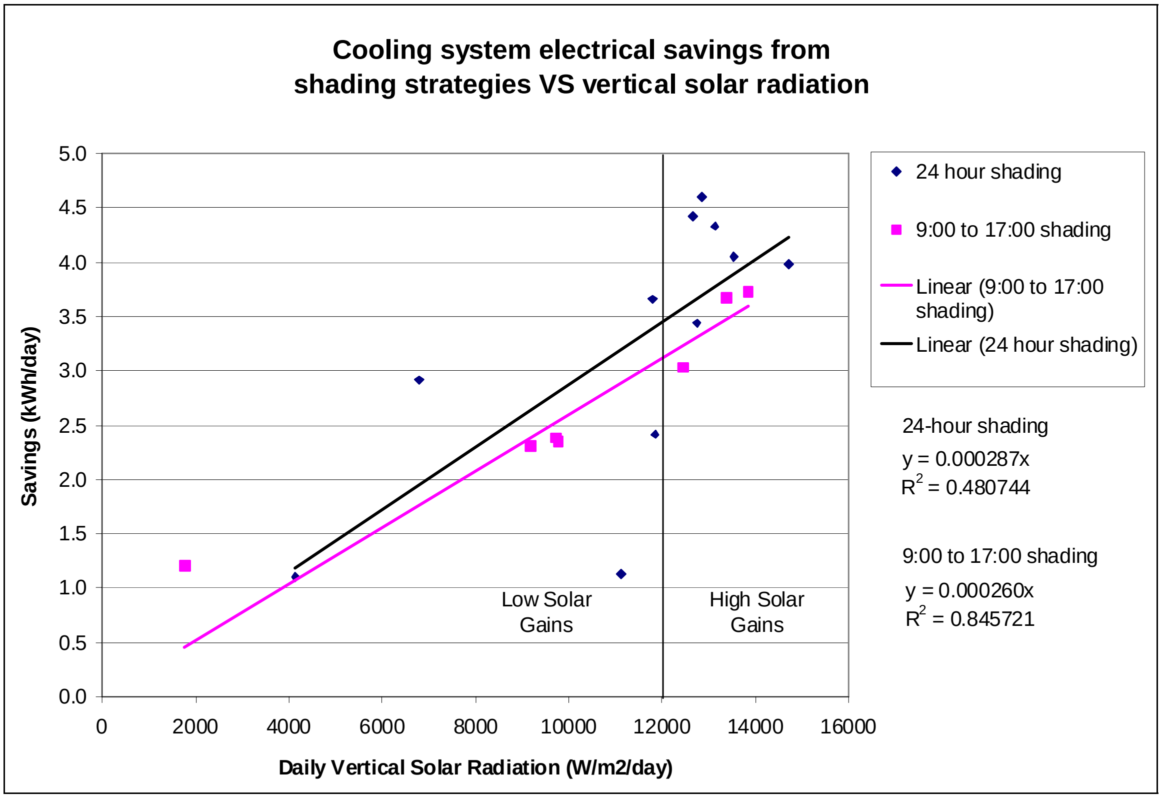


Figure 15 - Savings from Shading Strategies vs Daily Vertical Solar Radiation

Figure 16 presents a histogram of the varying daily amounts of vertical solar radiation throughout the 2005 cooling season. The cooling season at CCHT consisted of 128 days of air conditioner operation. This season was uncharacteristically warm for Ottawa, Canada, with a total of 460 cooling degree-days above 18°C (Environment Canada reports a 30-year average for Ottawa of 244.6 cooling degree-days above 18°C). Out of the 128 days, 38 days experienced a total vertical solar radiation in excess of 12000 $kJ/m^2/day$. During this season, the Test House with the standard benchmarking blinds configuration – interior Venetian blinds in the down and horizontal position - would be expected to consume 3822 kWh of cooling energy. The trend lines in Figure 15 predict that the 24-hour shading strategy would produce a total of 378 kWh of cooling energy savings, while the 9 to 5 shading strategy would produce slightly less savings at 342 kWh over the cooling season. This is equivalent to a seasonal savings of 9.9% and 9.0% in total cooling energy for the two respective strategies.

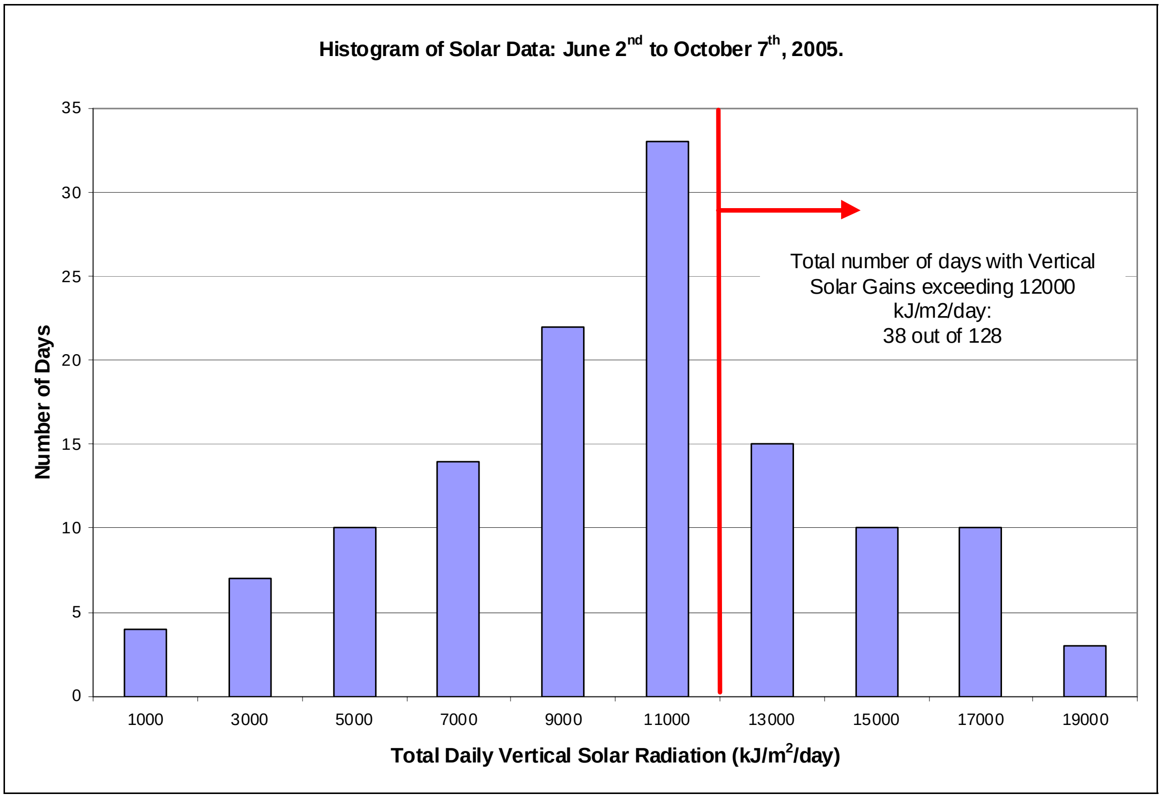


Figure 16 - Histogram of Total Daily Vertical Solar Radiation, Summer 2005

5.4 Glass Temperatures

Window pane surface temperatures were observed throughout the experiment. Particular attention was paid to the maximum surface temperature reached and the temperature differential between the edge and centre of glass.

Practical experience indicates that while the glass and seal themselves are capable of withstanding high temperatures, the temperature limits for the glazing unit are defined by the temperature differential between the center of the glass and the edge of the glass (Barry, 2006 and Lichtenberger, 2006). When the edge of the glass is cooler than the centre, tensile thermal stresses are produced that can lead to breakage (Sasaki, 1970). The higher the differential, the higher the tension introduced in the glazing unit. Window cracks are generally initiated at an edge defect created in manufacturing. Thermal cycling to high temperatures encourages damage to appear and propagate. For this reason, the centre to edge temperature differential should be less than 30°C in order to avoid potential breakage, particularly if the cut edge quality is poor.

Figure 17 and Figure 18 show the measured window surface temperatures at the centre and bottom edge of the interior pane. Under benchmarking conditions, the Test House interior window surface temperature reached a maximum of 45.7°C. The highest temperature occurred at the edge of the window. With the reflective shades in place, much higher surface temperatures were reached. The highest surface temperature was measured at the centre of the Test House window, reaching a maximum of 68.7°C, nearly 30°C higher than the normal operating conditions.

On the last day of the shading experiment, August 26th, the shade was removed from its frame and secured directly to the window. Temperatures were monitored, and at noon the shade was removed due to very high surface temperatures on the inner pane. At this time, the temperature at the centre of the Test House interior window pane surpassed 82°C, roughly 40°C higher than the temperature of its twin pane in the Reference House.

In the cool early morning hours of August 25th and 26th, there is some evidence that the shades were insulating the window. On these nights the shades remained in place and the outdoor temperature dropped below the 21°C interior temperature. In Figure 18, the window temperatures in the Test House can be seen to drop below those of the unshaded Reference House windows, providing evidence that the shades were trapping heat inside the house.

Figure 19 shows a plot of the temperature differential between the centre and edge of the window. In normal benchmarking operation, the maximum differential occurs in the middle of the day, when the edge of the window was up to approximately 5°C warmer than the centre of the window. The shades produced a much higher surface temperature differential. On sunny days, the temperature at the centre of the window was up to 29.7°C hotter than the edge. This was considered to be at the 30°C limit of safe operation.

Although no windows were broken during this experiment, repeated cycling at these high temperatures from prolonged use of the shades could lead to window damage.

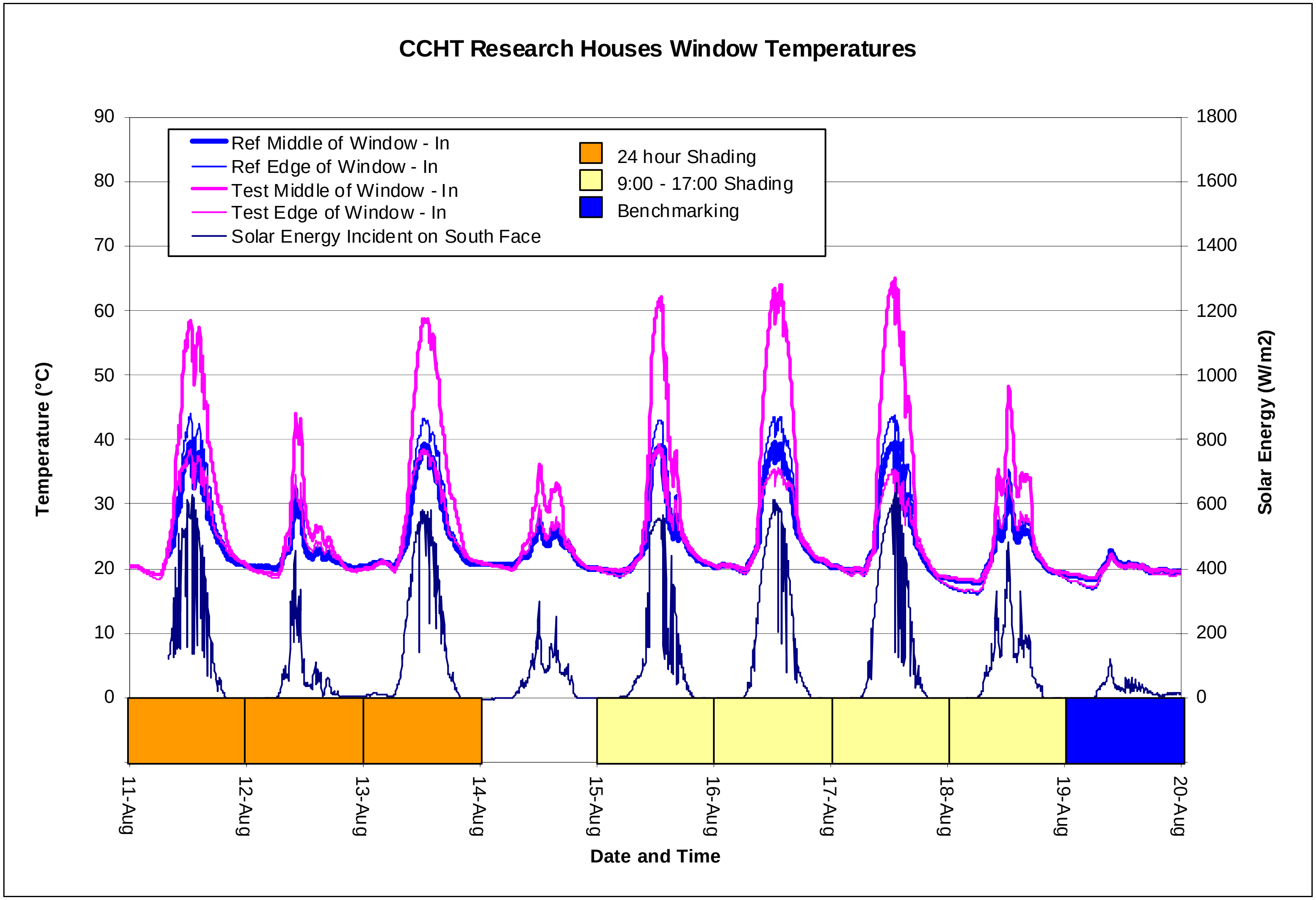


Figure 17 - Window Surface Temperatures August 11th to August 19th

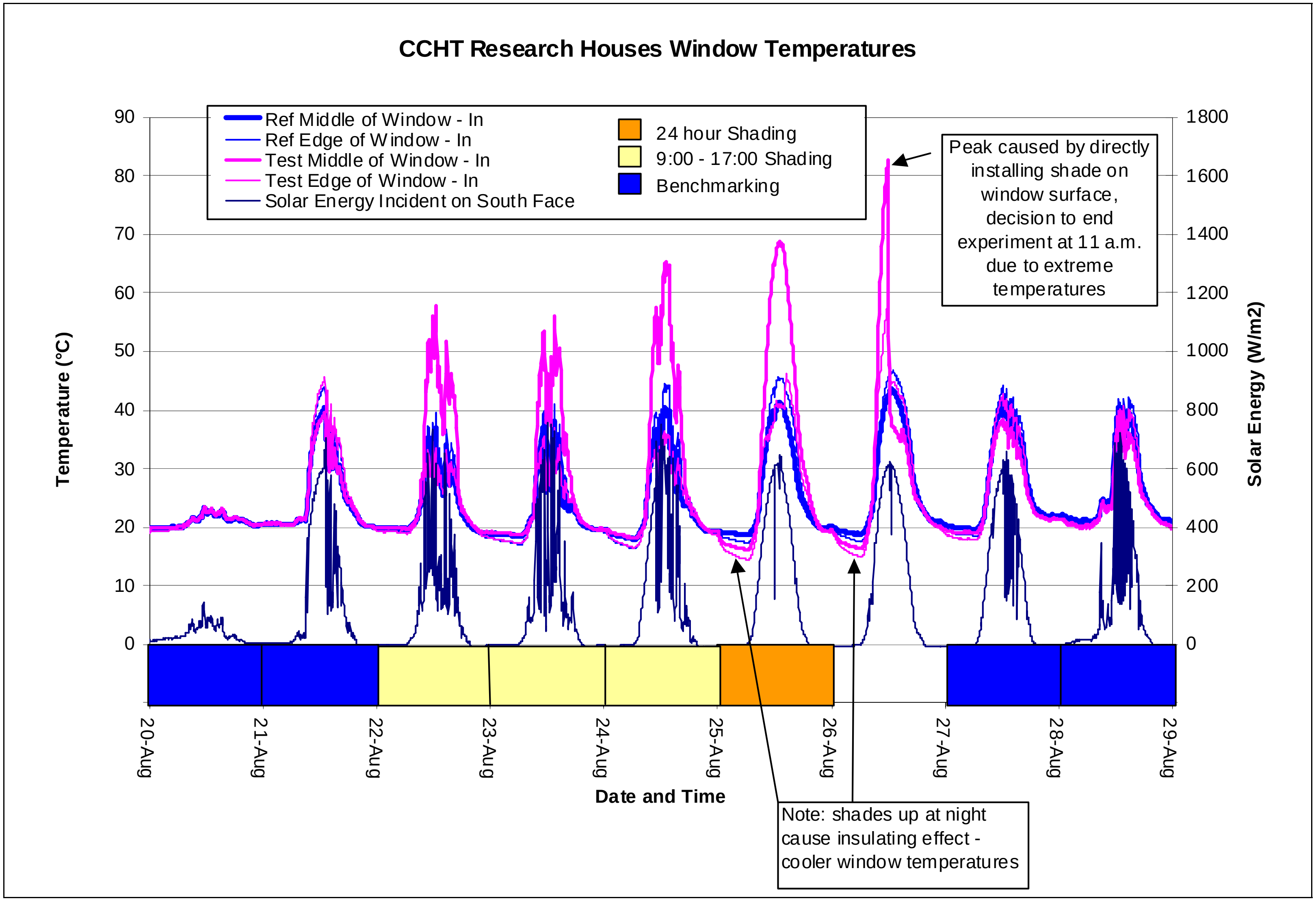


Figure 18 - Window Surface Temperatures – August 20th to August 29th

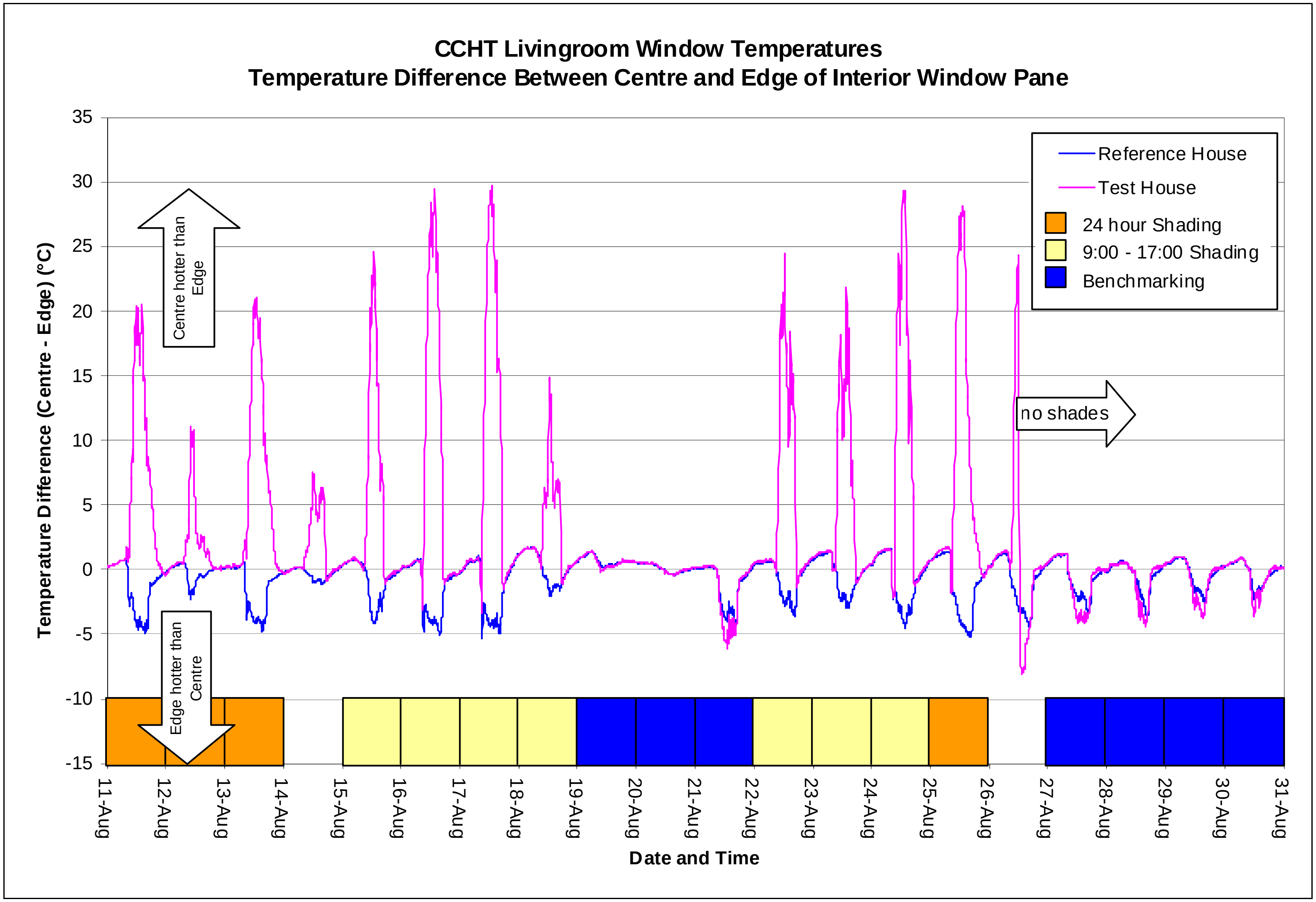


Figure 19 - Surface Temperature Differential between Centre and Edge of Interior Window Pane

5.5 House Humidity

It was predicted that since the use of shades resulted in a reduction in air conditioner on-time, the cooling system would not remove as much moisture from the air, and the humidity would be higher in the shaded house. This should be detected as an increase in humidity levels in the Test House during the shading experiment. Some difference in humidity was detected during the daytime hours when the shades had the greatest impact on the cooling system, see Figure 20. During the day, humidity levels in the Test House rose approximately 0.7 grams of water vapor per kilogram dry air (g_w/kg_{da}) above the levels in the Reference House. This is equivalent to roughly 2% RH at 21°C. However, this small increase in humidity is within the 2% RH accuracy of the humidity sensor and therefore should not be considered significant.

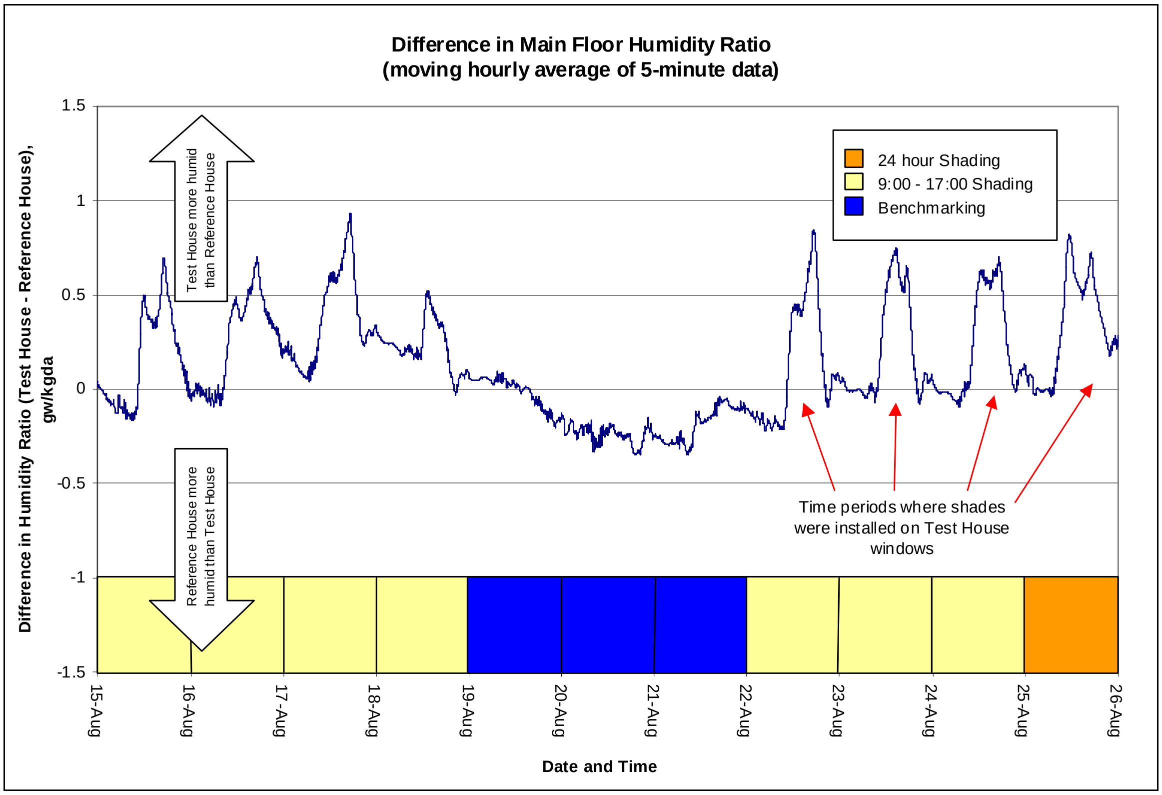


Figure 20 - Difference in Main Floor Humidity Ratio during 9a.m. to 5 p.m. Shading

6 Discussion

The 24-hour strategy proved only slightly more effective than the 9 a.m. to 5 p.m. strategy at providing energy savings during this experiment. Over the entire heating season it is predicted that cooling system electrical savings from the 24-hour shading strategy would be only 0.9% higher than savings from the 9 to 5 shadings strategy. In total, the 24 hour shading strategy is expected to produce seasonal savings of approximately 9.9%, while the 9 to 5 shading strategy would produce seasonal savings in cooling electrical consumption of 9.0%. The main cause of this difference was the shading of the west-facing window. This window remained covered in the evening during the 24-hour shading strategy, reducing evening solar gains to the house and producing additional savings. There is also some evidence – from window temperatures and the 9 a.m. to 5 pm analysis of the consumption data – that removing the shades at 5 p.m. in the 9 a.m. to 5 pm shading strategy allowed the hot window surface to radiate heat into the house.

Table 8 provides a summary of the results from the reflective shading experiment, and the previous Venetian blinds and Exterior shading trials. Generally, the reflective shades proved more effective at reducing air conditioner cooling loads than the interior Venetian blinds, and less effective than the exterior shades. The 9 a.m. to 5 p.m. savings of the Venetian blinds (12%) was countered by nighttime heat gains from heat trapped between the blind and the window radiating back into the house overnight. On the clearest of days, the Venetian blinds produced only small cooling energy savings in the order of 1%. By contrast, both reflective shading strategies produced larger savings during the day (19-25%) and a substantial total daily savings (~12%) in cooling energy consumption on days with high solar gains. Exterior shading still remains the most effective strategy. This strategy generated daytime cooling energy savings of 77% and overall daily savings of 26%, when compared to the house’s daily cooling consumption with closed Venetian blinds.

Table 8 - Summary of Average Daily Savings from different Strategies on Days with High Solar Gains

Trial	Daytime savings (9:00 to 17:00)	Total Daily Savings Over 24 hours
Reflective shades 24 hour shading VS Venetian blinds down and slats horizontal	19%**	12%
Reflective shades 9 to 5 shading VS Venetian blinds down and slats horizontal	25%**	12%
Venetian blinds closed 24 hours* VS Venetian blinds open from 9 to 5	12%	<1%
Exterior blinds VS closed Venetian blinds * 24 hour shading	77%	26%

* Savings results are taken from Galasiu et al., 2005.
Note: savings percentages shown in this table are based on an average of the experiment data for each trial, and are not extrapolated to the entire season.
** Differences in daytime savings from the two strategies is attributable to differing weather conditions during the trial periods

Window temperatures and temperature differential across the glazing unit achieved high levels during the shading experiments, increasing the chance of window breakage. The low-e coating on the third surface of the window contributed to these high temperatures. Lower surface temperatures would be expected on a clear glass double pane window.

More tests are required to determine whether the temperature levels on other types of windows would be within a safe range.

Some features of the houses may affect results, including the fact that they are unfurnished. Without furnishings, the houses contain less thermal mass than a typical inhabited house. Thus, the houses would respond more quickly to changes in temperature and retain less heat from the day. The extent of this mass effect has yet to be evaluated.

A large amount of scatter was present in the data for the daily vertical solar radiation and energy savings relationship (Figure 15). This is partially due to the small quantity of data, but also may be in part a result of the lack of shading on the east-facing windows of both houses. In the early morning hours, the Reference House may have experienced more solar gains than the Test House on days with sunny mornings. In order to construct a better trend line, future tests should be planned to include shading on a minimum of 3 facades: East, South and West.

7 Conclusions

In the summer of 2005, the performance of reflective shading devices was evaluated at CCHT. These shades were installed on the south and west facing windows of the CCHT Test House. Two shading strategies were employed: shading 24 hours and shading 9 a.m. to 5 p.m. Cooling energy consumption (the electrical consumption of the air conditioner compressor and furnace fan), window surface temperatures and house humidity were evaluated.

Results from the experiment revealed that the reflective shading devices produced substantial savings in cooling energy consumption throughout both shading strategies. Savings were the highest on days with the highest incident solar radiation, days when the shades were most effective at reducing solar gains. During the test period, the 24-hour shading strategy produced an average savings of 4.14 kWh/day (12%) on the days with the highest solar gains, and 3.28 kWh/day (9.1%) savings over the entire test period. The 9 a.m. to 5 p.m. shading strategy produced slightly lower absolute savings in kWh, with an average of 3.48 kWh/day (12%) savings on days with high solar gains, and 2.67 kWh/day (10%) average savings for all days the test period. Seasonal calculations predict a cooling system electrical consumption savings of 9.0% for the 9 a.m. to 5 p.m. strategy, and 9.9% for the 24 hour shading strategy over the entire 2005 cooling season at the CCHT Test House.

The majority of savings from the shading strategies was produced between the hours of 9 a.m. and 5 p.m. During this period of time, the 24-hour shading strategy produced an average savings of 2.31 kWh/day (14%), while the 9 a.m. to 5 p.m. shading strategy produced an even higher average savings of 2.95 kWh/day (24%). Outside the hours of 9 a.m. to 5 p.m., the 24-hour shading strategy produced additional savings on these same days of approximately 0.90 kWh/day. By contrast, during the non-shaded hours, the 9 a.m. to 5 p.m. strategy produced an increase in consumption of 0.63 kWh/day. It is likely that the 24-hour shading strategy provided this additional nighttime savings due to the shading of the west-facing window after 5 p.m. reducing evening solar gains to the house.

The window surface temperatures at the centre and edge of the interior pane were evaluated. While shaded, surface temperatures at the centre of the window were roughly 30°C higher than normal operating conditions, reaching a maximum of 68.7°C on the sunniest day. The temperature differential between the centre and edge of glass approached the 30°C limit. For this reason, this use of the reflective shades with argon filled windows with a low-e coating on surface 3 should not be recommended. Use of the shades in this manner would contribute to increased thermal stresses outside the normal operating limits of the window, and could lead to breakage.

The small gap (~3 cm [1 inch]) between the window surface and the shading device did help to alleviate high temperatures slightly – without this air gap, the surface temperature at the centre of the window exceeded 80°C by 11 a.m.

The shading experiment did not reveal any appreciable increase in house humidity levels due to the decrease in air conditioner operation (associated with cooling energy savings). The measured humidity increase was less than 2% RH in all cases, below the accuracy of the sensor.

8 Recommendations for Future Work

A number of additional tests could be conducted to further explore the nature of the reflective shades, and evaluate their effectiveness:

- The same 24-hour shading strategy could be evaluated on days with cooler nights (where the outdoor temperature dropped below the interior air temperature). It is expected that on such nights the shades may have insulating properties that would prevent heat losses, decreasing the overall savings from this strategy.
- The shading devices could be installed on clear glass windows (no coating). This would permit the evaluation of surface temperatures to determine whether this would be a safer application, or whether temperatures would exceed safe operating limits.
- A reflective shading film could be evaluated to isolate the savings from the reflective property of the shade from the thermal properties of the trapped air in the bubbles. Surface temperatures should also be observed during these trials to check whether window temperatures remain within a normal operating range without the insulation.
- The radiant barrier nature of the shade material prevented the heat dissipation into the house, and caused the glazing temperature to approach the limits of safe operation. This is not a typical application for this type of reflective product. Further studies are required to examine the performance of other interior shading products, including those that are commercially available.

This experiment also generated a few general recommendations for all future shading work at the CCHT twin-houses:

- A longer trial period is necessary for each configuration to generate a strong relationship between cooling energy savings and solar radiation. A minimum of 2 weeks in each configuration is recommended, with the possibility of extension depending on weather.

- Shades should be installed on the windows of 3 façades of the Test House at minimum: East, South and West. This will help eliminate differences caused by morning and evening solar gains, and reduce scatter in the data.

9 References

1) Barry, Christopher, Pilkington North America, Personal communications, October 2006.

2) Galasiu, A.D.; Reinhart, C.F.; Swinton, M.C.; Manning, M.M. Assessment of Energy Performance of Window Shading Systems at the Canadian Centre for Housing Technology (IRC-RR-196), May 2005.

3) 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)

4) Lichtenberger, Werner, TruSeal Technologies, Personal communications, November 2006.

5) Sasaki, J.R., "Potential for Thermal Breakage of Sealed Double-Glazing Units" in Canadian Building Digest (CBD 129), September 1970.

Appendix A - 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.

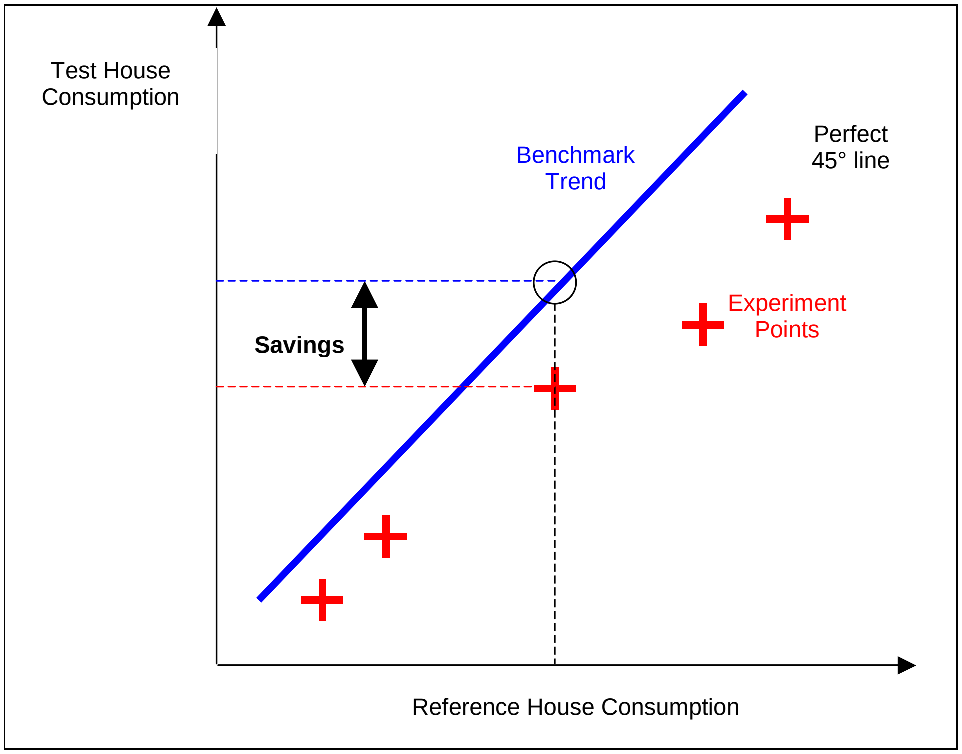
CCHT Simulated Occupancy Schedule

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

Device	Water Utility	Draw	Time	Duration
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 B - Savings Calculation Method

The technique used to calculate the consumption savings at the CCHT twin house facility is described graphically below. Each red cross on this graphic represents the consumption data for a single day of an experiment with a new technology installed in the Test House. For a given day, the Reference House consumes a certain amount of energy. Given the amount consumed by the Reference House and the benchmark trend line, we can calculate how much energy the Test House would consume without the new technology (shown by the dashed blue line). To calculate savings, the measured energy consumption of the Test House during the experiment (shown by the dashed red line) is then subtracted from the expected Test House consumption without the technology. This is equivalent to the vertical distance between the experiment data point and the Benchmark trend.



Graphic Representation of the Savings Calculation Method for Summer Testing

The benchmark trend line is used in place of the benchmark data in order to minimize random errors. On any given day, some scatter is expected in the results both for the Reference House and the Test 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 C – Energy Consumption Graphs

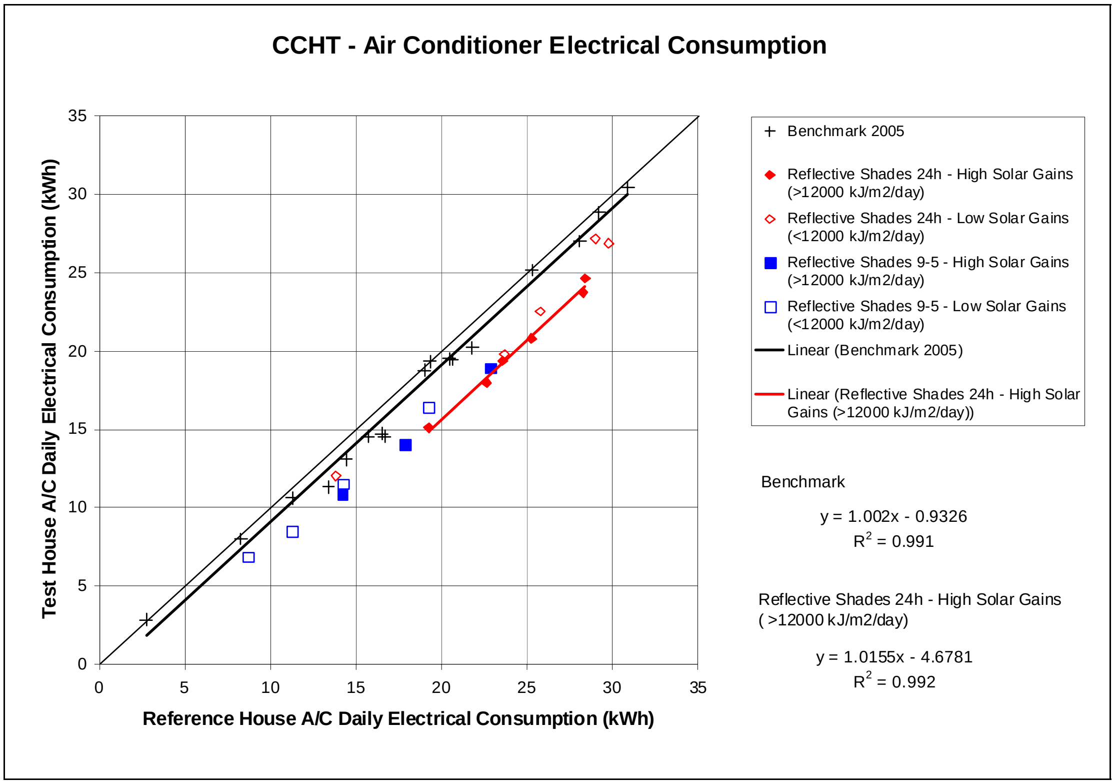


Figure C-1: Air Conditioner Compressor Electrical Consumption

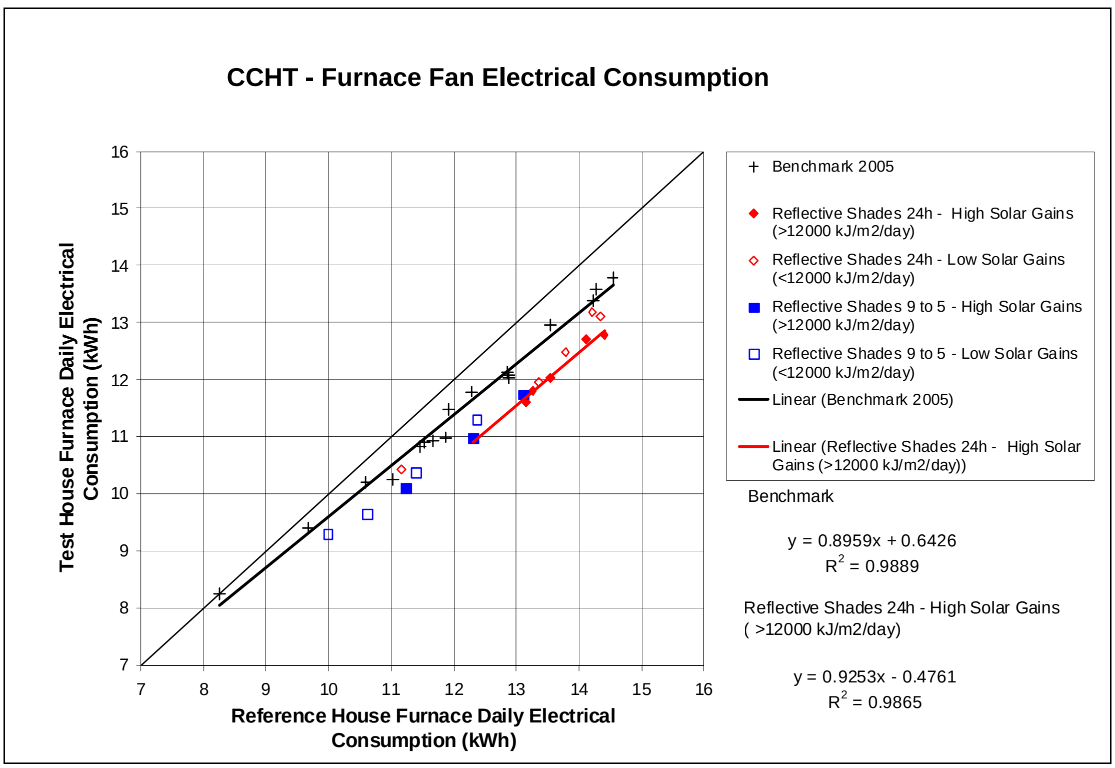


Figure C-2: Furnace Fan Electrical Consumption