Benchmarking of energy savings associated with energy efficient lighting in houses

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Final Report

Benchmarking of Energy Savings Associated with Energy Efficient Lighting in Houses

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EXECUTIVE SUMMARY

Energy efficient compact fluorescent lighting fixtures are becoming more commonly available in the marketplace for homeowners. The replacement of energy efficient lamps in houses would certainly reduce the electrical energy use and power demand; however, would also affect the space heating and space cooling energy needs. The purpose of this project is to establish inter-dependence of lighting on the overall energy usage in housing. Based on the inter-dependence effects, the overall impacts of compact fluorescent lamps (CFL) in housing applications can be evaluated. The following tasks were accomplished:

- benchmarking testing was conducted at the Canadian Centre for Housing Technology (CCHT) facility to develop reliable power and energy use profiles;
- verification of an internal gains model for HOT2000 algorithms; and
- extrapolation of potential impact of energy efficient lighting on different types of housing.

Lighting Energy Use

- The housing surveys showed that, on average, lighting energy use is about 3.4 kWh per day in Canadian houses. The lighting energy use accounts for about 5% to 8% of the annual utility costs.

Characteristics of Compact Fluorescent Lamps

- The manufacturers' ratings of the power demand for lamps were good and reliable for the energy modelling purposes. The difference in published rating and measured wattages of the compact fluorescent and conventional incandescent lamps ranged was approximately ±1.2 W – or about ±4%.
- The power factor of the compact fluorescent lamps ranged from 0.56 to 0.59. The incandescent lamps had a power factor of 1.0.
- The kVAr measurements for the whole house showed that the reactive power is slightly lower for CFL lighting than conventional lighting. Therefore, the lower power factor of the CFL lamps does not appear to be an issue because their lower reactive power more than compensate for it.

CCHT Testing during the Heating Season

The CCHT testing of the conventional incandescent and the compact fluorescent lighting showed the following results:

- The compact fluorescent lighting can reduce electricity demand and provide significant energy savings. Based on a typical lighting schedule for the house, the daily energy savings are about 67%.
- The reductions in the lighting energy use are almost offset by increase in the space heating requirements. The lighting energy is utilized as internal gains for the house. The results showed that 83% to 100% of lighting energy consumption could contribute to the internal gains.
- It appeared that the different ventilation strategies, either continuous or intermittent, did not have any impact on the overall energy savings associated with CF lamping.

CCHT Testing during the Cooling Season

The CCHT testing of the conventional incandescent and the compact fluorescent lighting during the summer season showed the following results:

- The compact fluorescent lighting can reduce electricity demand and provide significant energy savings. Based on a typical lighting schedule for the house, the daily energy savings are about 67%.
- The reduction in lighting energy use also reduces the cooling loads. The energy analysis showed that about 80% of the lighting energy internal gains are associated with cooling demand.
- The use of CF lighting also reduces the ON time run of the cooling equipment by 20% or more.

Potential Estimates of Benefits of Compact Fluorescent Lighting

Internal heat gain models were verified successfully. The thermal archetype was based on the age, location and type of the house with conventional lighting energy consumption at about 3.4 kWh/day. It was assumed five conventional incandescent fixtures were replaced with compact fluorescent fixtures. Based on this scenario, conventional lights with 77 W of five fixtures used for three hours/day were replaced with CFL of 19 W of five lamps used for three hours/day. The reduction in daily lighting energy use is about 0.87 kWh.

- The electrical energy savings are about 318 kWh per year with CF lighting. The reduction in lighting energy consumption is about 26%. The whole house electricity load reduction (annual energy use) is about 3.7%.
- The electrical demand savings are about 0.29 kW with CF lighting.
- The increase in the annual space heating energy consumption is about 0.6% to 1.7%.

- The reduction in the space cooling energy use ranged from 4% to 9.5% for the CF lighting. The ON time operation of cooling equipment ranged from 10% to 18%.
- The utility costs showed that even in the 'heating only' scenario, the compact fluorescent lighting positively saved the utility costs. The cooling season savings significantly adds to the cost savings. The lighting replacements also positively reduce the utility costs in all electric houses.
- Assuming the cost of five CF lighting fixtures of about $30, the simple payback period is three to six years for non-air-conditioned houses. A house with summertime air-conditioning, would accelerate the simple payback period form 2.5 to five years.

Overall, compact fluorescent lighting contributes positively to energy and cost savings in typical Canadian houses.

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ACKNOWLEDGEMENTS

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Anil Parekh of the Sustainable Building and Communities (SBC) group of the CANMET Energy Technology Centre conceived and led the research team. The project team included Frank Szadkowski of SBC; and Mike Swinton and Marianne Manning of the Canada Centre for Housing Technologies (CCHT). The project team sincerely appreciates CCHT Research Committee for their report review and technical support.

Benchmarking of Energy Savings Associated with Energy Efficient Lighting in Houses

1. INTRODUCTION

In recent years, due to the substantial reductions in the incremental costs associated with energy efficient lighting fixtures, their use in housing is becoming more prevalent. The energy efficient lighting fixtures offer substantial potential for reducing the electrical power consumption and energy use. The use of these energy efficient lighting fixtures also influences the need for house heating and cooling.

There are a number of field studies available for retail and commercial buildings showing the increase in the need for heating and the reduction in the cooling loads associated with the replacement of existing conventional lighting with the energy efficient lighting[1]. Residential use of lighting is different than the retail and commercial sectors. There is a selective use of lamps/fixtures in houses depending on occupant's needs. As shown in Figure 1, space and hot water heating is predominant in Canadian housing. Figure 2 shows the annual costs associated with various energy use in a typical house. The unit cost of different sources of energy also plays a key role in identifying the potential retrofit measures. The lighting energy use accounts for about 5% to 8% of the annual utility costs. The replacement of energy efficient lamps in houses would certainly reduce the electrical energy use and power demand; however, would also affect the space heating and space cooling energy needs. The purpose of this project is to establish inter-dependence of various internal loads, particularly lighting, on the overall energy usage in housing. Based on the inter-dependence effects, the overall impacts of compact fluorescent lamps (CFL) in housing applications have been determined.

1.1. Scope and Objectives

The purpose of this project was to determine the overall energy efficiency and power demand reductions feasible with energy efficiency compact fluorescent lamps in houses. As part of the project, benchmarking testing was conducted at the Canadian Centre for Housing Technology (CCHT) facility to develop reliable power and energy use profiles. The outcome of this project includes:

- the benchmark testing of energy efficient lighting at the CCHT research facility;
- the verification of an internal gains model for HOT2000 algorithms; and

[1] *Advanced Lighting Guidelines – Edition 2003, New Buildings Institute. Available at http://www.newbuildings.org. (Refer to Section 3.1.3 and Table 3-1).*

- extrapolation of potential impact of energy efficient lighting on different types of housing.

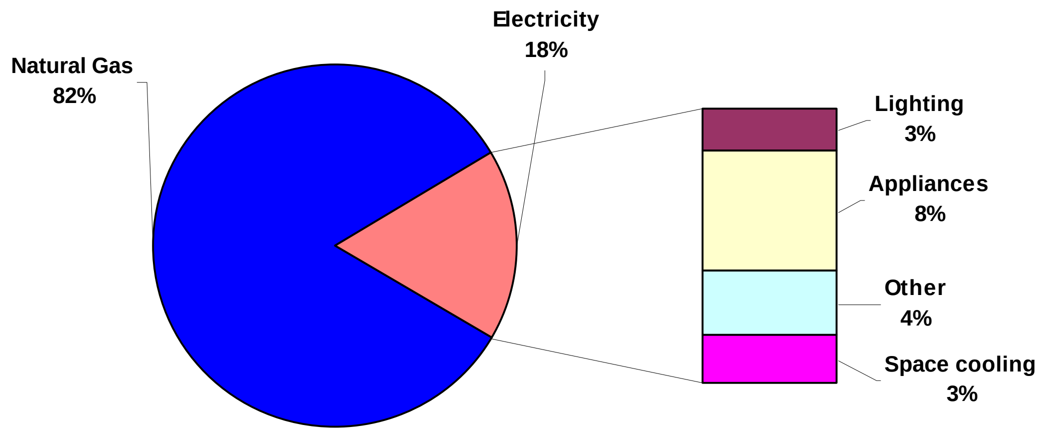

Figure 1. Typical annual energy use profile for a 2000 sq-ft house located in Toronto.

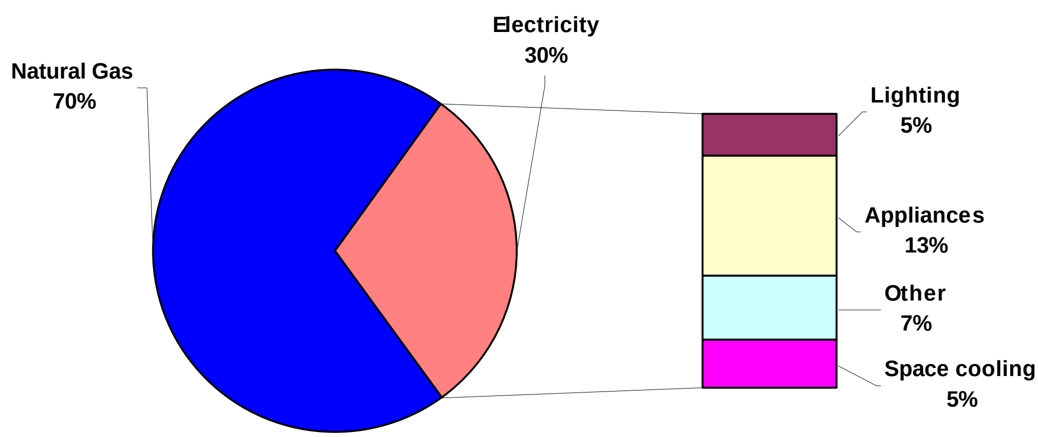

Figure 2. Typical annual utility cost profile for a 2000 sq-ft house located in Toronto.

1.2. Average Lighting Energy Use

Over the years, there have been a number of detailed housing surveys. From a set of 134 highly monitored houses[2], the following profiles were generated to define the lighting energy use in housing. Table 1 shows the typical lighting energy use profile for housing. Figure 3 shows the data analysis graph for the lighting loads. The best-fit equation shows the approximate correlation for the lighting energy use and the number of occupants in the house.

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[2] *Nova Scotia Report (NRCan) 1993; Efficiency Housing Database - Alberta (NRCan) 1993; Field Energy Audit Survey (NRCan) 1994, BC; Espanola Energy Efficiency Housing Retrofit Program, Ontario Hydro, Scanada 1989, ON; Airtightness and Energy Efficiency of New Conventional and R2000 Housing in Canada (NRCan) 1997.*

As per the above data, the average lighting energy use is about 3.4 kWh per day in Canadian houses. The data analysis for Alberta and Ontario houses (each consisting of more than 40 houses) showed that the average lighting energy use for Alberta was about 0.6 kWh/day more than that for Ontario. For the purpose of this study, the lighting energy use is assumed to be 3.4 kWh/day.

Table 1. Profile of base electric use patterns for single-family homes.

No. of Occupants	Average Lighting Energy Use, kWh/day	Standard Deviation, kWh/day
1	1.6	0.4
2	2.6	0.7
3	3.0	0.8
4	3.2	0.6
5	3.4	0.6
6	3.5	0.7
7	3.7	0.3

$$Lighting\_Energy\_Use = 1.6 + 0.9\sqrt{OccN - 1.0} \text{ kWh/day}$$

OccN = number of occupants

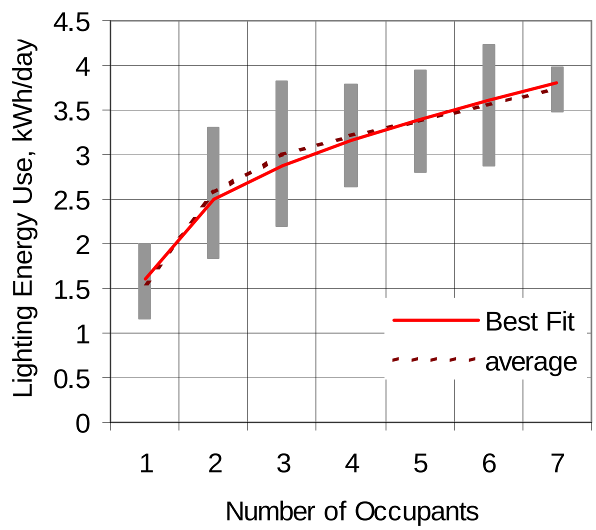


Figure 3. Profile of lighting energy use in Canadian housing.

1.3. Test and Verification Methods

The project objectives were accomplished with the following tasks:

1. *Benchmark testing of energy efficient lighting at CCHT research facility.* The Canadian Centre for Housing Technology (CCHT) consists of two well-defined

identical research houses (http://www.ccht-cctr.gc.ca/). This facility is jointly owned by the National Research Council Canada (NRC), Canada Mortgage and Housing Corporation (CMHC) and Natural Resources Canada (NRCan) and is located at NRC's Ottawa campus. The facility allowed for running the reference house with conventional lighting and the test house with the CFL (compact fluorescent lamps) and other energy efficient lighting. The benchmark testing included the following:

- Measurements of the power demand and lighting performance of conventional and energy efficient lamps.
- Comparison of the impact of energy efficiency lighting during the heating season using two options:
    - ❖ Intermittent ventilation – In this case, the ventilation system was "ON" only during the heating periods and there was no circulation of air in the house. This test simulated the operating conditions of old existing houses.
    - ❖ Continuous ventilation – In this test, HRV ventilation system was kept fully "ON" during the heating periods. This reasonably represented the new construction where dedicated ventilation is mandated.
- Comparison of the impact of energy efficiency lighting during the cooling season. The second test set was for a period of three weeks during the cooling season.

2. *Verifications of internal gain models of the residential energy analysis software programs.*

3. *Extrapolate results for different styles of housing and locations and prepare a report.*

1.4. Report Organization

This report is structured in the following main sections:

- Section 2 presents the results of the benchmarking tests at the CCHT during the heating and cooling seasons;
- Section 3 documents the review of internal gains models and verifications of HOT2000 energy simulations and shows a matrix of potential energy efficiency and power demand benefits associated with CF lamping in two different styles of houses at various locations; and
- Section 4 summarizes the findings.

2. ENERGY PERFORMANCE OF COMPACT FLUORESCENT LAMPS

The study focused on the impact of the compact fluorescent lamps on the annual energy consumption and power demand. This section provides a review of the average lighting energy use in Canadian houses and the field results of the benchmarking tests.

The Canadian Centre for Housing Technology (CCHT) facility provides a unique opportunity for verifying the difference between two different types of technologies. Visit the website http://www.ccht-cctr.gc.ca/ for a full description of the facility and the results of the comparison of two identical full-sized houses located on the campus of National Research Council in Ottawa. Appendix A provides brief overview of the CCHT facility.

2.1. Light Bulbs and CFL Characteristics

To check and qualify every light bulb used in the lighting experiment, two types of instruments were used. The first one is a Elcontrol VIP96 which gives the light voltage, intensity, power, power factor, volts-amps reactive, volts-amps and frequency. The second instrument is a 3060 Power Profiler by Basic Measuring Instrumentation. The Power Profiler can give instantaneous information (snapshot) or hourly, daily, reports.

The types of light bulbs used are:

- 60W incandescent = 60W DuraMax Long Life by Philips
- 40W incandescent = 40W DuraMax Long Life by Philips
- Round CFL = 9W G25 Globe by Commercial Electric
- Compact Fluorescent Lamps = 15W Marathon Energy saver mini decorative twister by Philips

Figure 4 illustrates the test set up for the lamps.

Each test report informs about:

- Instantaneous power (max and min power, power consumption plot)
- Instantaneous volts-amps (max and min volts-amps, volts-amps plot)
- Billing demand (demand interval, max and min demand, demand plot)
- Load duration curve
- Total power consumption (flat rate, billing demand, consumption)

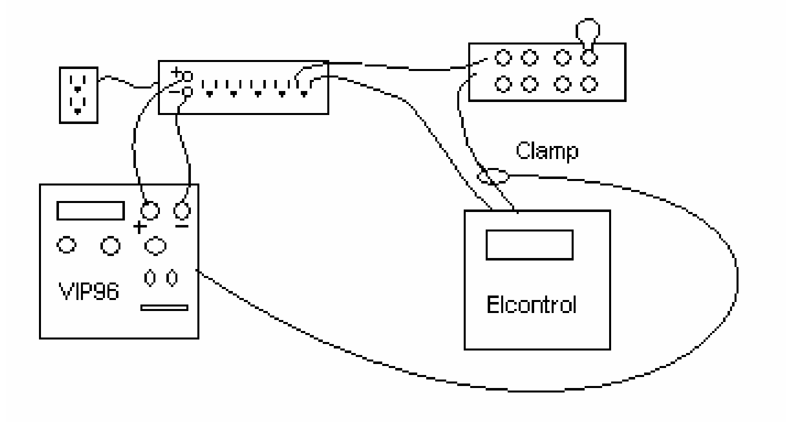


Figure 4: Electric circuitry

- Volts-Amps report (max and min volts-amps reactive, volts-amps reactive plot)
- True Power Factor
- Max and min true power factor
- True power factor plot
- Displacement factor (max and min displacement factor, displacement factor plot)
- Voltage THD (max and min voltage THD, voltage THD plot)
- Current THD (max and min current THD, current THD plot)
- Voltage 5^{th} harmonic (max and min voltage 5^{th} harmonic, voltage 5^{th} harmonic plot)
- Current 5^{th} harmonic (max and min current 5^{th} harmonic, current5^{th} harmonic plot)
- Voltage (max and min voltage, voltage plot)
- Current (max and min current, current plot)
- Neutral-Ground voltage (max and min ground voltage, ground voltage plot)
- Frequency (max and min frequency, frequency plot)

Snapshot informs about:

- Power consumption
- Instantaneous power + sinusoid
- Power factor (power, volts-amps, volts-amps reactive, power factor, dPF)
- Harmonics (fundamental frequency)
- Phase A-N Volts (THD)
- Phase A current (THD)
- Phase A voltage spectrum (fundamental volts, fundamental frequency, harmonics)
- Phase A current spectrum (fundamental amps, fundamental frequency, harmonics)

- Phase a power spectrum (power, fundamental frequency, harmonics, power)
- Voltage and current (phase A-N, neutral-ground, phase A)
- Neutral-ground voltage (crest factor, form factor, neutral-ground voltage plot, neutral-ground current plot)

For all light bulbs used, a snapshot report was produced.

The Elcontrol VIP96 helped verify the accuracy of the 3060 Power Profiler and verifying the constancy of the light bulbs of a same kind. If the voltage, intensity, power, power factor, volts-amps reactive, volts-amps and frequency given by both the Elcontrol VIP96 and the 3060 Power Profiler were close to each other, it was easy to conclude that both instruments are accurate. In the same way, if two bulbs of the same kind would give the same results with the Elcontrol then it’s possible to conclude that they are constant. Table 2 gives the various results obtained with the Elcontrol.

When measuring the previous parameters, experimenters observed that the readings are not as stable with the compact bulbs (round and compact) than with the regular ones.

Some tests were done by turning on the light suddenly to explore the effect of this action on the various parameters. Since the shortest period for reports is one hour, the measuring scale was unable to show any fluctuation or the time of response.

Using the information provided in Table 2 and Table 3, the following are typical observations:

- The manufacturers’ ratings of the power demand for lamps were good and reliable for energy modelling purposes. The difference in published rating and measured wattages of the compact fluorescent and conventional incandescent lamps ranged by about ±1.2 W or about ±4%.
- The power factor of the compact fluorescent lamps ranged from 0.56 to 0.59. The incandescent lamps had a power factor of 1.0.
- Table 3 shows some interesting power factor measurements for the whole house. The mean values of the power factor for the Reference and Test houses are close – indicating that overall, the power factor is not an issue. However, when observed, the minimum value of PF differs significantly by about 0.06 or about 7% - indicating that CFL lamps do have lower PF especially when they start up. The kVAr measurements showed that the reactive power is slightly lower for CFL lighting than the conventional lighting. Therefore, the lower power factor of the CFL lamps does not appear to be an issue because their lower reactive power more than compensates for it. Measured data also showed the total harmonic distortions (THD) which are significantly higher for CFL lamps associated with the current; however, the THD associated with voltage were much less.

Table 2: Light bulbs parameters obtained with a Elcontrol VIP96 meter

Light bulb	Manufacture Rating W	Measured Data						
		volts	mA	W	PF	VAr	VA	Hz
compact 1	15	116	219	14.3	-0.56	-21.1	25.6	60
compact 2	15	116	235	15.9	-0.59	-21.8	26.7	60
compact 3	15	117	238	15.3	-0.58	-22.7	27.7	60
used compact 1	15	117	221	14.9	-0.57	-21.3	25.9	60
used compact 2	15	117	219	14.6	-0.57	-21	25.6	60
Round 1	9	117	133	8.82	-0.56	-12.9	15.6	60
Round 2	9	117	138	9.3	-0.59	-13.1	15.9	60
Round 3	9	117	131	8.89	-0.58	-12.6	15.4	60
used round 1	9	117	134	8.93	-0.57	-12.9	15.8	60
used round 2	9	117	140	9.27	-0.57	-13.5	16.4	60
40W 1	40	117	337	39.5	1	0	39.5	60
40W 2	40	117	338	39.6	1	0	39.6	60
40W 3	40	117	336	39.4	1	0	39.4	60
used 40W 1	40	117	333	39.3	1	0	39.6	60
used 40W 2	40	117	337	39.4	1	0	39.4	60
60W 1	60	117	509	59.9	1	0	59.7	60
60W 2	60	117	499	59.3	1	0	58.3	60
60W 3	60	117	525	61.4	1	0	61.4	60
used 60W 1	60	117	502.5	58.8	1	0	58.75	60
used 60W 2	60	117	505	59.2	1	0	59	60

Figure 5. Compact fluorescent lamp in a Test House.

Table 3. Summary of power quality measurements for the whole house using CF and conventional lamps.

Date	Condition	Power Factor		Kvar		Total Harmonic Distortion								Frequency		
		MIn	Mean	Mean	Max	V1		V2		I1		I2		Min	Mean	Max
						Mean	Max	Mean	Max	Mean	Max	Mean	Max			
24-Mar	Benchmark	85.374	95.667	0.2463	1.449	0.5253	0.7520	0.7722	1.032	5.809	18.6678	1.969	22.887	59.929	60.001	60.063
25-Mar	Benchmark	87.114	95.731	0.2458	1.380	0.5101	0.8725	0.7756	1.156	5.854	17.807	1.973	38.723	59.936	59.997	60.071
26-Mar	Test	79.640	95.599	0.1998	1.285	0.5049	1.3625	0.7424	4.635	27.164	96.445	2.045	38.097	59.941	60.000	60.371
27-Mar	Test	79.718	95.554	0.1943	1.359	0.4988	0.9211	0.7572	1.108	27.392	97.116	2.034	46.431	59.939	59.998	60.048
28-Mar	Test	79.727	95.527	0.1950	1.478	0.5059	0.8532	0.7479	1.089	27.421	98.230	1.984	35.272	59.919	59.998	60.055
14-Apr	Test	79.829	94.041	0.1914	1.266	0.4405	1.0230	0.6912	1.057	27.824	100.46	2.043	57.369	59.942	59.998	60.059
15-Apr	Test	80.221	94.103	0.1902	1.283	0.5454	1.0460	0.7834	1.009	25.413	98.313	2.022	34.846	59.944	59.998	60.055
16-Apr	Test	80.346	94.046	0.1888	1.213	0.5538	1.0060	0.7916	1.089	27.449	99.337	2.045	39.454	59.946	60.001	60.055
17-Apr	Test	80.499	94.081	0.1895	1.204	0.5030	0.9576	0.7481	1.011	27.270	113.59	2.019	52.427	59.940	59.998	60.050
18-Apr	Test	80.412	94.258	0.1891	1.123	0.4634	0.9701	0.6860	1.025	27.200	98.444	2.027	38.46	59.944	59.992	60.058
Mean, Benchmark		86.244	95.699	0.246	1.415	0.518	0.812	0.774	1.094	5.832	18.237	1.971	30.805	59.933	59.999	60.067
Mean, Tests		80.049	94.651	0.192	1.276	0.502	1.017	0.743	1.503	27.142	100.24	2.027	42.795	59.939	59.998	60.094
Data from		Query 5 Col P&Q Min of values	Query 6 Col P&Q Mean of values	Query 6 Col N Mean of values	Query 4 Col N Max of values	Query 3 Col C Mean of values	Query 2 Col C Max of values	Query 3 Col D Mean of values	Query 2 Col D Max of values	Query 3 Col F Mean of values	Query 2 Col F Max of values	Query 3 Col G Mean of values	Query 2 Col G Max of values	Query 5 Col R Min of values	Query 6 Col R Mean of values	Query 4 Col R Max of values

For Benchmarking, all Power Factors are Lagging.
For 26 March Test, of the 96 periods of 15 minutes, 95 periods have Lagging, 8 have Leading PFs.
Other test days are similar.

THD, V2 Max for 26 March seems to have been a unique event.

For the EE Bulbs:

Power Factor: The minimum is lower, and the mean is slightly lower.
So it looks like the EE bulbs do have lower PF, perhaps especially when they start up.
VAR: The mean and max are lower. So it looks like the lower power of the EE bulbs more than compensates for their lower.PF.

THD, Voltage: The mean is slightly lower, but the max is significantly higher.

THD, Current: I1: Mean and Max are significantly higher. I2: Mean is slightly higher, Max is significantly higher.

The lower power factor of the EE bulbs does not apperar to be a problem because therir lower power more than compenstates for it, producing lower VARs.

EE Bulbs do produce significantly higher THD, particulary in current.

CCHT Houses during the winter months.

2.2. Lighting Schedule

Several changes to the normal lighting schedule and test protocol were made at the CCHT houses. As shown in Figure 6, the lighting schedule was changed to enable reliable measurements of electricity demand for lighting and its implications on the space heating and space cooling energy use. The normal lighting energy use is about 3.4 kWh/day which was increased to about 10.2 kWh/day with conventional fixtures. The target was to obtain a difference of about 7.0 kWh/day with CFL lighting.

Figure 6. CCHT lighting schedule for energy efficient lighting project

CCHT Lighting Schedule & Proposed Changes for Energy Efficient Lighting Project						
Current (normal) Schedule:						
Second Floor:		On time:	6	hours per day.		
	6	bulbs of	60	W =	2.16	kWh/day
	3	bulbs of	40	W =	0.72	kWh/day
	Total:				2.88	kWh/day
First Floor:		On time:	3.75	hours per day.		
	4	bulbs of	60	W =	0.90	kWh/day
	0	bulbs of	40	W =	0.00	kWh/day
	Total:				0.90	kWh/day
Total For House:					3.78	kWh/day
Proposed Schedule:			User inputs: yellow background:			
With Incandescent Bulbs (Benchmark, and Ref House during experiments)						
Second Floor:		On time:	7	hours per day.		
	11	bulbs of	60	W =	4.62	kWh/day
	8	bulbs of	40	W =	2.24	kWh/day
	Total:				6.86	kWh/day
First Floor:		On time:	5	hours per day.		
	9	bulbs of	60	W =	2.70	kWh/day
	3	bulbs of	40	W =	0.60	kWh/day
	Total:				3.30	kWh/day
Total For House:					10.16	kWh/day
		Increase over normal schedule:			6.38	kWh/day
With Compact Fluorescent Bulbs (Benchmark, and Test House during experiments)						
Second Floor:		On time:	7	hours per day.		
	11	bulbs of	15	W =	1.16	kWh/day
	8	bulbs of	7	W =	0.39	kWh/day
	Total:				1.55	kWh/day
First Floor:		On time:	5	hours per day.		
	9	bulbs of	15	W =	0.68	kWh/day
	3	bulbs of	7	W =	0.11	kWh/day
	Total:				0.78	kWh/day
Total For House:					2.33	kWh/day
Difference due to Compact Fluorescent Bulbs:					**-7.83**	**kWh/day**
If actual is 85% of Nominal:			**-6.66**	**kWh/day**		
Compact Fluorescent Bulbs Required (not including spares):						
	15 W bulbs (to replace 60W incandescents):				20	
	7 W bulbs (to replace 40 W incandescents):				11	

2.3. Heating Season Tests

The heating season tests included the following:

- Benchmarking with conventional lights during March 24 and 25, 2004, and December 24 to 28, 2004.
- Testing with CF lamps in the Test House and conventional lamps in the Reference House during the following periods:
  - March 26 to 28, 2004 with continuous ventilation strategy;
  - April 15 to 18, 2004 with continuous ventilation strategy;
  - December 30 to January 5, 2005 with continuous ventilation strategy; and
  - January 7 to 16, 2005 with intermittent ventilation strategy

2.3.1. Benchmarking Tests

As per the CCHT test protocols, the test and research houses were set up and operated with identical conditions to develop a full profile for the reference. As shown in Figure 7, the lighting power demand for both houses followed identical patterns of power draw with less than 0.4% difference in power demand.

Figure 7. Profile of lighting power demand for Reference and Test houses.

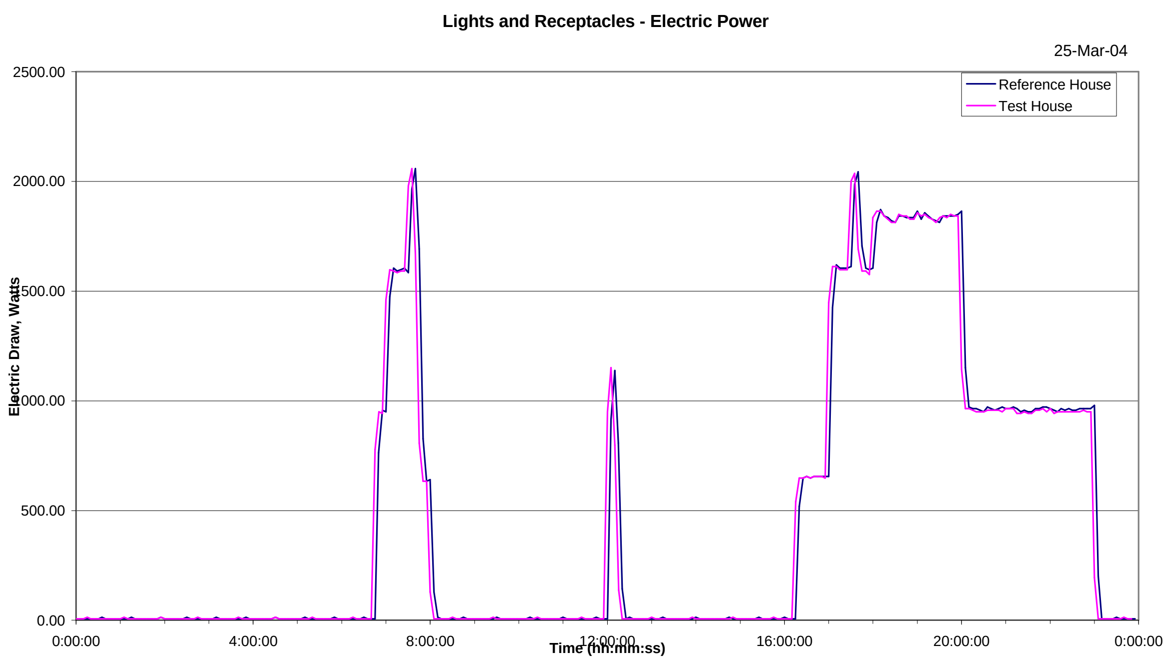


Table 4. Benchmarking results of Test and Reference houses.

	Lights and Receptacles Daily Electrical Consumption (kWh)		Difference		Furnace Gas Consumption, MJ		Difference
Date	**Reference House**	**Test House**		**Date**	**Reference House**	**Test House**	
24-Mar-04	10.76	10.72	0.4%	24-Mar-04	204.19	209.21	-2.5%
25-Mar-04	10.80	10.76	0.4%	25-Mar-04	205.46	199.91	2.7%
24-Dec-04	10.74	10.69	0.5%	24-Dec-04	420.10	422.11	-0.5%
25-Dec-04	10.75	10.69	0.5%	25-Dec-04	423.38	437.64	-3.4%
26-Dec-04	10.81	10.74	0.7%	26-Dec-04	441.97	446.25	-1.0%
27-Dec-04	10.72	10.67	0.4%	27-Dec-04	423.12	433.15	-2.4%
28-Dec-04	10.82	10.77	0.4%	28-Dec-04	400.56	406.21	-1.4%
average	**10.77**	**10.72**	**0.5%**	**average**	**359.83**	**364.93**	**-1.2%**

Two sets of benchmarking tests were conducted prior to the evaluation of energy efficient compact fluorescent lighting. Table 4 shows the summary of the benchmarking energy use data gathered for each day. The reference data showed that daily energy consumption associated with lighting was within 0.05 kWh per day or about 0.5% and seemed to be within the measurement limits. The space heating energy use, measured in terms of furnace natural gas consumption, showed that both houses were relatively closely operating. The difference in the furnace energy consumption for two houses was about 5 MJ per day or about 1.2%. This again seemed to be within the measurement accuracy of gas flow meters.

2.3.2. CFL Tests

Once the benchmarking tests were successfully completed, all light bulbs in the Test House were replaced with appropriate compact fluorescents. Figure 6 shows the list of lamps and the operating schedule. The CFL testing was conducted during the following periods:

- for 3 days during March 26 to 28, 2004 with continuous ventilation strategy;
- for 4 days during April 15 to 18, 2004 with continuous ventilation strategy;
- for 7 days during December 30 to January 5 with continuous ventilation strategy; and
- for 10 days during January 7 to 16, 2005 with intermittent ventilation strategy.

CFL Test with Continuous Ventilation Strategy

In this test, HRV ventilation system was kept fully 'ON' during the heating periods. This reasonably represented the new construction where dedicated ventilation is required at all times. The ventilation system operated at full capacity (about 65 L/s) when the house required heating and the furnace was operating. In the non-heating periods, when the furnace was 'OFF', the ventilation system operated at half capacity (about 30 L/s) to provide fresh air to the house. In both houses the ventilation is distributed through the main air distribution system using the furnace fan.

Figure 8 shows the profile of lighting power demand for the Reference and Test houses. In both houses, the light operating schedule was identical and provided similar profiles. Test House with CFLs showed significant reduction in the electric power demand associated with lighting. The power demand reduction was about 62%.

Table 5 shows the measured data of lighting energy use and the space heating energy requirements for the Test and Reference houses. The lighting energy use in the Reference house with conventional lighting ranged from 10.74 to 10.83 kWh/ day with an average of 10.77 kWh/day. This was close to the initial benchmarking results. The lighting energy in the Test house with CFL lighting was about 3.44 to 3.49 kWh/day with an average of about 3.47 kWh/day. The lighting energy use in both houses was not dependent on indoor or ambient conditions.

Figure 8. Profile of lighting power demand for Reference and Test houses.

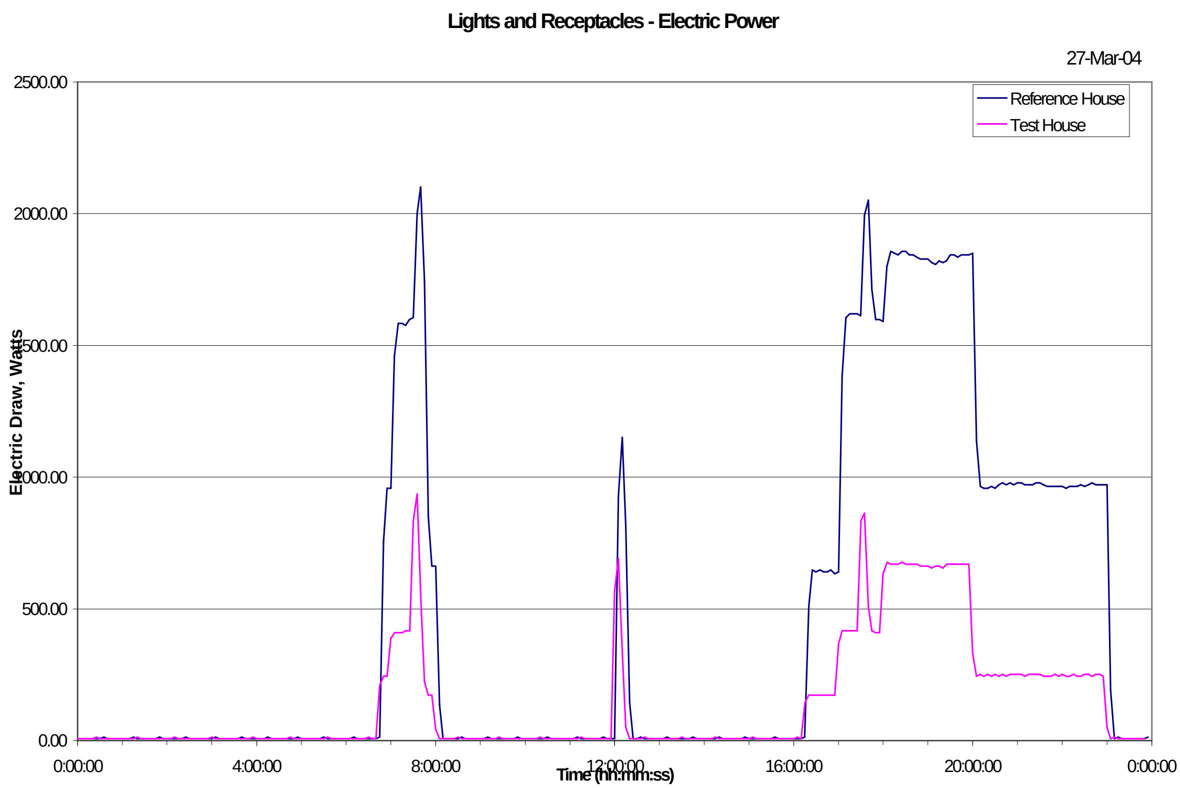


Table 5. Measured results of lighting energy and the space heating energy use in Test and Reference houses – continuous ventilation strategy.

	Lights and Receptacles Daily Electrical Consumption (kWh)		Difference		Furnace Gas Consumption, MJ		Difference
Date	**Reference House**	**Test House**		**Date**	**Reference House**	**Test House**	
26-Mar-04	10.80	3.45	68.0%	26-Mar-04	145.14	156.65	-7.9%
27-Mar-04	10.82	3.47	67.9%	27-Mar-04	104.74	124.96	-19.3%
28-Mar-04	10.80	3.47	67.9%	28-Mar-04	106.27	130.14	-22.5%
15-Apr-04	10.83	3.49	67.8%	15-Apr-04	95.23	112.18	-17.8%
16-Apr-04	10.75	3.46	67.8%	16-Apr-04	83.19	103.89	-24.9%
17-Apr-04	10.80	3.48	67.8%	17-Apr-04	89.74	113.34	-26.3%
18-Apr-04	10.77	3.47	67.8%	18-Apr-04	91.21	121.37	-33.1%
30-Dec-04	10.74	3.49	67.5%	30-Dec-04	359.21	389.05	-8.3%
31-Dec-04	10.78	3.49	67.7%	31-Dec-04	251.78	278.61	-10.7%
1-Jan-05	10.79	3.46	67.9%	1-Jan-05	222.99	246.23	-10.4%
2-Jan-05	10.79	3.48	67.8%	2-Jan-05	430.62	469.38	-9.0%
3-Jan-05	10.76	3.48	67.7%	3-Jan-05	281.94	315.11	-11.8%
4-Jan-05	10.75	3.49	67.5%	4-Jan-05	280.09	305.23	-9.0%
5-Jan-05	10.58	3.44	67.4%	5-Jan-05	342.36	372.36	-8.8%
average	**10.77**	**3.47**	**67.8%**	**average**	**206.03**	**231.32**	**-15.7%**

The space heating energy use varied depending on the outdoor conditions. The space heating requirements ranged from 83 to 430 MJ/day representing about 15% to about full (100%) space heating load for the house. The 14-day test period covered the full range of the heating season enabling the comparison of the effects of energy efficient lighting. The data showed the following trends:

- The compact fluorescent lighting in the Test house reduced the daily electricity consumption by about 7.3 kWh. This accounted for about 67.8% of the daily lighting energy use.
- The space heating energy use increased to compensate for the reduction in the lighting energy use. The space heating energy use increased from 11.5 to 38.8 MJ/day with an average of about 25.3 MJ/day. This ranged from 8% to 33% of the daily space heating load. It was observed that the increase in the space heating load was associated with the overall heat losses.

Using the measured data, an energy balance analysis was performed to determine the utilization factor for the lighting energy use and its impact on the space heating energy requirements.

Figure 9 shows the comparison of the furnace energy consumption for the house with conventional and CF lighting. As shown, there is somewhat increase in the space heating loads in the Test house with CF lighting compared to the space heating loads in the Reference house with conventional lighting.

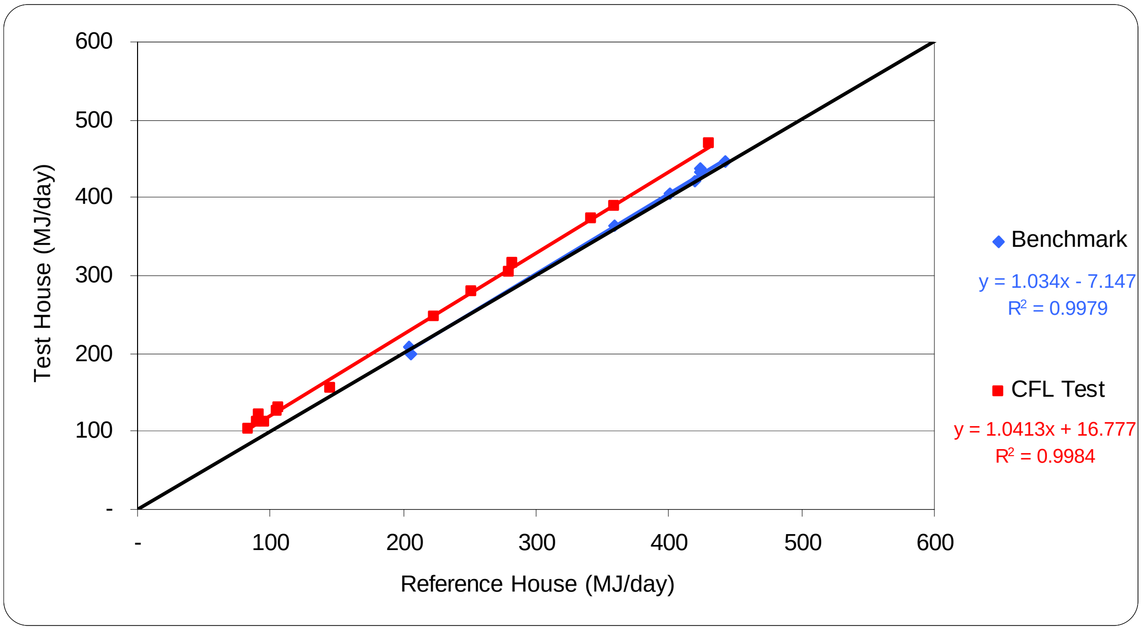


Figure 9. Comparison of furnace energy consumption with conventional and energy efficient lighting.

The following, Figure 10, shows a brief summary of energy analysis of energy efficient lighting at the CCHT. In this case, continuous air circulation is maintained at all times. The detailed analysis showed the following trends:

- If all of the energy used for lighting were utilizable as space heat, then the increased natural gas use due to more energy efficient lighting would be equal to the reduced energy for lighting divided by the efficiency of the furnace. For the experiments conducted at the CCHT, the conventional incandescent lights in the Reference house used an average of 10.77 kWh/day while the compact fluorescent lamps in the Test house used an average of 3.47 kWh/day. Thus, the reduced energy for lighting was 7.3 kWh/day which is about 26.27 MJ/day. The high efficiency furnace used during these tests has a rated efficiency of 92%, so the theoretical increase in natural gas consumption in the Test house should be 26.27 MJ/day / 0.92 = 28.55 MJ/day.

- The measured average natural gas consumption in the houses, averaged over the 14 days, was 231.32 MJ/day in the Test house, and 206.03 MJ/day in the Reference House with the difference at 25.29 MJ/day. The measured difference divided by the theoretical consumption is 0.886 which indicates that 88.6% of the lighting energy is an usable internal gain.

  Figure 10 shows the lighting energy utilization factor for different outdoor conditions. The lighting energy utilization factor ranged from 83% to 100%. For given lighting loads, the higher the heat loads (cold temperatures), the lower the lighting energy utilization factor.

Analysis:

Lighting during benchmarking:

	Average kWh/day		
Ref House	10.77		
Test House	10.72		
Difference	0.05	0.48%	This difference is considered insignificant, and is not considered in further analysis.

Lighting during testing:

	Average kWh/day	
Ref House	10.77	
Test House	3.47	
Difference	7.30	67.76%

Theoretical Difference in Natural Gas Consumption:

Difference in lighting during tests in MJ/day divided by Furnace Efficiency

Lighting difference in MJ:	26.27	MJ/day	
Difference in Furnace Gas:	28.55	MJ/day	Based on 92% efficiency of furnace

Difference in Measured Furnace Gas Use:

Directly from Measured Gas Use during Testing

	Average MJ/day	
Test House	231.32	
Ref House	206.03	
Difference	25.29	12.27%

Percentage of Internal Gains from Lighting that are Utilized: 88.6%

Including Offset from Hi-Efficiency Benchmark:

Difference: 27.37 MJ/day

Percentage of Internal Gains from Lighting that are Utilized: 95.9%

Figure 10. Energy balance analysis of internal gains associated with lighting and the space heating loads.

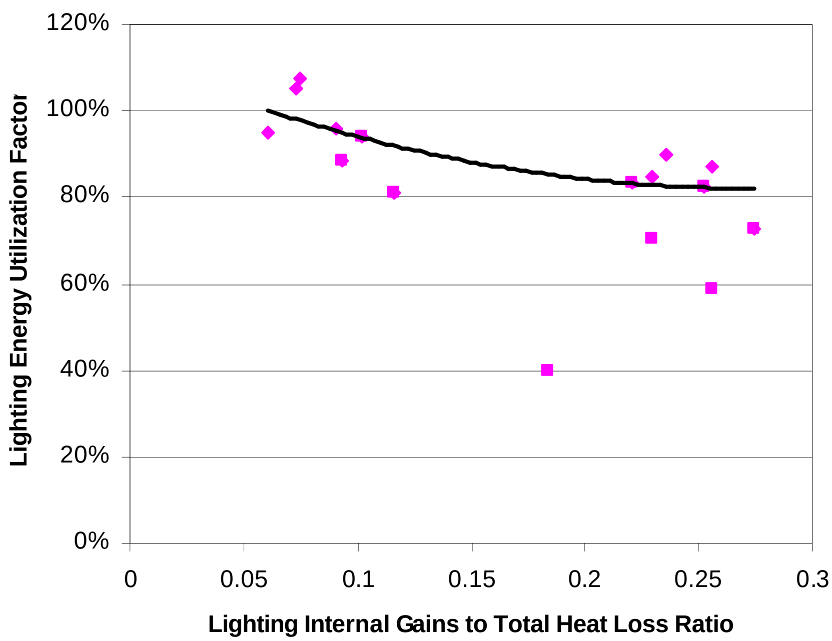


Figure 11. Utilization lighting energy gains to offset space heating requirements.

- The data analyses showed that majority of lighting related internal gains are utilized for offsetting the need for space heating needs. The losses are mainly due to lights near windows and glazed doors where the lighting energy escaped through glazed windows.

CFL Test with Intermittent Ventilation Strategy

In this test, HRV ventilation system was "ON" only during the heating periods. When the furnace was "OFF," there was no ventilation. This reasonably represented the ventilation and air distribution in old houses. The ventilation system operated at full capacity (about 65 L/s) when the house required heating and the furnace was operating. In both houses the ventilation is distributed through the main air distribution system using the furnace fan.

Table 6 shows the measured data of lighting energy use and the space heating energy requirements for the Test and Reference houses. The lighting energy use in the Reference house with conventional lighting ranged from 10.30 to 10.79 kWh/ day with an average of 10.64 kWh/day. This was close to the initial benchmarking results. The lighting energy in the Test house with CFL lighting was about 3.37 to 3.51 kWh/day with an average of about 3.45 kWh/day. The lighting energy use in both houses was not dependent on indoor or ambient conditions. Figure 12 shows the comparison of space heating energy requirements with conventional and CF lighting.

The space heating energy use varied depending on the outdoor conditions. The space heating requirements ranged from 211 to 346 MJ/day representing about 30% to about 85% space heating load for the house. The 10-day test period covered the full range of the heating season enabling the comparison of the effects of energy efficient lighting. The data showed the following trends:

Table 6. Measured results of lighting energy and the space heating energy use in Test and Reference houses – intermittent ventilation strategy.

	Lights and Receptacles Daily Electrical Consumption (kWh)		
Date	Reference House	Test House	
7-Jan-05	10.30	3.37	67.3%
8-Jan-05	10.35	3.38	67.4%
9-Jan-05	10.35	3.39	67.2%
10-Jan-05	10.74	3.49	67.5%
11-Jan-05	10.81	3.51	67.6%
12-Jan-05	10.77	3.50	67.5%
13-Jan-05	10.79	3.50	67.5%
14-Jan-05	10.77	3.48	67.7%
15-Jan-05	10.76	3.43	68.2%
16-Jan-05	10.79	3.47	67.8%
average	**10.64**	**3.45**	**67.6%**

	Furnace Gas Consumpion, MJ		
Date	Reference House	Test House	
7-Jan-05	305.23	343.26	-12.5%
8-Jan-05	271.48	302.64	-11.5%
9-Jan-05	284.58	321.39	-12.9%
10-Jan-05	285.63	319.70	-11.9%
11-Jan-05	308.56	341.41	-10.6%
12-Jan-05	368.24	408.54	-10.9%
13-Jan-05	211.80	235.88	-11.4%
14-Jan-05	231.28	254.68	-10.1%
15-Jan-05	304.65	343.10	-12.6%
16-Jan-05	346.58	378.33	-9.2%
average	**291.80**	**324.89**	**-11.4%**

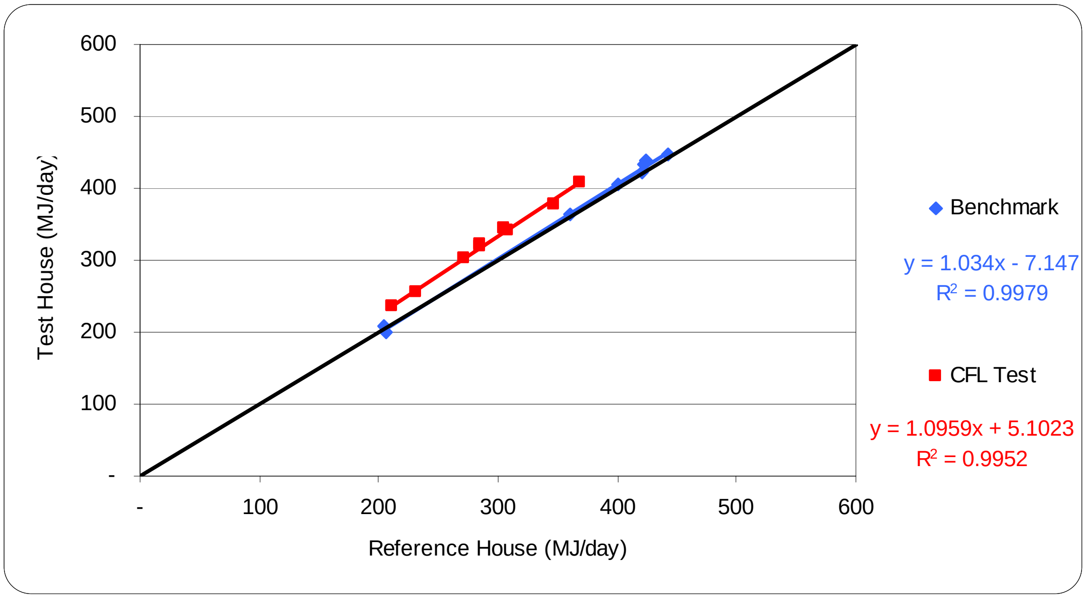


Figure 12. Comparison of furnace energy consumption with conventional and energy efficient lighting – intermittent ventilation.

- The compact fluorescent lighting in the Test house reduced the daily electricity consumption by about 7.2 kWh. This accounted for about 67.6% of the daily lighting energy use.
- The space heating energy use increased to compensate for the reduction in the lighting energy use. The space heating energy use increased from 22 to 38 MJ/day with an average of about 33 MJ/day.

Using the measured data, an energy balance analysis was performed to determine the utilization factor for the lighting energy use and its impact on the space heating energy requirements.

The measured average natural gas consumption in the houses, averaged over the 10 days with intermittent ventilation strategy, was 324.9 MJ/day in the Test house, and 291.8 MJ/day in the Reference house, so the difference is 33.1 MJ/day. The measured difference divided by the theoretical consumption is 0.908, which indicates that 90.8% of the lighting energy is an usable internal gain. Day by day analyses showed that the lighting internal gain utilization ranged from 87% to 100%.

Analysis:

Lighting during benchmarking:

	Average kWh/day		
Ref House	10.77		
Test House	10.71		
Difference	0.06	0.51%	This difference is considered insignificant, and is not used in further analysis.

Lighting during testing:

	Average kWh/day	
Ref House	10.64	
Test House	3.45	
Difference	7.19	67.57%

Theoretical Difference in Natural Gas Consumption:

Difference in lighting during tests in MJ/day divided by Furnace Efficiency

Lighting difference in MJ:	25.89	MJ/day	
Difference in Furnace Gas:	29.42	MJ/day	Based on 92% efficiency of furnace

Difference in Measured Furnace Gas Use:

Directly from Measured Gas Use during Testing

	Average MJ/day	
Test House	324.89	
Ref House	291.80	
Difference	33.09	11.34%

Percentage of Internal Gains from Lighting that are Utilized: **90.8%**

Including Offset from Hi-Efficiency Benchmark:

Difference: 27.37 MJ/day

Percentage of Internal Gains from Lighting that are Utilized: **93.0%**

Figure 13. Energy balance analysis of internal gains associated with lighting and the space heating loads with intermittent ventilation strategy.

2.3.3. Summary of Heating Season Results

The CCHT testing of the conventional incandescent and the compact fluorescent lighting showed the following results:

- The compact fluorescent lighting can reduce electricity demand and provide significant energy savings. A typical 40 W incandescent lamp can be replaced by an equivalent 9-W compact fluorescent lamp. Based on a typical lighting schedule for the house, the daily energy savings are about 67%.
- The reduction in the lighting energy use is almost offset by increase in the space heating requirements. The lighting energy is utilized as internal gains for the house. The results showed that 83% to 100% of lighting energy consumption could contribute to the internal gains.
- It appeared that the different ventilation strategies, either continuous or the intermittent, did not have any impact on the overall energy savings associated with CF lamping.

2.4. Cooling Season Tests

The following section summarizes the results of the benchmarking tests conducted at CCHT for determining the energy savings associated with the energy efficient lighting system and its effects on the cooling loads during the summer cooling season.

CCHT houses during the summer months.

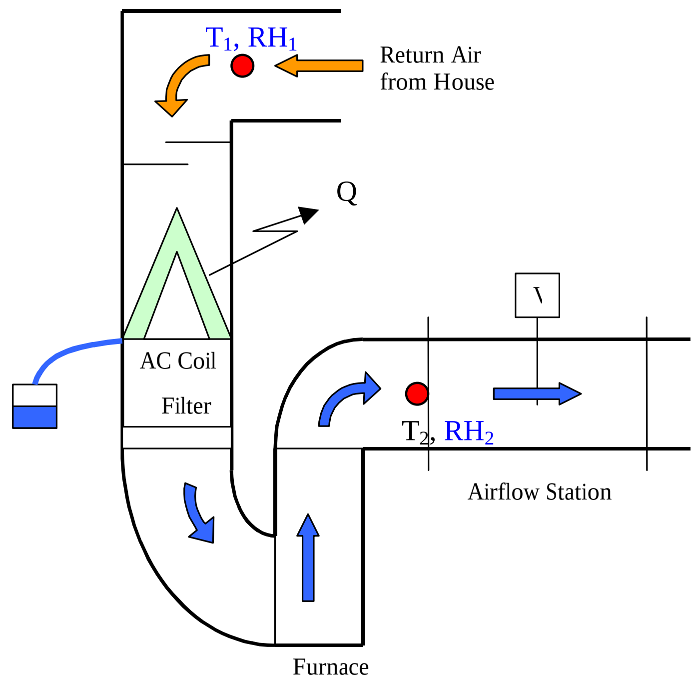
2.4.1. Set-up of Air-Conditioning System

The CCHT air-conditioning system was reconfigured recently to enable accurate measurements of the amount of energy and the amount of moisture being removed by the AC systems in both the Test and Reference houses. This new set up required two thermocouple grids, and two RH sensors. Since the air stream is no longer splitting into three ducts directly off the AC coil, only the existing airflow meter is needed. AC-coils are certified for installation on the supply side of a gas furnace, or on the return side of an electric furnace[3]. The set up, shown in Figure 14, provides reliable measures of power demand, energy measurements and moisture removals.

Once the air conditioning system set up was properly calibrated, we performed a week-long test to compare the air conditioning loads, temperature profiles and the energy use for both Test and Reference houses keeping all aspects identical. These test results showed the following trends:

Indoor temperature measurements: Figure 15 and Figure 16 show the return air duct temperatures for two locations. One is in the bathroom return air (passing through the HRV) and the other is from the living room area which is returned through the main return air plenum. These profiles showed that the indoor temperatures were closely analogous in Reference and Test houses. The overall difference was less than 0.2 ^{o}C, which is within the measurement accuracy.

[3] We also reviewed the manufacturer's standard recommendations for placing the AC coil. Some manufacturers do not allow the placement of AC coil on the return side of a gas furnace. The reasoning behind the gas-furnace restrictions dates back to when gas furnaces had standing pilot lights. The heat from the pilot light would cause the cold air coming off the coil to condense inside the furnace and cause corrosion problems. For the electric furnace, it was thought that if the drain pan overflows on a supply-side installation the electric furnace could short out. The Olsen furnaces in the Research Houses do not have standing pilot lights – so corrosion is less of a concern. We did confirm and clarify about this set up with the furnace manufacturer.



$Q = p * V * (h_1(@ T_1, RH_1) – h_2(@ T_2, RH_2))$

Where:

Q = Energy removed by AC
V = Air Volumetric Flow Rate
T = Average Temperature
RH = Relative Humidity
h = Enthalpy of Wet Air
p = Density of Air

Figure 14. Air conditioning system configuration at CCHT houses and location of sensors.

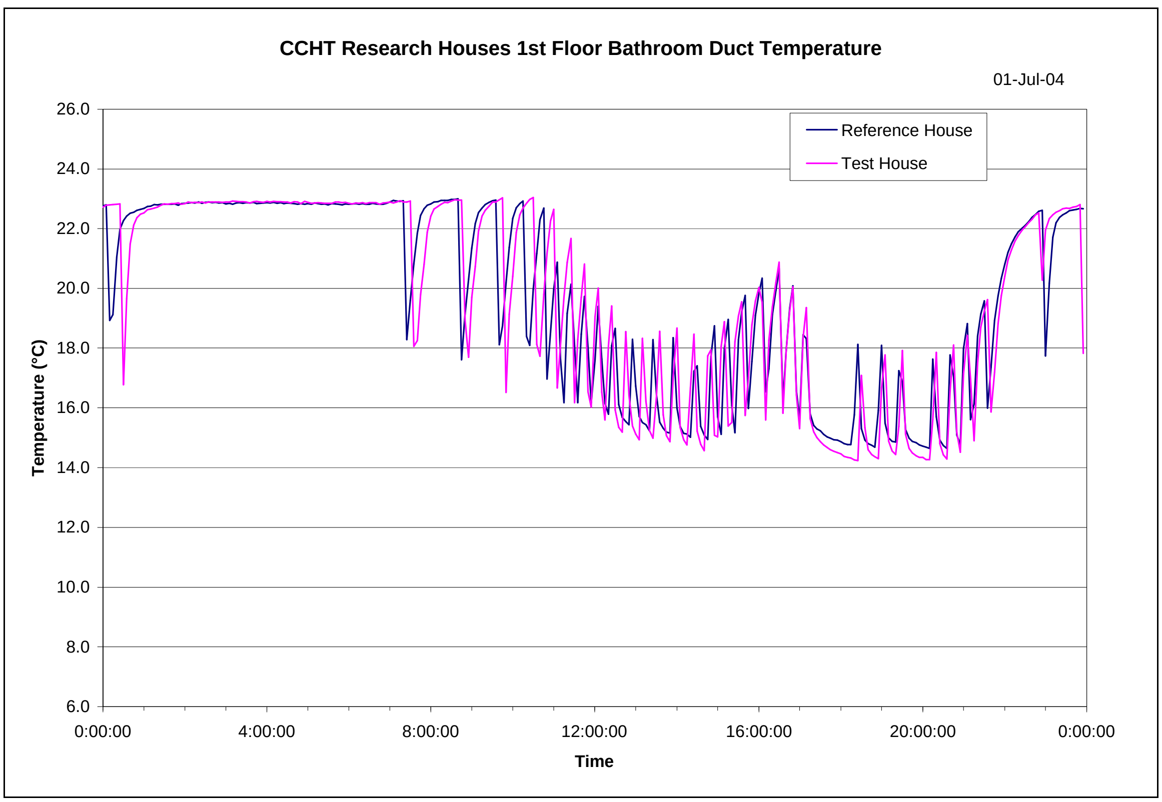


Figure 15 - First Floor bathroom bathroom duct temperature profile.

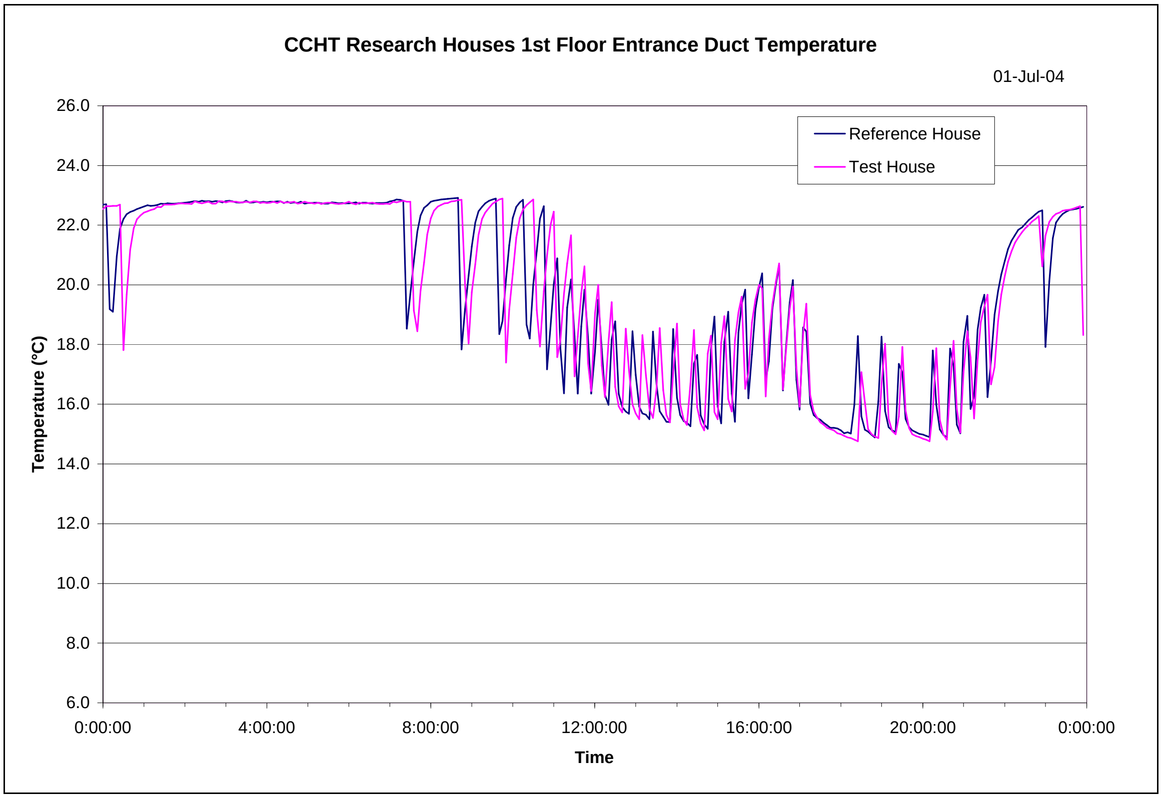


Figure 16 - First Floor entrance duct temperatures profile.

Air flow measurements: The following tables contain the average of 10 manually-read airflow readings (cfm) for each of the nine points in the duct cross-section.

Table 7 - Reference House Airflow Measurements - Circulation Speed (cfm)

	A	B	C
1	726	656	707
2	635	591	656
3	486	558	578

Average: 621 cfm
Centre of duct to Average: 1.0508
Average of 10 Campbell readings after adjustment: 627 cfm

Table 8 - Reference House Airflow Measurements - AC Speed (cfm)

	A	B	C
1	1419	1296	1443
2	1281	1165	1315
3	990	1057	1108

Average: 1230 cfm
Centre of duct to Average: 1.0558
Average of 10 Campbell readings after adjustment: 1236 cfm

Table 9 - Test House Airflow Measurements - Circulation Speed (cfm)

	A	B	C
1	772	762	717
2	574	554	507
3	371	371	350

Average: 553 cfm
Centre of duct to Average: 1.0018
Average of 10 Campbell readings after adjustment: 530 cfm

Table 10 - Test House Airflow Measurements - AC Speed (cfm)

	A	B	C
1	1508	1466	1402
2	1097	1073	989
3	691	750	716

Average: 1077 cfm
Centre of duct to Average: 1.0037
Average of 10 Campbell readings after adjustment: 1056 cfm

The Test house showed a larger range of airflows within the duct than the Reference house – reaching higher speeds at the top of the duct, and lower speeds at the bottom. However, the overall average air speed in the Test house remained lower than the average air speed of the Reference house in both circulation and cooling settings.

Relative humidity measurements: Figure 17 shows the profile of indoor humidity levels in the Reference and Test houses. Overall, test house has about 4% to 8% more humidity than the reference house. In terms of 'moisture loads', this can affect the air conditioning energy use by 1% to 3%.

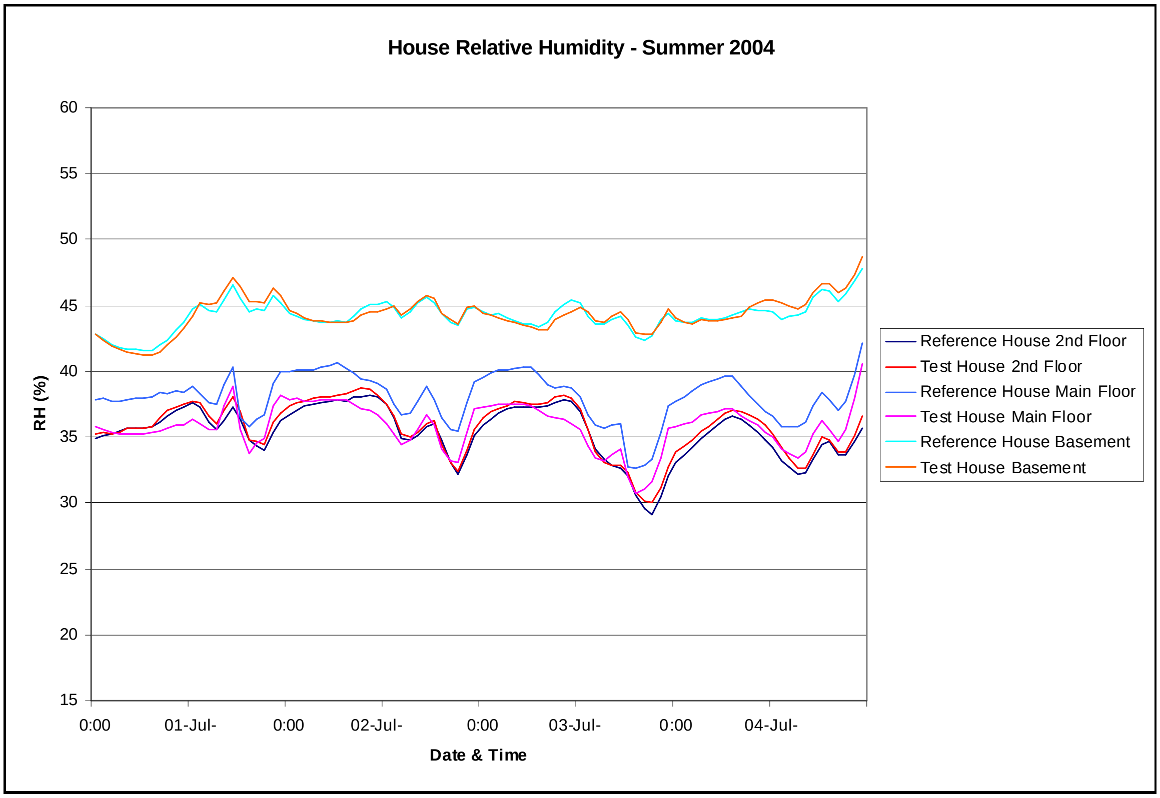


Figure 17 - House Relative Humidity Summer 2004

2.4.2. Benchmarking AC Energy Contributions

Table 11 shows the air-conditioning system energy performance. The net energy removed by the air conditioning system in Reference and Test houses were compared. These results showed that the net energy removed is within the measurement accuracy (maximum of 4% difference – or about 8 MJ/day).

Figure 18 shows a graph of the comparison of net energy removed by the air-conditioning system. This is as close as it gets for cooling load measurements. The co-relation coefficient is 0.997 – very close to 1.0 which is an ideal case.

Table 11 - AC Energy Contributions

	Energy Removed during AC (MJ/day)		Energy Added during Circulation (MJ/day)		Net Energy Removed (MJ/day)	
Date	Reference	Test	Reference	Test	Reference	Test
01-Jul-04	158.5	150.5	20.3	10.8	138.3	139.7
02-Jul-04	169.5	159.5	17.3	10.8	152.2	148.7
03-Jul-04	222.5	210.0	13.9	9.7	208.6	200.3
04-Jul-04	247.6	230.7	15.4	4.6	232.2	226.1

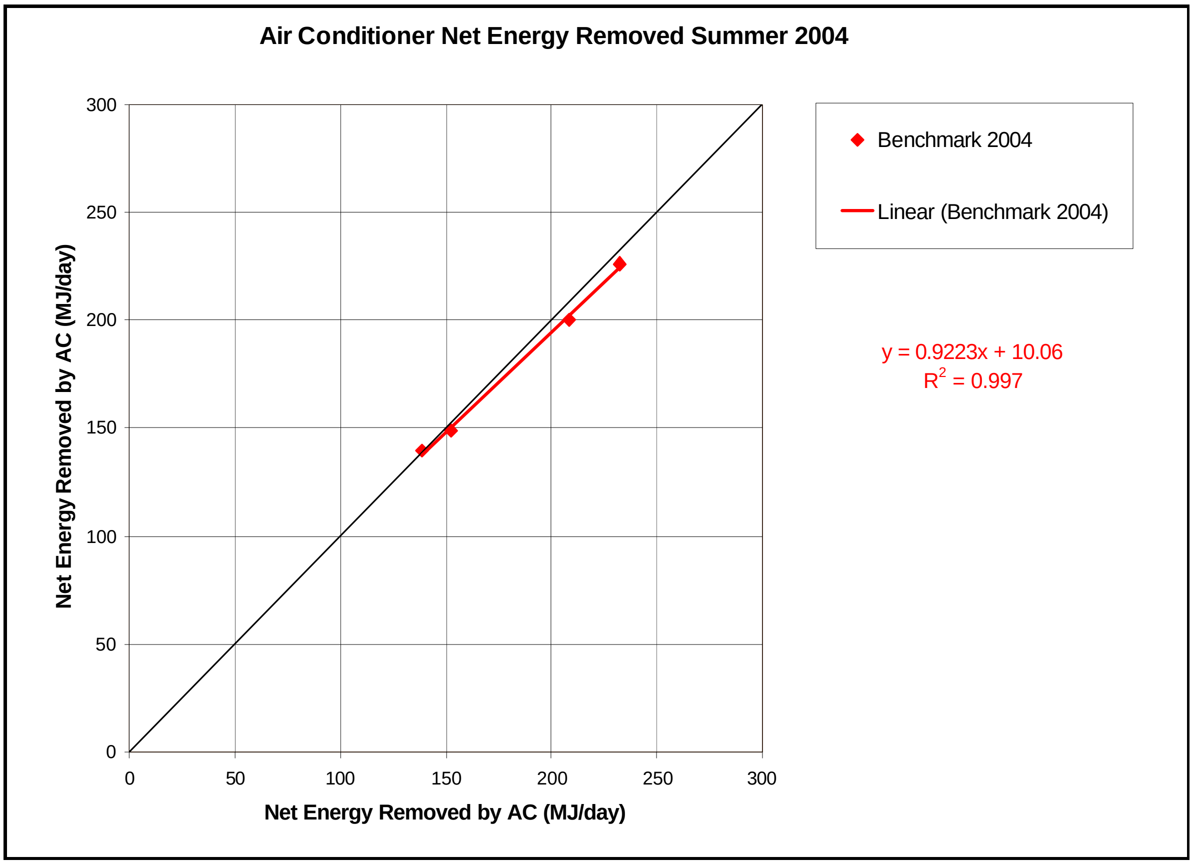


Figure 18 - Net Energy Removed by AC system - Summer 2004

2.4.3. CFL Tests

As shown in Figure 19, the lighting schedule was changed to enable reliable measurements of electricity demand for lighting and its implications on the space heating and space cooling energy use. The normal lighting energy use is about 3.4 kWh/day which was increased to about 10.2 kWh/day with conventional fixtures. The target was to obtain a difference of about 7.0 kWh/day with CFL lighting. This set up is similar to heating season testing of two different lighting fixtures. For the cooling season, we used all previously calibrated lamps (except for two burned out incandescent lamps) for the test period.

These tests were conducted during the August 10 to August 30, 2004 for a period of 21 days. Maximum outdoor temperatures ranged from 20 ^{o}C to 28.3 ^{o}C during the period. The air conditioning system operated from about 330 to 830 minutes per day (5.5 to 13.8 hours per day) in the Reference house and about 200 to 752 minutes per day (3.3 to 12.5 hours per day) in the Test house.

Table 12 shows the daily total of the energy consumption associated with the lighting and the air-conditioning loads.

Figure 19. CCHT lighting schedule for energy efficient lighting during the summer season.

CCHT Lighting Schedule & Proposed Changes for Energy Efficient Lighting Project

Current (normal) Schedule:						
Second Floor:		On time:	6	hours per day.		
	6	bulbs of	60	W =	2.16	kWh/day
	3	bulbs of	40	W =	0.72	kWh/day
	Total:				2.88	kWh/day
First Floor:		On time:	3.75	hours per day.		
	4	bulbs of	60	W =	0.90	kWh/day
	0	bulbs of	40	W =	0.00	kWh/day
	Total:				0.90	kWh/day
Total For House:					3.78	kWh/day
Proposed Schedule:			User inputs: yellow background:			
With Incandescent Bulbs (Benchmark, and Ref House during experiments)						
Second Floor:		On time:	7	hours per day.		
	11	bulbs of	60	W =	4.62	kWh/day
	8	bulbs of	40	W =	2.24	kWh/day
	Total:				6.86	kWh/day
First Floor:		On time:	5	hours per day.		
	9	bulbs of	60	W =	2.70	kWh/day
	3	bulbs of	40	W =	0.60	kWh/day
	Total:				3.30	kWh/day
Total For House:					10.16	kWh/day
		Increase over normal schedule:			6.38	kWh/day
With Compact Fluorescent Bulbs (Benchmark, and Test House during experiments)						
Second Floor:		On time:	7	hours per day.		
	11	bulbs of	15	W =	1.16	kWh/day
	8	bulbs of	7	W =	0.39	kWh/day
	Total:				1.55	kWh/day
First Floor:		On time:	5	hours per day.		
	9	bulbs of	15	W =	0.68	kWh/day
	3	bulbs of	7	W =	0.11	kWh/day
	Total:				0.78	kWh/day
Total For House:					2.33	kWh/day
Difference due to Compact Fluorescent Bulbs:					**-7.83**	**kWh/day**
If actual is 85% of Nominal:			**-6.66**	**kWh/day**		
Compact Fluorescent Bulbs Required (not including spares):						
	15 W bulbs (to replace 60W incandescents):				20	
	7 W bulbs (to replace 40 W incandescents):				11	

Table 12. Results of energy consumptions for the lights and the air-conditioning (plus fan).

	Lights and Receptacles Daily Electrical Consumption (kWh)			A/C & Furnace Daily Elect. Consumption (kWh)			
Date	Reference House	Test House	Difference	Reference House	Test House	Difference	Apparent COP
14-Aug-04	10.8	3.4	7.3	20.8	18.1	2.6	2.8
15-Aug-04	10.7	3.4	7.3	23.8	20.5	3.2	2.3
16-Aug-04	10.7	3.5	7.2	25.7	22.4	3.3	2.2
17-Aug-04	10.8	3.4	7.4	24.7	21.3	3.4	2.2
18-Aug-04	10.7	3.4	7.3	27.0	24.1	2.9	2.5
19-Aug-04	10.8	3.4	7.4	25.7	22.7	3.0	2.5
20-Aug-04	10.8	3.4	7.3	19.7	15.8	3.8	1.9
21-Aug-04	10.7	3.4	7.3	18.9	16.7	2.1	3.4
22-Aug-04	10.8	3.5	7.4	20.2	16.7	3.6	2.1
23-Aug-04	10.7	3.4	7.3	18.8	16.4	2.4	3.0
24-Aug-04	10.8	3.4	7.4	17.4	14.9	2.5	2.9
25-Aug-04	10.7	3.4	7.3	22.6	18.8	3.8	1.9
26-Aug-04	10.8	3.4	7.3	28.1	24.8	3.3	2.2
27-Aug-04	10.7	3.4	7.3	29.7	26.0	3.7	2.0
28-Aug-04	10.8	3.4	7.4	34.8	31.5	3.3	2.2
29-Aug-04	10.8	3.5	7.3	17.2	13.9	3.2	2.3
30-Aug-04	10.7	3.4	7.3	16.6	13.3	3.3	2.2
Average	10.8	3.4	7.3	23.0	19.9	3.1	**2.3**

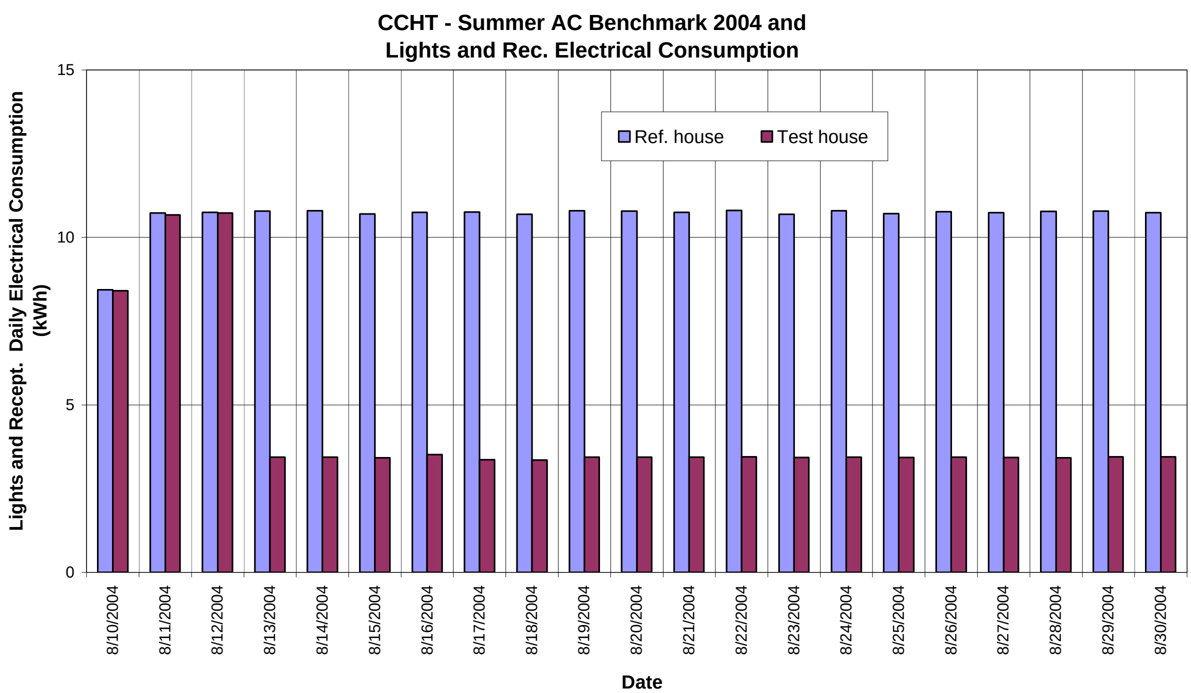


Figure 20. Profile of lighting energy consumption.

The above results showed the following trends:

- The CFL lamping reduced the lighting energy consumption by 7.32 kWh per day. Figure 20 shows the profile of daily lighting energy use for the test and reference houses.
- The air conditioner (compressor) and the air distribution fan energy consumption reduced by about 2.1 to 3.8 kWh per day depending on the ambient conditions. On average, the difference in the air-conditioning energy loads was about 3.1 kWh per day for the test period.
- As shown in Table 12, the apparent (simple) coefficient of performance of the air-conditioning system was determined using the reduction in cooling load by the same amount of lighting load. The apparent COP was ranging from 1.9 to 3.4 with average of 2.3 over the test period. This aspect was further evaluated using the detailed simulation of hourly weather loads and the part performance of the air-conditioning system. The energy analysis showed that about 78% of the internal gains due to lighting are associated with cooling. The manufacturers' data for the AC system shows the COP rating of about 3.0. This analysis will be further extended with various levels of lighting loads and climatic conditions.
- There was also an attempt to correlate the cooling loads with the outdoor temperature. With several attempts, as shown in Figure 21, we found that the maximum ambient dry bulb temperature showed a better correlation with the cooling loads. The average ambient temperature for the day did correlate well with the cooling loads. Again, this would be further elaborated with the analysis of solar gains data.
- Figure 22 shows the correlation of the "ON" Time for the air-conditioning system for the test and reference houses. The use of CF lighting also reduces the ON time run of the cooling equipment by 20% or more.
- The tests showed that the CFL lighting provides savings of 7.3 kWh per day along with reduction in the air-conditioning load by 3.1 kWh per day. This amounts to a total reduction in electrical energy use by about 10.4 kWh per day for the test period.
- Results showed that the CF lighting reduces the electrical energy use and the power demand both for lighting and the air-conditioning loads.

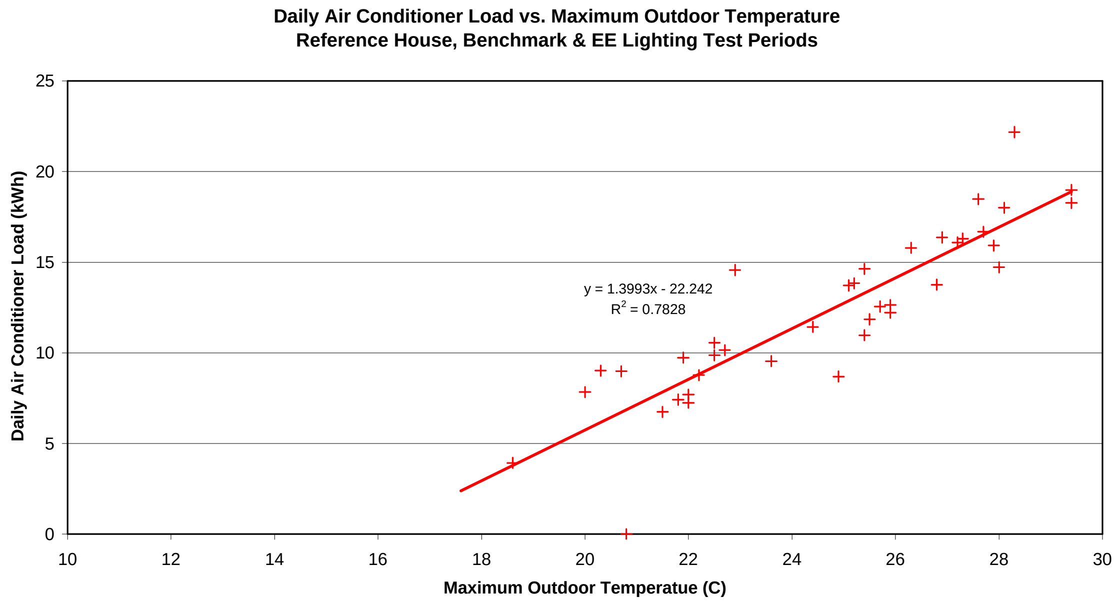


Figure 21. Correlation of maximum outdoor temperature and the daily cooling load.

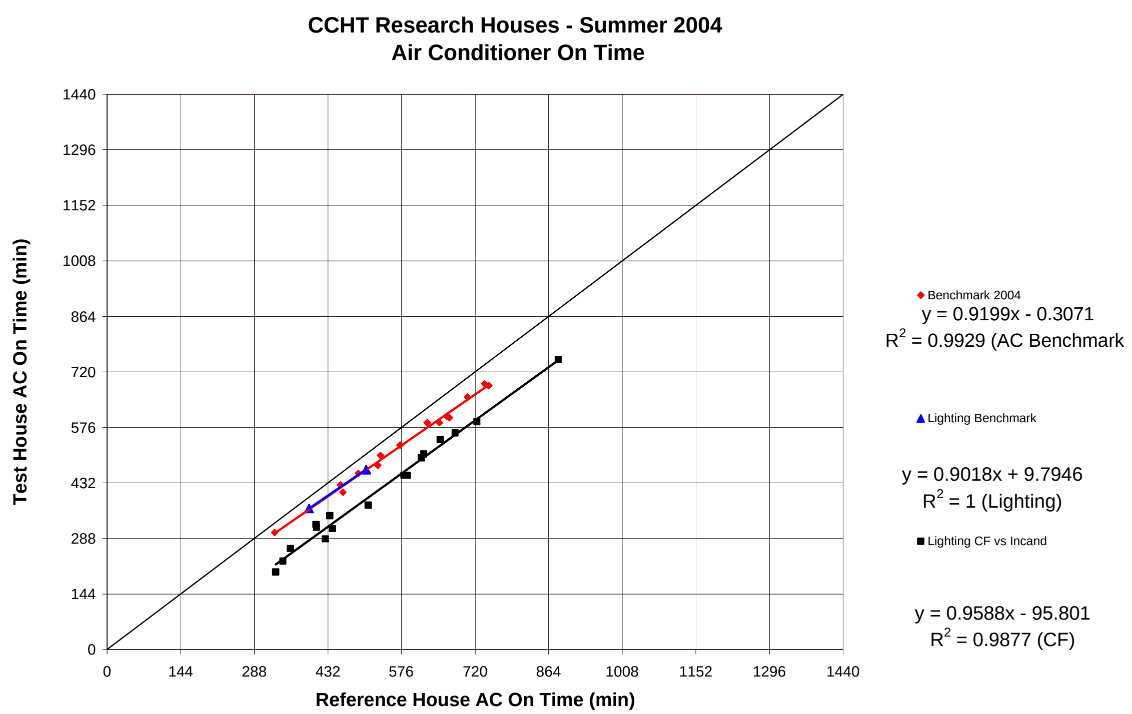


Figure 22. Correlation for the AC ON time.

2.4.4. Summary of Cooling Season Results

The CCHT testing of the conventional incandescent and the compact fluorescent lighting during the summer season showed the following results:

- The compact fluorescent lighting can reduce electricity demand and provide significant energy savings. A typical 40 W incandescent lamp can be replaced by an equivalent 9-W compact fluorescent lamp. Based on a typical lighting schedule for the house, the daily energy savings are about 67%.
- The reduction in lighting energy use also reduces the cooling loads. The energy analysis showed that about 80% of the lighting energy internal gains are associated with cooling demand.
- The use of CF lighting also reduces the ON time run of the cooling equipment by 20% or more.
- It appeared that the different ventilation strategies, either continuous or intermittent, did not have any impact on the overall energy savings associated with CF lamping.

2.5. Summary

The CCHT houses provided a unique research and test facility to accurately determine the impact of conventional incandescent and energy efficient compact fluorescent lighting on the whole house performance. The measured power draw for the incandescent and compact fluorescent lamps compared well with manufacturers' specifications. The compact fluorescent lighting reduces the electric power demand and energy consumption significantly.

On a whole house basis, the compact fluorescent lighting did not seem to cause concern for the power factor penalty.

The energy efficient lighting systems do affect the space conditioning requirements. During the heating season, the compact fluorescent lighting reduces the internal gains thereby increasing the space heating energy use. The CCHT test showed that 83% to 100% of lighting energy use offset the space heating energy use.

During the cooling season, the compact fluorescent lighting reduces the internal gains; thereby, reducing the space cooling energy use. So, during the cooling season, the lighting energy reductions and the cooling energy reductions are additive. The test results also showed significant reductions in the electrical power demand for lighting and cooling.

The above findings are further used to verify the internal heat gain models and also to determine the overall energy and cost impact of conventional and energy efficient lighting options in Canadian homes.

3. IMPACT OF ENERGY EFFICIENT LIGHTING IN HOMES

3.1. Internal Heat Gains

The house energy simulation methods provide reliable and accurate estimates of the monthly and annual energy use and power demand. The energy simulation methods incorporate 'house as a system' approach and integrate various energy flows. The internal gains associated with lights, appliances and human occupancy form a key component. Over the last 30 years or so, detailed studies have been conducted to assess the impact of internal gains on the thermal loads. Most of these studies reported on the effects of internal gains due to combined energy consuming, heat producing equipment and systems. The following is a quick review of these studies and their findings:

- In 1983, Larry Palmiter showed that the heat generated by appliances offset the need for space heating. The thermal utility of internal gains depended on the amount of internal gains and associated overall heat losses. The larger the heat losses the better the utilization of internal gains.[4]
- During 1983-86, the National Research Council of Canada (NRC) conducted theoretical and experimental investigations on utilization of internal gains. The internal gains associated with appliances and domestic hot water systems were measured. These investigations showed that the utilization of internal gains largely depended on the overall heat losses of the building. Figure 23 shows a profile of the internal gains model developed as part of the work.[5,6]
- Subsequently, Craig Wray and Gren Yuill did an experimental study at the University of Manitoba to assess the utilization of internal heat gains[7]. The study provided confirmed the approach taken by NRC work with some modifications to the utilization factors.
- As shown in Figure 23, the difference between the two models (Yuill and Barakat) originated from different assumptions. The Barakat model interpreted the internal gains as a direct load. The Yuill model considered that the heat emitted by internal gains contains a prominent radiation component which increases the exterior building envelope temperature causing greater thermal

[4] *Palmiter L. and Kennedy M., "Annual Thermal Utility of Internal Gains," Progress in Passive Solar Energy Systems, Volume 8, Proceedings of the National Solar Conference, Santa Fe, NM. 1983.*
[5] *Barakat S., "Internal Heat Gains from Domestic Hot Water Use in Houses," ASHRAE Transactions, vol 90, Part 2, pp 51-58, 1984.*
[6] *Barakat S. and Sander D., "The Utilization of Internal Heat Gains," ASHRAE Transactions, vol 92, Part 1A, pp 103-115, 1986.*
[7] *Wray C. and Yuill G., "Modification of Internal Gain Utilization Model," Prepared fro the R2000 Program, Energy, Mines and Resources Canada, 1987.*

losses. Both these models produce almost equivalent results of whole house annual energy estimates. The Yuill model is implemented in the HOT2000[8].

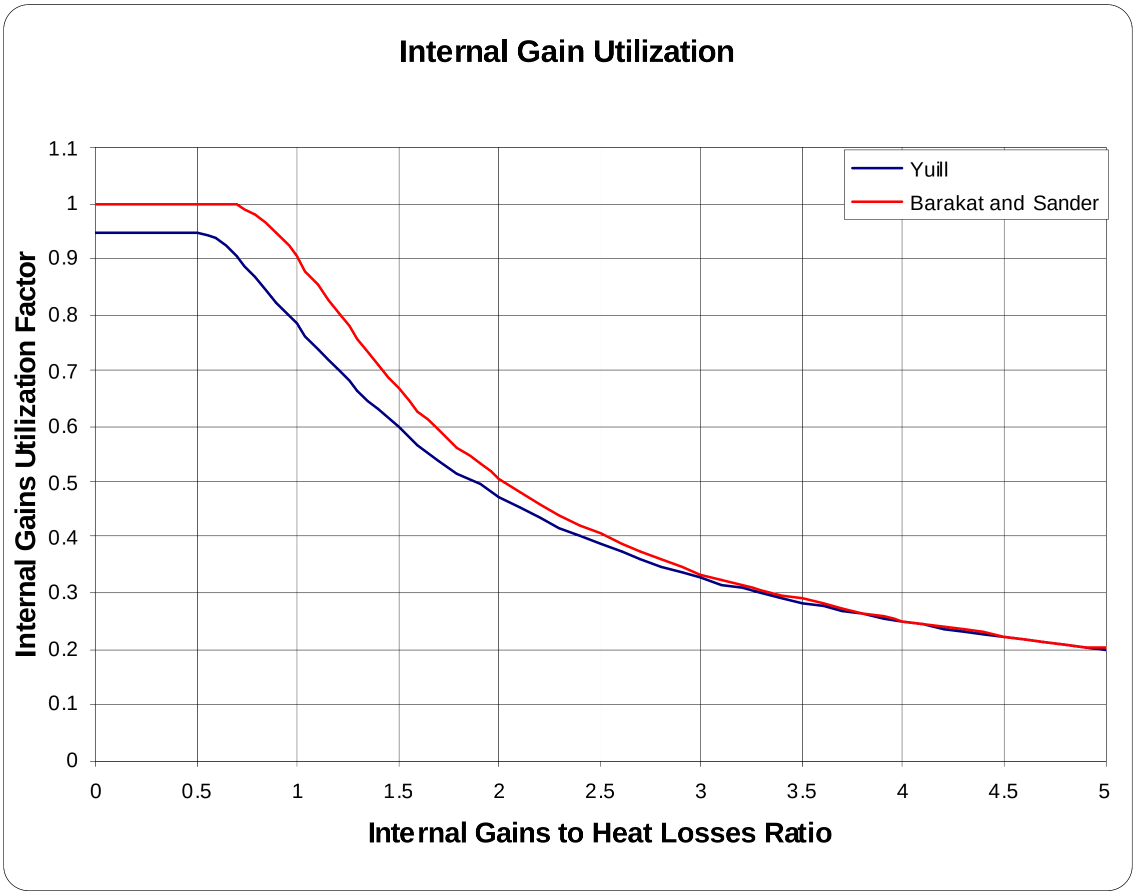


Figure 23. Utilization on internal heat gains.

- In 1994, the Canadian Electrical Association did a comprehensive study on the assessment of the impact of internal gains on thermal loads.[9] The study findings are summarized as follows:

  No matter the type of lighting fixture (incandescent, fluorescent or halogen), the electric energy consumed by the lamp is mostly converted into sensible heat by the lamp itself and the remaining portion converted into light radiation. The light radiation produced by a lamp is distributed in two ways. On one hand, it is absorbed by the interior surfaces of the residence and then retransmitted for the most part indoors in the form of sensible heat. On the other hand, a fraction is transmitted directly outdoors through the windows. In the later case, however, considering the fact that the shape factor between a

[8] *HOT2000 – Energy Estimating Software, Natural Resources Canada. Free download at http://www.sbc.nrcan.gc.ca/software_and_tools/software_and_tools_e.asp.*

[9] *Canadian Electrical Association, "Assessment of the Impact of Internal Gains on the Thermal Loads in the Residential Sector." Prepared by Hydro Quebec. 1994.*

window and a lamp is usually small (approximately 0.05) and that the window also reflect a fraction of incident light radiation indoors, the fraction of light energy which is lost outside is insignificant relative to the electric energy consumed by the lamp. Total electric energy of a lamp could thus be considered as mostly converted into sensible energy. This range of utilization factor is from 0.8 to 1.0.

- Using the CCHT data for the two types of lighting, the current HOT2000 model was compared. The comparison showed remarkable closeness of potential estimates with the measured data. The HOT2000 energy analysis software is capable of properly evaluating the interactive impacts of different lighting strategies.

3.2. Energy Savings Associated with Compact Fluorescent Lighting

One of the key questions is, what is the overall impact of the energy efficient compact fluorescent lighting compared to conventional incandescent lighting in homes? To develop these estimates, the following matrix was developed.

Table 13. Matrix for the energy saving estimates.

Lighting Retrofits	Type of Houses (Thermal data based on vintage)		Heating Fuel Types	Location
At least five fixtures replaced with CFL	Existing Houses (built in 1970)	Single-detached (2-storey, full basement)	Electric	Montreal, QC Quebec City, QC
			Oil	Halifax, NS Saint John, NB St. John's, NF
			Natural Gas / Propane	Toronto, On Ottawa, On Winnipeg, MB Edmonton, AB Vancouver, BC
	New Houses (built in 2005)	Single-detached (2-storey, full basement)	Electric	Montreal, QC Quebec City, QC
			Oil	Halifax, NS Saint John, NB St. John's, NF
			Natural Gas / Propane	Toronto, On Ottawa, On Winnipeg, MB Edmonton, AB Vancouver, BC

3.2.1. Assumptions:

The following lists assumptions for energy analysis:

- A two-storey house with 186 sqm (about 2,000 sqft) of heated floor area. The thermal archetype based on the age, location and type of the house. Each house is maintained at 21 ^{o}C (main floors) and 19 ^{o}C (storage and basement rooms) during the heating season. During the cooling season, the house is maintained at 25 ^{o}C during the summer months.
- Conventional lighting energy consumption is about 3.4 kWh/day.
- Replacement of five conventional incandescent fixtures with compact fluorescent fixtures. Based on this scenario, the conventional lights with 77 W and five fixtures used for three hours/day are replaced with CFL of 19 W and five lamps used for three hours/day. The reduction in daily lighting energy use is about 0.87 kWh.
- Table 14 shows the annual average fuel costs for year 2004 for different locations.

Table 14. 2004 Annual average fuel costs (Energy Statistics Handbook).

	Natural Gas	**Electricit y**	**Oil**
Location	**$/m3**	**$/kWh**	**$/L**
Vancouver, BC	0.486	0.062	
Edmonton, AB	0.264	0.082	
Saskatoon, SK	0.405	0.0901	
Winnipeg, MB	0.449	0.0609	
Toronto, ON	0.465	0.0856	
Ottawa, ON	0.465	0.0856	
Montreal, QC		0.0621	
Quebec City, QC		0.0621	
Saint John, NB		0.0756	0.773
Halifax, NS		0.0985	0.748
St. John's, NF		0.089	0.695

3.2.2. Estimates of Energy Savings for the New Homes

Using the above assumptions, detailed house models were generated using the HOT2000 energy analysis software. For each house, requirements for space heating, space cooling, lighting energy and demand were documented. Table 15 summarizes the energy analysis results on an annual basis. The following trends were noted:

- The electrical energy savings are about 318 kWh per year with CF lighting. The reduction in lighting energy consumption is about 26%. The whole house electricity load reduction is about 3.7%.

Table 15. Estimates of annual energy and cost savings associated with CFL in typical new homes.

New Housing

	Options		Annual Energy Impacts				Annual Cost Savings		
Location	Base Case Lighting	Upgrade Lighting	Savings in Lighting Energy	Savings in Space Heating		Savings in Space Cooling	Heating Only Cost Savings	Heating +cooling savings per year	Cost Savings without 'Take Back'
	kWh/day	kWh/day	kWh/year		Unit	kWh			
Vancouver, BC	3.40	2.53	318	-21.6	m3	49	$ 9	$ 12	$ 20
Edmonton, AB	3.40	2.53	318	-27.9	m3	38	$ 19	$ 22	$ 26
Saskatoon, SK	3.40	2.53	318	-25.2	m3	59	$ 18	$ 24	$ 29
Winnipeg, MB	3.40	2.53	318	-25.9	m3	61	$ 8	$ 11	$ 19
Toronto, ON	3.40	2.53	318	-23	m3	63	$ 16	$ 22	$ 27
Ottawa, ON	3.40	2.53	318	-23.9	m3	53	$ 16	$ 21	$ 27
Montreal, QC	3.40	2.53	318	-182.4	kWh	54	$ 8	$ 12	$ 20
Quebec City, QC	3.40	2.53	318	-184.2	kWh	55	$ 8	$ 12	$ 20
Saint John, NB	3.40	2.53	318	-25	L	60	$ 5	$ 9	$ 24
Halifax, NS	3.40	2.53	318	-22.4	L	52	$ 15	$ 20	$ 31
St. John's, NF	3.40	2.53	318	-29.6	L	40	$ 8	$ 11	$ 28

- The electrical demand savings are about 0.29 kW with CF lighting.
- The increase in the annual space heating energy consumption is about 0.6% to 1.7%.
- The reduction in the space cooling energy use ranged from 4% to 9.5% for the CF lighting. The "ON" time operation of cooling equipment ranged from 10% to 18%.
- The utility costs showed that even in the 'heating only' scenario, the compact fluorescent lighting positively saved the utility costs. The cooling season savings significantly adds to the cost savings. The lighting replacements also positively reduce the utility costs in all electric houses.
- The 'take back' effect – interaction of lighting with other loads, significantly reduces the potential estimates of overall cost savings associated with lighting. For example, for a new house located in Vancouver without air-conditioning, the estimated energy cost saving is about $9 (includes lighting cost savings and additional expenditure for the space heating). If the lighting benefits were only considered, the electricity cost reduction amounted to $20. This indicates that there is a need to show an interactive impact for realistic evaluation of CF lighting benefits.
- Assuming the cost of five CF lighting fixtures of about $30, the simple payback period is three to six years for non-air-conditioned houses.

3.2.3. Estimates of Energy Savings for the Existing Homes

Using the above assumptions, detailed house models were generated using the HOT2000 energy analysis software. Each archetype represented a 1970s vintage period of construction. For each house, requirements for space heating, space cooling, lighting energy and demand were documented. Table 16 summarizes the energy analysis results on an annual basis. The following trends were noted:

Table 16. Estimates of annual energy and cost savings associated with CFL in typical existing homes.

Existing Housing

	Options		Annual Energy Impacts				Annual Cost Savings		
Location	Base Case Lighting	Upgrade Lighting	Savings in Lighting Energy	Savings in Space Heating		Savings in Space Cooling	Heating Only Cost Savings	Heating +cooling savings per year	Cost Savings without 'Take Back'
	kWh/day	kWh/day	kWh/year		Unit	kWh			
Vancouver, BC	3.40	2.53	318	-28.4	m3	57	$ 6	$ 9	$ 20
Edmonton, AB	3.40	2.53	318	-29.5	m3	40	$ 18	$ 22	$ 26
Saskatoon, SK	3.40	2.53	318	-27.6	m3	64	$ 17	$ 23	$ 29
Winnipeg, MB	3.40	2.53	318	-27.2	m3	66	$ 7	$ 11	$ 19
Toronto, ON	3.40	2.53	318	-24.1	m3	71	$ 16	$ 22	$ 27
Ottawa, ON	3.40	2.53	318	-24.9	m3	59	$ 16	$ 21	$ 27
Montreal, QC	3.40	2.53	318	-226.6	kWh	58	$ 6	$ 9	$ 20
Quebec City, QC	3.40	2.53	318	-247.6	kWh	58	$ 4	$ 8	$ 20
Saint John, NB	3.40	2.53	318	-27.7	L	66	$ 3	$ 8	$ 24
Halifax, NS	3.40	2.53	318	-30	L	56	$ 9	$ 14	$ 31
St. John's, NF	3.40	2.53	318	-35.6	L	40	$ 4	$ 7	$ 28

- The electrical energy savings are about 318 kWh per year with CF lighting. The reduction in lighting energy consumption is about 26%. The whole house electricity load reduction is about 3.7%. The electrical demand savings are about 0.29 kW with CF lighting.
- The increase in the annual space heating energy consumption is about 1%.
- The reduction in the space cooling energy use ranged from 4% to 9.5% for the CF lighting. The “ON” time operation of cooling equipment ranged from 10 to 18%.
- The utility costs showed that even in the ‘heating only’ scenario, the compact fluorescent lighting positively saved the utility costs. The cooling season savings significantly adds to the cost savings. The lighting replacements also positively reduce the utility costs in all electric houses.
- Assuming the cost of five CF lighting fixtures of about $30, the simple payback period is four to seven years for non-air-conditioned houses.

3.3. Summary

Compact fluorescent lighting has significant impact on the energy and cost savings in houses. These are based on the reduction in electrical power demand and annual energy use; increase in the space heating loads to offset the reduction in lighting energy; and reduction in the cooling energy use. Overall, the compact fluorescent lighting positively contributes to energy and cost savings in typical Canadian houses.

4. SUMMARY AND CONCLUSIONS

This project set out to establish the interactive effects of energy efficiency measures associated with compact fluorescent lighting in houses. As part of the work plan, using the Canadian Centre for Housing Technologies (CCHT) facility, detailed field investigations were conducted. The field data was further used in verifying the internal heat gains model within house energy analysis software. Energy and cost estimates were presented to show potential impact of CF lighting in typical homes in different locations. The compact fluorescent lighting has significant impact on the energy and cost savings in houses. These are based on as follows:

- reduction in electrical power demand and annual energy use;
- increase in the space heating loads to offset the reduction in lighting energy; and
- reduction in the cooling energy use.

Overall, the compact fluorescent lighting positively contributes to energy and cost savings in typical Canadian houses.

APPENDIX A: CCHT FACILITY

Description of the Test and Reference Houses

In 1998, twin houses were built at the Canadian Centre for Housing Technology to assess the energy performance of new and innovative energy efficient materials and components for houses in a Canadian context. The two research houses – the *reference house* and the *test house* – were built to a design submitted by a local builder for the project. The houses are typical in construction, appearance and layout of tract-built houses available on the local housing market. They are identical, and are built to the R-2000 standard - Canada's benchmark for energy efficient house design. The *reference house* is a typical 2-storey wood-frame house, with 210 m^2 of livable area, set on a cast-in-place concrete basement, with style and finish representative of current houses available on the local housing market. The house is built to meet the R-2000 Standard with a package that includes tight, well insulated assemblies, low-e argon filled sealed glazing units. It has a high efficiency sealed combustion condensing gas furnace, a power-vented conventional hot water heater and a heat recovery ventilator. The furnace, water heater and gas fireplace are all vented through the wall, eliminating the need for chimneys.

The same trades built the houses by stages in sequence from one house to the other; e.g. footings were poured in one house then the next, then basement walls etc. The houses were never more than two weeks apart in the construction process at any point in time. Construction was stopped at the pre-drywall stage for 2½ weeks to allow the installation of over 250 sensors in each house. As well 21 electric, gas and water flow meters were installed. The houses were completed in January 1999. We refer to one house as the "*reference house*", which is intended to remain unchanged through the various experiments at the facility. The second house is referred to as the "*test house*", in which different energy efficient technologies are assessed. The technologies are always installed in such a way that the test house can be returned to the original configuration which we refer to as the "benchmark configuration".

The house has an airtightness characteristic of 1.07 ach @ 50 Pa – well below the R-2000 requirement of 1.5 ach @ 50 Pa. The monitoring and control room is located in an isolated room built in the garage with special conduits leading to each floor, to run wiring. The conduits were sealed on completion or the wiring. The *test house* was notionaly identical to the *reference house*, but this had to be verified through the commissioning process. For example, its airtightness characteristics was 0.97 ach @ 50 Pa – 10% lower than the reference house.

The research houses also feature standard sets of major appliances typically found in North American homes. A system based on home automation technology simulates human activity by operating appliances, lighting and other equipment according to an identical schedule in both houses. The simulated occupancy system is also used to monitor energy performance. Table 17 lists selected characteristics of the two houses, and Table 18 lists the meters installed.

Benchmarking

The objective of benchmarking was to account for any remaining post-commissioning differences between the houses, and record these statistically, to give a point of reference for any future technology assessments. Benchmarking the houses occurred over the period from November 1999 to the end of January 2000. Benchmarking the space heating consumption, theoretically the more challenging exercise, turned out to be simpler in that the results confirmed that the objective of the design was met – virtually overall identical thermal performance, on a statistical basis.

Figure 24 shows the benchmarking of the test house against the reference over the same period. It is noted that whereas each day's result is not necessarily a perfect match,

Table 17. Selected characteristics of the Test and Research houses.

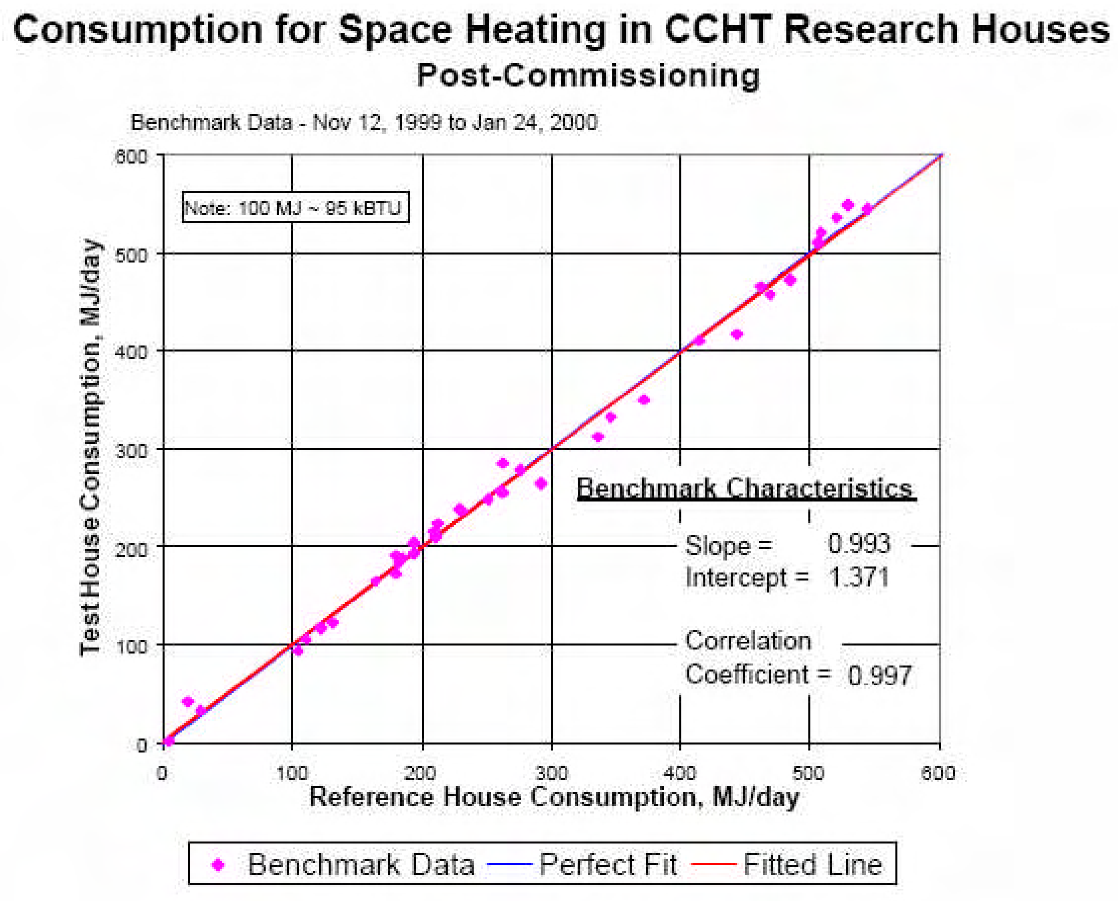
Component	Characteristic
Construction Standard	R-2000
Storeys	2
Liveable Area	210 m^2
Basement	Poured concrete, full basement.
Garage	Two-car, recessed into the floor plan; isolated control room in the garage
Attic	RSI 8.6
Walls	RSI 3.5
Rim Joists	RSI 3.5
Exposed floor over the garage	RSI 4.4 with heated/cooled plenum air space between insulation and sub-floor.
Basement Walls	RSI 3.5 in a framed wall. No vapour barrier.
Basement floor	Concrete slab, no insulation
Windows	Low-e, insulated spacer, argon filled, with argon concentration measured to 95%.
Window Area	South Facing: 16.2 m^2 Total: 35.0 m2
Air Barrier System	Exterior, taped fiberboard sheathing with laminated weather resistant barrier. Taped penetrations, including windows.
Airtightness	Reference 1.07 ach @ 50 Pa; Test House 0.97 ach @ 50 Pa
Heat recovery Ventilator	High Efficiency (84% nominal)
Furnace	Condensing gas @ 91% efficiency (as measured)
Hot Water Heater	Conventional, induced draft @ 67% efficiency (as measured).
Air conditioning	High efficiency - SEER 12 (nominal)

Table 18. List of energy meters installed in each house.

Electric Meters		Gas Meters	
1	Heat Recovery Ventilator	1	Furnace
2	Furnace	2	Hot Water Heater
3	Dishwasher		
4	Clothes Washer	**Water Meters**	
5	Refrigerator	1	Main (entire house)
6	Air Conditioner	2	Second Floor
7	Dryer	3	DHW
8	Stove	4	Kitchen Sink
9	Main Panel	5	Dishwasher
10	Lights & Receptacles		
11	Control Room		
12	Exterior Lights		
13	Brown Plates (Monitoring)		
14	DHW power vent Fan (added)		

statistically, this is a near-perfect result, with the slope being measured only 0.7% lower than a perfect fit with a slope of “1”. We interpret this result as follows: small differences associated with daily comparisons appear to be random, and cancel out, given a large enough sample of points. As well, the house airtightness and hot water consumption were both documented to be slightly different, so it is important to note that the excellent space heating correlation is the result of the net cancellation of many small differences in the house’s total energy system.

Figure 24. Benchmarking of CCHT houses.



Experience in interpreting results of subsequent assessments with this facility suggests that approximately one to two weeks of data (7 -14 data points) are sufficient to give a good statistical estimate of performance. This should be also accompanied by weather patterns sufficiently variable as to develop data points distributed over a substantial portion of the range of house energy consumption. A strategy of alternating technologies from week to week was adopted to ensure that each technology was operated in different conditions throughout the heating season.

Further Information

Detailed information on the CCHT facility is available from http://www.ccht-cctr.gc.ca.