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Improving Moisture Management and Cooling Energy Use in Residential Buildings

Boualem Ouazia PhD, Marianne Manning, Mike Swinton, Hayssam Barhoun PhD

National Research Council Canada

ABSTRACT

A survey on Canadian household energy use has shown that energy consumed in the residential sector for space cooling has more than doubled from 1990 to 2002 (SHEU 2003). The penetration rate of air-conditioning systems increased along with the cooling requirements (expressed by the cooling degree-days). This survey showed that almost 45 percent of Canadian households were equipped, in 2003, with some type of air-conditioning system (window/room air conditioner, heat pumps, or central AC) where central air conditioning systems were the most prevalent. A significant difference in their penetration rate exists between different regions in Canada, in favour to Ontario, where nearly three out of every four households were equipped with an air conditioning system.

Improved ventilation rate by use of central cooling systems has increased the latent cooling part and a higher amount of humidity leading to high interior moisture levels. One technology that can help reduce the electricity consumption along with reducing the latent cooling load for residential air-conditioning is the use of an Energy Recovery Ventilator (ERV).

This paper provides an experimental evaluation of the efficiency of an ERV for a range of summer temperatures in Ottawa Canada, including humid summer days. The evaluation was achieved using the twin houses at the Canadian Centre for Housing Technology (CCHT), and their 'side-by-side testing' to measure the real impact of the installation of the ERV. Significant electrical energy savings and improved indoor humidity control were achieved.

INTRODUCTION

In the past three decades, building structures have been built tighter to reduce air infiltration and conserve energy used to precondition the air coming into the building. Energy conservation efforts have lead to more airtight buildings. Harriman et al. (1999) emphasized the increasing part of latent load in cooling requirements. This study has shown that latent loads are always higher than sensible loads for every region in the United States with the exception of desert climates. In order to provide an acceptable indoor air quality as recommended by the American Society of Heating, Refrigeration, and Air-Conditioning Engineers in ASHRAE Standard 62-1989 and its current revision 62.2 (ASHRAE 1999), the use of mechanical ventilation systems became more accepted. These systems are capable of providing a controlled rate of air change and respond to the varying needs of occupants and pollutant loads, regardless from outdoor conditions.

However, the focus on indoor air quality has often lost sight of the moisture component especially when related to humid climate conditions where the latent load is prevailing. It has been noted that some houses built meeting ASHRAE standards in the hot and humid climate and equipped with a dedicated ventilation system were reported to have longer periods of elevated interior relative humidity (RH > 60%) relative to conventional houses without dedicated ventilation systems (Rudd 2003).

An adequate ventilation approach requires not only air exchange but also indoor humidity control. Occupants, when subjected to high space humidity in the cooling season, respond by lowering the space thermostat setting in an attempt to feel comfortable. This results in cooling the interior space further, most often increasing the space relative humidity along with the likelihood of condensation of moisture on supply air ducts, floors, and other building surfaces. Another solution to deal with excess of moisture is the use of a stand-alone dehumidifier. These systems use large amounts of electricity, are expensive to operate and are useful only a couple of months a year in some (northern) regions like Ottawa, which is categorised as a cold humid climate. Also, an energy-efficient home may need little cooling during periods of mild temperature, but humid months may result in insufficient dehumidification and higher than desired indoor humidity.

Recently, in order to deal with the magnitude of moisture present in outside air and its consequences on IAQ, more ventilation designs are including Energy Recovery Ventilators (ERVs) to improve the system's efficiency. Besides providing controlled ventilation, ERVs are able to filter, humidify, dehumidify, heat, or cool the incoming fresh air. HRVs (Heat Recovery Ventilators) use the same principle as ERVs but they only recover heat. Some models are also equipped with automatic humidity sensors that increase the ventilation rate when needed but no moisture recovery is made. HRVs were initially designed and used in Canada and the northern part of the United States, using cold-climate ventilation strategies. ERVs are now beginning to see wider use in the southern climate (southern United States) and during warm and humid summer months in Canada for removing moisture from the incoming air.

This paper highlights the growing needs for energy savings measures in the Canadian residential market, presents a field study to assess the energy performance of an innovative Energy Recovery Ventilator (ERV) in a single-detached house compared to the heat recovery ventilator technology. Field tests were conducted at the CCHT facility, which consists of two identical research houses, allowing a side-by-side testing. A comparison of the energy performance of the two houses is performed with the ERV installed in the Test House and the HRV installed in the Reference House (both coupled with the central air conditioning system).

Trends in Canadian household characteristics and energy use

Several extensive surveys for the energy use of households were conducted over the last years in Canada with continuing objective to assess the changing characteristics of households and their energy consumption across Canada (NEUD 1997 and SHEU 2003).

The last survey, "2003 Survey of Household Energy Use" has reported a noticeable increase in the energy consumed in the Canadian residential sector for space cooling (energy consumption has more than doubled from 1990 to 2002). Cooling requirements, expressed by the cooling degree-days has also increased (Figure 1).

In parallel, there has been a noticeable increase in the penetration rate of air-conditioning systems in Canadian households. Figure 2 shows that almost 45 percent of Canadian households were equipped with some type of air-conditioning system in 2003. Within Canada, there were significant regional differences in the penetration rates of air-conditioning systems. The regions with the warmest summers i.e. Quebec, Ontario and the Prairies had the highest penetration rates for air-conditioning systems. Ontarian households are the most equipped with nearly three out of every four households equipped with an air-conditioning system in 2003 (Ontario account for 60 percent of all the residential air-conditioning systems in Canada (SHEU, 2005).

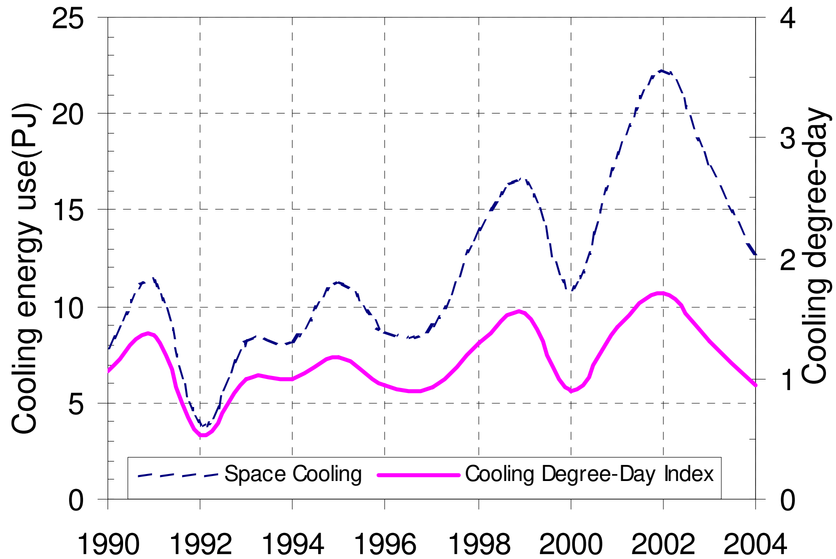

Figure 1: Residential air conditioning energy use and corresponding cooling degree-day index – SHEU 2003

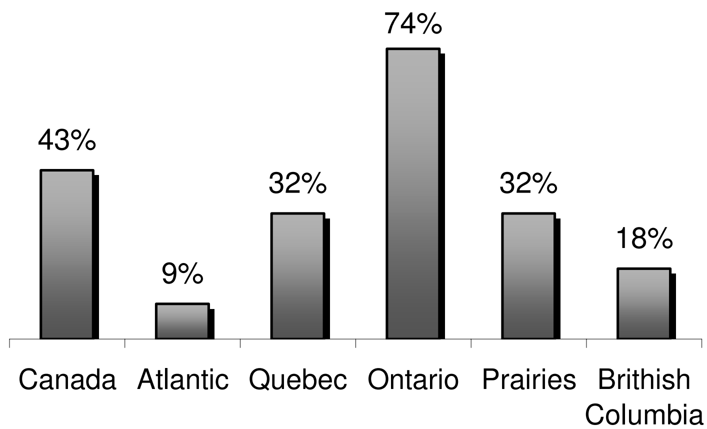

Figure 2: Penetration Rate of Air-Conditioning Systems by Region – SHEU 2003

Types of air conditioner available to consumers include window/room air conditioners, central air conditioners and heat pumps. Central air-conditioning systems were the most prevalent type of air-conditioning systems where over 25 percent of households were equipped with in year 2003 (Figure 3). Window/room air conditioners came second, with

15 percent of households. The third type of air-conditioning system, heat pump, was not prevalent across the country. Only 4 percent of households were equipped with. It was also noted that central air conditioners were more prevalent in larger dwellings, such as single detached or double/row houses, while window/room air conditioners were more installed in smaller dwellings, such as apartments and mobile homes.

Since 1993, surveys of energy use in households made by Natural Resources Canada have shown that central air conditioners are most installed types of new air conditioning systems in new houses. Data from SHEU–2003 show a clear advantage for the penetration rate for central air conditioners. It has increased by 32 percent compared to 13 percent for and window/room air conditioners. These trends have concurred with warmer-than-average Canadian summers since 1998, with the exception of the summer of 2000.

As reported in the Trends in Energy Characteristics of Homes in Canada (1997), among houses with central ventilation, the system is used more often year-round in new houses (70.6%) than older houses (59.2%); also, more new houses than older ones have systems with heat recovery (60.8 % and 36.9% respectively). Three of four 1994 new houses equipped with central ventilation in New Brunswick, Ontario, and British Columbia have systems with heat recovery [*].

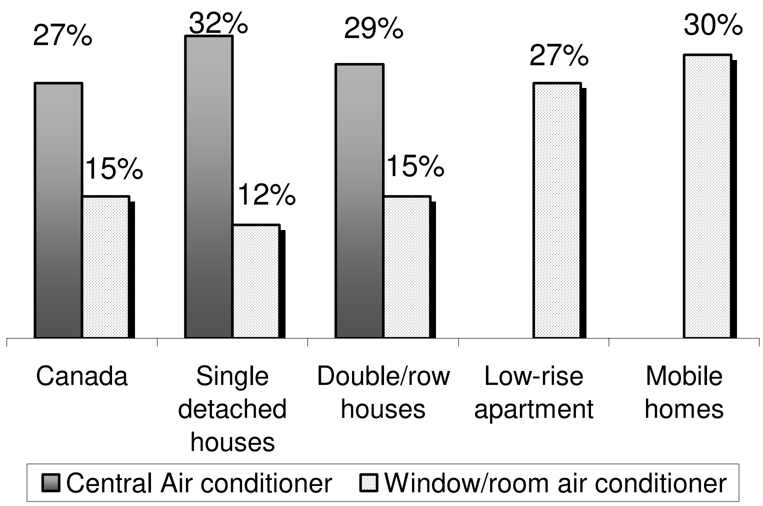

Figure 3: Penetration rate of central and window/room air-conditioning systems by dwelling type – NEUD 1997

The energy Recovery Ventilator is an emerging technology and no statistical data are available yet about their use. Our aim in this study is to assess the energy savings using an Energy Recovery Ventilator compared to a Heat Recovery Ventilator by field tests for the climate of Ottawa. This field trial was made using the Canadian Centre for Housing Technology's research facility, two identical detached houses. A description of the CCHT facility is made in the following section.

[*] *It should be noted that these data pertain strictly to the urban segment of the population, where the use of air conditioner is likely to be higher.*

THE CCHT TEST FACILITY

The Canadian Centre for Housing Technology (CCHT) features twin research houses, the Reference House and the Test House to evaluate the whole-house performance of new technologies in side-by-side testing (Figure 4). Built to the R-2000 standard, the twin houses offer an intensively monitored real-world environment for energy performance and thermal comfort. Features of the houses are listed in Table 1. In addition to these features, the houses include a simulated occupancy system based on home automation technology that simulates the daily water draws and electrical loads of a family of four. The internal heat gains from the occupants are also simulated (Swinton *et al.*, 2001).

Table 1: CCHT Research House Specifications

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	Low-e coated, argon filled double glazed windows Area: 35.0 m^2 (377 ft^2) total, 16.2 m^2 (174 ft^2) South Facing
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

Figure 4: CCHT Houses

The experiment consists first of operating the houses with identical HVAC systems to generate benchmark performance characteristics. Then, *test house* is modified using innovative energy saving components or systems that are being assessed – the Energy Recovery Ventilator (ERV) in this case. The resulting change in performance was documented relative to the benchmark configuration. The *test house* is used to assess only one component at a time, on a week-by-week basis. On completion of the assessments, the *test house* is returned to its starting (benchmark) configuration and the benchmark is re-confirmed.

AIR-TO-AIR HEAT EXCHANGERS

Heat Recovery Ventilator (HRV) and an Energy Recovery Ventilator (ERV) are air-to-air heat exchangers that transfer heat energy (and in some cases, moisture) from one airstream to another through a plate heat exchanger that separates the supply and exhaust stream. Plate heat exchangers contain no moving parts and can be located in any relatively clean stream. A typical heat or energy recovery unit is shown in Figure 5, both are designed to provide fresh air into a building while exhausting an equal amount of stale air.

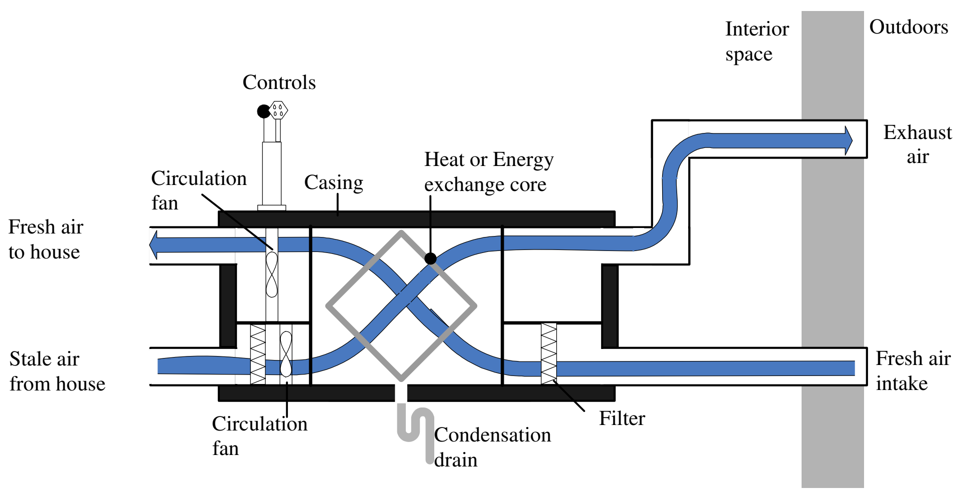

Figure 5: HRV and ERV schematic

The core in an HRV is constructed of propylene or aluminium media and transfers sensible energy (dry bulb temperature) from one airstream to the other. The ERV has HM (Heat Moisture) plate heat exchanger as a core, constructed of permeable membrane that is capable of transferring sensible energy and latent energy (dry bulb temperature and moisture transfer) from one air stream to the other. Most plate heat exchangers consist of a stack of ribbed plates; easy to clean surfaces.

During the heating season, the HRV captures heat from the outgoing air and uses it to preheat the incoming fresh air. During the air-conditioning season, an HRV can reverse this heat-exchange process, removing some of the heat from the incoming air and transferring it to the outgoing air. An ERV is designed for use in warm humid areas with heavy air conditioning use. The ERV will transfer both sensible and latent heat from the incoming fresh air to the outgoing stale air thereby reducing the ventilation cooling load on the air conditioning system.

APPROACH

The HRV and ERV units were installed in the CCHT twin houses with exhaust connected to bathrooms and kitchen and the supply connected to the return plenum of the HVAC system to be mixed with the recirculated air. They were operated over two weeks to develop a comparison between the energy performance of the Test House with the ERV to the Reference House with the HRV. The benchmark was conducted for one week with an HRV in both houses before and after the two testing weeks. For the first testing week, the two systems (HRV and ERV) operated with a low airflow rate of 65 cfm (110 m^3/h). The second week, the airflow rate was set to 115 cfm (195 m^3/h). Changes in houses performance due to the ERV were observed through side-by-side comparison for a range of weather conditions.

During the assessment, the consumption of the air conditioning (compressor and the condensing fan) and the furnace in the test house were measured. The A/C (compressor and condensing fan), furnace (circulating fan) and total cooling energy (including the HRV or ERV fan) consumptions for each house were recorded for each day of operation and compared graphically.

The house temperature is regulated by a standard programmable thermostat located in the main floor hallway at mid-wall height. Throughout the summer of 2004, the thermostat set point was nominally at 24°C, maintaining the house main floor temperature at roughly 23°C. The second floor remained approximately 2 to 3 degrees Celsius warmer than the main floor, while the basement remained 2 to 3 degrees Celsius cooler. The thermostat located in a centre of the main floor had a very narrow band in both houses of about± 0.1 ºC.

Benchmarking

The houses, both with high efficiency HRVs, were operated to show that they are thermally as identical as possible, before installing the ERV in the test house. Figure 6 shows the benchmarking of the Test House against the Reference House over the same period. Results represented a good statistical fit; with the slopes being measured few percent lower than a perfect fit (slope of "1"). Also the "before" and "after" trends are very similar. This similarity indicates that the performance of the houses remained unchanged in terms of energy consumption by the ERV experiment.

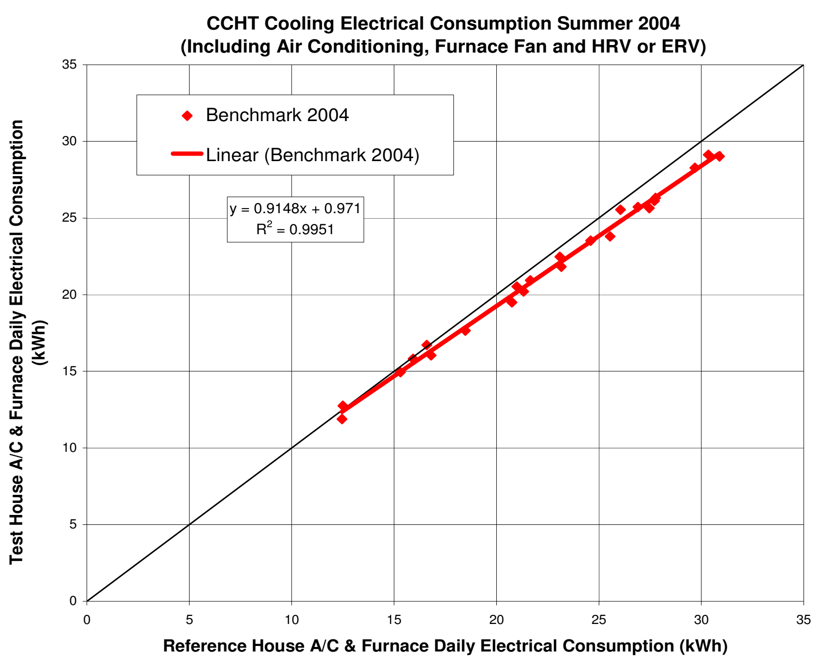

Figure 6: Cooling benchmark data and statically fitted line

RESULTS

This section compares the operation of the two houses, the Reference House incorporating the Heat Recovery Ventilator (HRV) and the Test House incorporating the Energy Recovery Ventilator (ERV). One should note that the CCHT houses are built extremely airtight (see Table 1 for the airtightness) and they have limited moisture sources. The simulated occupancy of a family of four created moisture from bath, shower and dishwashing and estimated to be 1.81 L/day based on published ranges provided in literature. This study did not include simulation of moisture from occupants.

The houses were compared in term of: airflow, average indoor air temperature and humidity, and energy consumption. In this paper we present only the temperature and relative humidity profile along with the energy consumption.

Results with low Incoming Air Flow of 65 cfm (110 m^3/h)

The average indoor temperature in the Reference House (with HRV) and the Test House (with ERV), and also the outdoor temperature over the testing period with an air entering flow of 65 cfm are shown in Figure 7. This graph shows that both systems were very close in maintaining the average indoor temperature.

On the other hand, the indoor average relative humidity in the CCHT houses is shown in Figure 8. The relative humidity in the Test House is noticeably lower compared to the value in the Reference House, showing that ERV controls better the humidity in the house by transferring a part of the incoming air moisture content to the (drier) air leaving the house.

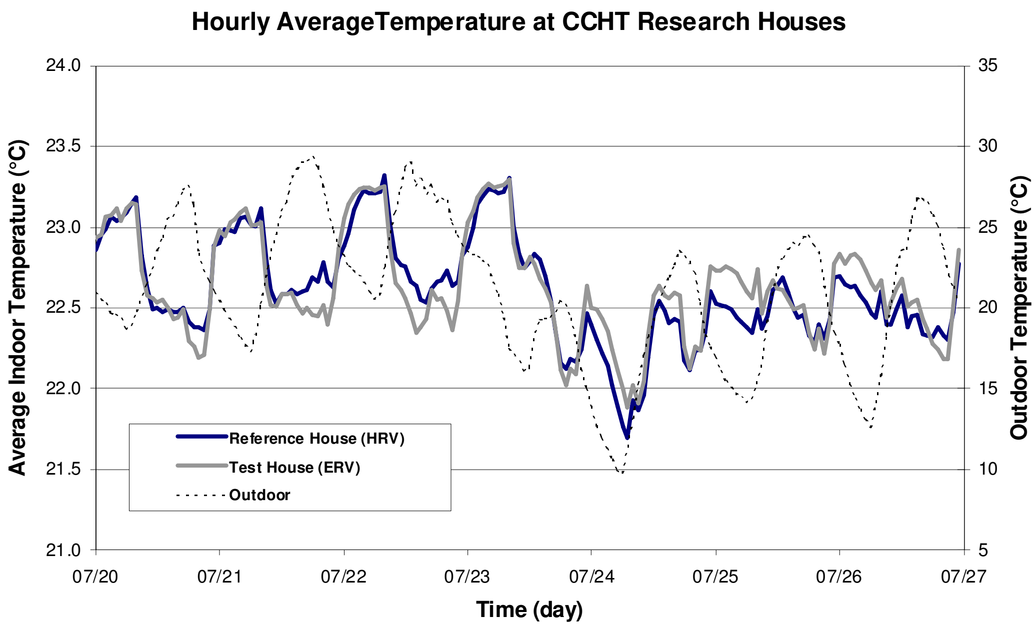

Figure 7: Indoor and outdoor temperatures at CCHT houses - 65 cfm

The daily average, maximum and minimum indoor and outdoor temperature and relative humidity are shown in Table 2, where also daily cumulative air conditioning electricity and cooling electricity consumption were summarized. The air conditioning electricity consumption saving using an ERV instead an HRV went up to 13.6% (compressor and condensing fan only). The corresponding cooling (this includes the compressor, condensing fan, and air handler fan electricity consumption) electricity consumption saving went to 9.75%.

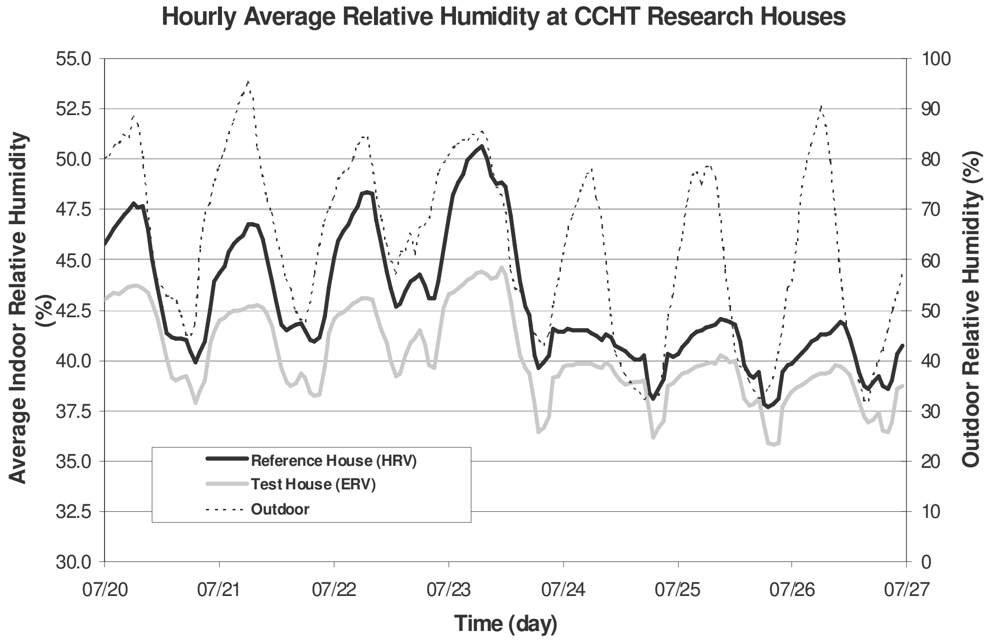

Figure 8: Indoor and outdoor relative humidity at CCHT houses - 65 cfm

Table 2: Temperature, RH, cumulative A/C and cooling energy consumption - 65cfm

Day		Outside		Ref House		Test House		HRV	ERV	A/C Consumption			Cooling Consumption		
		T(°C)	RH(%)	T(°C)	RH(%)	T(°C)	RH(%)	(KWh)	(KWh)	Ref (KWh)	Test (KWh)	Diff (%)	Ref (KWh)	Test (KWh)	Diff (%)
1	Avg	22.4	67.4	22.7	44.0	22.7	41.4	2.2	2.2	17.6	15.4	12.4	31.5	28.8	8.5
	Max	27.6	88.6	23.2	47.8	23.2	43.7								
	Min	18.7	44.9	22.4	39.9	22.2	37.9								
2	Avg	23.7	70.7	22.8	43.7	22.7	40.8	2.2	2.2	19.9	17.2	13.6	34.2	30.8	9.8
	Max	29.3	95.4	23.1	46.8	23.1	42.8								
	Min	17.3	47.9	22.5	40.9	22.4	38.3								
3	Avg	24.9	71.6	22.9	45.2	22.8	41.5	2.2	2.2	19.7	17.2	12.7	33.9	30.8	9.2
	Max	29.0	84.4	23.3	48.3	23.3	43.1								
	Min	20.5	57.3	22.5	42.7	22.3	39.2								
4	Avg	19.5	66.6	22.8	46.0	22.8	41.8	2.2	2.2	11.9	11.1	6.1	24.7	23.8	3.8
	Max	23.6	85.4	23.3	50.6	23.3	44.6								
	Min	15.0	43.1	22.1	39.6	22.0	36.4								
5	Avg	17.0	51.7	22.2	40.5	22.3	39.0	2.2	2.2	8.8	8.6	2.2	20.8	20.6	1.2
	Max	23.5	78.0	22.6	41.5	22.8	39.9								
	Min	9.8	32.3	21.7	38.1	21.9	36.2								
6	Avg	19.4	54.3	22.5	40.3	22.6	38.7	2.2	2.2	11.5	11.5	-0.3	24.1	24.1	0.0
	Max	24.5	78.6	22.7	42.1	22.8	40.2								
	Min	14.2	32.3	22.3	37.7	22.2	35.8								
7	Avg	20.2	57.8	22.5	40.2	22.6	38.4	2.2	2.2	13.9	12.6	9.0	26.9	25.4	5.6
	Max	26.8	90.4	22.8	41.9	22.9	39.7								
	Min	12.6	31.9	22.3	38.6	22.2	36.4								

The hourly cumulative air conditioning electricity at CCHT research houses is presented in Figure 9. The cumulative air conditioning electricity consumption after a week of test in the Test House was 9.3% lower than the Reference House.

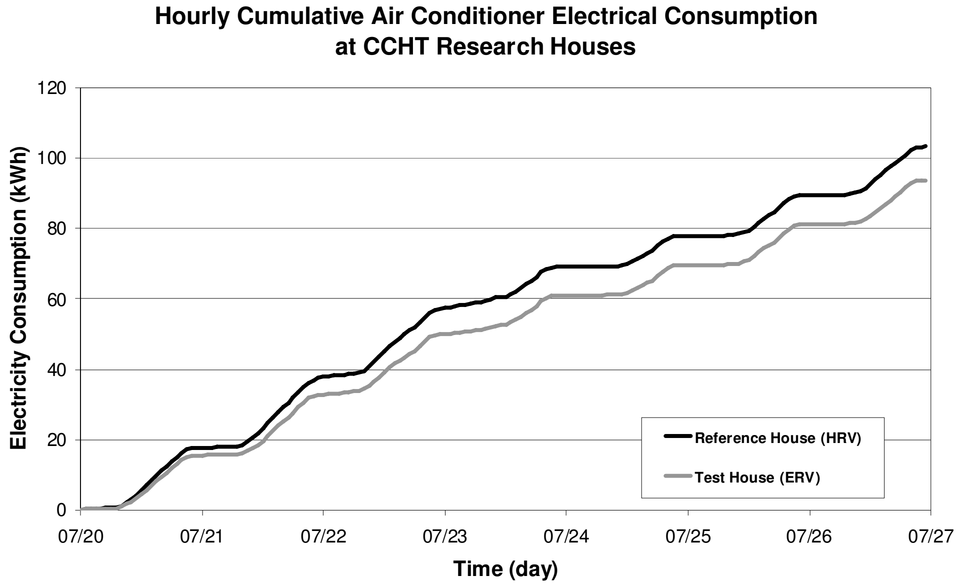

Figure 9: Cumulative A/C electricity consumption at CCHT houses - 65 cfm

Results with high Incoming Air Flow of 115 cfm (195 m^3/h)

Figure 10 shows the indoor average relative humidity in the Reference House and the Test House. Similar results were found for the ERV at the high airflow of 115 cfm providing better humidity control than the HRV. Figure 11 shows the hourly cumulative air conditioning electricity at CCHT research houses. The use of an ERV during the test period reduced also the air conditioning electricity consumption in the Test House by up to 12%.

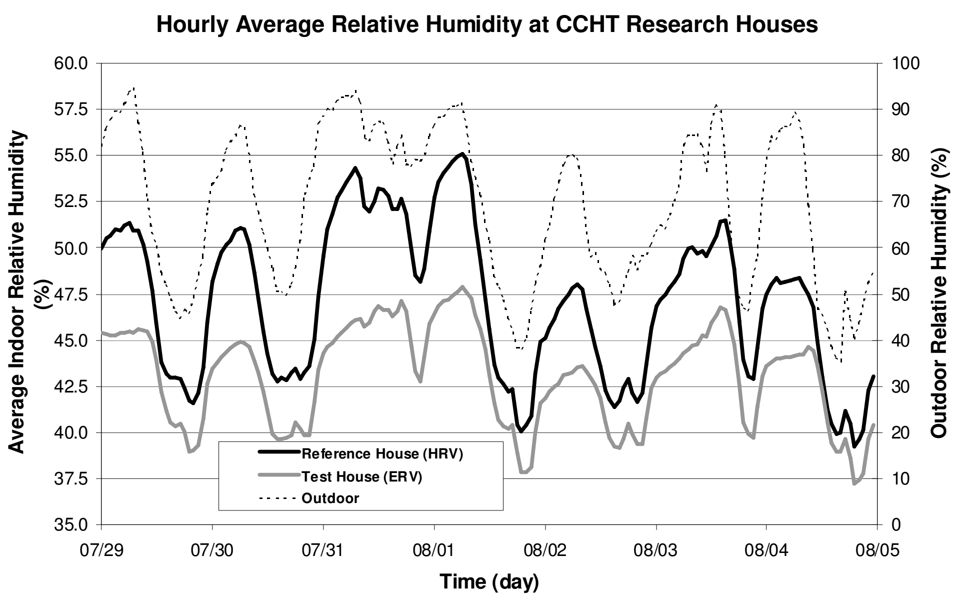

Figure 10: Outdoor and indoor relative humidity at CCHT houses - 115 cfm

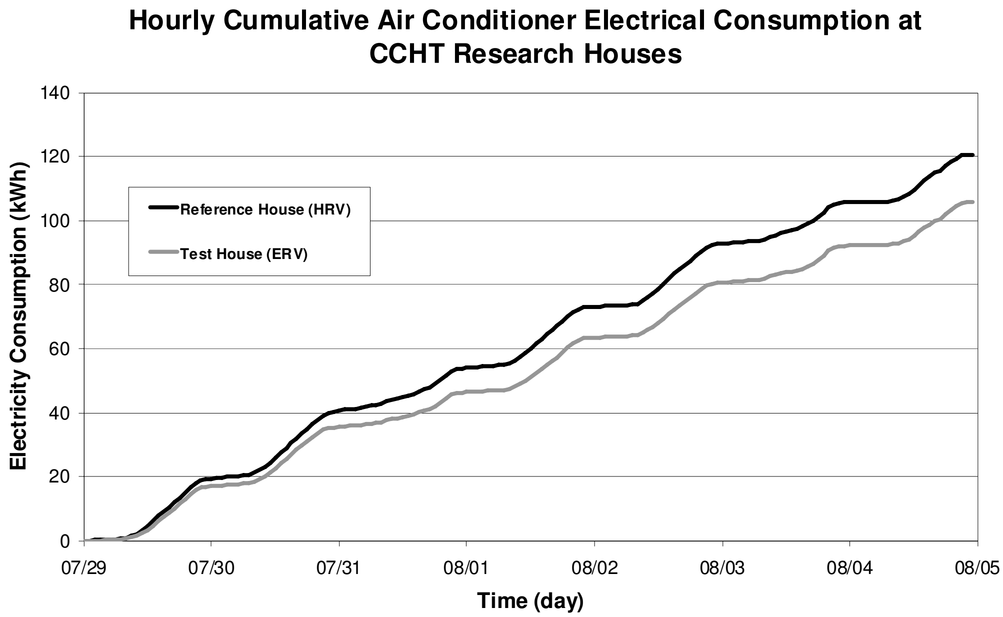

Figure 11: Cumulative A/C electricity consumption at CCHT houses - 115 cfm

The daily average indoor and outdoor conditions are shown in Table 3. The table includes also the air conditioning electricity consumption, which shows that using an ERV saved from 8% to 20% in air conditioning electricity consumption. The corresponding cooling electricity consumption saving went from 5.3% to 12%.

Table 3: Temperature, RH, cumulative A/C and cooling energy consumption – 115 cfm

Day		Outside		Ref House		Test House		HRV	ERV	A/C Consumption			Cooling Consumption		
		T(°C)	RH(%)	T(°C)	RH(%)	T(°C)	RH(%)	(KWh)	(KWh)	Ref (KWh)	Test (KWh)	Diff (%)	Ref (KWh)	Test (KWh)	Diff (%)
	Avg	23.2	68.6	22.8	46.8	22.8	43.1								
1	Max	29.1	94.7	22.9	51.4	23.0	45.6	4.7	4.6	19.2	16.7	13.0	35.7	32.6	8.8
	Min	17.1	44.8	22.6	41.6	22.5	39.0								
	Avg	23.9	69.9	23.0	46.5	22.9	42.3								
2	Max	29.9	87.1	23.3	51.1	23.4	44.9	4.7	4.6	21.2	18.7	11.6	38.2	35.2	8.1
	Min	18.7	49.7	22.7	42.8	22.5	39.6								
	Avg	22.4	85.8	23.0	51.9	23.0	45.6								
3	Max	25.4	93.9	23.4	54.3	23.4	47.1	4.7	4.6	13.5	10.8	20.2	29.0	25.5	12.0
	Min	20.7	77.8	22.6	48.1	22.4	42.8								
	Avg	22.7	65.7	22.8	47.7	22.8	43.4								
4	Max	26.2	91.4	23.3	55.1	23.3	47.9	4.7	4.6	19.1	17.0	10.8	35.8	33.2	7.4
	Min	19.8	38.2	22.4	40.1	22.4	37.8								
	Avg	23.3	62.5	22.8	44.6	22.9	41.5								
5	Max	28.5	80.1	23.2	48.0	23.2	43.6	4.7	4.6	19.6	17.2	12.3	36.3	33.3	8.3
	Min	18.2	47.7	22.6	41.4	22.5	39.2								
	Avg	22.3	70.5	22.9	48.1	22.9	43.9								
6	Max	25.7	91.0	23.3	51.5	23.4	46.8	4.7	4.6	13.1	11.7	10.5	28.4	26.6	6.3
	Min	19.9	46.4	22.4	42.9	22.4	39.7								
	Avg	20.5	61.4	22.6	44.3	22.8	41.7								
7	Max	25.3	89.3	22.9	48.4	23.0	44.6	4.7	4.7	15.1	13.8	8.4	30.9	29.3	5.3
	Min	16.0	35.4	22.4	39.2	22.4	37.2								

DISCUSSION

The real impact of the installation of an ERV in a Canadian house was evaluated for a range of summer temperatures in Ottawa including humid summer days. Summer 2004 cooling data revealed that the ERV helped maintaining lower levels of indoor relative humidity compared to the HRV, dealing only with heat recovery as shown on **Figure 12**. Despite the moderate weather experienced in the summer of 2004 (outside temperature not exceeding 28^{o}C), results showed the potential in reducing the cooling energy consumption by use of an ERV instead of a HRV (**Figure 13**).

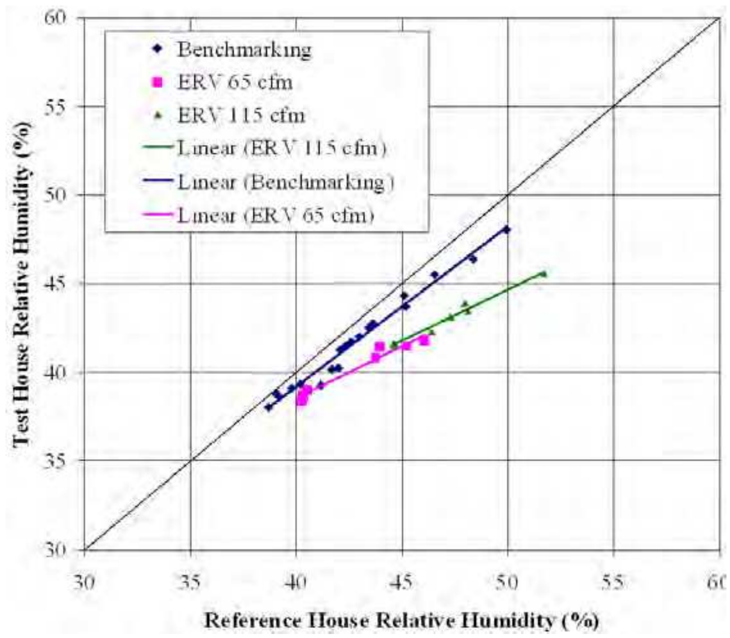

Figure 12: Average indoor relative humidity in CCHT research houses

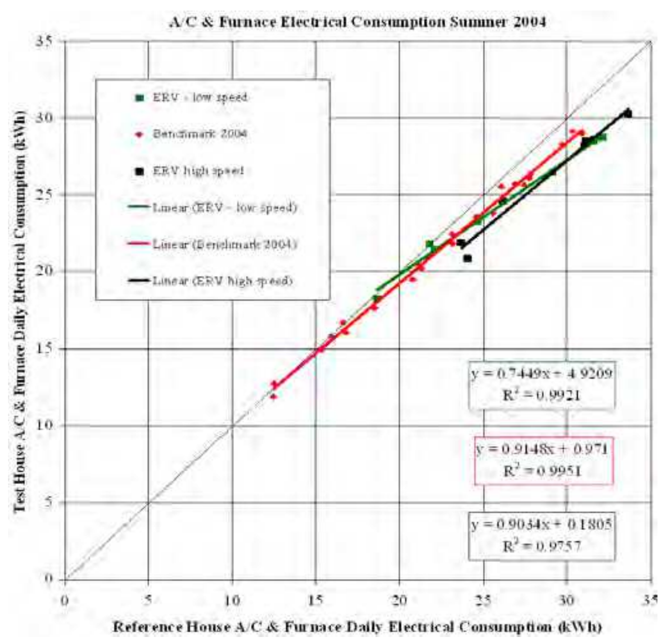

Figure 13: Cooling electricity consumption

CONCLUSION AND RECOMMENDATIONS

Incorporating an Energy Recovery Ventilator (ERV) in the Test House in the summer time not only offered more efficient humidity control compared to the Reference House but showed also a reduction in air conditioning electricity consumption (up to 20%) in particular and cooling electricity consumption (up to 12%) in general. This comparative analysis revealed the following:

- Improved indoor humidity control on warm and humid days.
- Significant reduction of air conditioning and fan circulation energy consumption.
- Measured trends indicate potential for even higher cooling energy saving under more extreme summer conditions.

The release of vapour due to occupants and their activity are significant and can reach up to 14 L of water per day for a family of four people (Christian, J.E. 1994). The simulated occupancy created only 1.81 L/day of moisture from shower, bath and dishwashing but did not include moisture from floor mopping, clothes drying, cooking, humans, plants and fire wood storage (12.2 L/day). Further experiments should be conducted with internal moisture generation to take into account the contributions due to the occupants and their activities.

ERV recovers a part of the moisture from the incoming air by passive transfer between two air streams. It has to be coupled with the central A/C system to provide a better management for the moisture load. The sensible load is still recovered by the central A/C. Another more effective way to deal with the cooling load especially in humid conditions is the use of desiccant evaporative cooling systems.

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