Moisture Control and Cooling Energy Use in Residential Buildings

Boualem Ouazia, Hayssam Barhoun
National Research Council Canada

Kamel Haddad
Natural Resources Canada

ABSTRACT

Energy consumed in the Canadian residential sector for space cooling has more than doubled from 1990 to 2002. Cooling requirements, expressed by cooling degree-days have also increased. In parallel, there has also been a noticeable increase in the penetration rate of air-conditioning systems: almost 45 percent of households were equipped with some type of air-conditioning system in 2003.

A comprehensive ventilation approach requires not only air exchange but also indoor humidity control. In hot and mild humid weather, ambient ventilation air presents a much greater latent load on the building than a sensible one. Occupants presently use air-conditioning systems or dehumidifiers in order to reduce the moisture level inside. These systems use large amounts of electricity, are expensive to operate and are useful for only a couple of months a year in some regions, e.g. Ottawa. An energy-efficient home may need little sensible cooling during periods of mild temperature, but still require dehumidification typically resulting in higher than desired indoor humidity.

This paper presents a field study conducted at the Canadian Centre for Housing Technology (CCHT). The performance of an innovative Energy Recovery Ventilator (ERV) in a single-detached house research facility, compared to the enthalpy performance of a Heat Recovery ventilator (HRV) in an identical house next door, to achieve appropriate indoor humidity levels was assessed. The paper also presents the design of an ongoing project on a Desiccant-based Evaporative Cooling System, coupling active desiccant dehumidification with indirect evaporative cooling, as an alternative to the conventional vapor-compression air-conditioner for residential application.

1. INTRODUCTION

The evolution of the notion of comfort along with the increasing requirements for ventilation in low-rise residential buildings has raised many challenges to the air conditioning industry: inadequate ventilation may lead to poor indoor air quality and to consequences such as sick building syndrome, or excessive indoor contaminants concentrations. While increasing fresh air ventilation rate on the other hand may lead to a high humidity level.

Also energy efficiency improvement measures over recent decades have almost exclusively reduced the sensible cooling loads (better roof and wall insulations, reduced windows U-values, etc.), while latent loads (primarily due to ventilation, infiltration, and occupants) have not changed substantially (in some cases they have increased) resulting in a proportional increase of the latent load over the sensible load.

With airtight buildings, the use of mechanical ventilation systems to fulfil the requirements of acceptable indoor air quality (as recommended in many standards, e.g. ANSI/ASHRAE 62-1999 has become more acceptabe and widespread. However, in hot humid weather, ventilation may increase interior moisture levels potentially doing more harm than good. Multiple building failures, discomfort, and poor indoor air quality have been linked to elevated interior humidity levels (Moyer, 2004). It has also been reported that some houses equipped with a dedicated ventilation system, despite the fact that they were designed to ASHRAE standards, were having longer periods of elevated interior relative humidity (RH > 60%) compared to conventional houses without dedicated ventilation systems (Rudd, 2003). This finding is related to the fact that central air conditioning systems cannot respond to the need of moisture removal once the temperature setpoint is met. The problem of elevated humidity in energy-efficient homes in humid climates is the result of interior moisture generation combined with lowered sensible heat gain, leading to less cooling system operation and an inadequate match of the equipement latent capacity to the latent load.

Conventional central air-conditioning systems based on the vapor compression cycle have a rated Sensible Heat Ratio (SHR) of around 75%. The operation of these systems is controlled using only a thermostat and any moisture removed from the space is a by-product of the temperature control. In humid climates the required design latent load of the space to maintain comfortable conditions can be high with a space design SHR significantly less than 75%. In this case using a conventional air-conditioning system leads to uncomfortable conditions with high indoor humidity levels. In many parts of Canada, occupants presently use air-conditioning systems or dehumidifiers in order to reduce the moisture level inside. These systems impose an increased burden on the grid, are expensive to operate and are useful only a couple of months a year.

According to energy use data (published by the Office of Energy Efficiency of Natural Resources Canada) the total electricity consumption for space cooling of residential buildings in Canada has almost doubled from 1998 to 2005. The relative increase in cooling electricity consumption during this period is especially significant for Ontario (82%) and Québec (186%). In 2005 about 86% of Canadian residential buildings with a cooling system installed use a central air-conditioning system.

Central mechanical ventilation systems were reported (NEUD NRCan report 1997) to be used with heat recovery year-round more often in new houses (60.8 % of new houses have systems with heat recovery compared to 36.9% for houses built before 1994). Three out of four houses built since 1994 were equipped with central ventilation and HRV in New Brunswick, Ontario, and British Columbia.

This paper present results of a field study undertaken with an ERV coupled with a conventional vapour compression air-conditioner to achieve better indoor relative humidity and reduction in cooling electricity consumption. A design of a desiccant-based evaporative cooling system for residential application as a viable alternative cooling technology is also described and presented. Mainly driven by thermal energy, desiccant cooling, does not use any ozone depleting refrigerant, can deal with latent load more effectively and thereby improves indoor environment by providing drier air. It can also reduce energy consumption, peak electricity demand, and then GHG emissions.

2. FIELD STUDIES

2.1 *Canadian Centre for Housing Technology (CCHT)*

The Canadian Centre for Housing Technology 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 (Figure1). Built to the R-2000 standard, they are extensively monitored for energy performance and thermal comfort. These houses have been calibrated and are nearly identical (Swinton, 2001). To simulate the normal internal heat gains of an occupied house, the CCHT test and reference houses feature identical "simulated occupancies", which are activated by electronic controls commonly used in home automation packages with over 60 on/off events per day. The activities of a family of two adults and two children are simulated. Events include: the operation of major appliances (dish-washer, stove, clothes-washer & drier), lights, and water draws (shower, bath, kitchen sink). Incandescent bulbs are used to simulate sensible heat gains from humans (60W per adult, 40W per child) at various locations in the house. The simulated occupancy was enhanced to inject an equivalent amount of moisture that would result from bathing, showering and dishwashing estimated to be 1.81 L/day (Christian, 1994).

Figure1: Canadian Centre for Housing Technology (CCHT)

2.2 Air-to-air energy recovery heat exchangers

Air-to-air energy recovery heat exchangers include Heat Recovery Ventilators (HRVs) and Energy Recovery Ventilators (ERVs). A typical heat or energy recovery unit is shown in Figure 2. They both are designed to provide fresh air into a building while exhausting an equal amount of stale air. The core in an HRV transfers only sensible heat from one air stream to the other. The term ERV is used to describe a unit with an enthalpic core that transfers moisture as well as heat from one air stream to the other. When indoor air is warmer than outdoor air (winter), incoming cold fresh air is warmed utilizing the heat recovered from the stale air before it is exhausted to the outdoors. When indoor air is cooler than outdoor air (summer), the HRV will help in cooling the incoming fresh air with the stale air that is being exhausted. The ERV is designed for use in warm humid areas with heavy air conditioning use. The ERV transfers both sensible and latent heat from the incoming fresh air to the outgoing stale air thereby reducing the load (related to ventilation) on the air conditioning unit.

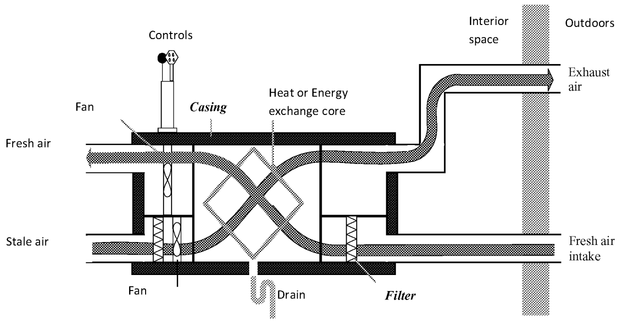

Figure 2: HRV and ERV Schematic (Energuide; ERV)

2.3 *ERV Coupled with Conventional A/C System*

The HRV and ERV units were monitored for two weeks using the CCHT houses. The whole house energy performance was monitored for the *test* house with the ERV and compared to the *reference* house with the HRV. The benchmark tests, to confirm that the *test* and *reference* houses have nearly identical cooling energy consumption, were conducted for one week with an HRV in both houses before and after the two week test period.

The first week of testing consisted of operating the HRV and the ERV at a low speed of 110 m^3/h, while during the second week the airflow rate was set to 195 m^3/h. The effect of the ERV on the performance of the *test* house was observed by comparing the *test* house energy consumption to that of the *reference* house. The electricity consumptions of the air conditioning unit (compressor and condenser fan), the furnace (circulating fan), and the total cooling (including HRV or ERV fan) were recorded, in both houses, for each day of operation and compared graphically.

2.4 *Results*

In both houses, the temperature is regulated by a standard programmable thermostat located in the main floor hallway at mid-wall height. The thermostat has a narrow dead band in both houses, about ±1ºC. Throughout the summer of 2004, the thermostat set point was nominally at 24°C, maintaining the house main floor temperature at roughly 23°C. Temperatures on the second floor were approximately 2 to 3 degrees warmer than the main floor temperature, while the basement remained 2 to 3 degrees cooler.

The indoor average relative humidity in the *reference* (with HRV) and *test* (with ERV) houses is shown in Figure 3 and 4. The relative humidity in the *test* house is noticeably lower (up to 10%) compared to the value in the *reference* house, showing the ERV's enhanced control of indoor humidity by transferring some of the water vapor in the incoming air to the stale drier air leaving the house. Although the RH level in both houses was inside the comfort zone, the HRV may have difficulties maintaining an acceptable humidity level when indoor moisture sources are greater compared to the ERV.

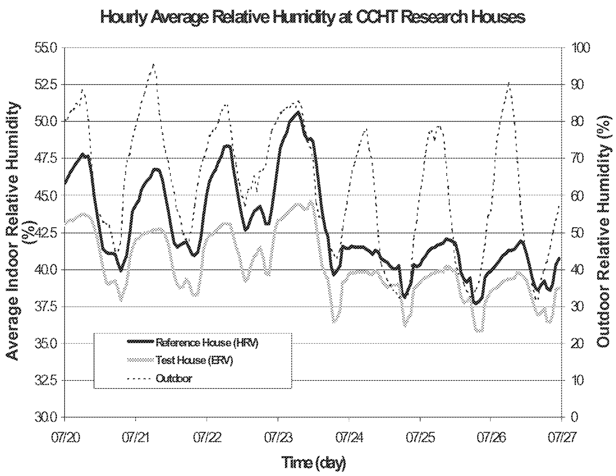

Figure 3: *Indoor and outdoor relative humidity - 110 m^3/h.*

The hourly cumulative air conditioning electricity at CCHT research houses (*reference* house incorporating an HRV and *test* house incorporating an ERV) have shown that the air conditioning electricity consumption in the test house is 9.3% lower than the *reference* house with a ventilation airflow of 110 m^3/h, and 12% lower with an airflow of 195 m^3/h.

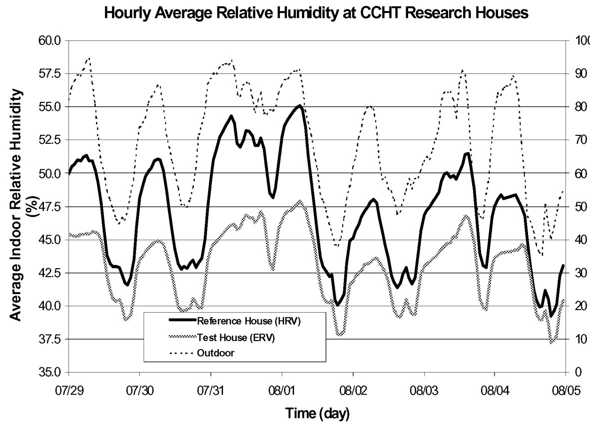

Figure 4: *Outdoor and indoor relative humidity - 195 m^3/h*

2.5 *Desiccant Evaporative Cooling (DEC)*

A desiccant evaporative cooling system is composed of three principle components: the desiccant wheel, the sensible wheel and the indirect evaporative cooling. Figure 5 shows a schematic of the desiccant evaporative cooling unit designed for the CCHT houses and figure 6 the psychrometric process. Two counter current air streams, the process (H' to I) and the regeneration (A to G) air streams drive the operation of the desiccant dehumidification / cooling system.

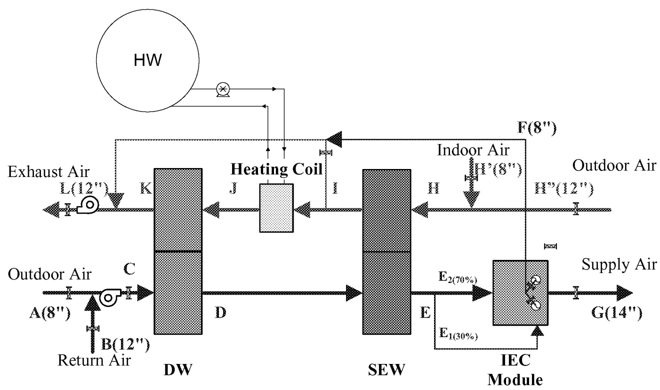

Figure 5: *System schematic.*

The desiccant wheel is regenerated using a coil supplied by hot water from a gas fired domestic water heater. A sensible wheel is used after the desiccant wheel to pre-cool the process air. The excess heat is transferred to the regeneration air stream (reducing the load on the heating coil).

Indirect evaporative cooling (IEC) incorporates direct evaporative cooling and sensible heat transfer. The direct evaporative cooling process tends to cool the air by adding water into it. An indirect evaporative cooling incorporates two air streams, the primary air stream called "process stream" sensibly cooled without adding any water into it, and a secondary wet stream called "working stream" where the water is added.

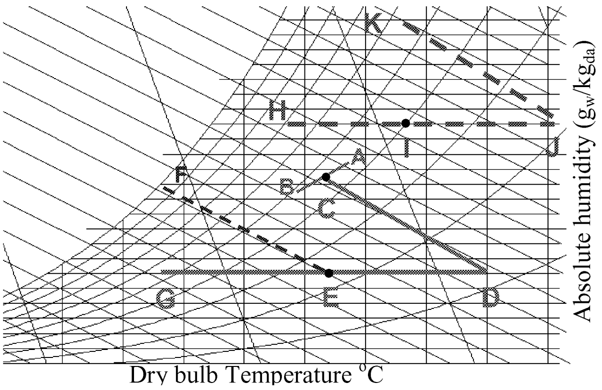

Figure 6: *DEC cycle presented on a psychrometric chart.*

Sate A to C: On the process side, return air from the conditioned space (state A) and fresh outdoor air (state B) are mixed and introduced in the process air at state C.
State C to D: Air is dried, resulting in hot, and dry air D. This increase in temperature is due to the release of heat of condensation of the water vapour when the desiccant material removes moisture.
State D to E: Hot and dry air is then cooled sensibly and heat is transferred to the regeneration air stream.
State E: Inlet of the IEC, the process air stream is split into two air streams.
State E to F: Air stream (E-E1-F) is humidified as it passes through wet channels and then supplied to the conditioned space.
State E to G: Air stream (E-E2-G) passes through dry channels, transfers its heat through the plates to the first stream (wet side) where it is carried away by the warm humid exhaust air stream.
State H" to H: On the regeneration side the air stream is a mix of mainly outside air (state H") and a small portion (state H') of indoor air (exhaust duct from the kitchen and bathrooms).
State H to I: Air is preheated by passing through the SEW to recover heat captured by the wheel's structure from the process air stream.
State I to J: Preheated air passes through a hot water coil, in which circulates hot water heated by a gas-fired heater. Air is thus heated up to the required regeneration temperature of the desiccant material.
State J to K: Hot air passes through the desiccant wheel in order to regenerate the desiccant. Warm and very humid air at state K is joined by the IEC first wet air stream before it is exhausted.

2.6 Modes of operation

The desiccant evaporative cooling unit can operate in different ways to meet the indoor air cooling requirements. The system is controlled by a dehumidistat in conjunction with the usual thermostat achieving a better indoor air quality: When only sensible cooling is needed (temperature over the set point), the process air blower and the indirect evaporative cooler will run to cool the air. When dehumidification (latent cooling) and/or sensible cooling are needed, all the subsystems will run to provide dehumidification and cooling to the conditioned space.

3. SIMULATION

A brief summary of the simulation work associated with this project is provided in this paper. All the simulation results are generated using a 5-minute time step using weather files for the cities of Ottawa and Montreal for the year 2001. The TRNSYS simulation environment is used to create a model for the CCHT test house with a vapour-compression unitary-split air-conditioning system. The system is controlled to maintain an indoor space temperature of 25.5 ± 0.5 °C. In this case, the predicted total number of hours where conditions inside the space fall outside of the ASHRAE comfort zone is 155 for Ottawa and 263 for Montreal. A second TRNSYS model was created for the CCHT house with the desiccant evaporative cooling system. In addition to the dry-bulb temperature control, the wet-bulb temperature on is controlled so that it is maintained within the range 18 ± 0.5 °C. The total number of hours that the system is not able to maintain conditions inside the space within the ASHRAE comfort zone is only 81 for Ottawa and 132 for Montreal.

The predicted total electricity consumption of a unitary air-conditioner, with a high COP of 4.15, is 383 kWh for Ottawa and 482 kWh for Montreal for the summer of 2001. For the desiccant evaporative cooling system, the predicted electricity consumption for Ottawa and Montreal is 276 kWh and 340 kWh while the heat input required for the regeneration of the desiccant wheel is 1611 kWh and 1922 kWh, respectively. These results are very encouraging because they represent a reduction in electricity consumption of the order of 28% for Ottawa and Montreal, when the desiccant evaporative cooling system is used instead of the conventional system.

4. CONCLUSIONS & PERSPECTIVES

This report presented two field studies on improving indoor humidity control and energy use in cooling applications for residential buildings: Energy Recovery Ventilator and Desiccant Evaporative Cooling. The assessment of the first technology (ERV) has been completed and the second technology (DEC) is in progress at the Canadian Centre for Housing Technology (CCHT).

Incorporating an ERV in the *test* house in the summer time not only offered more efficient humidity control compared to the *reference* house with an HRV, but also showed reductions of up to 12% in the cooling electricity consumption over the analyzed period.

The second part describes the ongoing field study, using the same twin-house facility, on Desiccant Evaporative Cooling system. The DEC unit will be challenged in the next field trial taking place in summer 2008 under hot and humid conditions.

Preliminary results from the simulation study of the desiccant evaporative cooling system for a residence indicate that the system can be associated with substantial reductions in electricity consumption compared to a conventional vapour compression system. At the same time the desiccant evaporative cooling system is better able to maintain comfort conditions inside the space by decoupling the sensible and latent functions of the HVAC system.

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