VENTILATION SYSTEMS WITH HEAT RECOVERY CAPABILITIES ARE BENEFICIAL BUT, WHERE AND WHEN?

Augustino Binamu, Ralf Lindberg

Tampere University of Technology, Department of Civil Engineering, Tampere, Finland.

ABSTRACT

Researchers worldwide are striving to find out ways by which heat energy used to warm buildings can be optimally minimized. One way has been the use of ventilation systems with heat recovery capabilities. However, to date no defined standard specification on where and when these systems should be used. This study investigates the appropriate degree of air tightness of the building envelope and temperature difference range under which a ventilation system with heat recovery capability can operate optimally. The study involved various measurements including indoor and outdoor temperatures, wind speed and direction, solar radiation, building air tightness, infiltration/exfiltration, heat energy used to heat the building, and heat energy recovered from the extract air. Three different test buildings with different degrees of air tightness were used. Mechanical ventilation systems with air-to-air heat recovery were used to ventilate the buildings. A tight correlation between the envelope air tightness, the internal/external temperature differences and the energy recovered was confirmed. The tighter the building envelope the higher the performance of the systems in terms of energy recovery. Initial results show that up to 4.036 kWh/m^3 could be recovered from the extract air in three heating months depending on the air tightness of the building envelope, building materials used, and the climatic conditions. The colder the outdoor climate, the greater the quantity of the energy recovered.

KEYWORDS: ventilation systems, heat recovery, building air tightness; energy conservation, ventilation

INTRODUCTION

Energy-efficient designs and construction stipulates tighter building envelopes and use of mechanical ventilation systems with heat recovery (MVHR) in residential buildings as a measure to conserve energy used for heating. However, there are still ambiguities on the exact degree of air tightness of the building envelope and the temperature difference range (outside and inside) where MVHR systems can operate efficiently and with maximum benefit.

In some countries with very cold climates the law demand construction of buildings with high degree of air tightness with the provision of MVHR to ensure sufficient ventilation and energy savings [1,2]. The Belgian Institute for Standardisation also gives some building air tightness guidelines for specific cases but without particular requirement [3]. For instance, for houses operating under balanced mechanical ventilation, the air change rate at 50 Pa pressure difference should be $n_{50} < 3\ h^{-1}$, while for buildings operating under balanced mechanical ventilation system with heat recovery $n_{50} < 1\ h^{-1}$.

In comparison with the exhaust only systems, balanced systems control air flow rates in each ventilated space and therefore provide a better ventilation efficiency, prevent discomfort due to cold draughts, acoustic annoyance due to noise, and prevent pollutant migration (e.g. dust, radon etc.) from outside [4]. In addition, MVHR makes it possible to adjust ventilation rates according to needs by transferring air from one room to another and energy saving through the heat recovery system. However, buildings equipped with such ventilation systems must be sufficiently air tight in order to prevent infiltration and exfiltration heat loses. Persilly [5] reported that envelope leakage, even in a relatively tight house could result in over-ventilation relative to the residential ventilation requirement in ASHRAE Standard 62-1989 [6] during severe weather. This has been particularly observed for houses with significant levels of duct leakage. He suggested that tighter building envelope and reduced duct leakage should be built in order to avoid over-ventilation. In another study [7] it was confirmed that, the determination of energy balance, based on simple estimation of the air flows due to mechanical ventilation and/or air infiltration and exfiltration by using a constant air change rate is in most cases inaccurate unless the house is very air tight.

The foregoing discussion shows that the building air tightness and the external and internal temperature difference are important factors for operation of MVHR systems. Proper design of buildings should apply principles and ways leading to a good balance between interior comfort and efficient use of energy. Energy for heating buildings can be reduced by appropriate technical measures as well as by active and passive utilisation of solar energy (including seasonal solar heat storage). Also by improving thermal insulation of external walls and roofs, and by means of the heat recovery from the ventilation exhaust air and domestic hot water. This paper aims to extend the existing knowledge by determining where (in terms of envelope air tightness) and when (in terms of external temperature) can MVRH systems operate effectively and with maximum benefits.

MATERIALS AND METHODS

Test Buildings

The tests were carried in three of the six test buildings constructed in a moderately exposed parking area within the compound of Tampere University of Technology. The buildings' external walls were made of different materials, which included polyurethane insulated wooden frame wall (Bldg. No. 1), insulated log wall (Bldg. No. 3), and autoclaved aerated concrete block wall (Bldg. No. 5). The floor area of each test building was 2.4 x 2.4 m^2 and the free floor to ceiling height was 2.6 m. Both the ceiling and the floor consisted of two layers of foamed polyurethane elements with overall thickness of 200 mm. All the buildings had two well-insulated outer doors fixed one after another. The buildings had no windows. The calculated U-value of the roofs and the floors for all the buildings was 0.19 $Wm^{-2}K^{-1}$. The U-values of the walls of the buildings were 0.17 $Wm^{-2}K^{-1}$, 0.29 $Wm^{-2}K^{-1}$, and 0.35 $Wm^{-2}K^{-1}$ for building No. 1, 3, and 5 respectively.

The buildings were heated by using electric radiators. Additional heat in the indoor air was obtained from the control and monitoring equipment such as computers etc. During the tests the indoor air temperature was maintained constant at 20°C ± 1°C. Balanced mechanical ventilation systems with air-to-air heat recovery, (PARMAIR IIWARI Ex S) were installed into the three test buildings. The air change rates in the buildings were set at 0.5 h^{-1}, slightly higher compared to the outdoor air change requirement for residential buildings in ASHRAE Standard 62-1989 [6] of 0.35 h^{-1}. The exhaust and supply air flows were slightly unbalanced (supply air flow was approx. 0.8 of the exhaust air flow). The air ducts/pipes were insulated by 100-mm mineral wool. Water vapour was produced by continuously heating water that was kept in a container inside each building to provide additional moisture content in the indoor air of 2 g/m^3 for occupancy simulation. The indoor RH varied between 25.3 and 45.2% depending on the moisture content in the outdoor air.

Data Collection

Several measurements including indoor and outdoor air temperatures, relative humidity, solar radiation, wind speed and direction, building air tightness, infiltration/exfiltration, heat energy used for heating the buildings, recovered energy, and energy used by the ventilation system were taken. The indoor air temperature was monitored at three levels and the average value was taken as the indoor temperature. Exterior temperatures were monitored over the roof, under the floor, and on the exterior wall surfaces. The supply air temperature was monitored at two points before entering the heat exchanger and at one point when it leaves the heat exchanger before entering the room. Similarly, the extract air temperature was monitored at two points just as it leaves the heat exchanger and before being sent outside the buildings. The temperatures were measured by using calibrated semiconductor sensors (T-type) and cooper-constantan thermocouples (Cu-Ko, Cu-CuNi). Humidity sensors were used to measure the RH inside and outside the buildings. The wind speed and direction was measured at a 10-m height from the ground by using a wind speed meter that was fixed on a steel mast at building No. 2. For the wind speed measurements, a 3-cup anemometer was used whilst the wind direction was defined by using a wind streamer. Solar radiation intensity was measured by using a solar meter, which was fixed on the eaves of the building No. 1. The air tightness of the buildings was determined by using fan pressurisation method at a 50 Pa pressure difference as described in [8]. Uncontrolled air infiltration and/or exfiltration rates were determined by using tracer gas technique (concentration decay method). In this technique, tracer gas (CO_2) was injected into the buildings until a concentration level of 4 g/m^3 was achieved. Concentration decay of the tracer gas was then automatically monitored over a period of 3 to 4 days until it reached 0 g/m^3. The average air infiltration/exfiltration flow rates $\overline{Q}$ (h^{-1}) were then calculated by using Eqn. 1 [9].

Where, V is the volume of the ventilated space in m^3, $C(t_1)$ and $C(t_2)$ are the percentage concentrations of the gas at time t_1 and t_2 in hours respectively.

$$\overline{Q} = V \frac{\ln \frac{C(t_1)}{C(t_2)}}{t_2 - t_1} \tag{1}$$

The recovered energy E_R (kWh), from the extract air for the three buildings in three months period (Nov.-Dec. '99 and Jan. '00) was calculated by using Eqn. 2. Where, ρ is the air density (1.2 kg/m^3), C_p is the specific heat capacity of air (1.0 kJ/kg.K), Q_{mv} is the design ventilation air change rate through the system (0.5 h^{-1}), and V is the volume of the ventilated space (m^3). T_{after} and T_{before} are the temperatures of the supply air after and before it enters the heat recovery system respectively.

$$E_R = \rho . C_P . Q_{mv} . V . \sum_{i=1}^{n} \left(T_{after} - T_{before} \right) / 3600 \tag{2}$$

The total ventilation (including infiltration) energy input, E_{vtot} (kWh), was calculated by using Eqn. 3, whereas the heating degree-hours were determined as shown in [10].

$$E_{vtot} = \lfloor (Q_{mv} + Q_{\inf})V.\rho.C_p.D_h \rfloor / 3600 + E_{syst} \qquad (3)$$

Where, Q_{inf} is the infiltration air change rate (h^{-1}), D_h is the heating degree-hours (K), 3600 is a constant, which converts the h^{-1} into s^{-1}, and E_{syst} is the energy used to operate the system (kWh). Measured E_{syst} was approx. 141 kWh for each building in the three months. Equations 1 and 2 were solved first in order to determine the values for Q_{inf} and E_R which were then used in the calculations for the total ventilation (including infiltration/exfiltration) energy input, E_{vtot}.

RESULTS

The wind speed, buildings' air tightness at 50 Pa pressure difference, and the air leakage (infiltration/exfiltration) measurement results are shown in Table 1. The values for the measured and calculated total heating energy, ventilation energy, recovered energy, and heating degree-hours for Nov.–Dec. '99 and Jan. '00 are shown in Table 2.

Table 1. Wind speed, air tightness, and air leakage values for the three buildings

Building No.	Wind speed, v [m/s]	Air tightness at 50 Pa pressure difference [h^{-1}]	Infiltration/exfiltration air change rate, $\overline{Q}$ [h^{-1}]
1	1.65	0.97	0.008
3	1.26	Not obtained	0.079
5	1.98	1.27	0.035

Figure 1 illustrates the relationship between the external temperature and the temperature gained by the supply air from the extract air via the heat recovery (HR) system in one week. The same trend was observed throughout the monitored period. However, this particular week was chosen because it had the lowest recorded weekly mean outdoor temperature so far, of –7.93°C. As it can be seen (see Fig. 1), the lower the external temperature, the higher the recovered heat. The highest recorded value of the temperature gain was 22.16°C, which corresponds to the lowest recorded external temperature of (-20.27°C). The last row in Table 2 gives the sum of the values for the three buildings.

Table 2. Measured and calculated energy input, recovered energy, energy loss and heating degree-hours for Nov.–Dec. '99 and Jan. '99.

Building No.	Total heating energy input, $E_C + E_V$(msrd) [kWh]	Vent. Energy input (E_{Vtot}), [kWh]		Recovered energy, E_R [kWh/m^3]	Energy loss by conduction, E_C [kWh]	Heating degree-hours, D_h [°C]
		E_V(msrd) Measured	E_V(calc) Calculated			
1	367.25	259.25	237.77	3.794	108	38098.76
3	573.00	252.00	257.55	3.552	326	40240.39
5	558.04	326.00	240.20	4.036	232	37084.65
Sum	1503.29	837.25	735.52	11.382	666	115423.8

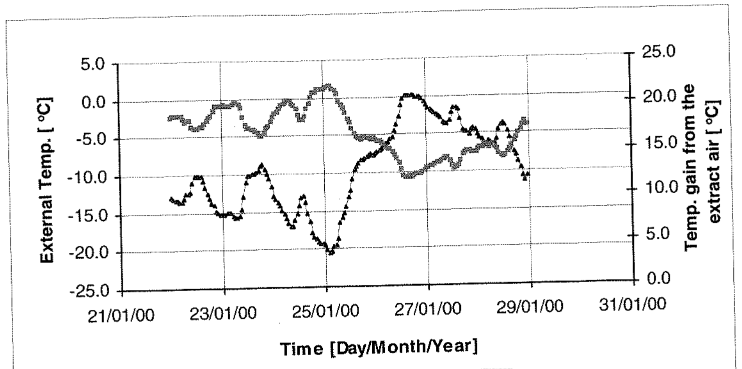

Figure 1. The relation between the external temperature and the temperature gained by the supply air from the extract air via the heat recovery system

DISCUSSION

The obtained results show that the buildings' air tightness and the internal/external temperature difference are consistent with the preposition that there is a correlation between the performance of the MVHR systems and these two variables. A tight correlation is evidenced by the values from each of the test buildings. The experimental setup is a laboratory-like setup but the situation simulated is very similar to real circumstances where MVHR systems are used. Theoretically, temperature gain by the supply air should be equal to the temperature loss by the extract air after heat recovery. In contrast, even after the heat recovery the temperature of the extract air remained higher than it was expected. This raised some suspicions that both the extract and the supply air might have gained some heat that was produced by the fan motors. Designers and manufacturers of the systems need to pay a particular attention to this fact. Proper insulation for both the heat exchanger and the ventilation pipes is crucially important.

CONCLUSIONS

There exists a tight correlation between the envelope air tightness, the internal/external temperature difference and the energy recovered by the MVHR systems. Further, the energy saving as a result of making use of the MVHR systems is significant enough to merit the adaptation of these systems in all residential buildings. However, for maximum benefits from these systems (including high performance), the air tightness of the buildings to be ventilated should strictly not exceed 1 air change per hour (ach) at 50 Pa pressure difference. Further research is underway to determine the mean outdoor temperature above, which no energy savings can be made through heat recovery. The colder the outdoor climate the higher the quantity of the recovered energy.

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