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EFFICIENCY OF VENTILATION SYSTEMS WITH HEAT RECOVERY AS A FUNCTION OF THE AIR TIGHTNESS OF THE BUILDING ENVELOPE

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ABSTRACT

The process by which heat energy is recovered from exhaust air for re-use within buildings is termed ventilation heat recovery. Among other factors, air infiltration can greatly impair the total energy performance of a system and in some cases, the recovery process could expend more energy than the actually recovered. Moisture problems and severe contamination of the indoor air can also result from air leakage through the building envelope. An investigation on the impacts of the envelope air tightness to ventilation heat recovery system performance has been carried out. The performance evaluation took into consideration other factors such as hourly climatic data in form of statistical relationship between wind speed and direction, temperature differences (inside and outside) and heat gain from solar radiation. The tests were carried out in three experimental houses built of different building materials and having different degree of air tightness. The air tightness of these buildings was determined by using tracer gas method. Balanced mechanical ventilation system with air-to-air heat recovery was implemented. Heat recovered from the exhaust air, wind speed and direction, indoor and outdoor temperatures, and heat gain from solar radiation were continuously recorded and the total thermal energy consumption within two heating months was evaluated. The research is on going but initial results have indicated that the air tightness of the building envelope has a significant impact on the heat energy performance of the system. It was noted that for an airtight building, the wind speed and direction has no great influence on the air change rate of the building. However, excessive air-infiltration resulting from poor envelope air tightness leads to uncontrolled energy loss. The colder the outdoor climate the greater the need for ventilation heat recovery.

KEYWORDS

Air change rate, air infiltration, building air tightness, heat energy, indoor air quality, performance, temperature difference, and ventilation heat recovery.

INTRODUCTION

Since the innovation of mechanical ventilation systems, their design has progressed from extract systems, supply systems to balanced extract and supply systems, a recent modification being the inclusion of heat recovery devices in the balanced ventilation systems. The interaction of ventilation with energy and indoor air quality has made the design of ventilation systems much complicated. Modern ventilation designs aims to optimise the energy used to heat and/or cool buildings in order to produce energy-efficient designs and operating practices without jeopardising the indoor air quality. As an attempt to fulfil this aim, heat recovery devices were introduced into ventilation systems. The function of a ventilation heat recovery device is to optimally recover the thermal energy from the extract air, but to effect such optimisation; data are necessary on all basic parameters influencing the ventilation heat recovery efficiency. The overall aim is to establish the principles controlling the efficiency of ventilation systems with heat recovery, so that the systems may be operated to better results and more economically.

Air infiltration can greatly impair the total energy performance of the system and in some cases, the recovery process could expend more energy than the actually recovered (Liddament 1996). Moisture problems and severe contamination of the indoor air can also result from air leakage through the building envelope. Infiltration can undermine the thermal insulation, can lead to interstitial damp and rot and even the creation of destructive ice boils within the façade (Brundrett 1999). The optimum performance of ventilation system as well as energy control and comfort conditions is dependent on the air tightness of the building envelope. Excessively leaky buildings will interfere with the performance of modern mechanical ventilation systems and will greatly reduce the net efficiency of heat recovery devices (Limb 1994, Liddament 1996, and Virtanen 1993). Air infiltration due to poor air tightness of the building envelope adds further to lack of control and energy waste and can contribute to noises, discomfort and concealed condensation problems (Orme 1998 and Orr and Figley 1980).

The fundamental design criterion for energy efficiency ventilation is to minimise the space heating and cooling loads while maintaining adequate indoor air quality. It has been reported that the only way to control the ventilation rate of a building is to have a tight building envelope (Elmroth *et al* 1983, Gusten 1989), and a properly designed and operated mechanical ventilation system. Unless air infiltration is controlled, the mechanical ventilation goals will be compromised and zones will end up over- or under-ventilated. Jackman (1984) argued that air tightness and ventilation standards must be introduced in conjunction with good building design to ensure that indoor air quality problems and energy loss are avoided. Hens (1998) pointed out that the air tightness of the building envelope has the status of a key performance requirement. If not guarantied, a set of other performances loses part of their predictability and usability. Heat loss, heat gains and moisture response of the opaque parts of a building for example, largely depends on it. As Roberson *et al* (1998) put it, it costs less to tighten a building's shell and provide mechanical ventilation than to heat excessive amounts of infiltration air.

Although much is known about the operation of mechanical ventilation systems, little attention has been paid to the mode of operation of ventilation systems with heat recovery and, in particular, to the effects of the air tightness of the building envelope and climatic conditions on the efficiency of heat recovery. This research investigates the performance of mechanical ventilation systems with heat recovery with regard to the air tightness of the building envelope as it may lead to more ventilation energy savings.

EXPERIMENTAL PROCEDURE

Test Buildings

The tests were carried in three of the six test buildings constructed in a parking area within the compound of Tampere University of Technology, western part of Finland. The buildings' external walls are made of different materials, which include 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 is 2,4 x 2,4 m^2 and the free floor to ceiling height is 2,6 m. Both the ceiling and the floor consists of two layers of foamed polyurethane elements with overall thickness of 200 mm. All the buildings have two well-insulated outer doors fixed one after another. The buildings have no windows. The colours on the façade of the buildings are greyish white (building no. 1), light green (building no.3), and old rose (building no. 5). The calculated U-value of the roofs and the floors for all the buildings is 0,19 $Wm^{-2}K^{-1}$. The U-values of the building walls are 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 computer etc. During the heating season the indoor air temperature was maintained constant at 20 ± 1°C. Balanced mechanical ventilation systems with air-to-air heat recovery, (PARMAIR IIWARI Ex S) were installed into the three test buildings. Full details of the ventilation system can be obtained from the manufacturer*. The air change rate in the buildings was adjusted to 0,5 l/h. Water kept in a container inside every building was continuously heated to provide additional moisture content in the indoor air of 2 g/m^3 in order to simulate the indoor conditions as in a living house. The indoor RH varied between 25.27 and 45.21 % depending on the moisture content in the outdoor air.

Measurements

The study involved various measurements including indoor and outdoor air temperatures, relative humidity, wind speed and direction, solar radiation, building air tightness, infiltration/exfiltration, heat energy used for heating the buildings, and energy used by the ventilation system. 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 being supplied into the room. Similarly, the extract air temperature was monitored at two points just as it leaves the heat exchanger and before being dispatched 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 earth surface 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 (Fasano *at el.* 1998). Uncontrolled air in-/ex-filtration rates were determined by using a 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 gas was then automatically monitored over a period of 3 to 4 days until it reached 0 g/m^3. The average air infiltration flow rates $\overline{Q}$ (h^{-1}), were then calculated by using Eqn. 1 (Etheridge *et al* 1996).

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

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

RESULTS AND DISCUSSION

The air infiltration measurement results are shown in column 2 of Table 1. These results were unreliable for building no. 5. It is believed that this has been caused by the reaction between the tracer gas used (CO_2) and the CO_3 within the concrete wall that might have taken place. It is therefore recommended to use other tracer gases than CO_2 for air infiltration measurements in buildings with walls composed of cement. No correlation was found between the obtained air leakage results and the prevailing wind speed and direction. This suggests that wind speed and direction have no great influence on the infiltration air change rates of buildings that are very airtight.

The energy recovered E_R (kWh), from the extract air for the buildings no. 1, 3, and 5 within a period of two months (Nov. and Dec. 1999) was calculated by using Eqn. 2 and the results are presented in column 5 of Table 1. 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 ventilation air after and before it enters the heat recovery system respectively.

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

TABLE 1
MEASURED AND CALCULATED VALUES FOR INFILTRATION AIR CHANGE RATES, TOTAL VENTILATION ENERGY INPUT, AND ENERGY RECOVERED

1	2	3	4	5
Building No.	Measured infiltration air change rate, Q_{inf} [h^{-1}]	Measured total energy input, E [kWh]	Calculated vent. energy input, E [kWh]	Calculated energy recovered, E_R [kWh]
1	0.12	231.80	183.56	32.535
3	0.23	379.86	206.52	32.637
5	0.53	399.8	237.74	38.279

The total ventilation energy input used to heat the incoming air was computed by using Eqn. 3 where the respective values of air infiltration rate of the buildings were used in place of Q_{inf}. Column 4 of Table1 shows the results of the calculated ventilation energy input.

The measured total energy consumption within the test buildings (see Table 1) includes energy used by the radiators, energy used by computers, and energy used for heating water to provide 2 g/m^3 additional moisture content in the indoor air. The calculated ventilation energy input includes that used to operate the system, which is approx. 64 W per hour. Building no. 5 had the highest calculated ventilation energy input including the recovered energy that is 15 % and 14.7 % higher compared to building no. 1 and 3 respectively.

Comparisons between the calculated ventilation energy input values and the calculated energy recovered values (see Table 1) don't make much sense in this case due to the small volume of the buildings. However, if the volumes of the buildings were to be 300 m^3 (max. volume that can be ventilated by the tested system), total energy recovered in two months for the three buildings would have been 2068.72 kWh.

Ventilation heat can be recovered only from the proportion of the air that passes through the heat exchanger. The efficiency of the heat recovery, H_{eff}, was taken as the percentage of heat recovered from the exhaust air that is used to pre-heat the supply air. Assuming H_{eff} of the system to be 60%, the energy input, E (kWh), needed to heat the incoming air in each of the three buildings was calculated by using Eqn. 3 (Liddament 1996). Where, Q_{inf} is the infiltration air change rate (h^{-1}), Q_{mv} is the mechanical ventilation air change rate (h^{-1}), V is the volume of the ventilated space (m^3), n is the total number of ventilating hours, T_{int} and T_{ext} are the

$$E = \left[Q_{\inf}.V + Q_{mv}.V\left(1-\frac{H_{eff}}{100}\right)\right].\rho.C_p.\sum_{i=1}^{n}(T_{\text{int}} - T_{ext})/3600 \qquad (3)$$

hourly average internal and external air temperatures respectively. Eqn. 3 was solved for arbitrary values of Q_{inf} ranging from 0.1 to 2.0 h^{-1} for the three buildings. The E versus Q_{inf} profile for the three buildings is as shown in Figure 1. As demonstrated in Figure 1, an increase in air infiltration is directly proportional to the energy input, which shows that the system's energy efficiency reduces as the air infiltration increases. An increase of 0.1 air change per hour (ach) in infiltration air will reduce the energy efficiency of the system by approximately 11 % depending on the internal and external temperature difference.

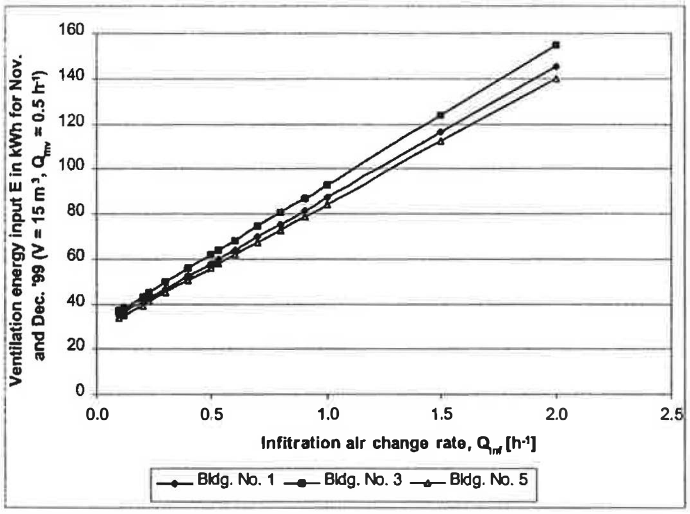

Figure 1: Increase in ventilation energy input as the quantity of air infiltration increases

From Figure 1, it appears that building no. 5 has the lowest ventilation energy input compared to that of building no. 1 and 3. In contrast, the same building had the highest calculated ventilation energy input (refer Table 1). This can be explained by the fact that in Figure 1, all the buildings are considered to be having the same infiltration rates, which is not actually the case. In the figure, the positions of the buildings have rather been determined by the value of their recorded hourly average temperature difference (internal and external) that was summed together over the two months. Building no. 3 had the highest hourly average tempera difference value and hence its first position in Fig. 1, in terms of ventilation energy input. It is importa note however; that, when we consider the recovered energy alone, the higher the temperature differ (internal and external), the higher the quantity of energy recovered. This signifies the importance of recovery devices in severe climates and it will be discussed in details in another paper.

CONCLUSIONS

This study sought to investigate the impacts of the building air tightness and climate on energy efficien a ventilation system with heat recovery. Though the study is on going, initial results have shown clearl the air tightness of the building envelope has a significant impact on energy efficiency of a ventil system. For an air tight building, the wind speed and direction has no great influence on the in-exfiltration air change rates of the building. If the heat exchanger system is kept within the ventilated s it should be well insulated and air tight to prevent extract air from regaining heat from the ventilated s The ventilation air ducts/pipes should also be well insulated to avoid energy loss through the extract air results of this study will be presented during the conference.

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