

COMPUTER MODELLING OF HYBRID VENTILATION FOR COOLING APPLICATION

William Turner^{1,2†}, and Hazim Awbi¹

¹University of Reading, UK
²Monodraught Ltd, Wycombe, UK

ABSTRACT

This paper presents further developments in a new study of a hybrid ventilation system suitable for use in domestic buildings or classrooms. Currently the hybrid system is used solely for providing fresh, warm air. The system consists of a wall-mounted convector unit coupled with an extract fan to draw the air into the convector. Fresh air from outside is tempered by circulating water around an internal heat exchange coil, before it passes into the room. This allows a constant supply of clean, filtered, conditioned air. Previous work involved the development of a computer model to predict air flow rates through the system installed in a small room (Turner & Awbi 2006), and testing the potential for the unit to be used for cooling.

This study attempts to further explore the behaviour of the unit through the use of multi-zone modelling. Three convectors were simulated in a small apartment under a range of varying weather conditions. It was found that the extract fan was the dominant factor governing the air flow through the system, and that prevailing winds could increase the rate of ventilation.

KEYWORDS

Hybrid Ventilation, Multi-zone Modelling.

INTRODUCTION

Throughout the developed World one of the dominant consumptions of energy is the heating and air-conditioning of buildings. Rising energy prices incurred from diminishing fossil fuel resources mean that alternative solutions need to be investigated. One such alternative is the use of renewable energy for providing the heating and cooling required to maintain desirable comfort levels.

Hybrid ventilation is a term used to describe a system that utilises both mechanical and natural ventilation processes. Natural ventilation systems are a cheap and environmentally friendly way to improve indoor air quality. However, usually these systems are let down by a lack of control mechanisms to regulate the amount of delivered ventilation- especially during winter months. By introducing a certain degree of mechanical systems such as control measures, ventilation rates may be regulated and the costs and environmental impacts associated with operating an all year-round air conditioning system avoided (Delsante & Vik 2002, Hielselberg 2002, Van Heemst 2001).

There exists a hybrid ventilation system currently marketed in Europe by a Danish-based company. This is a wall mounted unit that allows outside air to pass through it, driven by pressure differences. These pressure differences occur due to wind pressure against the unit, air temperature differences between the internal and external environments, buoyancy within the room and the use of a ceiling mounted extract fan. A heat exchange coil inside the unit circulates hot water from the building's central heating system. As the external air flows over the heated coil the air is warmed before it enters the room. This warm air then mixes with the internal air in the room via convective processes and is then passed through the exhaust fan. A heat-recovery unit is also available to minimise the heat loss to the outside environment.

The benefit of this system is to provide warm air that is also fresh and thermally conditioned to ventilate the room. Its main employment so far has been within school classrooms in Scandinavia, where the air-tightness of buildings and below-zero outside air temperatures in winter pose ventilation difficulties.

[†] William Turner: Tel: + 44 (0) 118 378 7182
E-mail address: w.j.n.turner@reading.ac.uk

The ventilation unit is available in two sizes. The larger has a maximum airflow of around 100 ls^{-1} and the smaller has a maximum airflow of around 50 ls^{-1} .

Previous work attempted to ascertain the potential for the convector unit to provide a source of cool, fresh air during the summer months in a climate such as that found in the UK. This was achieved by circulating cold water through the heat exchange coil of the unit. This allowed air passing through the unit to be cooled rather than heated. A climatic chamber was built to allow the testing of the unit under controlled conditions. The potential for chilling the supply water to the unit by means of renewable energy is of particular interest. If this could be achieved, while similarly driving the extract fan with renewable energy, then the result would be an environmentally friendly, hybrid ventilation system.

Work outlined in this paper uses computer modelling to try to determine how such a unit would perform in a variety of weather conditions. This should help us to understand the number and type of units that should be installed in a building to provide adequate ventilation under a range of conditions.

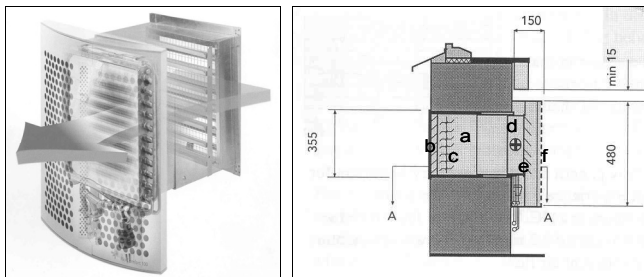


Fig.1. Ventilation unit diagram and cross-section (IKM)

METHOD

The ContamW program by NIST was used to perform the multi-zone modelling. It allows the study of airflow paths through a user defined environment with varying weather and climatic conditions.

A small, single storey apartment in an urban environment was modelled. It consisted of an open plan kitchen and living area, two bedrooms, a bathroom and a corridor linking them all together. The total floor space was 73 m^2 (see figure 2). The roof height was set at 3 m and all four sides of the building are exposed to the weather. A larger unit was placed in the kitchen and living area along with an extract fan to drive the ventilation. A smaller unit was placed in each of the bedrooms. All rooms had windows and doors which could be open or closed. A front door was located in the corridor. The power of the extract fan was chosen to help deliver the minimum required ventilation according to the British Government's 2006 Building Regulations (Part F). They necessitate a minimum ventilation rate of 22 ls^{-1} for a two bedroom dwelling of 73 m^2 . For this reason a 30 ls^{-1} extract fan was included in the model. Cracks in the building envelope are accounted for. These are primarily the external windows and front door.

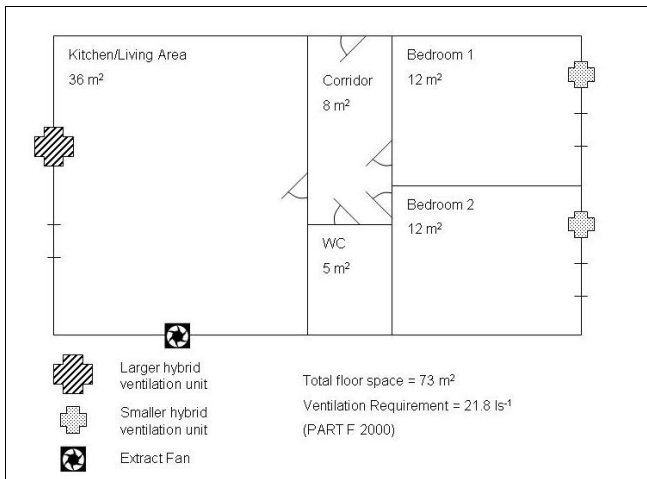


Fig. 2. Plan of modelled apartment

As an urban environment was modelled terrain factors were required to determine the wind strength. A local terrain constant of $c = 0.35$ was used with a wind velocity profile exponent of $a = 0.25$ (see equation 1).

$$\frac{v}{v_r} = cH^a \quad (1)$$

where v is the mean wind speed (ms⁻¹) at height H (m); v_r is the mean wind speed (ms⁻¹) measured at a weather station normally at a height of 10 m above the ground (Awbi 2003).

Wind pressure coefficients (C_p) for the walls were obtained (Swami & Chandra 1987) (see figure 3).

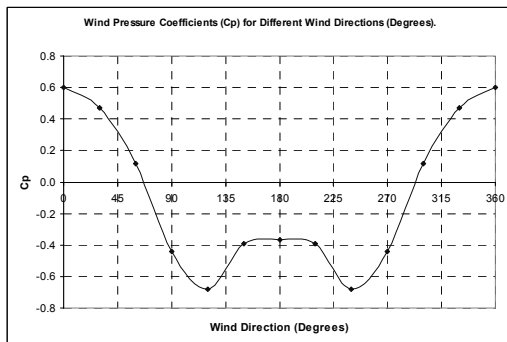


Fig.3. Wind pressure coefficients for low-rise building (Swami & Chandra 1987)

Air capacity curves needed to be input into ContamW so that the behaviour of the ventilation units could be modelled. These were obtained from the manufacturer's literature and show the ventilation rate in litres per second as a function of pressure in Pascals. Two graphs are shown, one for the smaller unit (figure 4) and one for the larger unit (figure 5). The blue lines represent the air capacity for a standard air filter and the red lines represent the use of an EU7 allergy filter.

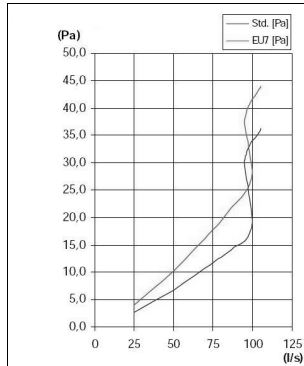
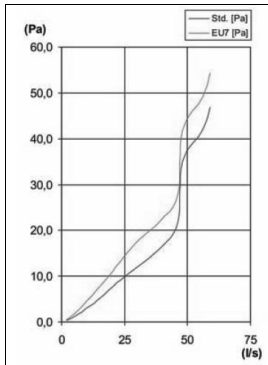


Fig. 4. Smaller unit air capacity curve (IKM) Fig. 5. Larger unit air capacity curve (IKM)

Test Conditions

To test the performance of the ventilation units their behaviour under different weather conditions would need to be analysed. The factors looked at were external ambient air temperature, wind speed and wind direction.

External ambient temperatures were tested over a range from 20 to 30°C with a constant wind velocity of 5 ms⁻¹ from a Northerly direction.

Wind speeds were tested over a range from 0 to 15 ms⁻¹ and at 8 compass directions (N, NE, E etc.) with a constant ambient temperature of 25°C.

For each of the tests the internal temperature inside the building was set to 20°C, absolute pressure was constant at 101.325 kPa, relative humidity was zero and the 30 ls⁻¹ extract fan operational. An additional test was performed with the extract fan switched off. For this the wind velocity was set to 5 ms⁻¹ in a Northerly direction, and an external ambient temperature of 25°C.

RESULTS

Ambient Temperature

The flow rate through the larger unit and two smaller units was plotted as a function of ambient temperature (see fig 5). The two independent flow rates through the smaller units have been combined into one figure as they are on the same side of the building.

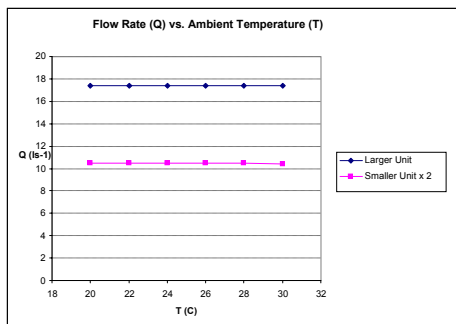


Fig. 6. Air flow rate through convectors with varying external ambient temperature

Wind Speed and Direction

Wind speeds of 0, 5, 10 and 15 ms^{-1} were calculated at 0, 45, 90, 135, 180, 225, 270, 315 and 360°. A wind direction of 0° represents a Northerly wind. Results are displayed in four charts. Up represents North and the numbers are flow rate in litres per second. The broken line is the flow rate for the larger unit and the solid line is for the two smaller units combined.

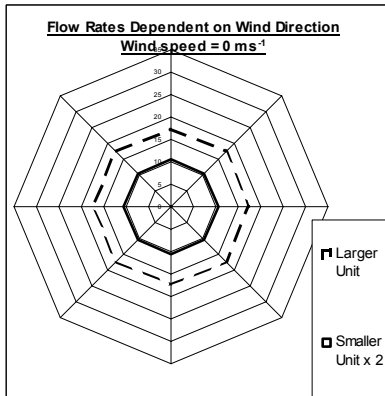


Fig. 7.

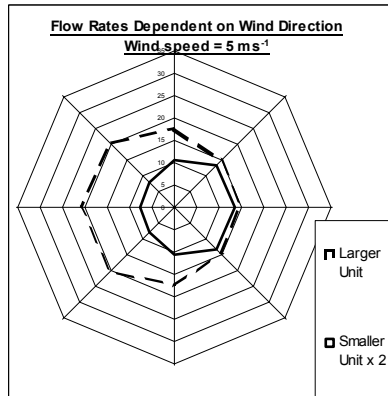


Fig. 8.

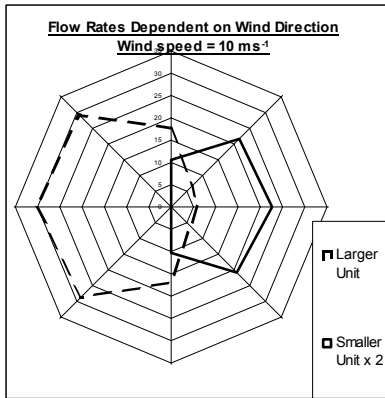


Fig. 9.

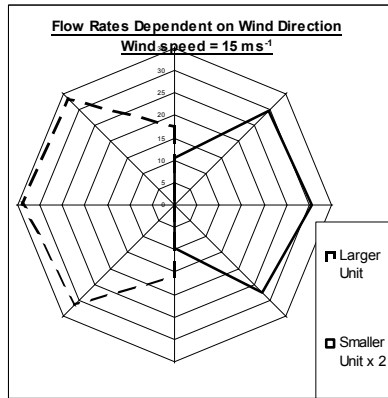


Fig. 10.

Fan Switched Off

With the fan out of operation the air had no feasible exit from the building and the flow rate reduced to near zero.

DISCUSSION

Ambient Temperature

Clearly from figure 6 we can see that the external ambient temperature has very little effect on the flow rate. Near constant air flow rates of 10.5 ls^{-1} for the two smaller units and 17.4 ls^{-1} for the larger unit are seen as the temperature increases from 20 to 30°. The fan was running at a near constant 30 ls^{-1} and it would appear that this had a more dominant influence on the system.

Wind Speed and Direction

Wind velocity had a much greater effect on the flow rates through the convection units. At 0 ms^{-1} wind velocity (figure 7) we see no difference on the flow rates with wind direction as expected. At 5 ms^{-1} (figure 8) we begin to see the wind direction start to influence how the air flow is distributed between the convectors. In this case a Northerly wind (0°) produces a flow rate through the two East facing smaller units of 10.5 ls^{-1} . For an Easterly wind (90°) this increases up to 13.4 ls^{-1} . Likewise, the flow rate through the larger unit increases from 17.4 to 20.6 ls^{-1} as the wind changes from North to West.

Figure 9 shows the effect of the convector's back dampers. Looking at the solid line for the two smaller units for a Westerly wind we see the flow rate drops to zero. This is because the wind strength is high (10 ms^{-1}) and the air coming into the building through the larger unit is trying to force its way back out through the two smaller units. The dampers of the smaller units shut and the air is directed through the fan and other cracks in the building envelope. This is even more evident in figure 10 when we see the same happening for the larger unit with the wind blowing from an Easterly direction.

Fan Switched Off

Switching off the fan meant that the air had no exhaust route from the building. This caused the flow rates through the units to drop to near zero (there was a very small amount driven by air pushing through cracks in the building envelope). Opening one or more of the external windows would promote ventilation once again, though this was highly dependent on the wind speed and strength and negated the filtering and cooling properties of the units.

CONCLUSIONS

External temperatures had little effect on the flow rates through the units as this is dominated by the extract fan. The units should therefore be able to function over a range of locations with varying temperatures and throughout the seasons.

It would appear that choice of fan is vital to a successful ventilation strategy involving the convectors. Under zero wind conditions it is the fan that drives the ventilation through the units. As the strength of the wind increases it plays a more important role. The direction of the wind starts to influence how the air flow is distributed between the convectors. With a prevailing wind direction at a particular site it would be possible to increase the ventilation rate by placing the convectors on a wall that faces the wind.

The internal dampers inside the convection units begin to operate when the wind reaches a high enough speed that the air tries to escape back through the units rather than the fan.

Assuming a relatively air tight building, switching off the fan then denies the air an exit route. For the convectors to continue to admit air into the building windows are required to be open. However, this then negates the cooling and filtering properties of the units. Likewise, closing an internal door that then isolates one of the units from the extract fan will also render the unit redundant. Future work will involve trying to provide a solution to this problem.

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ContamW software: <http://www.bfrl.nist.gov/IAQanalysis/>

IKM website: www.ikm.as