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Operation of Passive Stack Systems in Summer.

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OPERATION OF PASSIVE STACK SYSTEMS IN SUMMER

SUMMARY

The ventilation rate in a building depends on many things, one of which is the air temperature. The air temperature in turn depends in part on the ventilation rate. The effects of this relationship are generally overlooked in both thermal and ventilation models.

To study this effect a model has been developed which integrates the models GAINE and SILONA developed at CSTB. This allows the prediction of the natural ventilation rates caused by the actual temperatures in the building.

It has been used for predicting summertime temperatures and ventilation rates for a range of different ventilation and thermal parameters. In particular the difference between night and daytime ventilation rates and pollutant levels has been examined. The extract flow is found to be more stable at night than in the day.

1) INTRODUCTION

There has been a lot of work done on the ventilation of dwellings in winter. In those conditions there is a need to balance air quality against the desire to minimise heat losses.

In the summer the problems are different. The need for good air quality in all rooms remains, but there is often a problem of overheating. Problems to be overcome include the failure of wind dependent systems in calm weather and occupants concerns about leaving windows open.

For these reasons a study of the effectiveness of natural ventilation in summer was necessary. A system based on a vertical duct or passive stack from the living space was investigated using a computer code. This type of ventilation works by the stack effect which drives ventilation because of the difference in temperature between the air inside and outside the building. It can help to serve rooms which are otherwise hard to ventilate.

The model was produced by linking two existing models developed at CSTB. These were models of the ventilation and thermal performance of a building in isolation from each other. Results are presented for a range of building parameters, to give the significance of each one. The analysis concentrates on the value of extract flow predicted.

2) THE COMPUTER MODEL

MTV is a computer model which combines a ventilation model, GAINE, with a thermal model, SILONA. These two models are representations of different aspects of a building, and both were written at CSTB.

2.1) Description of GAINE

GAINE is a model of ventilation in multi-storey dwellings. Each level is treated as a separate zone, but each is linked to a common ventilation shaft. The model calculates the pressure in every level of the building and the duct, using iterative methods to balance the mass flows in and out of each level.

The equations used in the model are described elsewhere [1], but the model will be described briefly here. It is a normal 'mass balance' model, which assumes the following:

(a) A homogeneous air temperature in each room, perfect mixing
(b) That air is incompressible
(c) Steady state conditions
(d) The air inlet and extract opening are at the same level
(e) Infiltration can be represented by a single opening

Since GAINE did not include open windows I have introduced the equations for flow through a large opening from the model SIREN [1], which are the same as those used in the Building Research Establishment's model BREVENT [2].

2.2) Description of SILONA

SILONA [3] calculates the changes in temperature of a building with time, assuming a simple, fixed ventilation rate. It is a tool for studying heat transfer, but it is incomplete if there is much variation in ventilation rate with temperature.

It models the heat exchange between a single zone house and the outside world, using an electrical analogue to represent walls and windows by resistances and capacitances. Temperatures in the system are represented by voltages in the electrical model.

Heat exchange between inside and out by conduction, radiation and convection are included. The external temperature, solar gain and internal heat gains are needed for each hour. The model steps through time, recalculating the resultant and air temperatures each hour, using the Crank Nicholson scheme to approximate the governing differential equation. Because the thermal mass is represented by a capacitance, the model includes the delay in the temperature change of the building as compared to the air in it.

2.3) Description of MTV

Because of the interaction between ventilation rate and air temperature both of the above models are seen to be inadequate under some conditions. This is most clear when the ventilation rate is dominated by the stack effect, when there is a direct relationship between the air temperature and the flow produced.

The basic modelling method used is the following, known as the 'ping-pong' method. Each model is called in turn for each hour of each day. GAINE calculates the ventilation rate for the current temperatures, wind speed and direction. Then SILONA is called with the current ventilation rate and solar gain information, to predict the internal temperature. Then GAINE is called again with this newly calculated temperature, and recalculates the ventilation rate. This is then used as input for another call to SILONA and so on until the results are consistent.

For this study both models were called three times for each timestep, to ensure that a consistent pair of air temperature and ventilation rate had been calculated. It will be necessary to add a check on convergence to the model for future work. No problems with convergence were observed in this study. In using this method it is assumed that changes in the system will be small for any period of one hour modelled.

Using Meteorological Data

There are data available for a number of sites in France [4], which allow modelling to be done with real rather than assumed data. From the full data set, data have been extracted, for every hour of the test year, for external temperature, wind speed and direction, and solar radiation on a horizontal surface. While the temperature and wind speed are fed directly to the models the other data require some manipulation to be used in the model.

The wind direction affects the pressures on the surfaces of a building. Data from wind tunnel tests [5, 6] are used to set pressure coefficients on the surfaces, according to the wind direction. For values between those actually measured the model interpolates linearly on the known data.

The solar input data is given for a horizontal surface and must be converted to give the input to the walls of the house. This depends on the orientation of the wall, the date, time, and latitude of the site. The equations used for this were found in, for example, [7].

Calculating a pollutant level

For low ventilation rates it is not meaningful to compare arithmetic average values of the ventilation rate. This is because a large value for one hour may distort the result. A better idea of the effectiveness of a ventilation system can be seen from the calculation of a pollutant level.

In this model a constant rate of production of pollutant, R (gh^{-1}), is assumed. Assuming perfect mixing, and knowing the air change rate, A (h^{-1}), the total mass, m (g), of pollutant in the room is defined by:

$$dm/dt = R - A.m$$

If A and R are constant for one hour, and M_0 is the mass at the start of the hour, then at a time t (hours):

$$m = (M_0 - R/A).\exp(-A.t) + R.t/A$$

This model is used in MTV to calculate a total mass of pollutant in the room for each hour, assuming a constant production rate.

3) RESULTS FROM THE MODEL

3.1) The standard data

for a one storey, three room building, of floor area 60 m^2.

Data for GAINE

2.5,	Height of ceiling (m)
4,	Length of duct (m)
90,	Flow through air inlet under 10 Pa (m^3h^{-1})
150,	Flow into air outlet under 10 Pa (m^3h^{-1})
30,	Envelope leakage flow under 1 Pa (m^3h^{-1})
0.12,	Diameter of duct (m)
0.2,	Cowl suction coefficient ()

Data for SILONA

120,	Inertia of the room (kgm^{-3})
150.0,	Volume of room (m^3)
12.0, 3.0	Area of North wall, window respectively (m^2)
10.0, 5.0	Area of South wall, window (m^2)
0.5, 5.8	K value for wall, window ($Wm^{-2}K^{-1}$)
0.1, 0.2	Solar factor for wall, window, ()

The K (or U) value is the normal insulation factor for a building component. The solar factor is the proportion of heat from the sun getting through to the room. It is set low for the windows, 0.2, assuming that shutters or blinds would be closed in the day if the windows are left closed. Only the North and South faces of the building are considered in this model.

As well as the solar gains there are additional gains due to the activity of the people in the house. These have peaks at 13 and 20 hours, which correspond to typical peak cooking times.

3.2) Results for the standard data

The standard data as above was used to describe a dwelling, taken to be in Carpentras, in the south of France. The model was run for five months, May-September, to predict whole summer averages. These are shown below, with results predicted from GAINE assuming a constant internal temperature. The average external temperature was 22.8 °C for the day, and 15.0 °C for the night.

	T_{in} (°C)	AC (ach)	Extract Flow (m^3h^{-1})	Pollutant Level (g)	
Day	28.2	0.30	31.8	39.2	
Night	27.7	0.27	36.0	38.3	
Day	20.0	0.24	17.9	57.6	Fixed Internal Temperature
Night	20.0	0.21	24.7	56.9	Fixed Internal Temperature
Day	28.0	0.30	31.0	40.0	Fixed Internal Temperature
Night	28.0	0.28	36.2	39.1	Fixed Internal Temperature

Table 1: Results for the standard case

The considerable differences between the results for an assumed temperature of 20 °C and the full calculation show the value of the model. The average values predicted for a fixed 28 °C are close to the MTV results, but day by day results would be wrong.

The night pollutant level is slightly better than the day value, although the average air change rate is slightly less at night. This shows there is a difference between the averaging methods, and that night ventilation is more stable than day ventilation.

Figure 1 gives the distribution of the predicted extract flows. It shows that the day has a wider spread of values than the night. This is due to the wind speed having both greater variation and higher average values during the day.

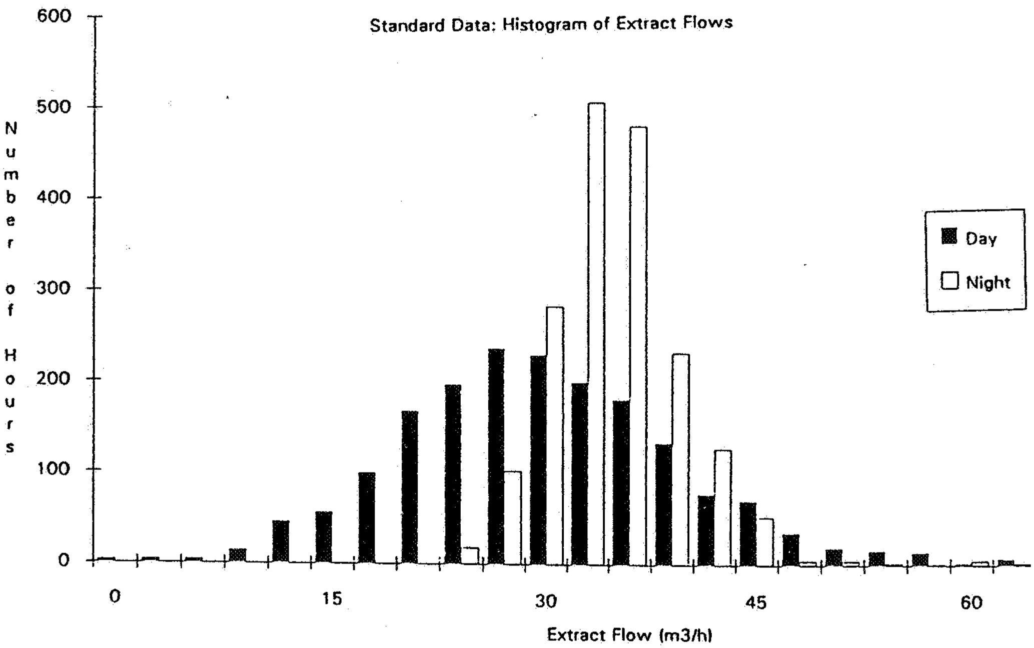

FIGURE 1

However the average of the night extract flows values is higher. This is because the stack effect occurring at night is larger than during the day, due to the lower external temperature. In this case the difference in stack effects is greater than the effect due to the higher daytime wind speeds.

3.3) <u>Sensitivity analysis</u>

The model was run a number of times, changing one parameter at a time to investigate the effect of each. The results are given in table 2. Night is defined as hours 21 to 08, day as 9 to 20.

(a) Inertia

By halving the building's inertia (using 60 (Kgm-3) instead of 120) and hence the thermal mass, the response time of the building temperature is reduced. This results in bigger swings in the internal temperature, but little change in the average temperatures and ventilation rates. In spite of this it is important for thermal comfort because of it's effect on peak temperatures. The inertia would have a bigger effect on the average results in cases where the ventilation rate was better controlled, as for example in g) below.

	T_{in} (°C) Day/Night	AC (ach) Day/Night	Extract Flow (m^3h^{-1}) Day/Night	Pollutant Level (g) Day/Night
Standard	28.2/27.7	0.30/0.27	32/36	39/38
(a) Inertia	28.4/27.5	0.31/0.27	32/36	39/38
(b) Solar Factor	33.5/32.2	0.33/0.30	38/41	34/34
(c) Cowl Coeff	28.3/27.3	0.36/0.29	42/40	36/36
(d) AIVC pc's	28.2/27.6	0.31/0.28	40/39	39/39
(e) Wind Shield	28.6/28.1	0.19/0.24	24/34	52/46
(f) Geographical Location of building				
La Rochelle, Average External temperature 19.2/15.4 °C				
Standard	25.6/25.3	0.42/0.37	47/42	27/29
Trappes, Average External temperature 18.0/13.0 °C				
Standard	24.1/23.8	0.33/0.29	38/38	35/38
(g) Results for windows open part of the time				
Open Day	26.8/26.6	5.82/0.27	42/35	4/29
Open Night	23.4/21.8	0.27/3.26	24/37	33/ 6
Occupant control	24.5/23.2	3.24/1.90	31/36	16/15

Table 2: Results for the sensitivity analysis

(b) Solar factor

Increasing the solar factor for the windows from 0.2 to 0.6 causes a large increase in the predicted internal temperature (of order 5°C). The solar factor is the proportion of solar energy getting into the building. The use of blinds, shutters or other protection reduces this factor and the temperature considerably.

(c) Effect of different cowls

By modelling a cowl with a coefficient of 0.7, instead of the value of 0.2 taken as standard, the effect of a better cowl design can be assessed. As expected the extract rate is increased by this change. The effect of this is larger for daytime, (+30%), than at night, (+10%), because of the higher average wind speeds during the day.

(d) Choice of pressure coefficient data

The standard run used pressure coefficient data from CSTB tests. A comparison was made with data from the AIVC for a similar building [6]. The only significant difference is in the predicted extract flows, which are higher for the AIVC data. The overall ventilation rate is nearly the same, so differences in other flows must balance these increases in extract flow.

(e) Location of house 1: Wind Shielding

The wind speeds used come from exposed sites, so to describe a different site the speed used is multiplied by a wind shield factor. Using a value of 0.5 halves the wind speeds and results in much lower daytime extract flows and ventilation rates. This effect is smaller at night, when the stack effect dominates.

(f) Location of house 2: Geographical

To show the effect of different weather types the standard results were compared with those predicted from data for two other sites. These were La Rochelle, on the Atlantic coast, and Trappes, near Paris [4]. For La Rochelle the wind speeds are higher than for the other sites further inland. As a result the extract flows and ventilation rates are higher and the wind effect dominates the stack effect, with the day extract rate higher than the night value. The results for Trappes show little difference between day and night, suggesting a near balance between wind and stack effects. As the location is less windy than La Rochelle and cooler than Carpentras, the result would be expected to fall between those two.

(g) Open Windows

Because of the high internal temperatures being predicted it is necessary to consider the effect on the ventilation caused by different window opening patterns.

(i) Windows open during the day

Opening windows for the day only results in more ventilation but only slightly lower temperatures, so is not ideal.

(ii) Windows open at night

In hot climates it is not unusual to maximise the ventilation at night, and then minimise it in the day, to keep the internal temperature down. This works because the cooler night air removes heat from the thermal mass, which retains this coolness the following day. This is seen to work well, giving a reduction of 5 to 6 °C, as compared to the standard case.

(iii) Occupant controlled window opening

In an attempt to model window opening behaviour, the following system was used; open for $T_{in} > 25$ °C, close for $T_{in} < 20$ °C. This method results in a reduction in temperature, but is not as effective as simple night time opening.

4) CONCLUSION

A model has been produced which provides a link between a thermal and a ventilation model. It introduces into each of these models the effect of the other, producing a tool for studying natural ventilation in summer.

The importance of introducing a thermal model into a ventilation model has been shown by the better information given by the new model, as compared to a model with a fixed indoor temperature.

A sensitivity analysis for the model has shown that:

. The inertia of the building and the choice of the source of pressure coefficient data does not greatly affect the results.
. The solar factor is a key parameter for the internal temperature, and must therefore be chosen carefully.
. The choice of cowl coefficient and the level of wind shielding used have a significant effect on the ventilation rate when it is dominated by the wind.
. The geographical location of the building is important.

Day flow rates have been seen to vary more than night flows, reflecting the larger variation and average size of wind speeds occurring. Apart from at La Rochelle, where the wind speeds are high, the night time ventilation rate is dominated by the stack effect. As a result, ventilation by vertical duct is seen to be more effective at night than during the day.

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