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THE USE OF PASSIVE SOLAR GAINS FOR THE PRE-HEATING OF VENTILATION AIR IN HOUSING

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SUMMARY

This paper describes the content and preliminary results of a study funded by the UK Department of Energy and administered by the Energy Technology Support Unit. The study is concerned to increase the performance of passive solar systems, mainly in housing, by direct coupling of ventilation heat load and solar gains.

1.0 INTRODUCTION

It is well established that the absolute performance of a passive solar system is sensitive to the size of the heating load. It is also clear that, as buildings become better insulated, so the ventilation heat loss (which in the absence of heat recovery, has a lower limiting value), becommes the major part. For example, a semi-detached house of area 100 m^2 with walls and roof U value .4, and double glazing, will have a fabric loss of about 110 W/°C. At 1 ac/h the ventilation loss will be about 85 W/°C. The study described here is concerned with the delibrate linking of the ventilation load with the passive solar gains.

The ventilation load has two important characteristics which make this approach is very promising. Firstly, unlike heat loss through the fabric, the ventilation load can be very local. If we consider a hypothetical (and ideal) case where all the ventilation air is drawn in through a single apperture, then the heating load will occur at this aperture, i.e. where the cool air enters the heated room.

Ideally, we would then design our building so that this position of maximum ventilation load coincides with the position where the solar gains are made. This location could be a sunspace or Trombe wall, or a direct gain room.

The second important characteristic is that the temperature threshold of the ventilation load is set by the external air temperature rather than the internal temperature. To illustrate this point consider the operation of a sunspace in a conventional circulation mode. In this case the gains made in the sunspace are conveyed to the heated interior as warm air, where they offset total fabric and ventilation loss. However, if the temperature of the air in the sunspace is less than the temperature of the heated space, the gains cannot be used. This severely limits the number of hours that the passive element will be producing useful energy although there is solar energy available in fig 1.

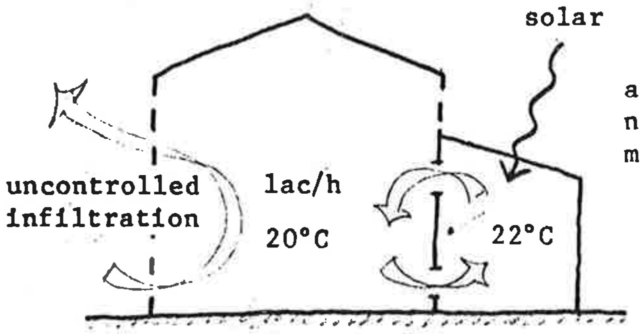
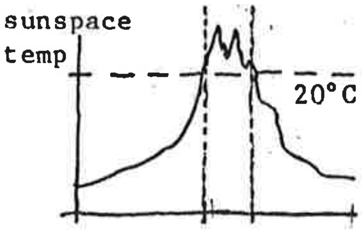


fig 1. circulation mode



threshold effect
limits operation

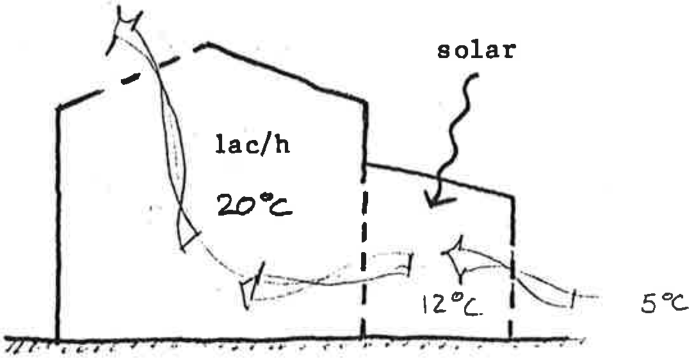


fig 2. vent pre-heat mode no threshold effect

If on the other hand, the infiltration rate of the house has been reduced to such an extent that air has to be deliberately let into the building, and if this air is drawn in via the sunspace, then any temperature increment, however small will be useful. This will greatly increase the 'operational hours' of the system in fig 2.

In particular, in climates with high proportions of diffuse radiation, the threshold effect can prevent operation in the circulation mode. This is further aggrevated by the contraction of the heating season in buildings with low fabric losses.

Some building types have a greater proportion of ventilation load due either to their high density of occupation or activities (such as industrial processes) which produce large quantities of pollutants. Buildings of this type are particularly suited to ventilating pre-heat systems and some examples of these types will be discribed later.

It is easy to accept the advantages of ventilation pre-heat in principle. It is less clear how possible it will be in practice. Several questions are raised - for example to what extent can the point at which ventilation air enters the envelope be controlled by design. Can uncontrolled infiltration be reduced sufficiently to require the specific provision of ventilation within the designers control? Once inside the building, can fresh air be distributed around the building to provide all spaces with sufficient air? How will these flow patterns be influenced by openings between rooms? And of fundamental importance, how will the flow of air be influenced by wind direction?

These questions range between issues of the aerodynamic characteristics of the building to the details of construction technology. This paper reports on the early stages of a study funded by the UK Department of Energy administered by the Energy Technology Support Unit. The study seeks to answer some of the questions above and ultimately come up with design recommendations which will be illustreated by case studies. Another object of the study will be to make proposals for the incorporation of suitable air flow algorithms in SERIRES (SUNCODE) the passive solar model adopted by the UK Department of Energy for the evaluation of buildings. Lastly the study will make proposals for the field trials using real buildings, and test cells operated by the Polytechnic of Central London.

2. Modelling

The author has already reported the encouraging results from a simple modelling exercise, (1). Here, the performance of a conservatory house was compared using varying arrangements of lightweight and heavyweight construction and using two modes of operation ventilation pre-heat and forced circulation with a fan switched by temperature differential. The results showed that the ventilation pre-heat mode was approximately 3 times higher in performance than the circulation mode, and furthermore was relatively insensitive to the disposition of thermal mass.

However, an important assumption had to be made in the modelling. This was that arbitrary fraction of the ventilation air was drawn from the conservatory. Furthermore, this fraction varied only with occupancy pattern and bore no relation to wind speed, direction and temperature difference, the climatic parameters which influence infiltration rates in reality. The encouraging performance was based upon an assumption that 60% of the ventilation air was drawn through the sunspace. The aim of this study is to substantiate that assumption.

2.2 The model

The thermal model FRED, which is described elsewhere (2) has been modified to include a simple airflow model, driven by windspeed, and temperature difference. Most simple infiltration models reported in the literature are for the purpose of overall infiltration rate predictions and do not attempt to model the interzonal air flow. Models which do this, ie those based upon a multi zone resistance networks, tend to be fairly complex. Whilst ultimately such a model may need to be incorporated in a multi zone thermal model, it will greatly enlarge the ovarall model and will call for much greater machine capacity.

In the work described here we have sought to simplify the air flow model as much as possible whilst still retaining sufficient detail to demonstrate the pre-heat mechanism, and to relate to measurable climatic parameters such as windspeed, direction and air temperature and measurable building parameters such as building height and air permiabilities.

The basis of the model is a thermal resistance network representing a three zone building, one unheated zone (sunspace) and two heated zones south zone and north zone respectively. Fig 3. In principle, there is no restriction to the number of nodes used, but for these preliminary studies between 10 and 14 are normally used.

The airflow model is illustrated in fig 4.

MW is the wind-induced transverse air flow and is described by the equation

$$MW = K.C. (1 + d \text{ Cos } 2.\ WD)\ WS$$

where K = the air flow permiability across the building
C = (pressure coeff)$^{\frac{1}{2}}$
d = directionality coefficient
WD = hourly wind direction
WS = hourly wind speed

(This equation is based on the assumption that flow is adequately described by $Q = \text{Const } (dP)^{\frac{1}{2}}$, where dP is pressure difference.

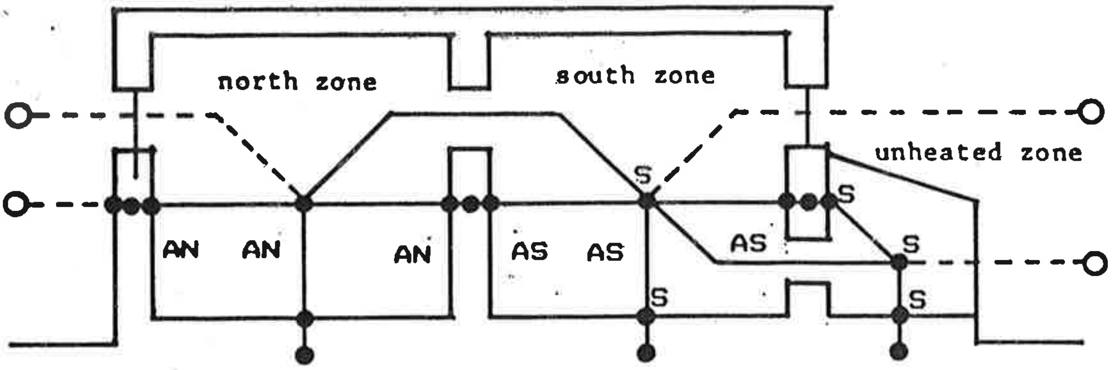
MN and MS are the air flows induced by the stack effect and ME is a transverse flow which occurs when the permialities controlling the stack effect are not equal in the N and S zone.

The stack flows are described by equations of the form

$$MS = \text{Const. } S\ (H\ dT)^{\frac{1}{2}}$$

Where S to the appropriate permiability
H = is the stack height
dT = is the mean temperature difference between inside and out and const. includes air density and mean absolute temperature.

We have the option of introducing a group of terms WN, WS and WE. These flows occur in a pattern similar to the stack induced flows, but are induced by aerodynamic suction through the roof (in practice, usually at the ridge).



S - nodes receiving solar input
AN - nodes receiving auxiliary input north
AS - nodes receiving auxiliary input south

fig 3

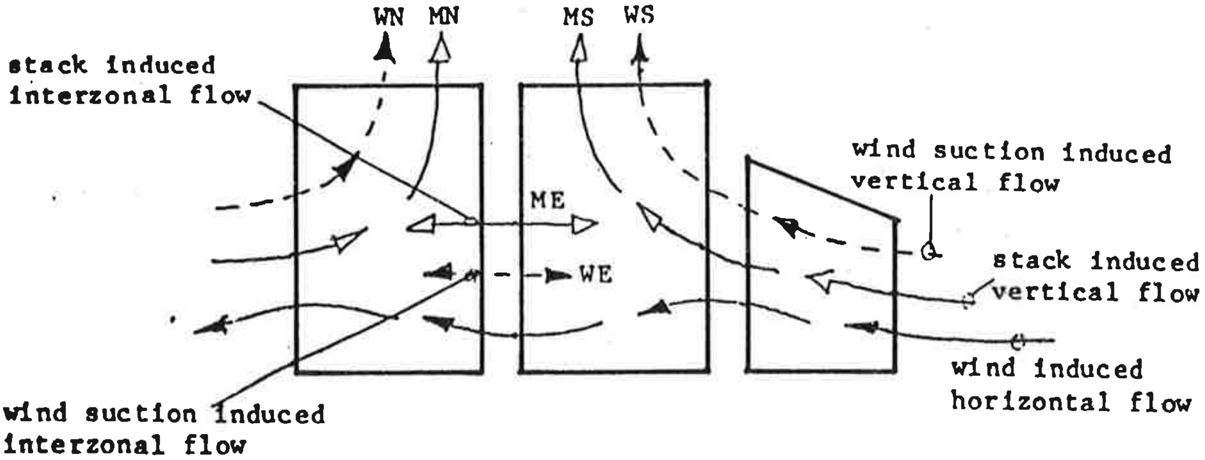
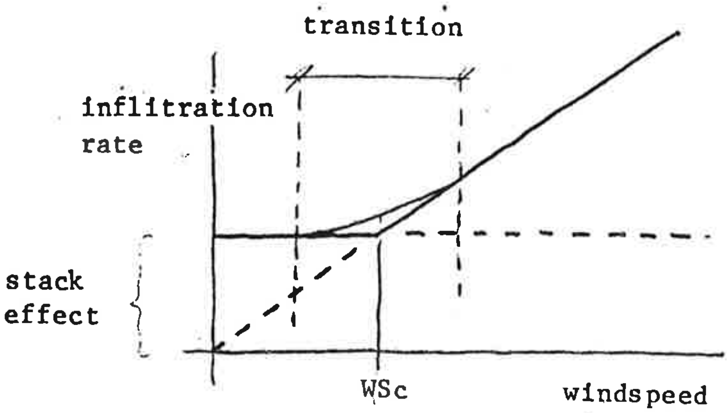


fig 4.



fig(5)

Four permiabilities are ascribed to the envelope. North wall, south wall, north roof and south roof. It is assumed that no resistance to flow occurs within the building. In practice we have adjusted values of permiabilities to give plausible infiltration rates, thus we must consider these permiabilities to be "effective permiabilties".

Many field studies of infiltration have established that at low windspeeds airflows are dominated by stack effect whilst at higher wind speeds it is dominated by wind pressure, and the two effects are not simply adittive. Various methods are adopted to described the transition from one mode to the other, the simplest being a point of transition as illustrated in fig. 5.

This approach must be described as empirical since it is not based upon a model of the physical process. More sophisticated transitions involve interpotation between ½ WSc and 3/2 WSc and we have used a hyperbolic fuction to describe the transition.

The physical model approach is to consider air flows through distributed openings in response to the similaneous pressure differences generated by stack and pressure. This introduces the concept of neutral pressure zone as illustrated in fig 6 where the pressure difference due to stack effect balances that due to wind.

This approach demands a knowledge of the distribution of air flow permiabilities and and pressence coefficients and represents a step up in the level of complication.

The British Gas Ventl (3) is such a model and thus may be used in conjuction with our thermal model. For the initial studies however, the simple empirical approach has been adopted.

2.2 The Building

The hypothetical building which was modelled corresponds to a 95 m^2 three bedroom terraced house insulated to current UK building regulations with the addition of floor insulation. The house has a lean-to conservatory on the south side. The house is modelled as three zones only, sunspace, south zone and north zone.

The building was simulated for a five day sequence using real hourly temperatures and solar radiation for February 1967. The hourly windspeed and direction was selected from a different sequence of days in order to illustrate the windspeed and wind direction dependence. In later use of the model eight months heating seasons of '5-day' months will be used where the days have been selected to give mean values of the four climatic parameters close to the real monthly mean.

now proving to be impossible we are having to use a full 180 days.

For the first run the same permiabilities were ascribed for the north and south parts of the building. The results show that at low windspeeds there is some vent pre-heating irrespective of wind direction, this being due to be stack induced air flow which draws half of the air via the south side. As the windspeed increases so the vent pre-heat contribution becomes direction dependant being largest when the wind is in the south and zero when in the north.

In the second run, the permiabilities have been made assymetic, but arranged to give approximately the same ventilation rate. The north roof permiability has been made four times as great as the south, whilst the south wall permiability has been made four times greater than the north wall. This leads to an increase in vent pre-heating performance. In particular it is now possible to draw the majority of the ventilation air from the south at low windspeeds, under stack effect (fig. 6).

WEATHER

		day 1	day 2	day 3	day 4	day 5
mean ambient temp	degC	4.5	3.1	4.9	3.8	4.9
mean windspeed	m/s	2.3	2.9	5.4	5.8	2.3
ave. wind direction	deg	350	270	226	163	350
total solar (vert.south)	kWh/sqm	1.9	1.0	0.4	2.3	0.5

SYMETRIC PERMIABILITIES

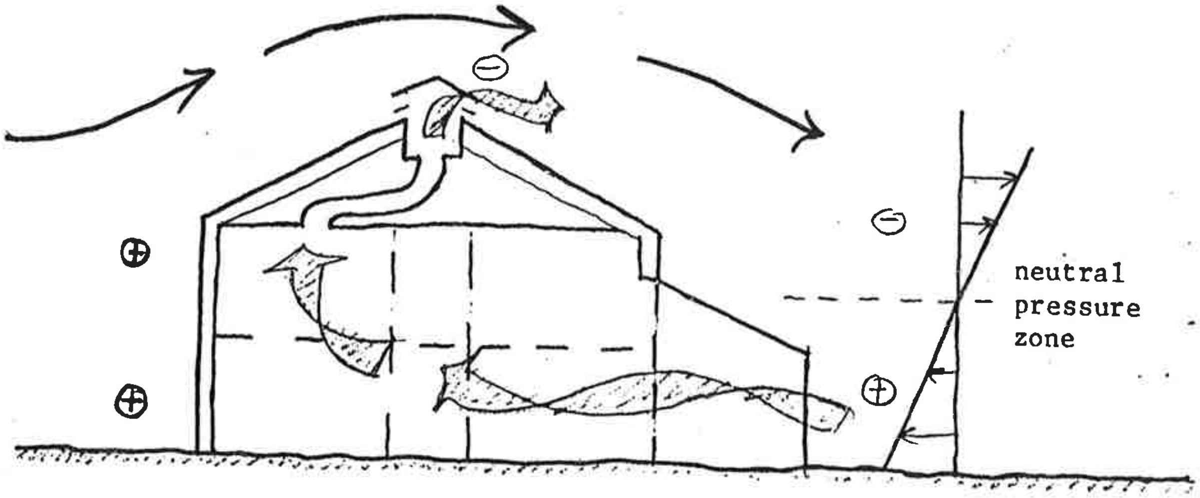
		day 1	day 2	day 3	day 4	day 5
total auxiliary south	kWh	15.4	23.3	35.7	41.5	19.8
total auxiliary north	kWh	26.5	17.7	13.2	12.8	26.3
total auxiliary	kWh	41.9	41.0	48.9	54.3	46.1
total pre-heat	kWh	2.5	4.1	4.4	15.7	1.5
pre-heat fraction	%	5	10	9	29	3
mean infiltration rate	ac/h	0.9	1.1	1.3	1.9	0.9

ASSYMETRIC PERMIABILITIES

		day 1	day 2	day 3	day 4	day 5
total auxiliary south	kWh	17.4	27.0	49.3	63.9	23.9
total auxiliary north	kWh	22.7	18.4	14.6	13.9	23.0
total auxiliary	kWh	40.1	45.4	63.9	77.8	46.9
total pre-heat	kWh	4.0	5.1	6.0	20.0	2.2
pre-heat fraction	%	10	11	10	26	5
mean infiltration rate	ac/h	0.9	1.2	2.0	3.0	0.9

Fig(6)

Note that the airflow model predicted much higher overall vent rates with wind from the south, due to  . We are not sure about this.



Suction at ridge elevates neutral pressure zone creating +ve pressure* on lee side to augement stack effect

fig(7)

*relative

2.3 Conclusions from the modelling

These preliminary modelling results indicate that ventilation pre-heating can be enhanced by the control of premiability distribution. They also show that vent pre-heat can be attained with stack induced ventilation alone.

Since wind induced ventilation is much more variable than stack effect, and since the wind often results in over-ventilation in the winter, it suggests a solution whereby the building is sheltered to such an extent that (except in exceptional high wind conditions), the ventilation remains stack effect dominated.

However, this approach could present problems at the end of the heating season where temperatures differentials are reduced and stack effect may be insufficient to provide adequate ventilation. Hopefully this question will be answered when more extensive modelling work has been completed.

Execessive wind sheltering may also present problems in summer at times of overheating riks, when temperature difficulties must be kept to a minimum and high ventilation rates are desirable.

Secondly, the simple air flow model cannot predict fluctuating air flows, the result of local turbulence which can have a significant effect on flow patterns at low wind speeds

Another simplification which may be significant is the way that the wind pressure coefficient is dealt with In field measurements, pressure coefficients are shown to be dependent on both wind directions and strength, and on position over the building envelope. This variation is dealt with empirically and rather crudely in the model with the cosine function of wind direction and by ascribing the wind suction term causing air flow out through the roof, as distinct from the transverse flow induced by pressure differences across the vertical faces of the building. However, local effects of other buildings, walls, earth mounds and vegetation, causing siginficant variations of pressure coefficient across individual faces of the building could be important and will be considered later in the study.

One possible engineering solution to the variability of windspeed and direction, applicable in a construction where the 'base level' permiability is very low, would be to use wind induced suction at roof level to lower the mean pressure of the building interior. This would have the effect of elevating the neutral pressure zone on the lee side (south) of the building, still allowing the major fraction of ventilation to be drawn in from the south. However, the degree of suction would have to be controlled to take account of windspeed and direction, and temperature. This could be done mechanically or electro mechanically using microprocessor based control logic (fig. 7).

Fan induced ventilation

Another possible solution is to dominate air flow for ventilation by mechanical means, thereby, apparently offering total control. A fan mounted in the wall between a conservataory and the heated zones of the house is in effect a way of guaranteeing positive pressure where and when it is required. Or, mechanical extraction could provide a controllable negative pressure which generate infiltration from the appropriate point.

However, caution must be taken not to use the mechanical ventilation to ventilate over and above what is already adequate natural ventilation. For mechanical ventilation to dominate natural ventilation significantly, would require high levels of envelope air tightness and considerable fan power. In the UK there is some reluctance on the part of many designers to provide mechanical ventilation in houses, partly because this necessitates further commitment to mechanical plant with its associated maintenance, noise, problems etc.

We have adopted a compromise solution in a design study carried out for the UK Department of Energy (4). Here, we have adopted measures to induce passive air flows which enhance vent pre-heat contribution, and have also used the heating systems for which employs an air heated radiant ceiling to mechanicaly draws in pre-heated ventilation air. This design study commenced before the current vent pre-heat study and thus only incorporates preliminary findings.

Another example of this compromise solution is Netley School, Hampshire, UK, which is approaching completion. This school, which was desiigned on the principles described in relation to an earlier school project at Locksheath (5), which was never built, also uses a fan driven heating system which has the option of re-circulation during the warm up period, or drawing fresh air from the conservatory, as occupancy demands.

Applications of ventilation pre-heating are not limited to new building. Many existing buildings have poor insulation levels and may be over ventilated. The addition of a sunspace or a conservatory may serve the triple function of protecting a poorly insulated facade, reducing the excessive ventilation, as well as pre-heating the ventilation actually required. These have already been discussed with particular reference to non domestic buildings by the author and the results of simple steady state analysis given (6,7).

CONCLUSIONS

At this early stage in the study we feel confident that the pattern of airflows into a passive solar building for the purpose of ventilation, has a considerable influence upon the solar performance, over and above the influence of a scalar infiltration rate. We have less confidence in how the necessary control of this air flow can be exercised at a practical level. However, we feel that a combination of manipulating external wind conditions, together with careful control of air permiability distribution, could lead to a significant improvement in passive solar performance.

This applies to indirect systems such as sunspaces, trombe walls and air collectors, as well as direct gain systems.

In existing buildings which may be poorly insulated and over ventilated, ventilations pre-heating may also be able to make significant savings. In non-domestic buildings with high density of occupancy such as schools and offices the high ventilation pre-heating would also be appropriate.

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