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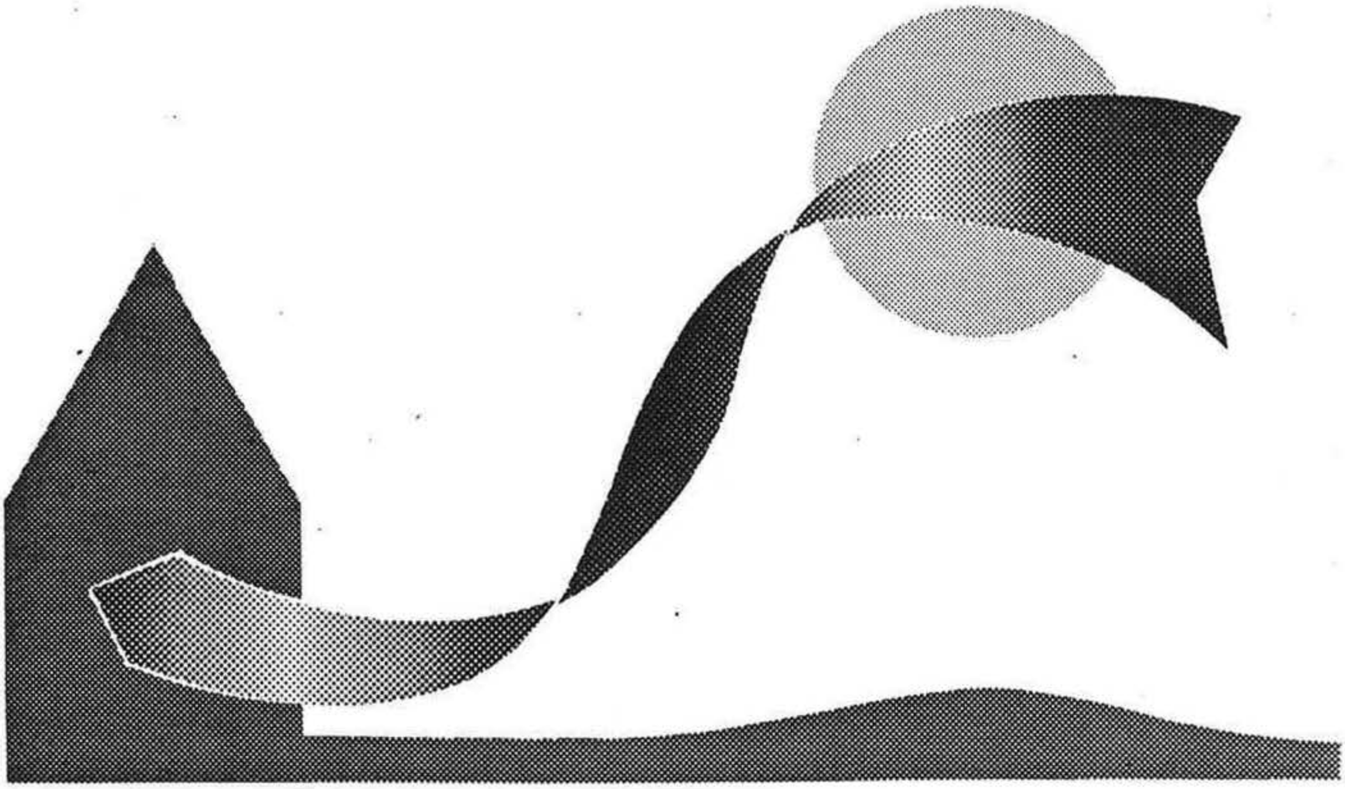
the use of PASSIVE SOLAR GAINS for the PRE-HEATING of VENTILATION AIR in houses



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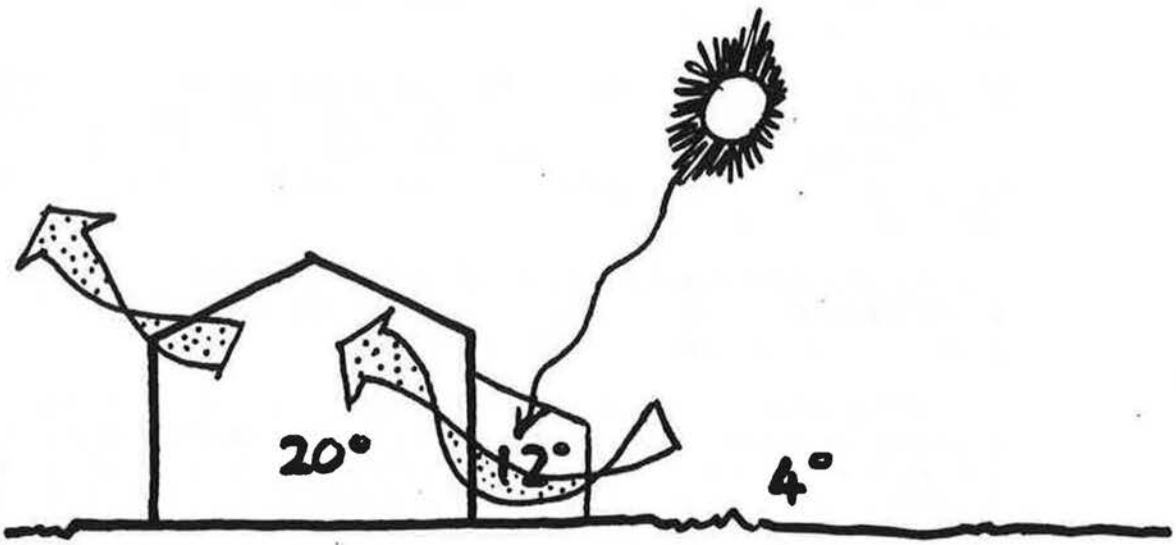
CONCLUSIONS

SUMMARY &

RECOMENDATIONS



The Principles of Solar Ventilation Pre-heating

1.1 CONCLUSIONS

The study establishes the principle of using passive solar gains to offset the heat loss associated with ventilation in houses. The principle is to allow solar gains to pre-heat the ventilation air before entering the heated part of the building, usually through a conservatory. Assuming thermostatic control of the space heating, any increment in temperature above ambient will then reduce the load on the heating system, by reducing the energy required to raise the incoming fresh air to comfort temperature. The process is referred to as Solar Ventilation Pre-heating or SVP.

SVP differs from conventional passive solar systems in that the conduction and ventilation heat loss are dealt with separately. The advantage is that there is no low threshold above which the available solar energy has to rise before it can be utilised, unlike systems such as Trombe walls. In this case unless the air in the collector space is above room temperature, the solar energy cannot be used to any significant degree.

SVP is particularly appropriate to low energy buildings where conductive losses have already been reduced by high levels of insulation, and thus ventilation losses have become the most significant component of heating demand.

Evidence from the simulation work and theoretical considerations carried out in this study suggests that SVP is the main mechanism by which a conservatory can reduce the auxiliary heating of a building, particularly in the buildings with insulation standards at or better than current Building Regulations.

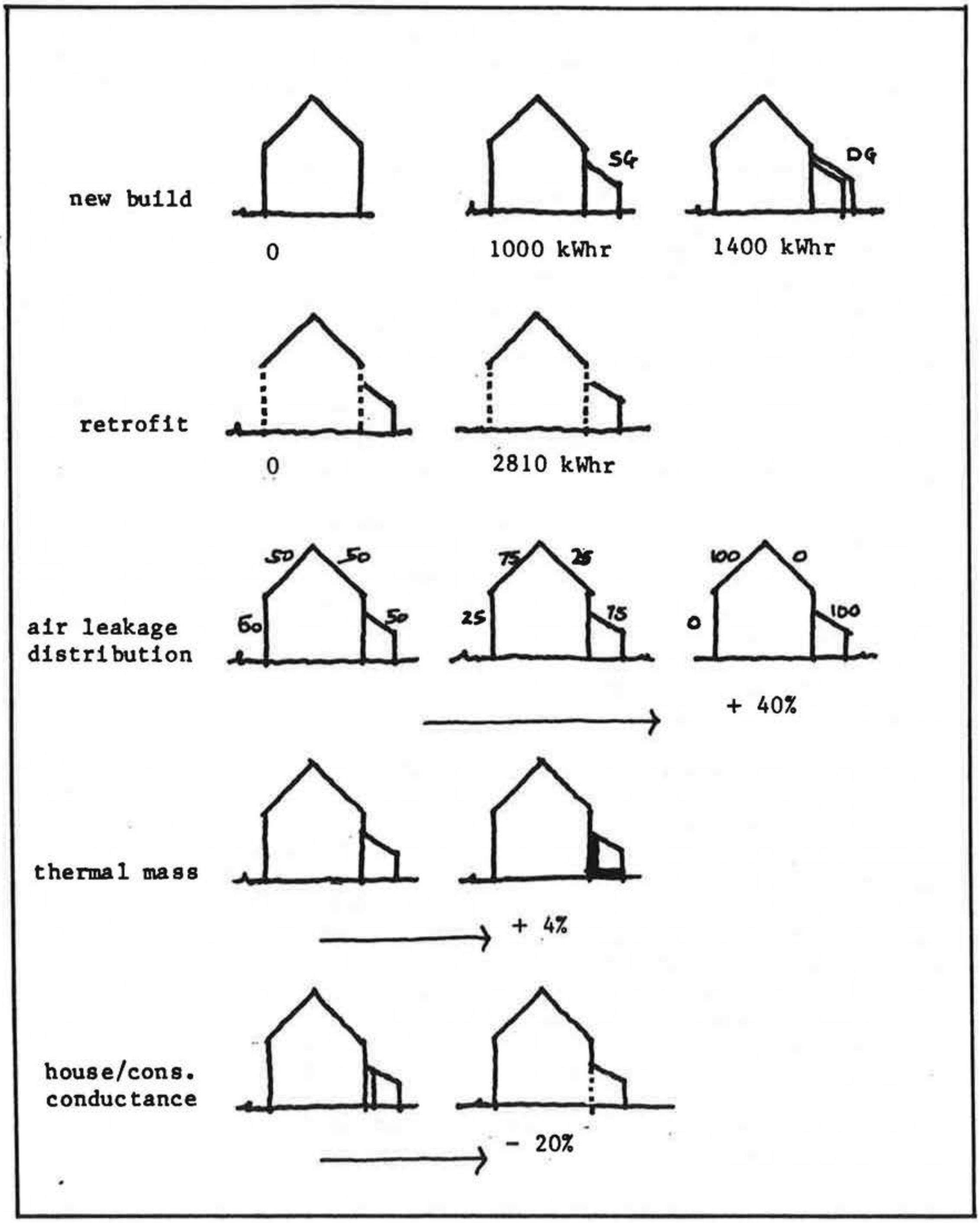
The main conclusions from the simulation are, as follows:-

Typical annual performance of a single glazed conservatory covering 11.6 sqm of wall on a well insulated $95m^2$ terraced house is about 1000 kWhr increasing to about 1400 kWhr for the double glazed conservatory. The house has a total heat loss of 113 W/˚C. This performance figure includes the reduced conduction losses, but the major component is SVP.

The retrofit case, where the house has a total heat loss of 318 W/˚C shows a marked increase in total performance but the increase in SVP peformance is only about 45% roughly corresponding to the increase in average ventilation rate from .9 to 1.4 ac/h (an increase of 55%).

Varying the air-leakage distribution from uniformly distributed to a distribution concentrated on the south wall and north roof increases the SVP performance by about 40%.

The SVP performance and the total performance is found to be relatively insensitive to the thermal mass in the conservatory, although as expected thermal mass shows advantages in limiting extremes of temperature. The results also show that total performance decreases as the conductance between the conservatory and the heated house increases. This indicates that there is no advantage in deliberately leaving the separating wall between the conservatory and house uninsulated.



Global performance of conservatory: summary of results from simulation study

The habitability of the conservatory is indicated by the number of hours spent at a temperature above 13°C. This was 1609 hours for the double glazed conservatory, or 1257 hours for the single glazed conservatory, comparing with 428 hours for the ambient temperatures. This is for a seven month heating season and thus shows, in the best case, that the conservatory is habitable for about 90% the time during the hours of daylight, or 30% of the total time.

Hitherto, conservatory performance figures used in most predictions have not been derived from the use of a model incorporating wind and stack driven airflows. The model used in this study has incorporated air flows, but has not shown a marked increase in conservatory performance. However, the use of such a model has supported earlier performance claims and by drawing attention to the mechanisim by which conservatories must operate may be able to ensure that these theoretical figures will be met in practice.

Since the SVP mechanism appears to be important in the performance of Passive Solar Systems, it was concluded that a passive solar model used for optimisation studies should include an airflow model.

Having established the performance of conservatories by simulation the effect of applying these to the UK stock is considered. Two previous studies, Turrent and Baker 1982, and Penz 1984 applied reference performance figures based upon simpler models, which were in fact fairly close to the performances obtained in this study. Thus this study can be seen to add support to the previous conclusions, including a predicted Reference Potential for passive systems in the UK of 3.7 mtoe by the year 2000.

Following the theoretical analysis and allowing a degree of intuition and conjecture, by considering the practical aspects of design and construction a number of Design Guidelines are derived. These are of course unproven, unlike many design guidelines which evolve by feed-back from the field. They must thus be seen as hypotheses for testing both by practical experiment and further theoretical analysis. Aspects considered include building shape and site layout, and the internal arrangement of rooms and openings. A conclusion that could be drawn from the guidelines as presented is that designing to optimise SVP performance does not demand large departures from existing design trends. Furthermore, the design of the conservatory itself does not incur significant extra cost over conventional conservatories.

This is demonstrated by the design studies for a house incorporating SVP principles.

However, in the evidence from field work on ventilation, and from theoretical considerations, it did emerge that in low energy buildings ventilation design must be given much more consideration than previously. This is to guarantee minimum ventilation rates on an hour by hour and room by room basis, to avoid serious reduction of air quality and the associated problems of condensation, mould growth, odours etc. A strong conclusion of the study was that SVP should be seen as a part of a package of energy conservation measures, in which ventilation design plays an important part. Its implementation should not only save energy but also improve internal air quality and comfort.

1.2 SUMMARY

Introduction and Current Related Work

The introduction describes the principle of SVP and then reviews a number of current related topics. These include monitored field trials at Abertridwr, New Bradwell and Linford. These trials offer important experimental evidence on solar performance and on ventilation.

Heat recovery, the use of the outgoing foul air to pre-heat the cold incoming air, via an air to air heat exchanger, is considered. Trials and theoretical analysis suggests that the equipment costs make cost effectiveness doubtful due to the moderate UK climate.

Work on other devices which produce solar heated air is reviewed. These include air collectors, thermosyphoning air panels (TAPs), and airflow windows. Whilst solar panels and TAPs both may produce solar heated air more efficiently than a conservatory, unlike the conservatory they have the exclusive purpose of energy collection. It follows that their cost effectiveness has to stand by energy saving alone and it has not yet been demonstrated that performance is sufficiently high to attain cost effectiveness.

Airflow through buildings

The main driving forces of natural ventilation are wind pressure and thermal bouyancy (or stack effect). These forces act as pressure differences across the building envelope which in general is leaky or permeable to air flow. One of the problems is that the magnitude of these forces, which are influenced by the temperature difference between inside and outside, windspeed and direction, is very variable. The resulting air flow pattern is further influenced by the distribution of wind and stack pressure over the envelope and the distribution of air permeability.

The basis of SVP, that is, the coincidence of the ventilation heating load with the point at which the solar gains are made, and the subsequent distribution of air to the rooms of the buildings, clearly demands a thorough knowledge of airflow through buildings. This is studied with reference to both theoretical principles and experimental evidence. Several key areas for consideration are identified:-

- external pressure distribution and influence of building shape and adjacent buildings,
- internal pressure and the distribution of air leakage over the envelope,
- the interaction between thermal, and wind pressure induced airflow.

From these considerations it is concluded that the distribution of air leakage over the envelope, and the provision of flow paths within the building, together with other factors such as building shape and site shelter, could be manipulated to optimise SVP performance. This optimisation would set out to encourage an air flow from the south facade of the building, where solar gains could be made, to the rest of the building, irrespective of wind direction, and in conditions where thermal bouyancy (or stack effect) dominated the flow pattern.

Although outside the main topic for investigation, the application of SVP principles to non-domestic buildings was briefly investigated. The general conclusion was that many non-domestic buildings offer considerable scope for SVP for two reasons - (i) the occupancy density is high compared with housing and thus the ventilation requirements greater in proportion, and (ii), generally being larger buildings they may often already have mechanical handling systems which will assist in the operation of SVP. However, the latter will also make heat recovery more viable which will tend to compete with SVP.

Other more specific conclusions include:-

From field studies and theoretical requirements for SVP there is some evidence to suggest that the optimum orientation for a terraced or semi-detached house with blank end walls, is somewhat east of south.

Full mechanical handling of ventilation would assist in both SVP performance and air quality, but would not be justified economically in this climate.

Local mechanical extract in areas of high contamination should be considered as part of a package of measures for SVP and ventilation control.

Local wind sheltering has a significant effect on overall house infiltration rate and may be of importance to SVP in reducing the frequency of wind-dominated air flow conditions.

The simulation results suggest that wind-induced infiltration shows a marked sensitivity to air leakage distribution for a constant overall air leakage (i.e. as measured by pressurisation test).

The SVP mechanism is not limited to conservatory/house systems but can take place in direct gain systems. Since SVP accounts for a significant part of the global performance, detailed passive solar models should include some kind of airflow model. The level of detail required is not yet apparent.

If whole house leakage cannot be reduced to a low level, necessitating purpose provided inlets, a larger conservatory will perform better since it will intercept a greater proportion of the incidental flow paths.

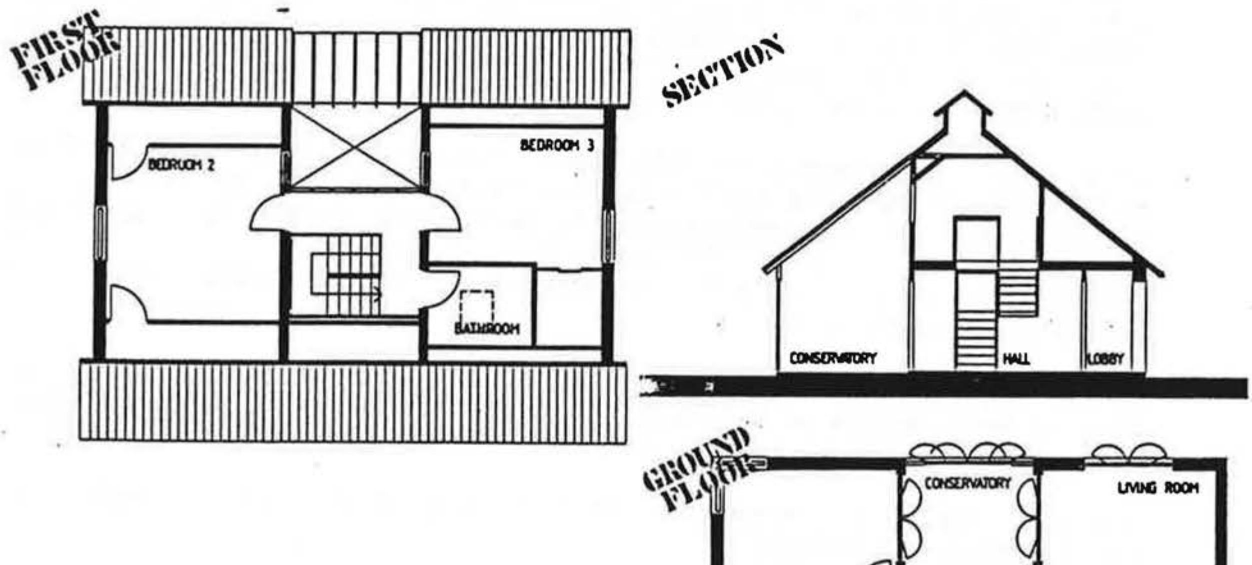
A number of building components which may be of use in the design of SVP houses are available already. These include self-regulating (constant flow) air vents, and acoustically isolating vents. Other components are suggested for development, including balanced flue solid fuel stoves and infiltration and solar sensing control systems.

Design tools

By design tools we mean manual or simplified calculation methods not involving simulation, and generally these methods do not include modelling of the physical mechanisms of SVP. Two methods however, do allow for a fixed fraction of ventilation air to be drawn from a conservatory. These are the Methode 5000, the simplified method adopted by the CEC Passive Solar Working Group, and the authors model 'ATRIUM'. Simulation modelling could be used to add suport to the performance predicted by these design tools.

Design studies

To make a small step in "testing" the Design Guidelines, a number of Design Studies were carried out in three categories - (i) new build where consideration for SVP is allowed to have maximum influence, (ii) new build where the departure from conventional design is minimal, and (iii) retrofit to a 1930's semi.



1.3 RECOMMENDATIONS

The results of this study suggest that work on SVP should proceed on two fronts.

Firstly, the need for more experimental data on the performance of conservatories specifically designed to operate in SVP mode should be met by field trials. An experimental house designed to SVP principles should be continuously monitored and subjected to shorter intensive investigations. The building would be occupied, but the intrusive nature of the monitoring would necessitate a sympathetic occupant, probably the researchers themselves. The monitoring levels and the building status would thus be similar to the Linford and Peterborough projects.

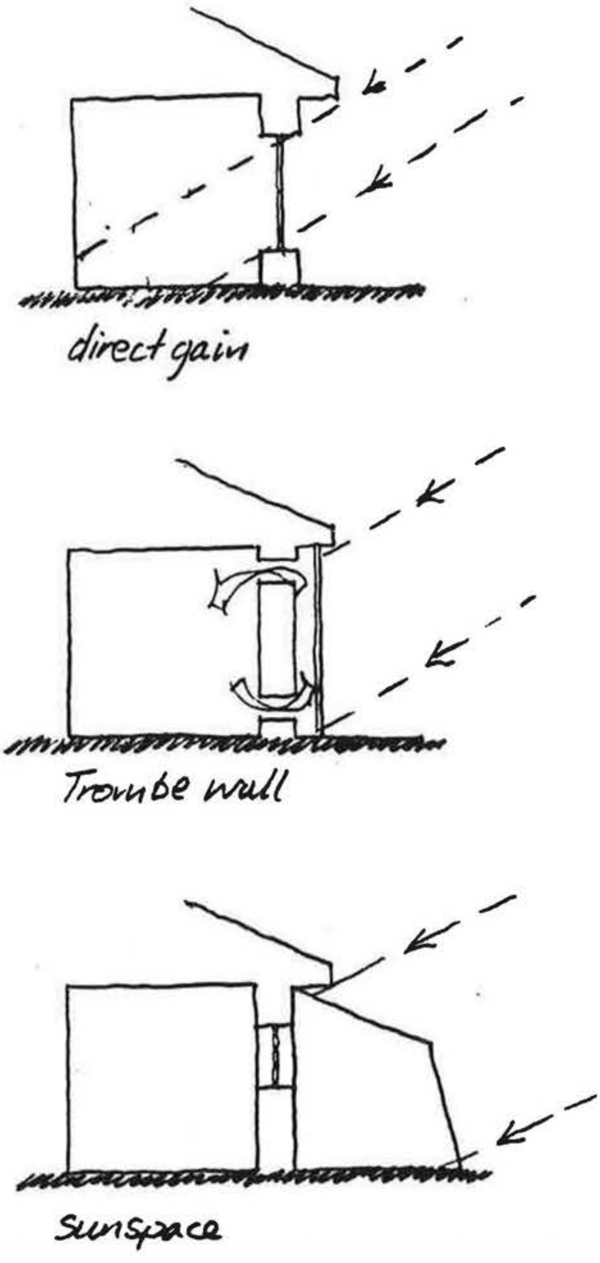
Secondly, a project should be mounted to incorporate an appropriate airflow model into the simulation model currently used for passive solar studies, i.e. SUNCODE. At the same time studies should be made with the existing airflow model incorporated in ESP to ascertain the level of detail required in the SUNCODE model. Once this work is complete a number of parametric studies in SVP could be undertaken at a greater level of detail than in the study here. The parametric studies using the simple model FRED, described in this report, could be continued to investigate other factors such as orientation and the SVP performance in direct gain systems.

Some of the questions primarily about airflow phenomena, may be able to be resolved by using airflow models as distinct from thermal models. For example further investigation by multi zone models such as VENT 1 or LEAKS. Air flow within the conservatory space - questions of stratification etc. could be investigated by 3 dimensional convective models such as PHOENICS.

Design studies should be further developed and assessed using the air flow/thermal models as they become available. Particular aspects which need investigation is partial mechanical handling of air, and controls.

The SVP field should be extended from housing to include commercial and institutional buildings.

2.1 INTRODUCTION



2.1.1 Passive solar systems.

2.1 Introduction

The cause of the heating load of a building is conventionally considered in two parts - the heat loss by conduction through the fabric of the envelope, and the heat convected away by intentional ventilation or uncontrolled infiltration. Passive solar gains have been considered to be capable of making a contribution to the total heating load, but in general no special attention has been paid to separating these two components.

Generally, passive gains have been considered to be made or delivered, to the heated and occupied space. Once in the heated space, the solar gains make a contribution to offset both categories of heat loss outlined above - indeed from inside the heated space the two are virtually indistinguishable due to the complex energy interchanges between air and surfaces. However, for some passive systems, there may be distinct advantages in separating out these two components of heat loss, and directing the solar gains to the ventilation loss.

The ventilation loss can be considered as the difference in heat content between the incoming (cold) air and the outgoing (warm) air. Thus any elevation in temperature, however small, which can be caused to the incoming air will reduce this temperature difference and hence the ventilation heat loss. This study concerns the application of solar energy to carry out this pre-heating, and explores the possible advantages over the more conventional approach to delivering solar gains to the heated space.

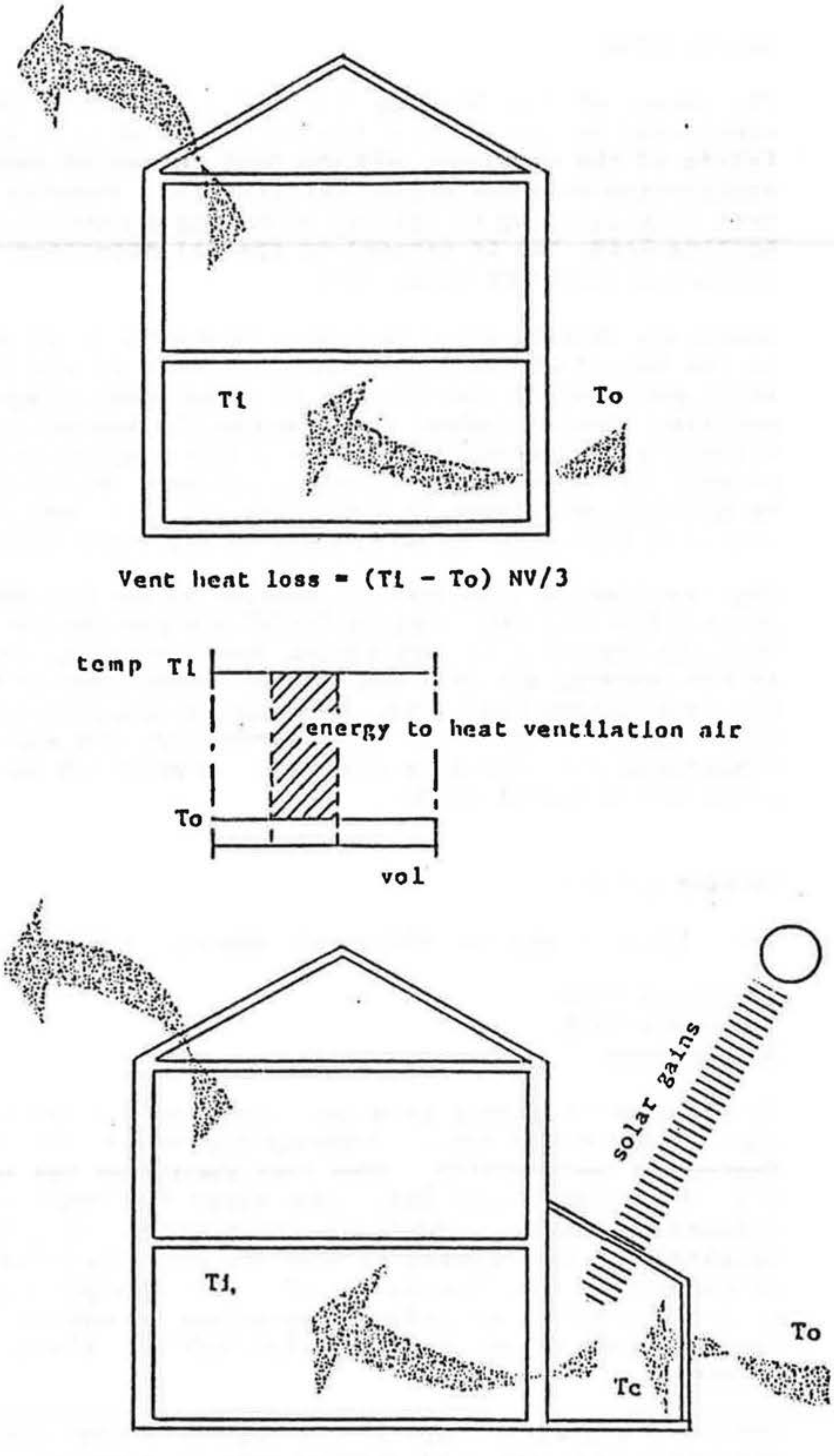
Passive systems

Three kinds of passive system are usually identified (fig. 2.1.1).

1) Direct Gain
2) Trombe Wall
3) Sunspace

In the case of direct gain the conversion of solar radiation takes place in the heated space, predominantly on surfaces which have varying degrees of absorptivity. Once this absorbtion has taken place energy flow to ambient can only take place by long-wave radiation or convection, both of which are inhibited by the glazing. One clear advantage of this system is that the converted radiation is always potentially usable, however small. The absorption of radiation will cause an elevation of surface temperature, irrespective of the original temperature (within realistic limits) i.e. there is no "threshold effect".

However, a disadvantage of the system is that the heated space is separated from the cold outside only by glazing. Although finite gains are still being made during times of low solar radiation, they are not sufficient to offset the losses. Action such as the use of shutters at these times will of course reduce these losses but, unless transparent, they will also eliminate the small gains. Thus there is an "effective threshold" when considering energy balance across the solar element.



2.1.2 The concept of solar ventilation pre-heating.

Indirect systems, Trombe wall and sunspace, are so-called because the solar gains are made in a secondary space, and are then conveyed to the heated space primarily by convection. (It is now almost certain, that for the UK no overall advantage can be gained by deliberately making the conduction of the Trombe wall or Sunspace wall large - the overall losses will always exceed the gains.) Early examples of Trombe walls and súnspaces employed natural convection to drive a circulation of air between the collecting space and the heated room. Later developments led to the use of small fans controlled by a temperature differential switch.

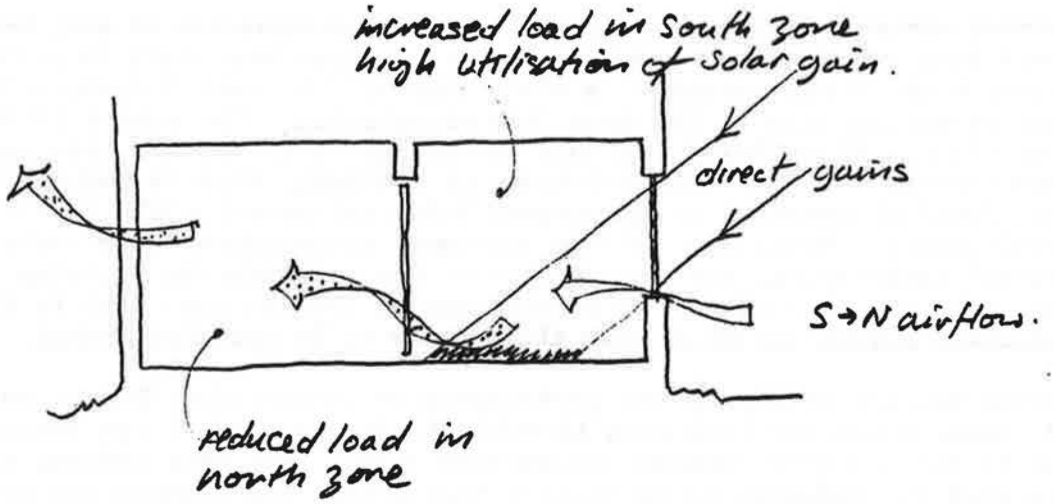
Indirect systems of these types, with a closed circulation of air, have a very distinct "threshold effect". It is clear that only when the temperature in the sunspace is above that of the heated room, will there be any net gain by the room from circulation. Two points follow from this. Firstly, when the building is occupied internal temperatures will be high relative to ambient, thus reducing the likelihood of sunspace temperatures being sufficiently high to yield useful gains. Secondly, if the sunspace temperature does exceed internal temperature, but during part of the day when the building is unoccupied, it is difficult to provide enough thermal mass (and in the approriate place), to carry over these gains to be occupied period.

Various factors affecting the performance of circulating Trombe wall and sunspace systems have been identified. As expected, large thermal mass in the sunspace reduces temperature swing, and thus reduces the time that the temperature is above a high datum, for example the room temperature. Also related to the effect of temperature differentials, it is found that in well insulated buildings (such as current building standards) the "time constant" of the building, (a product of the internal mass and the thermal resistance of the envelope) is great enough for there to be only small reductions in temperature during the unheated periods of the day. This applies even to buildings which are considered to be lightweight and have a fast thermal response to internal gains. Several simulations and some monitoring evidence, which will be referred to later, all point to the fact that in a well insulated building, the net useful convective heat flux from a circulating Trombe wall or sunspace, on an annual basis, is likely to be very small.

Ventilation pre-heating

Accepting that a finite flow of air through the building is an essential part of the environmental system, then if solar gains (or any other form of gain) are made to the air they will be useful whenever there is a heating load, and there will be no threshold temperature below which they are useful (fig. 2.1.2). As buildings become progressively better insulated, so the ventilation load becomes more significant, and thus an appropriate candidate for conservation measures.

Consider an attached sunspace to a well insulated house. The temperature in the daytime, on a cloudy winter day might be say 9°C whilst the external temperature could be 4°C. Any ventilation air drawn from the sunspace will thus have to be heated through only 10°C to reach 19°C rather than through 15°C, thus reducing the ventilation loss by 1/3.



2.1.3 Solar ventilation pre-heating in direct gain system.

Even when there is no radiation at all, the temperature in a sunspace will nearly always be above that of the outside. This is partly due to stored energy, and partly due to heat losses to the sunspace from the heated building. This heat would otherwise be convected away to the environment, but in this case it has a "second chance" to be convected back at a lower but still useful temperature. (It is similar to the principle of "dynamic insulation" currently being investigated in Denmark).

The flow of fresh air into the Trombe wall or sunspace will lower the average temperature in the collecting space. This may be a disadvantage in the case of the sunspace, but it will result in an increase in performance as a solar collector. This is because the heat losses across the glazing are reduced as the temperature differential is reduced.

Solar ventilation pre-heat (SVP) need not only apply to indirect gains. A direct gain system can also benefit from locating the greater part of the ventilation load in the part of the building where the solar gains are made. Since the utilisation of a free gain is always dependent upon the size of the load, it follows that if maximum loads can be concentrated in the solar zone of a building, the greater their utilisation of solar energy will be, (2.1.3).

Air flow control

In general, in domestic buildings of the UK, ventilation air is not handled mechanically, ie ventilation takes place partly by fortuitous infiltration and partly by openable windows and doors. (This is one of the reasons why heat recovery systems have not become popular in domestic buildings.) Air flow control is poor by such ad hoc methods and in most contemporary domestic buildings, little consideration is given to the flow of air from outside to inside, or the flow of air between rooms in the buildings.

Thus although theoretical studies suggest that SVP can make a major contribution, it is not clear how the flow of air from the sunspace to the house can be realised in practice. If infiltration could be reduced until it is significantly below the overall ventilation rate required for moisture and odour control, then some controlled ventilation will be necessary. This controlled fraction is likely to be in the form of kitchen and bathroom extracts, and there would probably be the opportunity to ensure that the make-up air was drawn from the sunspace rather than the outside.

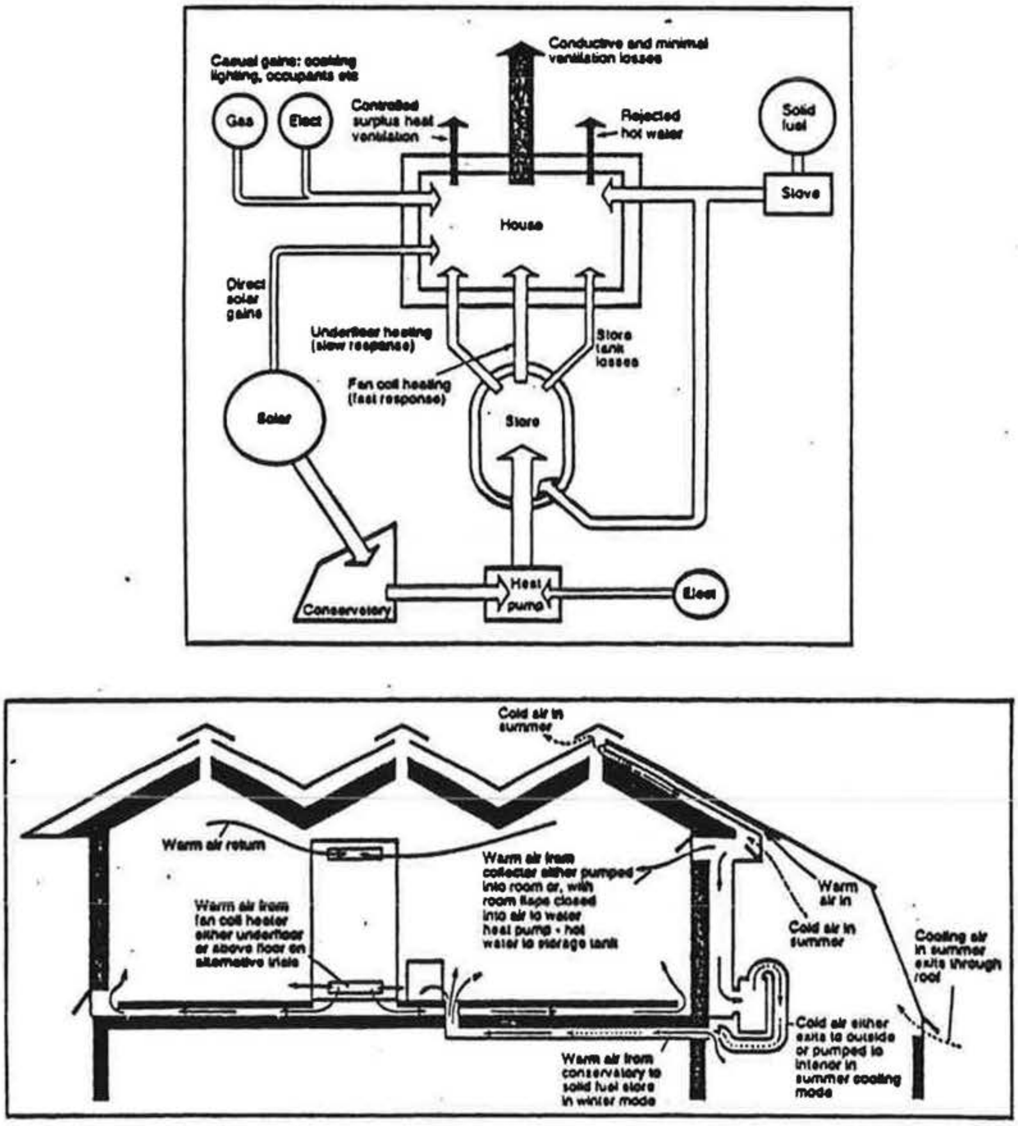
Furthermore, even loosely controlled ventilation such as that through door opening etc., could result in preferential flow from sunspace to house, particularly since the prevailing wind from the S and SW, (predominant in the UK) creates positive pressures on the sunspace side of the house.

Thus we identify the importance of:

a) reducing uncontrolled infiltration to a low value;
b) ensuring that a large fraction of this occurs via the sunspace and
c) ensuring that the remainder of the ventilation air is also drawn from the sunspace in a controlled way.

2.2 CURRENT RELATED WORK

2.2.1 Monitored low energy house at Peterborough



2.2.2 The LECS house. Source Kirk (2)

To attain these, (b and c) in particular), a much greater understanding of air flow behaviour in relation to building configuration and interzone air conductances will be necessary. Although this area has been studied for other reasons, it has not hitherto been a major issue in passive solar buildings.

It is useful to envisage an ideal solution. This would be a totally air tight envelope wih a base level "controlled infiltration" of about 1/2 ac/h attained by non-mechanical means e.g. ridge and stack affect, and regulated by some kind of self-acting constant flow device. This air would all be drawn from the sunspace. A further 1 ac/h (say) would be available for periods of peak contaminant production, e.g. cooking, drying, smoking etc - this would probably be provided by mechanical means, which would have the advantage of being easy to control with timeclocks, humidistats or other detectors. This air also would be drawn from the sunspace.

Evidence from monitored passive systems in the UK (and similar climates) is relatively scarce. However, that which does exist suggests that the contribution from a Trombe wall or sunspace, as part of a well insulated building will be small when used in a natural or forced circulation mode. Direct gain systems are also shown to have their absolute performance limited to a modest level, in highly insulated buildings.

This study sets out to investigate the enhancement of performance of these systems by linking the ventilation loss directly with the solar gains. After reviewing the rather scant evidence from the literature, technical issues concerning airflow and heat transfer are discussed. Parametric studies are then carried out on a hypothetical building, using a thermal simulation model incorporating a simple air flow model. From these results and other evidence a number of design guidelines are proposed which are subsequently used in the production of a number of design studies.