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The Energy Benefits of Sunspaces in Houses with Ventilation Heat Recovery.

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Summary

A heat recovery system reclaims heat from outgoing stale air, supplying it to incoming fresh air. The energy benefit is greatest if it supplies *all* the fresh air to the house and none enters via uncontrolled openings, hence *ventilation* heat recovery (VHR).

A sunspace (or conservatory) attached to a dwelling will almost always be at some temperature above ambient. Heat losses by conduction through the adjacent building fabric and ventilation losses via cracks will be reduced. This effect is modest; however, Baker [1] has proposed that drawing ventilation air from a sunspace can save substantial amounts of energy, provided ventilation can be preferentially drawn from the conservatory rather than through adventitious openings throughout the dwelling.

In a CEC Demonstration Project, the authors are using a variety of mechanical systems and retrofit conservatories to examine the benefits of such systems.

Data is presented which shows that the combination of VHR with sunspaces does not maximise the benefits of either. A variety of strategies is presented which attempt to optimise this combination - they illustrate the flexibility of the simulation model used; but do not succeed in justifying the sunspace/VHR combination. However, the study has shown that energy is available by heat pumping on the VHR exhaust.

Attention is also devoted to sunspace design parameters; glazing type is shown to have a considerable effect on sunspace temperature.

1 Introduction

Attached sunspaces can reduce the energy requirements of the dwelling to which they are attached. There are 3 distinct mechanisms by which this occurs: the sunspace receives direct solar gains; its presence affords "buffer" protection to the adjacent rooms, reducing conductive and convective losses; it pre-heats ventilation air entering the building via the sunspace.

Unfortunately, conservatories can also be accompanied by an *increase* in energy consumption. This is the result of the conservatory being regarded as extra living space and, accordingly, heated.

There are, therefore, 2 major areas of concern: firstly, to determine how to achieve the available energy savings most effectively; secondly, how best to avoid the sunspace actually *increasing* the energy consumption of the building.

Various approaches have been adopted in order to harness the available energy within sunspaces, and a selection of these are now outlined.

A group of council houses in Newham [2] have been equipped with solar roofspaces. This was done when the houses were being refurbished. Roofspace air is delivered directly to the house (see figure 1). The heated air is drawn down through a vertical duct, by means of a fan. The house has a separate heating system; in order to maximise the benefit of the roofspace air, the central heating setpoint is above the roofspace air setpoint. Monitoring revealed the savings due to the roofspace to be approximately 20% of the total energy requirements, though the savings varied considerably according to how conscientious the

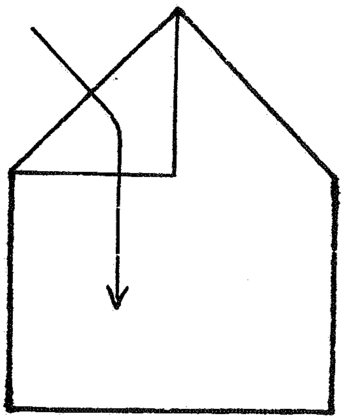

Figure 1 Roofspace air for pre-heat

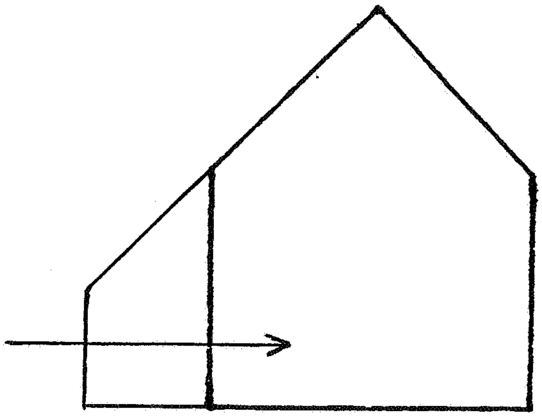

Figure 2 Conservatory air for pre-heat

occupants were, and also whether or not they used the potentially large day-time gains. This system can only use roofspace air advantageously if the roofspace air temperature exceeds that of the house.

Roofspaces have no concurrent amenity value, and are therefore only likely to be economic when roof refurbishment is necessary. A conservatory has amenity value; its contribution is a bonus. This is also its weakness; extracting heat from it reduces this amenity value. Also, it is generally less effective a collector than a roofspace due to its position. However, due to its prevalence this study is primarily concerned with conservatories.

When sunspace air is used directly, benefits can only accrue at times when the conservatory or roofspace temperature exceeds that of the house. However, in the case of tightly sealed dwellings, the heating of ventilation air is a substantial proportion of the energy load. Thus Baker [1] has identified that "the main role for sunspaces attached to well insulated houses is in pre-heating ventilation air". Using sunpaces in this way means that a benefit is gained at all times, because the sunspace always sits at a temperature above ambient.

The single-glazed sunspaces attached to a group of experimental houses in Peterborough [3] reduced the energy consumption by some 15%. The intention was to utilise the air in the sunspace for ventilation pre-heat (see figure 2), as well as anticipating the benefits of buffering. However, zone to zone air movement measurements indicated that much of the available energy could be lost; when the sunspace temperature is high, air is actually drawn from the living space to the sunspace. This suggests a fan is necessary if pre-heated air is to be systematically drawn from sunspace to living area. In these houses the kitchen and bathroom extract fans went some way towards achieving this.

As standards of air-tightness in houses have improved, the heating load due to the ventilation requirement has assumed increasing importance. One effective strategy is to install a warm air heating system with heat recovery. The delivered warm air also constitutes the ventilation to the house; nearly all the fresh air entering the house enters via the heating system.

If there is a sunspace attached to such a tightly sealed house it is possible to draw this fresh air from the sunspace. Air pre-heated in this way will tend to reduce the energy saving potential of the heat recovery unit. The savings from these features are unlikely to be additive, but they may exceed the saving from either feature alone.

A group of well insulated and tightly sealed houses at the Shenley Lodge Estate in Milton Keynes [4] have been constructed with solar roofspaces. Air from the roofspace is used as pre-heat to a Johnson-Starley [5] gas warm-air heating system with heat recovery (see figure 3). By this means solar pre-heat air is used whenever the heating system is operating; the roofspace air need not be warmer than the house air.

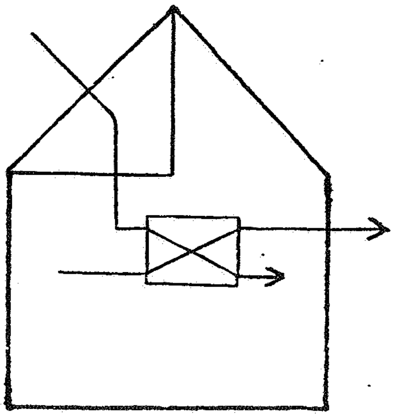

Figure 3 Roofspace air for pre-heat to a VHR

Delivering pre-heated roofspace air directly to the heat recovery unit allows the roofspace air to be used advantageously even when it is cooler than the house temperature, but a different shortcoming is introduced; pre-heated roofspace air is sometimes being cooled down by the outgoing stale air.

This study seeks to determine whether a conservatory, supplying pre-heated air to a VHR system (see figure 4), is capable of supplying useful amounts of heat to the main building. Different systems are examined in an attempt to overcome shortcomings highlighted by previous studies. The results emerging from Shenley Lodge show that the pre-heated sunspace air is sometimes actually *hotter* than the supply air emerging from the heat recovery unit. In order to take full benefit from the energy contained within the sunspace air, it has been suggested that the usual sequence of the air flow should change when this condition applies, so that fresh air first enters the heat recovery unit, then goes to the sunspace, before

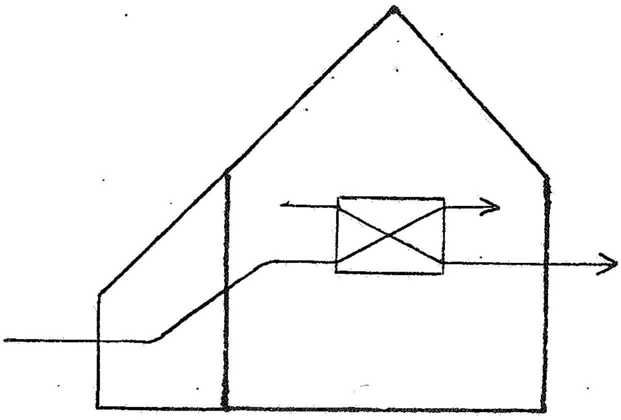

Figure 4 Conservatory air for pre-heat to a VHR

entering the house (see figure 5). When the temperature of the sunspace air falls back below that of the VHR output, the system reverts to the original sequence, air first entering the sunspace and then proceeding to the heat recovery unit.

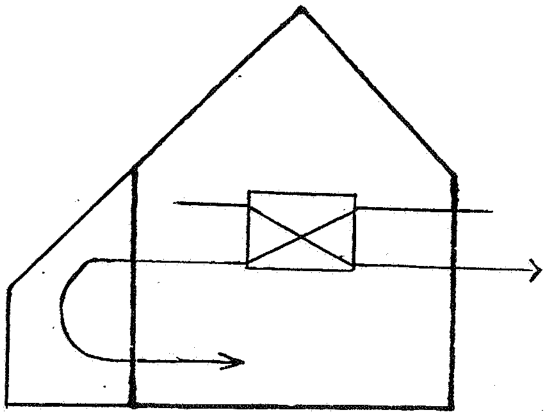

Figure 5 Air stream from VHR to conservatory to house

The impact on conservatory amenity value is also considered; here another issue arises. Sunspaces in the UK are often built to provide extra living space as well as to obtain a "garden in the house" effect. This means they are often heated. The actual construction of the sunspace, and the materials used, are therefore of great importance, whether or not the sunspace is to be used for pre-heated air for the house.

At the Stokkan house in Trondheim [6] the sunspace has been deliberately constructed using high performance glazing, and has been fully integrated with the rest of the house at the design stage. The sunspace is a pleasant area with an outdoor "feel" but with indoor furnishings and comfort expectation. In the relatively cold climate of Trondheim the sunspace is expected to provide worthwhile pre-heat, but at the very coldest times it will be heated. Although such an integrated approach can only be successfully adopted if the house is new-build, the experiences arising from this study can still be heeded for retro-fit applications.

This study is, therefore, also concerned to identify the design factors which influence its impact on the energy consumption of the dwelling.

2 Modelling

The APACHE [7] thermal simulation programme has been widely used throughout this study. APACHE allows a detailed building model to be simulated together with heating plant controlled by almost any control strategy. In particular the modal switching described in section 1 can be simulated, by defining 2 distinct modes of operation. Switching between the modes is controlled according to the setpoint, $(T_{sunspace} - T_{hrec}) = 0$. The temperatures $T_{sunspace}$ and T_{hrec} refer to the sunspace and the heat recovery supply to the house. The modes of operation are as follows:

(i) Air flows first through sunspace, then to the heat recovery unit, when $(T_{sunspace} - T_{hrec}) < 0$,
(ii) Air flows from the heat recovery unit to the sunspace, then to the house warm air ducting system, when $(T_{sunspace} - T_{hrec}) > 0$

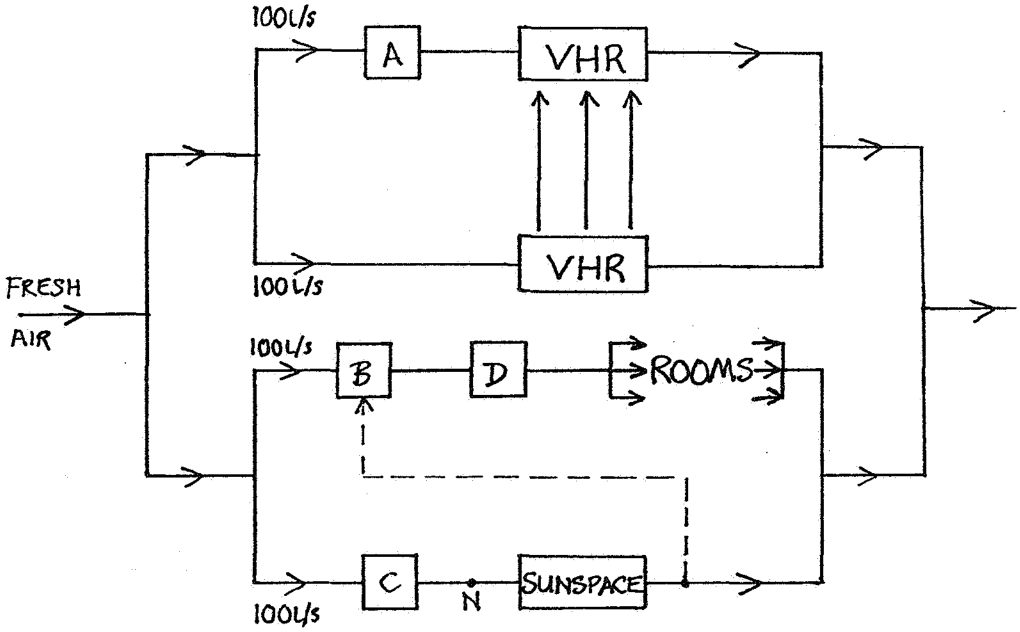

Figure 6 Air flow system diagram for simulating modal switching with APACHE

This situation is represented in APACHE by setting up a system diagram (see figure 6); this includes the air flow, the rooms and the heating components. The modal switching is accomplished by defining dummy heater batteries, which are able to "track" the temperature of any node to which they are referenced. In the first mode air flows into the sunspace from outside, is pre-heated, then enters the VHR unit, before being delivered to the rooms. This mode is in operation when dummy heater battery (A) tracks the temperature of air emerging from the sunspace and when dummy heater battery (B) similarly tracks the temperature at the VHR supply. The air stream, having been successively heated at both sunspace and VHR then proceeds to the rooms. Figure 6 shows the tracking connection for heater battery (B).

When the control condition dictates a change to the second mode, dummy heater batteries (A) and (B) are switched off and (C), tracking the VHR supply, and (D), tracking the sunspace, are activated.

Figure 7, showing temperatures at node (N) in the system, demonstrates the modal switching is occurring as sunspace and heat recovery temperatures cross over.

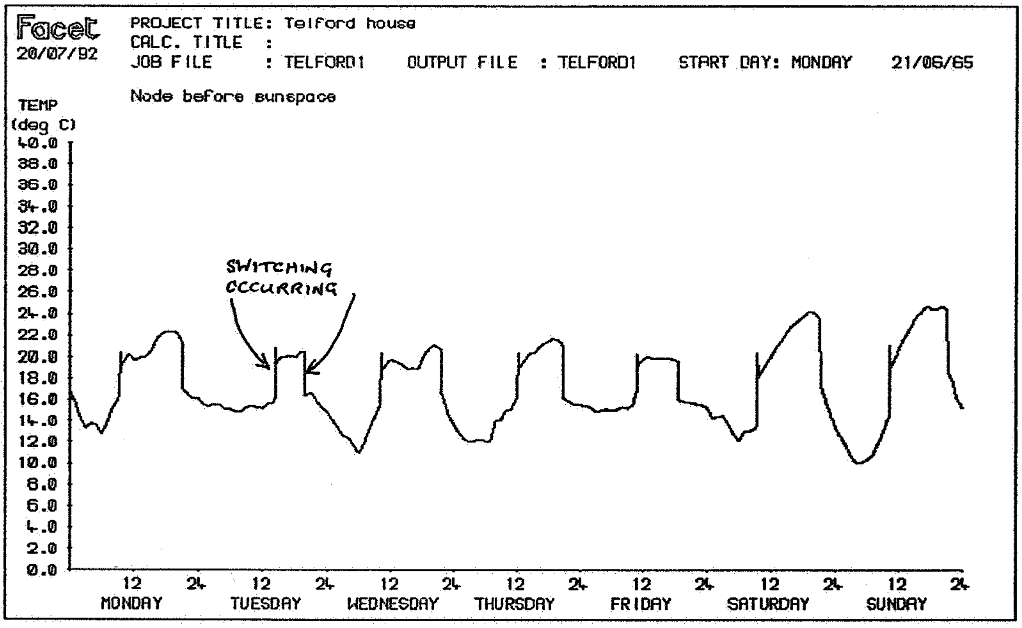

Figure 7 Temperature profile of node (N) showing modal switching

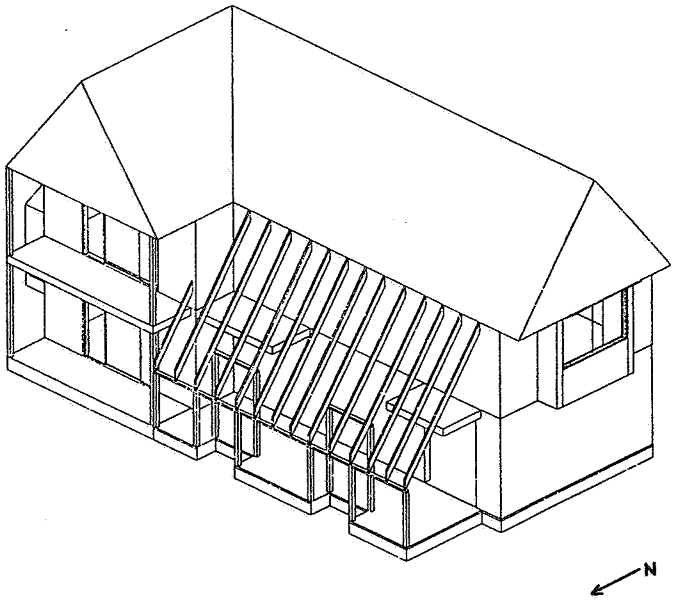

Figure 8 Telford test house

3 Test Houses

3.1 Telford test house

House 1, situated in Telford, is a lightweight, timber frame detached house, with a floor area of 190m^2. Figure 8 shows a projection of this house, produced using AutoCad. Tracer gas tests, using the Bruel & Kjaer [8] photoacoustic gas analyser for detection, were carried out and indicate an air change rate of 0.15, which increases to 0.31 if the solid fuel fire is lit. The sunspace is comparatively large (20m^2 floor area, 67m^3 volume), is single glazed, and is perceived primarily as an exterior zone for rearing young plants, and a buffer to each of the bedrooms.

The sunspace supplies ventilation pre-heat to a Genvex 315 [9] unit. This unit contains a cross-flow heat exchanger and an air-to-air heat pump. In the heat exchanger stale house air, from extracts in the kitchen and bathroom, surrenders heat to the incoming fresh air. The exhaust airstream then flows directly to the evaporator of the heat pump, and if the thermostat situated on the landing indicates a temperature less than 20°C, the heat pump is switched on. The fresh air is then heated further by passing over the condenser of the heat pump, before being ducted to bedrooms and lounge. If the additional heat available from the heat pump is not required, the Genvex operates in heat exchange mode only.

A damper enables fresh air to be drawn directly from outside when the sunspace temperature is likely to fall below a certain temperature, or when the house temperature is too high and requires only ventilation. Prior to installation of the Genvex unit the solid fuel fire was the only source of heat; consequently winter temperatures in the house have frequently been uncomfortably low.

Table 1 shows APACHE simulations conducted for this house.

TABLE 1: SIMULATED ENERGY CONSUMPTION, TELFORD TEST HOUSE

SUNSPACE PRE-HEAT	VHR	MODAL SWITCH	AUX. HEAT	ENERGY CONS. [kWh]	MIN. MONTHLY BEDROOM TEMP [°C]	MIN. MONTHLY SUNSPACE TEMP [°C]
No	No	No	Yes	15163	20.0	9.4
No	Yes	No	Yes	10846	20.0	9.2
Yes	No	No	Yes	13280	20.0	7.7
Yes	Yes	No	Yes	10353	20.0	7.7
Yes	Yes	Yes	Yes	10855	20.0	9.7
No	Yes	No	No	7302	15.9	7.4
Yes	No	No	No	7297	13.1	6.9
Yes	Yes	No	No	7029	16.4	7.2
Yes	Yes	Yes	No	7089	16.4	7.2

Two sets of results appear in the table; the first compares predicted energy consumption for this house if it is to be maintained at or above 20°C; the second set shows the results of simulations conducted for the installed system alone. Following monitoring of the house the simulation model will be fully calibrated; at present it is the *differences* between each of the results presented which are of interest, and these will now be discussed.

The simulations demonstrate that the savings from using sunspace air for ventilation pre-heat (with the VHR unit switched off), and those for using the VHR unit (with the sunspace left in buffer mode) are not additive.

With neither the VHR unit operating nor the sunspace being used for pre-heat, the projected energy consumption is 15163 kWh. Using the sunspace alone reduces this figure by 1883 kWh. Using the VHR unit alone reduces the figure by 4317 kWh. Using both together the reduction is 4810 kWh; if the savings were wholly additive this figure would be 6200 kWh. Given the presence already of the VHR system, the sunspace in pre-heat mode saves a further 493 kWh, which is approximately one quarter of the saving, had the saving been additive.

The saving produced in this way varies seasonally. Using the sunspace for ventilation pre-heat in preference to leaving it as a buffer zone saves nearly 500 kWh (4.8%). The saving varies from only 2% in January (absolute saving of 34kWh) to 8% in April (absolute saving of 59 kWh), and to 14.5% in July (absolute saving of 40kWh). This causes an average reduction in sunspace temperature of up to 2°C, which will reduce amenity value in the winter. This particular sunspace is not used for sitting, and is seen as an area exterior to the house.

When the VHR unit and sunspace pre-heat are used with no auxiliary heating, the overall reduction of energy consumption is about 3.7%, compared to leaving the sunspace simply as a buffer zone. The savings vary from 1.3% (14 kWh) in January to 7.7% (36 kWh) in April and 11.2% (26 kWh) in July. The total predicted energy saving is about 270 kWh. The pre-heat increases the average temperatures in the house by about 0.3°C in the depths of winter and by 0.8°C in the swing seasons. The sunspace temperature is reduced by 1.3°C - 2.0°C.

The greatest savings are during the swing seasons when the outside temperature may be quite low but the sunspace can be the recipient of large solar gains. Although the savings are small, they are being achieved at a very small extra cost, given the presence already of a sunspace. However, the sunspace temperature is lower, so there is a cost in terms of amenity value. The reduction in temperature is not very great, because this sunspace is quite leaky, so that even if air were not being drawn in for subsequent entry to the warm air heating system, it would suffer a substantial infiltration rate.

The anticipated energy benefit in switching modes, is not apparent from these simulations, although the sunspace is maintained at a higher temperature.

It is noticeable that for auxiliary heating to 20°C the simulation shows a significant *increase* in energy consumption. A possible reason for this is that the simple switching (according to a comparison of VHR output and sunspace temperature) may be causing the system to remain in mode 2 (VHR then sunspace) for longer than was originally intended. When the switch to mode 2 occurs fresh air is no longer drawn into the sunspace, so its temperature will rise, as will the temperature difference between the VHR output (now supplied directly by cold, fresh air) and the sunspace. The corollary of this is that when the sunspace temperature begins to fall, the system will remain in mode 2 substantially beyond a time at which it can more usefully operate in mode 1. If modal switching is to be used, its control needs devising very carefully.

An examination of some weekly profiles of temperatures for a typical week in April shows that, when the sunspace air is not being used for pre-heat (figure 9) the sunspace temperature exceeds that of the VHR supply for more than 40 hours, and the temperature difference is as high as 15°C. When the system is operating in sunspace pre-heat mode (figure 10), however, the times for which the sunspace temperature exceeds the VHR output temperature are is reduced by half and the differential is also much less. In general, simulations indicate

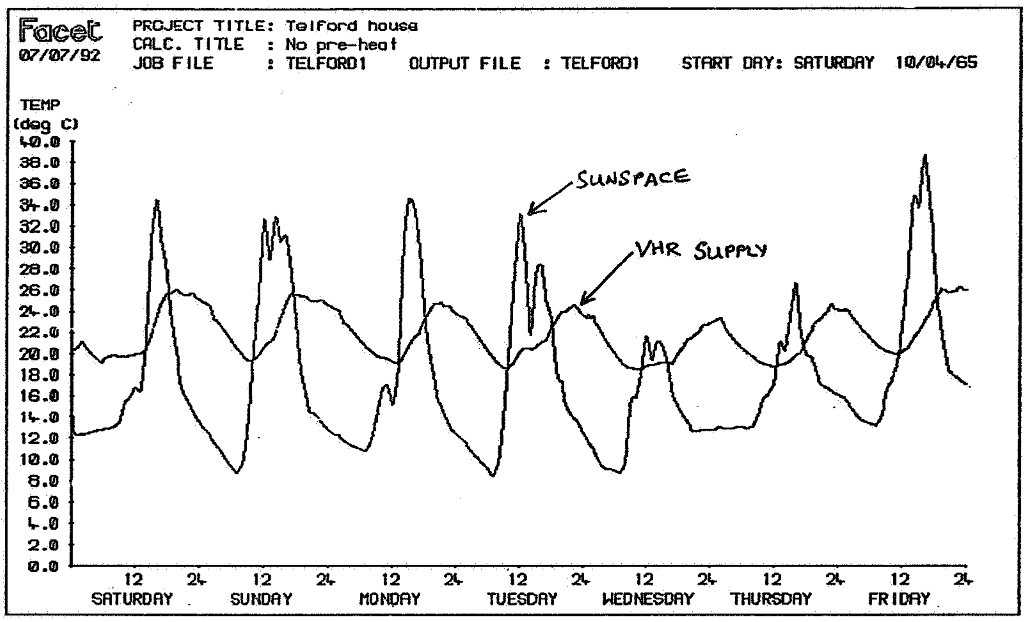

Figure 9 Temperature profile, no pre-heat

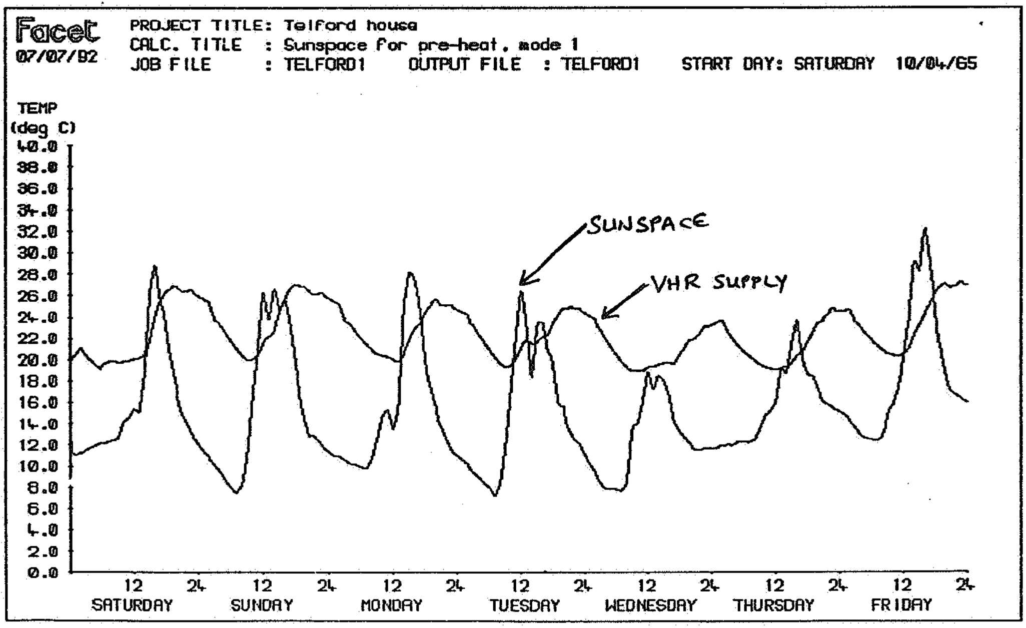

Figure 10 Temperature profile, with pre-heat

that when there is a constant flow of air through the sunspace there are few times when the sunspace temperature significantly exceeds the VHR supply temperature, except when the house temperature is already at a satisfactory level.

Using the sunspace for ventilation pre-heat to this particular house should be worthwhile, but only because the sunspace is not regarded as a sitting area by the occupants. The gains are slight, but they can be achieved at a correspondingly small overcost. The greatest benefit from sunspace ventilation pre-heat is derived when ambient temperature is low, solar radiation high, and heating to the house is required. It is also possible that there are times when the removal of heat from the conservatory not only heats the house but also cools the conservatory to a more comfortable temperature.

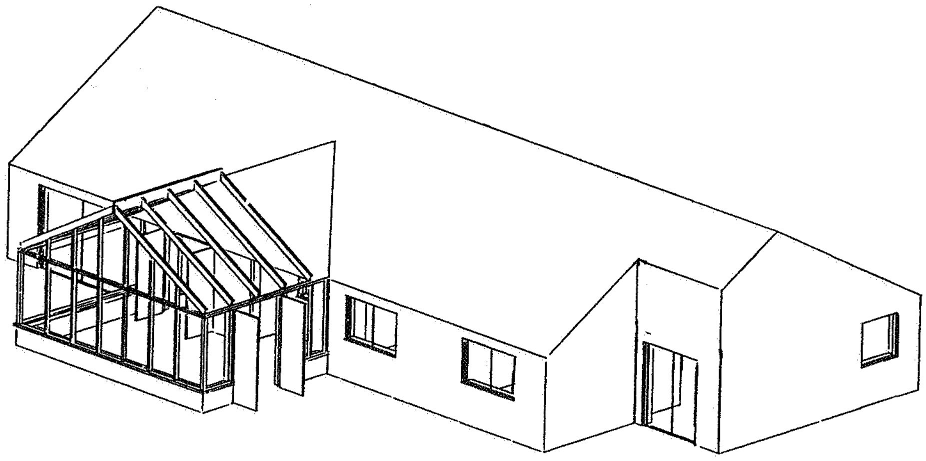

Figure 11 Bath test house, classical shape sunspace

3.2 Bath test house

House 2, situated in Bath, is a large, masonry construction, bungalow. Figure 11 shows an AutoCad projection of this house. It has an air change rate of 0.23, measured using the tracer gas method, together with the photoacoustic gas analyser.

The sunspace supplies ventilation pre-heat to a Johnson-Starley [5] gas warm air central heating system with flue gas heat recovery. The heat recovery unit is supplied partly by recirculation air, with sufficient extra air drawn from ambient or through the sunspace to meet the ventilation requirements of the 2 inhabitants.

The exhaust air from the heat exchanger flows across the evaporator of a heat pump; the compressor supplies heat to water in a closed pipe which runs to, and is embedded within, the sunspace floor. Thus the extra energy available from the heat pump is delivered to a low temperature sink, and helps offset the energy losses from the sunspace due to the pre-heat. The sunspace will not endure such large fluctuations of temperature, and careful control of the times and conditions for which the heat pump is switched on may increase the duration of thermal comfort in the sunspace for a small energy penalty.

An electronically controlled chain mechanism on the windows will be used for cooling. The sunspace is double glazed with a low-e film on one pane; it is perceived as an extra area of living space.

At the design stage, various shapes were considered, each having almost identical floor area and volume (see figures 11,12,13). Simulations indicate that the Wedge shape provides slightly higher winter temperatures (0.6°C warmer than the Upswept version, and 0.7°C warmer than the Classical shape); its major facade is due South whilst the other designs face 20° East of South. There is also slightly less over-heating incurred in the Wedge and Upswept versions, with their "reverse sloping roofs". A comparison of simulated house energy consumption for each sunspace shape reveals a less than 1% overall difference; for reasons of usable floor-space and aesthetic appeal, the Classical shape was chosen.

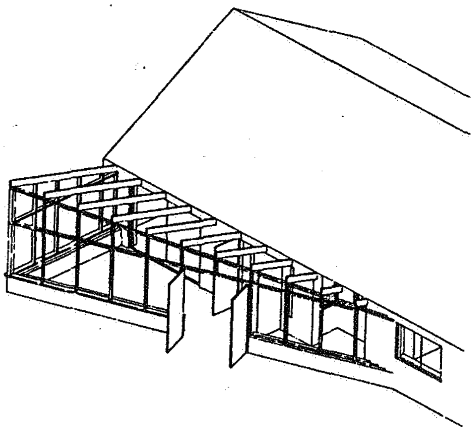

Figure 12 Wedge shape sunspace

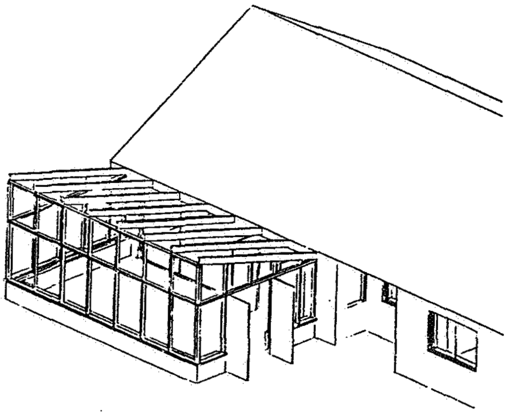

Figure 13 Upswept shape sunspace

Simulations have also been conducted to examine the relative benefits of different glazing types. Table 2 shows the daytime "over-temperatures" (amount by which the sunspace temperature exceeds ambient temperature) for the sunspace at Bath in January.

TABLE 2: SUNSPACE OVER-TEMPERATURES FOR VARIOUS GLAZING OPTIONS

GLAZING TYPE	DAYTIME OVER-TEMPERATURE °C
Single glazing clear float	2°C
Double glazing clear float	5°C
Double with clear float + low-e, air fill	7°C
Double with clear float + low-e, argon fill	8°C
Double with low iron + low-e	8°C

Weekly profiles for early January (figures 14 and 15) show a double glazed low-e coated, tightly sealed sunspace used to supply pre-heat is reduced to a worse thermal environment than a single glazed sunspace not being used. Figure 14 (no pre-heat) shows the double glazed sunspace is about 6°C warmer than the single glazed sunspace. When the double glazed sunspace is used for pre-heat, however, its temperature is reduced to 5°C **lower** than the single glazed sunspace.

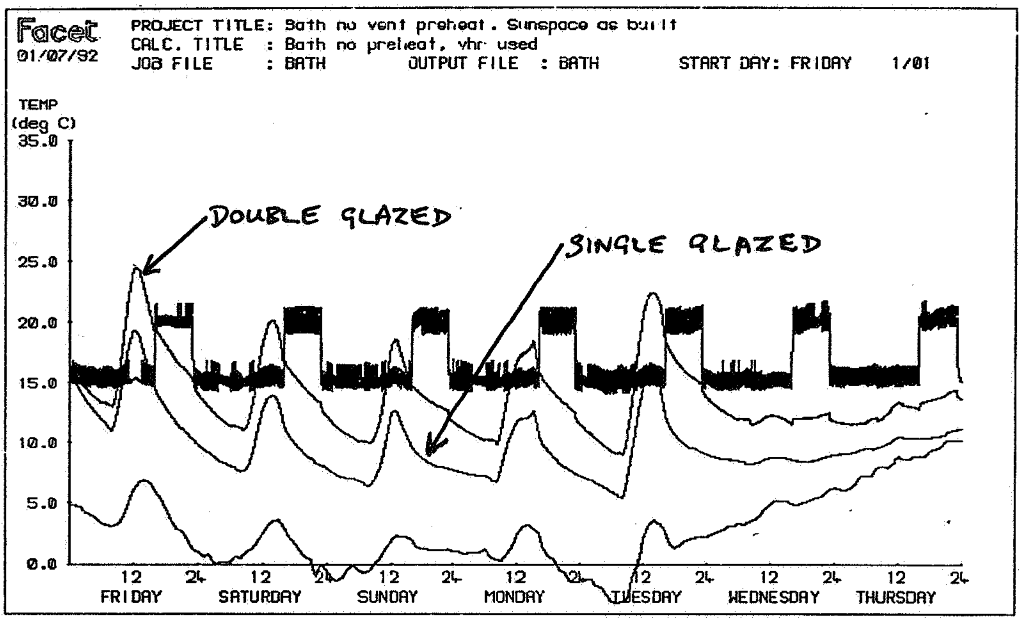

Figure 14 Temperature profile, no pre-heat

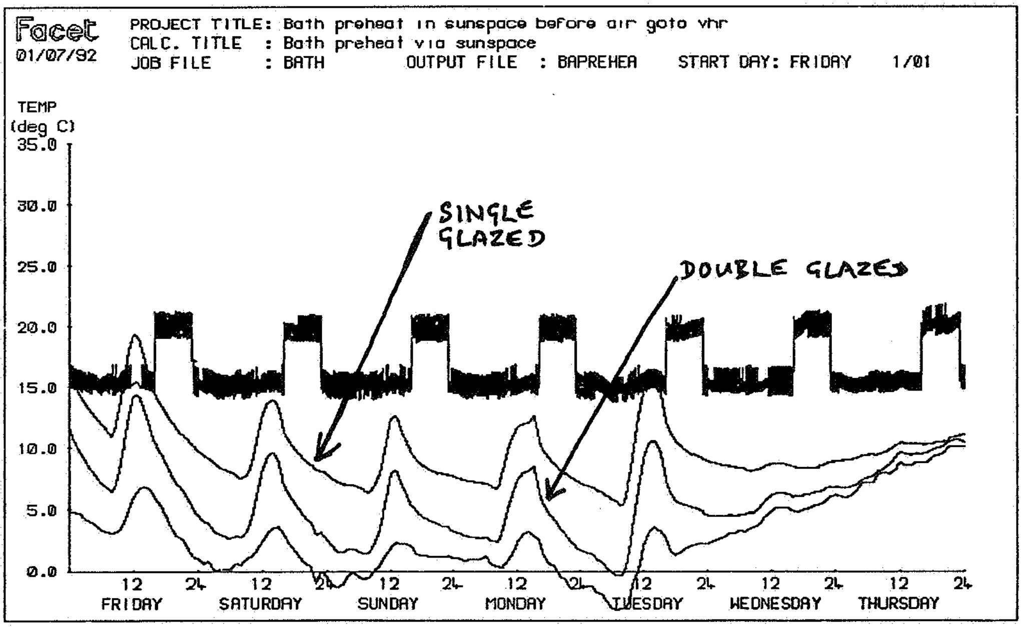

Figure 15 Temperature profile, with pre-heat

The work in progress to identify salient design parameters will continue, so that the influence of, for example, sunspace orientation, and frame and glazing bar construction, will be fully investigated.

4 Conclusion

(i) Simulation results suggest that using sunspace air for ventilation pre-heat to a heat recovery system produces a measurable benefit.

(ii) The simulations suggest that the individual benefits attainable by using sunspace air as ventilation pre-heat, and by using a ventilation heat recovery system are not additive.

(iii) If the sunspace is to be built anyway, and if there is already a warm-air heating system, the overcost to obtain this freely available energy is very small.

(iv) Drawing the air out of the sunspace for pre-heat has an adverse effect on the sunspace environment; the importance of this factor depends on how the owners perceive their sunspace. If it is seen as an area exterior to the house (as in the Telford house where it is used for protection for young plants, general storage area, and active play area), then lowering the temperature may not matter. If the sunspace has been carefully designed to provide a well sealed garden sitting room, then it is not sensible to use it for pre-heat since the temperature within can be lowered to below that of a single glazed sunspace.

(v) If the owners are likely to heat their sunspace, as occurs frequently in UK, then it would not be sensible to extract warm air; indeed, if people demand warm sunspaces, perceiving them as an additional living space, then the sunspace construction, particularly the glazing materials used, and the air-tightness, are matters for utmost care.

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