EuroSun 2012 – WINTER PERFORMANCE OF 2-STOREY SOLAR BUFFER SPACES IN GLASGOW DEMONSTRATION HOUSES

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Abstract

In 2011 the Mackintosh Environmental Architecture Research Unit (MEARU) monitored two demonstration houses each with geometrically identical 2-storey solar buffers. The houses were constructed to the same reasonably high energy-efficiency standards with low air permeability and mechanical ventilation with heat recovery (MVHR) but employing different construction systems – one more heavyweight than the other in terms of indoor thermal response; this situation reversed in the case of respective buffer spaces. To assess the 'true' performance of these dwellings sets of students occupied them for separate 2 week periods during February and December 2011, with identical 'living scripts' in order to reduce habitation variability. The 'living scripts' required heat settings to be consistent, with occupants in February allowed to open windows provided this was recorded. Such interventions between living room and main bedroom and buffer, the latter not linked to the MVHR, were of interest in terms of impact on space heating loads and informed key research questions for buffers in this context. Namely:

a) Would their presence tend to reduce or increase space-heating loads in winter?

b) Would their connection to MVHR be beneficial?

c) How would their performance compare with direct-gain windows to Passivhaus standard?

Keywords: Scotland, winter, sunspace, buffer, ventilation.

1. Introduction

1.1. Context

In an attempt to mitigate the damaging effects of greenhouse gas emissions, international governance has identified the need for the reduction in energy use and the output of CO_2 emissions. In Scotland (the setting for this research) the Government has identified ambitious target reductions in domestic regulated energy use, compared to 2007 technical standards, of 30% by 2010, 60% by 2013 and net zero carbon by 2016/2017 [1]. As domestic energy use represents 30% of total national energy use [2] there can be little doubt over the role this sector can play in helping to achieve the targetted reductions. Moreover, year on year the extent of effect of fuel poverty in Scotland is growing with most recent records showing that 33% of households now experience fuel poverty with 10% in extreme fuel poverty [3]. With a direct correlation identified between the increased prevalence of fuel poverty and the cost of fuel, an obvious need exists to not only improve the energy efficiency of new and existing dwellings but to also maximise the potential of passive systems which require no additional energy, or financial input to operate.

1.2. The Glasgow House Design

Against this context, Scotland's largest housing landlord, Glasgow Housing Association (GHA), undertook to design and construct two exemplar family dwellings which would serve to inform the design and construction of their future housing stock. The design of these dwellings was driven principally by the need to reduce the impact of fuel poverty and the aspiration that space and water heating could be provided for around £100 per annum. There was also a strong desire on the part of GHA to provide this housing in a low-rise, semi-detached or terraced form as opposed to the medium rise scale which predominates the contemporary approach to Scottish urban social housing.

To achieve the project aims, PRP Architects utilised 2 varied construction methodologies with a rendered and insulated clay block structure used in Plot 1 (white building in Figure 1) and a more traditional insulated timber kit with brindle brick cladding in Plot 3 (grey/ blue building in Figure 1). These designs incorporated high thermal performance fabric (design U-value of 0.15W/m^{2}K), high performance glazing (1.2W/m^{2}K), good levels of airtightness (4m^3/m^{2}h), mechanical ventilation with heat recovery (MVHR), high efficiency condensing gas boiler, solar water heating and integrated sunspaces. It should be noted that the orientation of these example buildings was set as a 'convenience' to existing site constraints and, therefore, not optimised for maximium gain for these sunspaces. This allowed testing of these spaces as a 'worst case' scenario orientation as could be experienced in future urban layouts.

Fig. 1. The 'Glasgow House' Development with Sunspaces to Principal Elevation.

1.3. Configuration of Solar Buffers and Heated Space

Respective construction types comprised a 5-apartment northerly half of $2^1/_2$-storey, east-west, semi-detached houses, with the southerly half of each of the two blocks left incomplete for demonstration and teaching purposes. This meant that only the two occupied buffer spaces would have benefited from heat lost from the adjacent heated rooms; thereby raising their temperature higher than the adjacent unoccupied ones and providing an additional pathway for heat loss via the party wall. Each buffer extended across the width of the main living space (approx. 4.0 m), with a clear depth of approx. 1.2 m and a total enclosed volume over two floors of over 25 m^3. The exterior of the buffer space comprised

10.72m^2 of vertical double glazing adjoining 4.87m^2 of glazing on a 45° pitch (both 1.2W/m^{2}K). The inner glazing between buffer and heated rooms has the same specification, but is much smaller in area (U-value 1.2W/m^{2}K; area 6.65 m^2). The glazing and the well-insulated concrete floor (U-value 0.13 W/m^{2}K; area 5.4 m^2) is identical for each construction type, but party walls and walls between buffers and heated accommodation vary. Buffers face 12.3° north of due west, each lined in the same material as the respective building's external finish i.e. Plot 3 having a greater thermal mass and heat buffering capacity.

1.4. Research Context

With the use of low carbon technologies and, significantly, two varied construction systems (one timber frame and one masonry) GHA had considerable interest in identifying both the overall and comparative performance of the dwellings. As MEARU had been involved with the project, in a consultancy role, from design stage they were employed by GHA to undertake the performance evaluations of the dwellings. On completion of this initial period of research, funding was awarded to the project by the Technology Strategy Board allowing further testing and analysis of the dwellings to be undertaken.

2. Research Methodology

2.1. Occupation Scenarios

As the two dwellings effectively represented unoccupied show homes, the evaluation of their true performance required that occupation was undertaken to replicate the dynamic conditions expected of domestic living. To mimic these 'family' conditions, MEARU recruited groups of 4 students to inhabit each of the houses according to defined occupancy guidance scripts. The guidance was designed to ensure that the dwellings were inhabited in accordance with the assumptions made by the UK Government Standard Assessment Procedure (SAP) to allow comparison between the buildings' simulated SAP performance and the actual performance. This process also ensured that, as far as reasonably practicable, a fair assessment could be made between the performance of the two dwellings. For the purposes of this paper the scenarios under consideration will be defined as SC1 and SC2 representing periods of study of 14th to 28th February and 5th to 16th December 2011 respectively.

2.2. Recording Methodology

Over the specified time periods the internal temperature (°C), relative humidity (%) and CO_2 concentration (ppm) were monitored in all apartments, kitchens and utility rooms of both dwellings. Measurements of these parameters were made at 1 minute intervals using Eltek GD-47 transmitters and recorded as a 5 minute mean value on Eltek RX250AL data loggers. In the case of sunspaces and bathrooms, due to the limitations of access to mains power supply,temperature and relative humidity only were monitored using Gemini Tinytag Ultra data loggers with data synchronised to the same time intervals as the Eltek equipment.

To ensure residents adhered to the occupancy guidance, individual diaries were kept recording periods of occupation and activity. As well as this, record sheets were provided at all door and window openings so that any periods of user affected ventilation could be accounted for.

No specific sub metering was used in the project so comparative assessment of energy use was based on mains gas and electricity consumption over the course of the monitoring period.

3. Discussion of Findings

3.1. Observations on Occupancy Periods

Both monitoring periods included archetypal wintry weather, with some falls of snow and icy conditions, as well as high winds and overcast conditions. Mean external temperatures of 5.63°C during SC1 and 3.33°C during SC2 were recorded. During SC1 the main thermostat in the hallway was set to 21°C throughout; while thermostatic radiator valves (TRVs) were at setting 4 during the first week. This led to overheating, particularly in Plot 1, with the consequence that the group of 4 occupants in this house opened windows between the living room and main bedroom and sunspace quite liberally (2481 miutes of window opening throughout monitoring period). On the other hand, with a similar level of overheating the residents in the timber-frame house did this quite frugally (215 minutes). This makes the first week particularly interesting in terms of contrasting approaches with respect to occupant intervention, and the consequent impact on the buffer space and overall energy consumption. In the second week, the TRVs were reduced to setting 2, which resulted in a steadier temperature level in the heated spaces of approximately 21°C and less window opening by the occupants of the blockwork house.

In the December monitoring the main thermostat was set to a lower level – 19°C – and the TRVs were left at setting 2 as for the second week in February. The other key difference in December was that occupants were specifically asked not to open any windows, unless there was a compelling reason in which case this should be meticulously recorded. In other words, the expectation was that rooms would not overheat and would be reliant on MVHR for fresh air, while the buffer function remained uncompromised – i.e. would not also be a supplementary means of regulating comfort whereby heating loads are likely to increase.

3.2. Do the Sunspaces Tend to Reduce or Increase Space-heating Loads in Winter?

In order to respond to this question, the potential for useful solar gains of the spaces must first be assessed and then considered against the fabric arrangement and users thermal control actions. Table 1 presents the useful gains of this glazed volume for the maximum, minimum and mean global radiation measurements across each monitoring period (figures for solar gain of sun spaces have been computed from incident global radiation measurements from Glasgow Bishopton weather station, acknowledging the as constructed, non-optimised orientation).

Date	Value	Global Radiation (kJ/m^2)	Global Radiation (kWh/m^2)	Sunspace Solar Gain (kWh)
28.02.11	Max	9961	2.77	18.9
19.02.11	Min	1075	0.30	2.05
SC1 Duration	Mean	4158	1.16	**7.91**
15.12.11	Max	2597	0.72	4.41
13.12.11	Min	312	0.09	0.55
SC2 Duration	Mean	1294	0.36	**2.21**

Table 1. Calculated Solar Gains for Glasgow House Sunspaces.

The values calculated for solar gain show that in all cases there is some gain to be made via the sunspaces. A whole house fabric heat lost test undertaken in March 2012, on both dwellings, showed that a mean daily input of heat of 31.57kWh and 25.93kWh was required in Plots 1 and 3, respectively, to retain a steady state internal temperature of 25°C. Against these values it can be seen that in a best case scenario, the sunspace could provide up to 30% of this energy but that this is reliant on the capacity of the design to usefully distribute these gains. This, in turn, is dependant on the arrangement of insulation elements, opportunity to move heat (primarily through ventilation), capacity of the fabric to store heat and occupant behaviour.

In the case of the Glasgow House the principal line of envelope insulation is set between the living spaces and the sunspace with only double glazed doors as a means for affecting air movement. This arrangement, therefore, only allows for useful heat gains to be directly transferred between the sunspace and adjacent living room or upper floor bedroom. Moreover, this is reliant on effective occupant action (i.e. opening and closing apertures at exactly the right moment). A review of the fine grain data for SC1 and SC2 (for the time being excluding SC1 P1, where a significant proportion of sunspace heat came from heat loss from the dwelling's living room and bedroom and not simply through solar gain) shows only 2 instances in total where sunspace temperature exceeds that of internal temperature. This fact alone is evident in showing the limited use and potential benefits of effective solar gains on the interior; the benefits are not what they might first appear when referencing only mean values. This fact may also seem to suggest that there are limited benefits of sunspaces in the Scottish climate but more in depth analysis shows that this is not the case.

Figure 2 illustrates the temperature profiles of the two sunspaces through SC1 with the external temperature also shown to provide a baseline. During the first week of this monitoring period the residents of Plot 1 attempted to control the internal temperature of their overly warm dwelling via frequent window opening – particularly from the living room to the adjacent, cooler buffer. This behaviour was confirmed by the window opening logging process, the occupant survey responses collated at the end of the project and also by the temperature profiles of Figures 2 and 3. In both instances the temperature of the sunspace is seen to increase rapidly as a similarly rapid decline is observed in the adjacent Plot 1 living room (Figure 3). This is not exhibited in the week 2 profiles or profiles for Plot 3, where internal heating was more controlled and window opening was not prevalent.

This stress initiated reaction to an overly warm space is commonplace amongst building users and in a recent EPSRC funded study was found to produce a significant energy penalty in respondents who intentionally overheat dwelling interiors to aid internal passive drying of laundry [4]. In real terms this behaviour represents a loss of thermal energy from the main insulation envelope to a thermally weaker zone but it simultaneuosly represents a better situation than would exist without the presence of the sunspace, where window opening to the outside would result in more significant heat loss. Over both monitored periods any ventilation to the sunspace represents environmental control to a volume with a mean temperature of 8.42°C as opposed to ventilating directly to the ambient conditions where the mean temperature was just 4.48°C over the same period. In these circumstances it can be seen that the presence of the sun 'buffer' space is of significant benefit and effectively creates a reduction in space heating load than would otherwise exist with the observed behaviour of occupant affected ventilation. In this guise the buffer is of use as an extended envelope 'reservoir' and has the potential to positively affect extremes of environmental conditions (both for temperature and air quality).

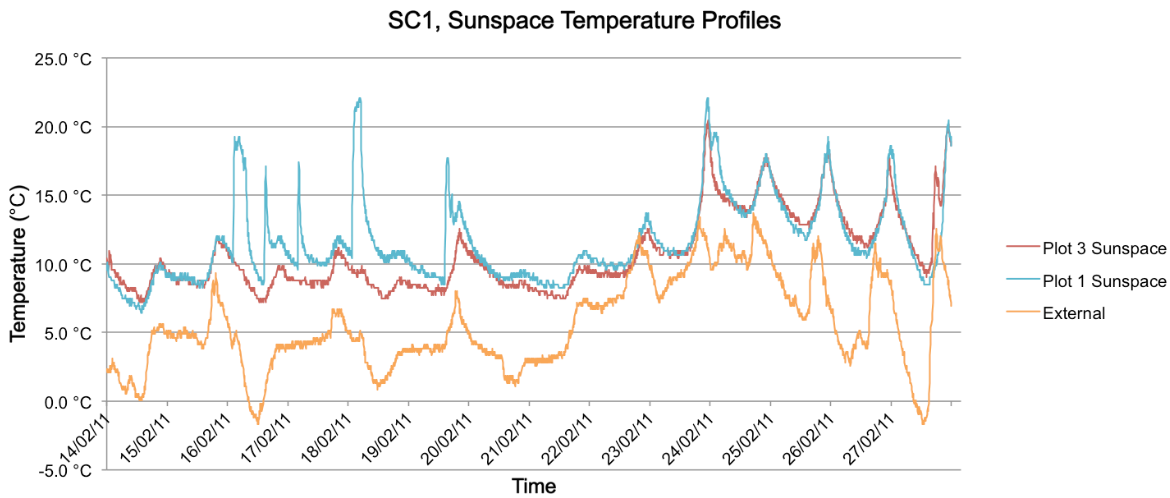

Fig. 2. Comparison of External and Sunspace Temperatures During SC1.

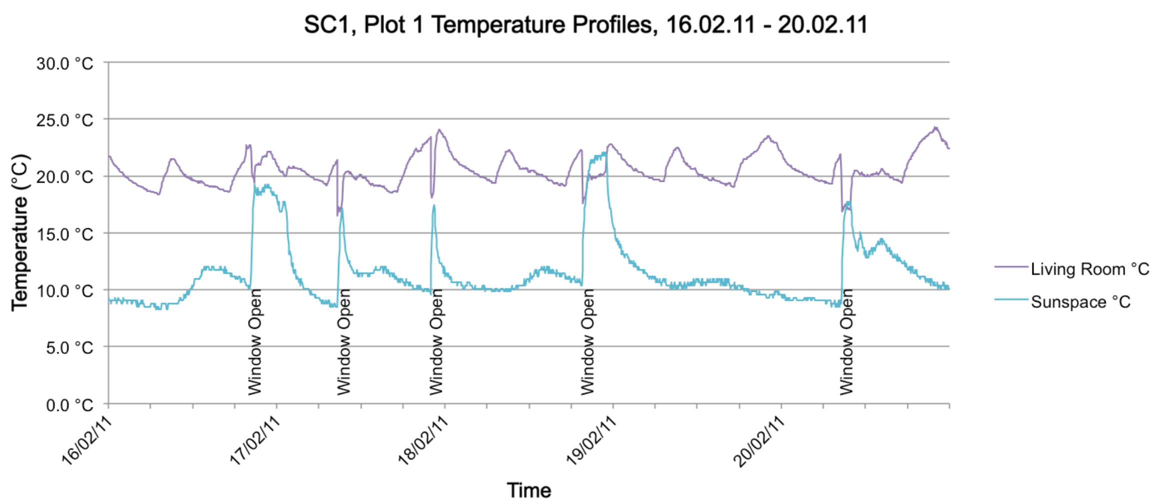

Fig. 3. SC1, Plot 1 Living Room and Sunspace Temperature Relationship.

With further reference to Figure 2 it is also interesting to note the performance of the two spaces where the effect of peaking and troughing (particularly in week two) is less pronounced in Plot 3 where the thermally massive dark brick lined interior is provided and peak temperatures can be more effectively dealt with.

3.3. Would the Connection of Sunspaces to MVHR be Beneficial?

The MVHR system installed in the Glasgow House project is a Vent Axia Sentinel Kinetic B model which operates as a continuously running balanced ventilation system extracting air from 'wet' spaces and supplying air to apartments. In addition, it has a manually operated 'boost' for dealing with periods of higher internal moisture gain. As a continuously operating and thermally indiscriminate system, the issues with connecting an extract to the sunspace suffers from similar problems to those identified with the exploration of direct ventilation; the mean temperature of the space across the monitoring period of 8.42°C does not compare favourably with that of the interior wet spaces mean temperature of 19.51°C. Endeavours to make useful gains from this space for thermal benefit of the rest of the dwelling would result in a reduction of the efficacy of the heat recovery process. If, however, changes to the design intent and fabric arrangement are supposed then there are scenarios where the connection of the MVHR system could be beneficial.

Installation of an extract from the sunspace could be of thermal benefit to the dwelling if it was fitted with appropriate sensors and actuators to ensure this aperture only became operational at times when the temperature of the sunspace exceeded that of the interior. While this presents a design possibility, the data from the monitored periods suggests that the frequency of this in winter would make the additional cost of the higher specification system and additional ducting unfeasible. There may be greater benefits of such an arrangement during 'shoulder' seasons but the oppportunity to assess this currently falls outwith the monitored data available.

An alternative approach could consider the use of the buffer space as an MVHR air inlet position. This would be of energy efficiency benefit to the system, as previously identified, the intake temperature would be above the exterior temperature and there would also be a benefit to fan power efficiency as the pressure variation across this more sheltered inlet would be significantly less than a severe exposure roof located inlet (as existing). This system would require a variation from the Glasgow House arrangement as it would need to be less tightly sealed i.e. open jointed to ensure a fresh air supply. This alteration would impact on the degree of difference between semi-enclosed and external temperatures but would certainly provide a higher mean temperature to that experienced in a more exposed location. While there may be energy benefits to this arrangement there is, however, the risk of air mixing and a reduction in the quality of air being drawn into the dwelling. This risk of reduced air quality, a possibility if the sunspace is in occupation or being used for passive drying for example,it would require further investigation and resolution if such an arrangement was to be used; critically, efforts to improve energy efficiency must not come at the expense of the quality of the internal environment.

Relative to this critical issue, the final beneficial use of a combined buffer and MVHR system is one which acknowledges the importance of Internal Environmental Quality (IEQ) alongside approaches to energy efficiency. In this instance the MVHR could be connected to the sunspace but for the primary role of extracting moisture from an incorporated passive laundry drying space. The reduced thermal efficacy of this move, on the MVHR system, could feasibly be counteracted by the reduction in the need to use energy intensive processes such as tumble drying at 3.5kW per cycle [5] or the prevalent practice of increasing domestic heating and then opening windows to exhaust moisture released during the drying process (evident in between 37% and 50% of respondents behaviour in study of the local area [5]). The incorporation of such passive drying spaces (although not necessarily connected to MVHR) has been successfully tested in Glasgow, such as at the Easthall domestic refurbishment project [6], and has the potential to dramatically reduce the moisture load within dwellings by up to 30% [5] and, therefore, avoid the associated issues of dust mite propogation [7] and the associated health issues of asthma, atopy, etc [8].

3.4. How Does Sunspace Performance Compare with Direct-gain Windows to Passivhaus Standard?

The use of double glazing with a U-value of 1.2W/m^{2}Krepresents a high performance system relative to Scottish Technical Standards backstop value of 2.0W/m^{2}K. Its performance is, however, markedly below the minimum 0.8W/m^{2}K standard promoted by Passivhaus – the increasingly cited benchmark for contemporary building performance. If, however, the thermal resistance of the whole construction from interior to exterior, across the sunspace, is considered then the effective U-value of this construction becomes 0.6W/m^{2}K. Moreover, the shelter this buffer provides removes issues of waterproofing, driving rain index and evaporative cooling for a significant portion of the external fabric construction, further improving thermal performance. These factors combined obviously compare very favourably to the standards of Passivhaus, particularly when the qualitative function of the intermediate buffer is included in the equation. The opportunity to utilise this semi-internal space for amenity gives it a value which increases its worth beyond any sort of technical analysis that could be derived from assessing U-value alone.

4. Conclusion

This paper has shown that provision of sunspaces can be of benefit within the Scottish climate, even with the low solar gains available through the winter season. In this context they are shown to reduce space heat demand when compared to observed occupant ventilation regimes. They are also shown to present feasible and interesting options for the potential to connect to whole house MVHR systems; several of which warrant further investigation and testing. Although not designed with the demanding standards of Passivhaus in mind, the incorporation of these spaces has the capacity to raise the performance of select construction elements to levels greater than those required by Passivhaus minima. Perhaps most importantly, the use of these spaces provides the potential for opportunistic extension of dwelling volume and the creation of increased amenity; welcome benefits in the context of social housing and with the prevailing condition of economically driven reduced space standards.

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