INNOVATIONS IN VENTILATION TECHNOLOGY

21ST ANNUAL AIVC CONFERENCE
THE HAGUE, NETHERLANDS, 26-29 SEPTEMBER 2000

TEST CELL MEASUREMENTS Of A SUPPLY AIR 'VENTILATED' WINDOW.

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SYNOPSIS

A currently unresolved problem in building design is the paradox between increasing demand for good thermal insulation, and the requirement for ample levels of ventilation, to maintain a healthy indoor environment. A possible solution to this problem is a supply air 'ventilated' window. This utilises an airflow between panes to pre-heat ventilation air to the building, and to reduce thermal convection losses thus reducing the window U-Value. At the base of the window is a vent to the external environment, allowing air inflow. This relatively cold air is heated by convection/conduction from the warmer inner pane and will subsequently rise, or be drawn up, entering the room through venting at the top of the glazing.

This paper describes an experiment to determine the thermal performance of two Supply Air 'Ventilated' windows of different aspect ratios. The experiments are carried out in advanced test cell facilities, and are intended to measure changes in thermal performance due to solar irradiation and aspect ratio. The windows show a significantly lower U-Value than conventional windows, and also achieve significant ventilation preheat especially in the presence of high solar irradiation. Aspect ratio appears to have a stronger influence on solar efficiency than it does on the window U-Value.

INTRODUCTION.

The need to reduce energy consumption has, in the last few years, become clear. With 42% [1] of the UK's end use energy going into the heating of domestic and commercial properties, improved building thermal insulation should be a priority.

A Supply Air 'Ventilated' window has been shown to be effective in reducing window U Value [2], [3] and [4], and pre-heating the ventilation airflow. In new super-insulated houses that have catered for the required ventilation levels, air ingress is now the single largest source of building heating demand [5]. The window consists of a multiple glazed window with airflow between two of the panes. Air enters the cavity from a vent to the outside at the bottom and is drawn into the room at the top. See Figure 1. When the outdoor environment is significantly cooler than the indoor, heat convected between the panes of glass will be picked up by this column of air and transported into the room reducing the window U-Value. At times of high incident solar irradiation this method can be used to deliver warm air flow to the building instead of high localised radiative heat fluxes, which can lead to thermal discomfort for the occupants.

However, previous work has not investigated all the factors that determine the window performance and comprehensive experimentation is therefore desirable. The experimental work described here follows on from extensive modelling and experimental work and concerns itself with the effect of window aspect ratio and solar irradiation on window performance.

The standard measure of a window's thermal insulation properties is the U-Value, in Watts/m^2.K. However this is conventionally the heat from the building entering the window. This is however not valid for a Supply Air 'Ventilated' window as it ignores the heat reclaimed in the ventilated cavity.

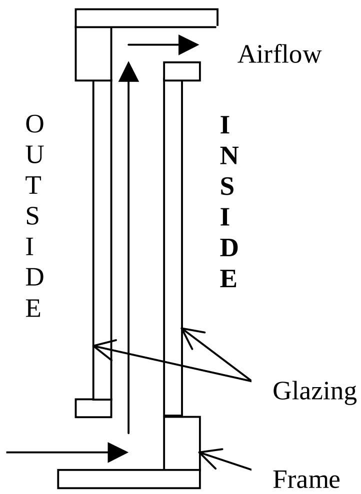

Figure 1. Principle of Supply Air Window Design

We therefore use the term Effective U-Value (Ue) which denotes the heat flux to the exterior from the outer pane and is the same as the U-Value for an unventilated window.
This paper discusses the installation of two supply air ventilated windows into an advanced test cell facility, and the results generated by the experiment.

TEST CELL DESIGN

The test site is situated on the edge of Cranfield airfield, in Bedfordshire, UK and belongs to the Enegy Monitoring Company (EMC). The table below summarises the parameters which describe the site. The site is unobstructed to direct solar radiation from the south.

Latitude	52.07°N
Longitude	0.63°W
Altitude	100 m
Exposure	Rural isolat
Ground reflectivity	0.2

Table 1: Site details

Figure 2 shows the internal dimensions of the room, and the size and the position of the test section provided for the window. The test section (1.2 m high by 2.0 wide) is in the South facing wall. The windows are embedded in a 1.2 by 2.0 m wall section made with the same materials as the south face of the test cell, and this section is then placed in the available hole.

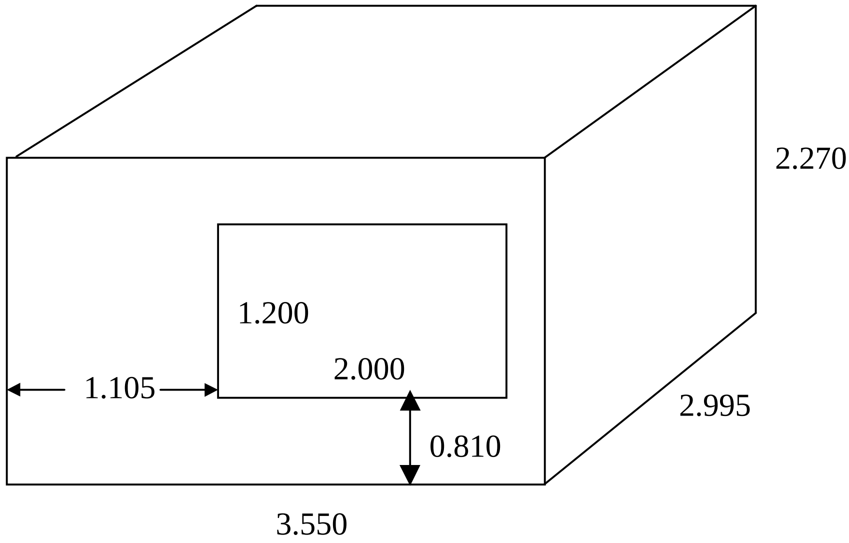

Figure 2: Internal dimensions of the test room

The table below gives the construction of the East, North and West walls of the test room. The convention adopted for listing the components of multi-layer constructions is to work from the outside inwards.

Material	Conductivity W/mK	Density kg/m^3	Specific heat J/kgK	Thickness m
MDF	0.080[1]	750[1]	1000[2]	0.0090
Styrofoam	0.033[3]	28[4]	1400[2]	0.0504[5]
Plasterboard	0.160[2]	950[2]	840[2]	0.0126

Table 2: Construction of test room East, North and West walls

The ceiling and floor are of similar construction with slightly different layer thicknesses in the case of the ceiling, and a vinyl covering on the upper surface on the floor.

Table 3 gives the construction of the South wall. Note that the door itself is of identical construction to the south wall, and the areas have been amalgamated

This detailed knowledge of the test cell construction allowed very accurate thermal simulation models to have been built and validated by the owners of the test cell and subsequently the heat flow through the test component can be accurately predicted.

Element Area	Material	Conductivity W/mK	Density kg/m^3	Specific heat J/kgK	Thickness m
FRONT 5.6031m^2	CLADDING	0.170	1300	1300	0.0030
	STYROFOAM	0.027[3]	28[4]	1400[2]	0.1000
	CLADDING	0.170	1300	1300	0.0030
DOORFRAME 0.0554m^2	CLADDING	0.170	1300	1300	0.0030
	MDF	0.080[1]	750[1]	1000[2]	0.1000
	CLADDING	0.170	1300	1300	0.0030

Table 3: Construction of South wall

The temperature of the test cell is controlled to a given set point which in this case is 35°C. This is higher then a dwelling's optimal indoor temperature, but a high temperature is required to maximise the heat loss through the window and to minimise the proportional size of the test cells inherent errors. All walls except the South facing wall are surrounded by a cavity heated to the same temperature as the internal set point temperature. This reduces heat fluxes across these walls, and their associated errors.

The test room features a mechanical ventilation system which allows a controlled and metered airflow to be directed through the building. For this project incoming air was drawn into the room through the ventilated window system, and exhausted through a sparge pipe located vertically midway along the North wall.

WINDOW DESIGN

Two windows were manufactured for this test cell experiment. These windows are to test the influence of size and solar irradiation on the supply air window performance. Sizes were selected as common designs of high aspect ratio. Each was mounted in a construction the same as the remainder of the Test Room front, as described in Table 3. Table 4 below summarises the areas of the windows tested and figure 3 shows initial blueprints for the window manufacture with the external vents marked with a v.

Sample	Framed size (mm)	Glazed size (mm)
Test Window 1	603 (H) × 1501 (W) = 0.905m^2	411 (H) × 1329 (W) = 0.546m^2
Test Window 2	1185 (H) × 500 (W) = 0.593m^2	994 (H) × 326 (W) = 0.324m^2

Table 4: Dimensions of windows submitted for testing

Both windows comprise of an inner double glazed unit with an air cavity fill, and an outer single pane. A low emissivity coating is situated on the ventilated cavity surface of the double glazed unit, (the normal position is usually within a sealed unit, but previous work has identified the ventilated cavity surface as the most effective [6]).

Also, pressure controlled vents were installed on the external air inlets to ascertain if these were effective at keeping the airflow constant. Keeping the correct and constant ventilation rate is an important requirement for supply air windows. Too little reduces indoor air quality, and the insulation properties. Too much and there is a subsequent energy penalty to heat the excess air.

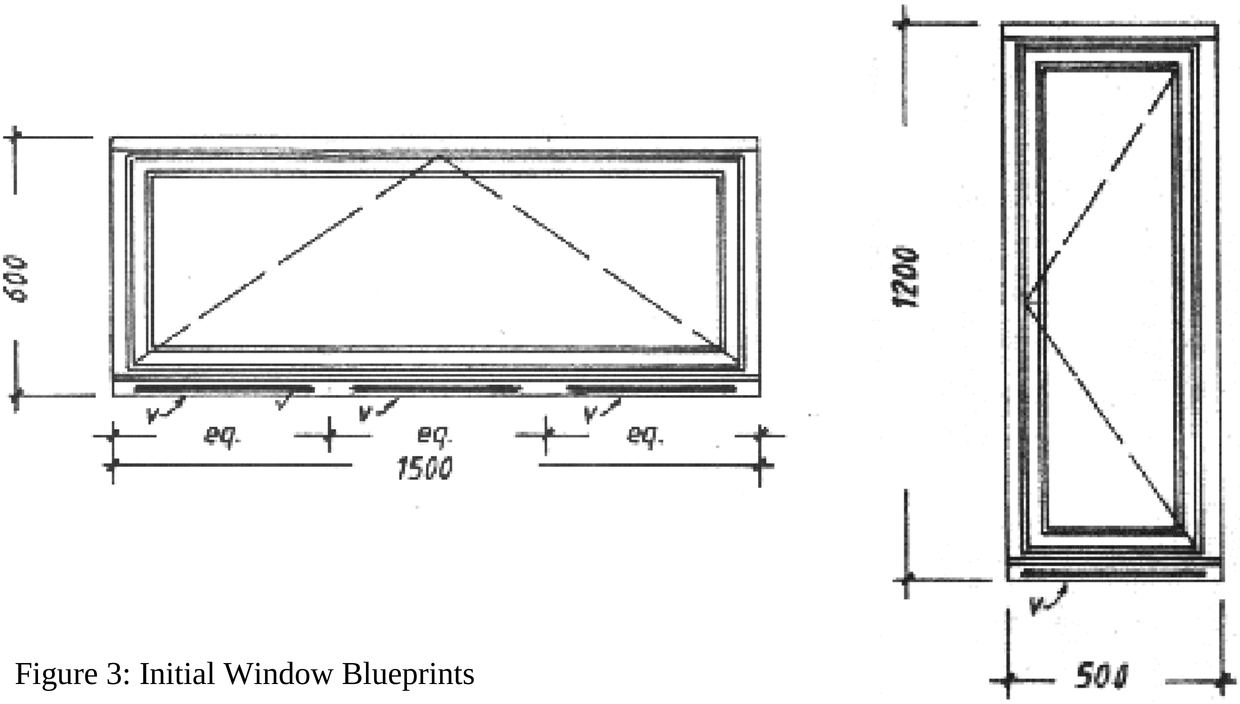

Figure 3: Initial Window Blueprints

MONITORING SYSTEM AND TEST PROGRAMME.

There is a comprehensive monitoring system in place that measures externally, air temperature, humidity, direct and diffuse vertical irradiation and wind speed. Internally, temperatures at numerous points in the room, velocity of incoming air, temperature of incoming air, ventilation air flow rates and surface temperatures are monitored. On the window itself temperatures are measured on the internal and external surfaces, and in the ventilated cavity at varying vertical and lateral positions.

Bulk temperature readings are measured every 5 minutes while more time variable factors i.e. air speeds, radiation and heat fluxes, are calculated every 10 seconds and then averaged over a 5 minute period.

The test phases are shown in table 5

The net heat flow through a normal window is a combination of heat losses by conduction, and heat gains due to solar radiation transmitted through the window. In the case of the ventilated windows tested here the air flow through the system adds a third heat transfer mechanism. Such a complex combination of heat flows cannot be measured directly. Instead it is inferred from an energy balance on the test room, by measuring the net power input to the room, and subtracting from it the ventilation load and the heat loss through the other room surfaces.

Test number	Purpose	Room configuration	Start date	Finish date
1	Calibration of test room front heat flux sensor	Setpoint: 35°C constant Ventilation: 1 ac/h nominal	165-99	175-99
2	Test of window system 1	Setpoint: 35°C constant Ventilation: 1 ac/h	192-99	201-99
		Setpoint: 35°C intermittent Ventilation: 1 ac/h nominal	202-99	211-99
3	Calibration check on test room	Setpoint: 35°C constant Ventilation: None	224-99	226-99
4	Calibration check on ventilation system	Setpoint: 35°C constant Ventilation: 1 ac/h nominal	228-99	230-99
5	Test of window system 2	Setpoint: 35°C constant Ventilation: 1 ac/h nominal	313-99	323-99
		Setpoint: 35°C intermittent Ventilation: 1 ac/h nominal	324-99	332-99

Table 5: Test Phases

Therefore to calculate the heat flux through the outer pane of the window and its Ue value we can use the following equation;

$$Q_w = Q_e - Q_v - Q_f - Q_c \quad \text{……………………………..(1)}$$

Where Qw is the window heat flux, Qe is the electrical energy supplied to heat the room, Qv is the ventilation heat load, Qf is the heat loss from the opaque part of the front face of the test cell and Qc

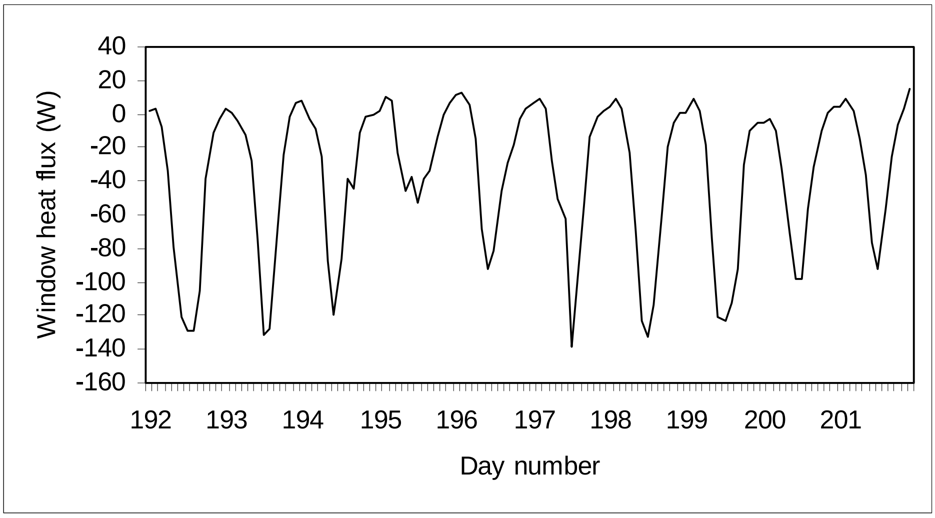

Figure 4: Heat flow through Window system 1

Window heat flux average values were calculated over progressively longer periods until it was found that using two hour average values gave a smooth measure of the window heat flow. Figure 4 shows the heat flow through the first window tested over the ten day period for which the test room was operated in the steady state. As expected the figure confirms that the window provides a net energy gain during the day, when it transmits a portion of the incident solar radiation into the room, and uses a further portion of the absorbed radiation to preheat incoming ventilation air.

It is clear from the figure that the heat flow through the window is strongly dependent on incident solar radiation. If the heat flow through the window is assumed to be linearly related to both temperature difference and radiation it can be expressed in terms of a U-value and an effective solar aperture:

$$Q_w = UA(T_i - T_e) - ES \qquad \text{.......(2)}$$

Where U is the window U-value, A is the area of the window, T_i is the internal temperature, T_e is the external temperature, E is the effective solar aperture, and S is the incident solar radiation level.

Dividing the equation by $A(T_i-T_e)$ gives: $Q_w / A(T_i-T_e) = Ue - E/A \; S/(T_i-T_e)$..........(3)

Thus a graph of normalised window heat loss against normalised solar radiation should be a straight line with intercept Ue and slope –E/A. This ratio of effective area to actual area can be viewed as a window efficiency: the proportion of available energy which is actually transmitted to the room. A whole range of factors contribute to reducing this below the theoretical maximum value of one:

- area of frame: this makes up approximately 40% of the total window area and so E/A cannot exceed 60%.

- shading by frame: because direct solar radiation does not fall on the window at normal incidence the frame causes further shading due to its depth,
- reflection from the glass

- reflection back out of the room from internal surfaces:

Figure 5 shows the resulting graph.

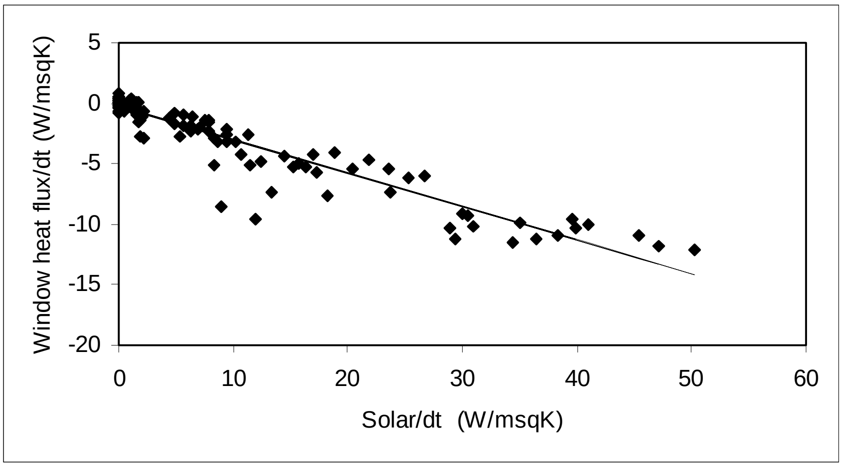

Figure 5: Dependence of window heat flow on solar radiation

The straight line fitted to the data indicates that the efficiency of the window is 27% with a random error of ±2%. The high leverage exerted by the points at high solar radiation make the estimate of window U-value unreliable (it is in fact slightly negative, although within the overall error band). The reason for this is that there are relatively few points for which solar radiation is actually zero (typically only three each night). Instead we estimate the U-value by examining the value of $Q_w/(T_i-T_e)$ at night. Figure 6 shows the result. On one night the heat loss never becomes positive. Taking the mean of the peak heat loss on each night where it was greater than zero gives a result of 0.42 W/m^2K.

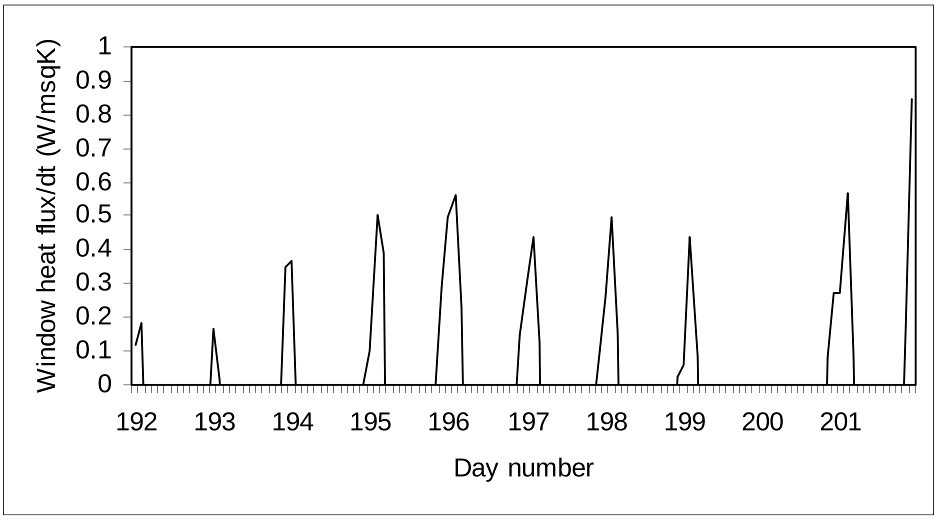

Figure 6: Normalised window heat flow at night.

The same analysis has been applied to the test on the second window. Table 5 summarises the results for both units.

The table indicates that the second window tested performs significantly better than the first in terms of solar collection efficiency.

	Window efficiency E/A	U-value W/m^2K
Window 1	27%	0.42
Window 2	42%	0.46

Table 5: Measured performance of window samples

The net window heat flux derived in the previous section is the result of three separate heat transfer mechanisms: conductive losses, solar gain, and ventilation air preheating. It is clear that the latter two energy flows are the most significant, and it is therefore of interest to see what their relative contributions are.

The temperature of the preheated ventilation air was measured as the air entered the room, and this allows the energy gained in this way to be evaluated. This in turn suggests an alternative way of analysing the performance of the window by regarding it as a solar collector in which the incoming ventilation air is the working fluid. This provides a further way of parameterising the measured performance.

Figure 7 shows the rate at which energy was transferred to the ventilation air over the course of the ten day test. Note that a positive ventilation preheat implies a gain to the room, and makes a negative contribution to net window heat flow.

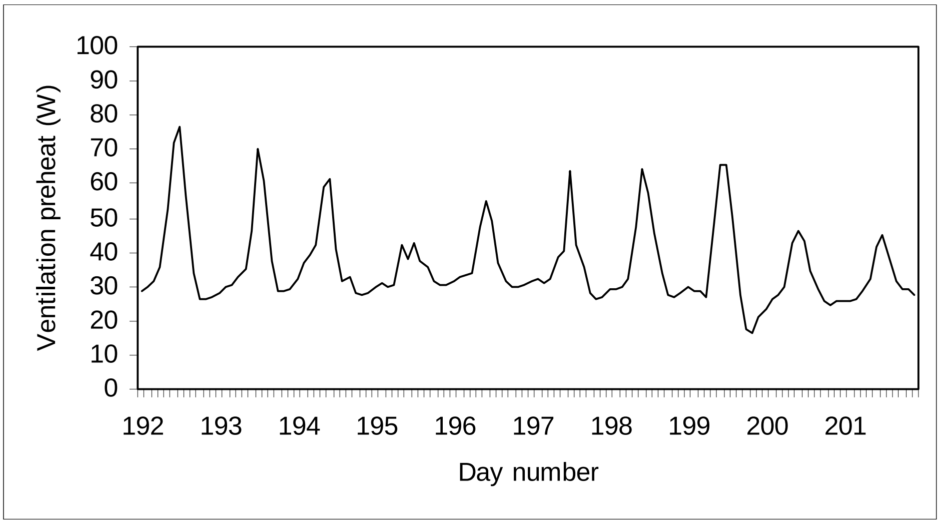

Figure 7: Window energy contribution due to ventilation preheat

The figure indicates that the ventilation preheat mechanism contributes roughly half of the daytime energy gain through the window shown on Figure 8.4. The figure also shows quite clearly the 'background' ventilation preheat which occurs as heat that would otherwise have been lost through the window is reclaimed. This element is present at all times. On top of it can be seen the effect of solar radiation, as the window starts to operate as a solar collector during the day. Figure 8 shows the close relationship between preheat and solar radiation.

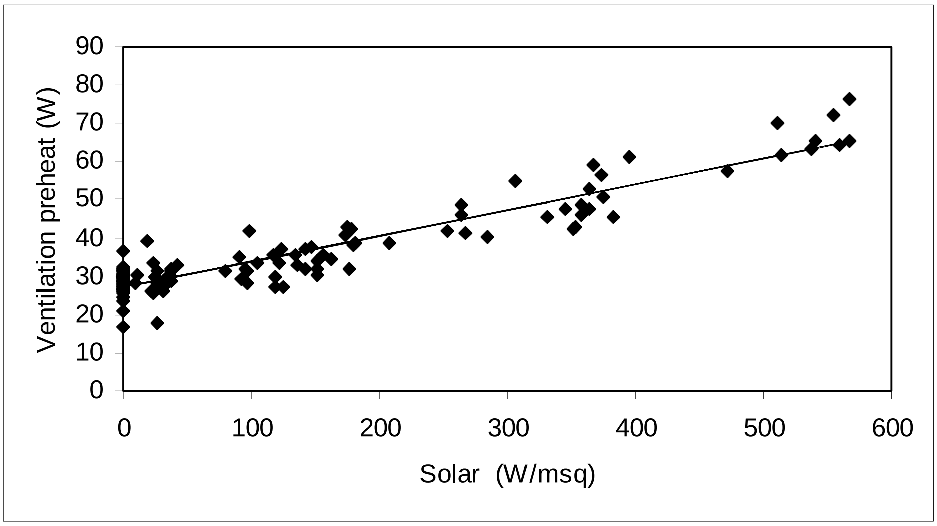

Figure 8: Dependence of ventilation preheat on solar radiation

The straight line fitted to the points indicates that the background preheat provided by this window is approximately 27W. The slope of the line is 0.067 m^2. This can be interpreted as the effective area being used for ventilation preheating. Given that the actual window area is 0.905m^2 the efficiency of the window when viewed as a solar collector is therefore 7.4%. This figure is low compared to the performance of a purpose built collector, but it has to be remembered that such a collector would be opaque – the transparency afforded by the ventilated window not only allows direct solar gains to be transmitted to the space, but also provides potentially valuable daylight.

Table 6 summarises the results for both windows.

	Background preheat W	Efficiency
Window 1	27	7.4%
Window 2	24	11.7%

Table 6: Measured performance of windows as solar collectors

The table again indicates that the second window tested performs significantly better than the first.

The error in Qw is, from equation 1, a function of the errors in Qe, Qv, Qc and Qf, and this error can be computed in terms of Ue Value for both the worst case and most statistically likely scenarios. This is shown in Figure 9. The errors are very consistent during both night and daytime and represent approximately $\pm$ 0.5 and $\pm$0.3 for worst case and statistical scenario respectively.

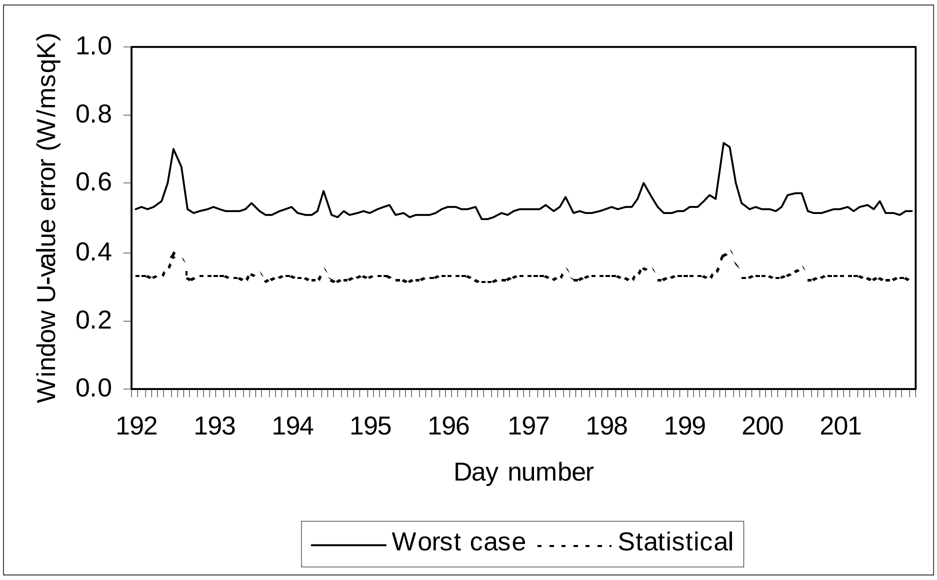

Figure 9: Window Ue-Value Error

CONCLUSIONS

These experiments have shown that supply air ventilated windows are very effective at reducing window Ue-Value. Both window designs display very similar Ue-Values which are far below what a similar unventilated window could expect to achieve (a triple glazed unventilated window with 1 low E coating and air filled cavities would have a U-Value of roughly 1.9). it therefore appears that aspect ratio is not a dominant factor in the window performance as long as the total area stays roughly equal. A narrower window would imply a higher air flow speed within the cavity for a given volume flow rate. This would lead to a lower U-Value as more heat is brought back into the room. However to keep equal areas, the window would have to be taller and this gives heat more opportunity to propagate across the gap. Therefore in general the smaller the window area the lower the Ue-Value, but aspect ratio is not vital.

The performance of the window as a solar collector does however vary significantly between designs. This is most likely due to the fact that in general the most solar irradiation is available at high solar elevations and the top frame creates a shadow over the window. This effect is more pronounced in the wider, lower window 1 and it's collector performance suffers. However, in the winter when the solar input will be desirable the sun will have a much lower elevation and it may well be better to have a low wide window for solar collection. A computational Fluid Dynamics analysis will be carried out to confirm this.

The windows also produce significant levels of ventilation pre-heat ranging from 30% at night to 70% in the day. In winter this will have a very positive impact on thermal comfort conditions compared to a standard trickle vent.

The only significant extra cost of ventilated windows is the extra provision necessary to allow cleaning of the ventilated layer, and therefore payback times will be favourable.

The Supply Air 'Ventilated' window would therefore appear to be a very good option over traditional glazing systems

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