# EXPERIMENTAL MEASUREMENTS AND CHARACTERISTICS OF THE SUPPLY AIR 'VENTILATED' WINDOW.

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## ABSTRACT

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.

An experimental set-up has been designed to test the performance of the window under various conditions. The behaviour of the window is shown, and the factors affecting it's performance discussed. The transition between laminar and turbulent airflow has a marked affect on the window properties, and a new relationship involving Grashof and Reynolds number is shown to determine the conditions at which this occurs.

Experimental results are compared to a computer simulation, which is then used to investigate the optimum design of window. Finally, the potential benefits of the window are discussed.

## INTRODUCTION

There is increasing pressure in many countries to reduce energy use as concerns over climate change grow. A large part of this is used in heating domestic and commercial properties (in the UK it accounts for approximately 42% [1] of end use energy). Therefore any improvement in building thermal insulation, on a large scale, will have a significant impact on energy use and associated emissions connected with climate change. This has resulted in legislation requiring higher levels of new building insulation, and this trend is set to continue. In Scandinavia great improvements have been made in the thermal insulation of the building stock, utilising advanced window design, better insulation and increased building air tightness. This latter method however causes problems in itself as it leads to reduced ventilation levels, causing humidity and contaminate build-up and in extreme cases Sick Building Syndrome (SBS). This in turn has lead to an increased awareness of the importance of ventilation and corresponding legislation, which appears to be at odds with the initial thermal insulation requirements. 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 [2]. A method of reducing this heating demand is therefore desirable

A supply air 'ventilated' has the ability to pre-heat the ventilation airflow with heat that for the most part would be lost through the window to the outside environment. It 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 such high localised radiative heat fluxes, which can be unpleasant for occupants in it's path.

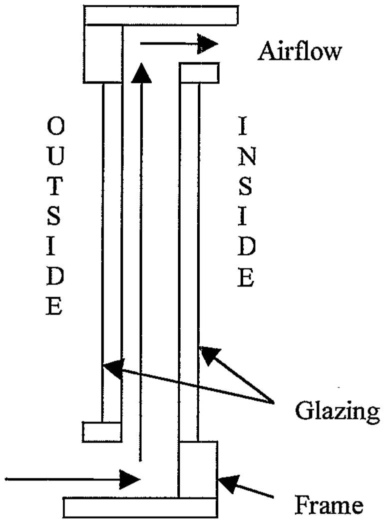



Figure 1. Example of Supply Air Window

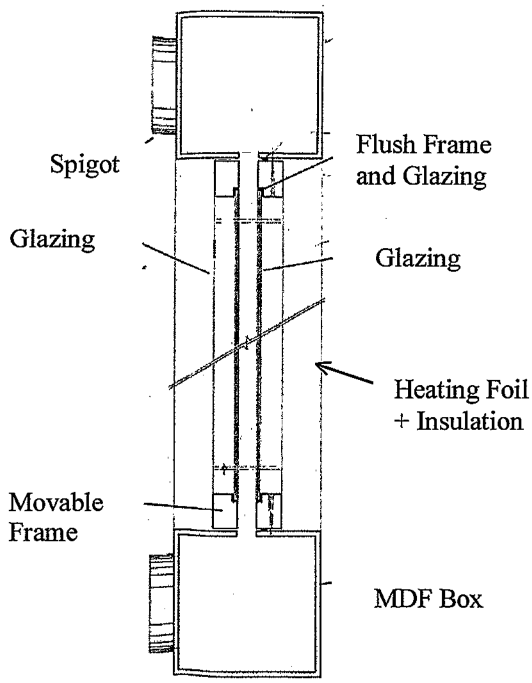



Figure 2. Experimental Set-Up

Although previous work has been done on this system, notably by Yuill [3], Barakat [4] and Wright [5] in Canada, Brandle [6] in the USA and Korkala [7] Finland, interest seems to have declined in the last decade. In spite of the encouraging results that were found, the research was often only theoretical. The best experimental work was probably done by Yuill in Canada, which did lead to a manufactured design. However, because of the extremely cold climate, problems with bringing in very cold air directly into the room made the design uneconomical. This paper will deal with the results from an experimental rig, which was designed and set up at the University of Westminster to measure thermal performance for different cavity widths, airflow rates and temperature differences. A new relationship based on experimental readings to determine the extent of turbulence is proposed. The predictions of an analytical model covering both laminar and turbulent flow are also shown which shows good agreement with the experiment. This model is then used to predict an optimum design of window that will go on for further testing. The results indicate that the window can be very effective at reducing window U-Value.

## METHODS

### Experimental Set-Up

A diagram of the window is shown in figure 2. It consists of a glass pane 6mm thick measuring 1.05 by 1.05m glued into a wood frame that allows one side of the glass to be flush with the frame. The glass has an absorption of 0.15, and an emmisivity of 0.84. This then has a MDF box fitted to the top and bottom with a 20-cm diameter hole in each for the placement of tubing. This allows a closed circuit to be formed for smoke tests. An identical framed glass pane is then slotted in and screwed into position opposite the first. These screws are then used to alter the gap width between panes. To heat the stationary pane a metal sheet is placed against the glass and screwed into place. Heating foil was then glued over this, and then overlaid with a sheet of MDF to provide back insulation. 2 Thermocouples were attached between the heating foil and metal to measure the level of heating. 6 Thermocouples were placed on the room side of the opposite pane at distances of 7, 14, 21, 42, 63, and 84cm from the bottom of the window, and 1 at the air inlet. 2 Dantec low flow anemometers were placed in the top MDF box pointing down into the cavity to measure flow rate and temperature of the rising air. The anemometers were placed at various points between the panes and the readings integrated to get average values. All thermocouples were connected to a Campbell CR10 data logger. The signals were converted to temperatures with a PC. Results were taken for cavity widths of 50 to 10mm, heating temperatures of 66 and 55°C and 3 air flow rates (free convective flow, and two forced flows). A fan fitted to the bottom spigot produced the forced convective flow. A perfectly steady flow is unlikely in a real building environment due to the fluctuations in outside wind pressure, and movements within. However, the next generation of window design, which will be tested in more realistic environments, will include pressure operated constant flow trickle vents on the outside and one way valves, which will hopefully produce reasonably steady conditions. The heating temperatures are unusually high due to the fact that the other pane will be at room temperature, instead of the –10°C that may be case in cold weather. The affects of solar radiation have not been included in this experiment, due to a lack of equipment and a desire to initially study the 'night-time' U-Value. Solar radiation will become an important factor in later experiments, along with the behaviour of the window with a passive stack ventilation system.

**Theoretical Analysis**

The theoretical analysis is based on a set of equations by Faist and Gay [8].
They assume that as glass temperatures vary slowly with time they can omit the differentials and rewrite the governing equations in a more convenient matrix form. Temperatures are then calculated using a step procedure, and free convective airflow rate is calculated after the last step and put back into the equations, until the temperatures converge. For a window of 1.05 metres in height we found that no more than 30 steps were required. The main parameters to now calculate are the free convective flow rates and heat transfer coefficients. Various equations were tried for each from [9], [10], [11], and [12]. The ones that gave the best comparison to experimental data are shown below.

The free convective airflow rate for turbulent [9] and laminar [10] flow is calculated by the equations;

$$V_{turb} = \sqrt{2 \cdot g \cdot H \cdot \left[ \left( \frac{T_{1av} - T_e}{\left( 8 \cdot \left[ e_A \cdot W \cdot 1/A_e \right]^2 + 2 \right) \cdot T_{1av}} \right) \right]} \qquad \ldots(1)$$

$$V_{lam} = \left[ W \cdot e_A / 12 \cdot \mu \cdot H \right] \cdot \Delta p \qquad \ldots(2)$$

where W and H are the window width and height, $T_{1av}$ is the average air cavity temp (K),$e_A$ is the air cavity width, $A_v$ is the vent (spigot) area, $\mu$ is the dynamic viscosity of air and $\Delta p$ is the pressure difference caused by the stack effect which is calculated by; [10]

$$\Delta p = -\rho_0 \cdot g \cdot T_0 \cdot h \cdot \left( \frac{1}{T_e} - \frac{1}{T_{in}} \right) \qquad \ldots (3)$$

where $\rho_0$ is the reference density at reference temperature $T_o$ and h is the stack height.

The convective heat transfer coefficients between the glass panes and the outside/inside are calculated from [11];

$$h_{0,5} = [0.1 \cdot (Gr \cdot Pr)^{1/3}] \cdot \frac{k_A}{e_A} \qquad \ldots (4)$$

Where Gr is the Grashof number, Pr is the Prandtl number and $k_A$ is the thermal conductivity of air.

Convective heat transfer within the ventilated layer for turbulent and laminar flow was taken from [9] as;

$$h_{3,4turb} = \left[ 4.9 + \frac{0.0606 \cdot x^{-1/2}}{(1.0 + 0.0856 \cdot x^{-0.7})} \right] \qquad \ldots (5)$$

$$h_{3,4lam} = 0.0158 Re^{0.8} \qquad \ldots (6)$$

$$\text{where; } x = \frac{H}{Re \cdot Pr \cdot D_H} \qquad \ldots (7)$$

and Re is the Reynolds number, and DH is the hydaulic diameter ($=2e_a$)

Radiative heat transfer coefficients are calculated from the standard equation found in [11]

$$hr = \frac{5.67 \cdot 10^{-8} \cdot (T_n^{\ 4} - T_p^{\ 4})}{(\frac{1}{\varepsilon_n} + \frac{1}{\varepsilon_p} - 1) \cdot (T_n - T_p)} \qquad \ldots (8)$$

where n and p are the required layer numbers, and ε is layer emmisivity.

It is now possible to calculate all the temperatures of the window. This leads to a calculation of U-Value, which we have taken to be the heat lost from the outside pane divided by the total temperature differential across the window, and it's area. Therefore

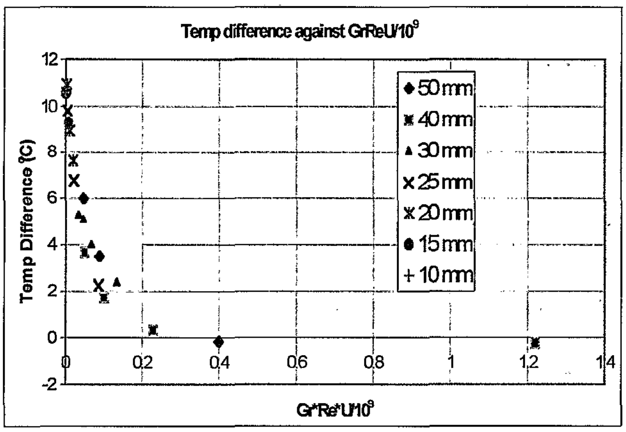
$$Uval = \frac{Q_{loss}}{(T_{in} - T_e) \cdot W \cdot H} \qquad \ldots (9)$$

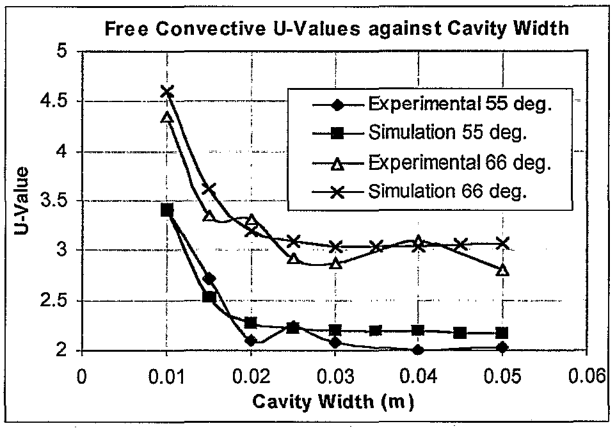
where;
$$Q_{loss} = [h_0 \cdot (\theta_{1av} - T_e) \cdot W \cdot e_A] + [hr_0 \cdot (\theta_{1av} - \theta_{sky}) \cdot W \cdot e_A] \qquad \ldots (10)$$

The heated air flow is not included in these calculations as this ventilation air stream will be at the required ventilation rate, which would have to come in from the outside through vents anyway (assuming the house is well sealed). Any heating given to this air has been already removed from the room due to conduction, convection and radiation, so the only heat flow of any importance is that flowing through the window to the outside. Obviously, if the ventilation air was to consistently enter the room at a higher than necessary rate then a large energy penalty could be incurred. This situation must therefore be avoided by controlled vents.

## RESULTS

A new relationship is proposed for the transition between laminar and turbulent flow. An existing relationship is given in [12] as Gr/Re >24 for turbulent flow. However this does not take into account different flow rates and as Re is proportional to V this ratio will decrease with increasing V even though that would produce more turbulence. In addition, a pattern was noticed in the temperature difference between the cavity air outlet temperature and the temperature at the top of the outer pane of glass that seemed to correspond to expected levels of turbulence. This makes sense as laminar flow would produce a larger temperature difference due to a larger temperature gradient across the cavity. This parameter was plotted therefore against Gr/Re for all flow rates and cavity widths at 66 °C and no pattern was discernible, but when plotted against $Gr*Re/10^9$ the following graph 1 was produced. When taking into account the different temperature levels an almost identical graph was produced for the 56°C experiment, so we have decided to use this as our turbulence measure with a value below 0.06 being laminar. This produces the free convective U-values shown in graph 2.

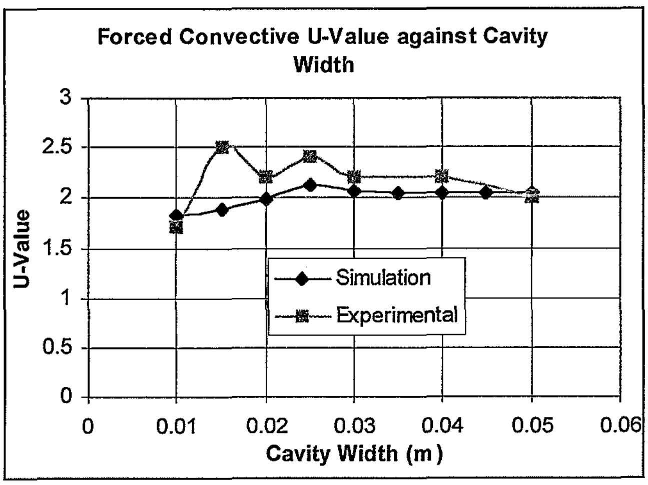



Graph1. ΔT against $Gr*RE/10^9$

Graph2. Free Convective U-Values

For forced convection at the recommended background ventilation level of $8dm^3/s$ [13] the U-Value is lowest at 10 mm as the air flow is at it's quickest. This is shown in graph 3. It is even quicker at 5mm but this would require a very large Passive Stack Ventilation system to run it.




Graph 3. Forced Convective U-Values

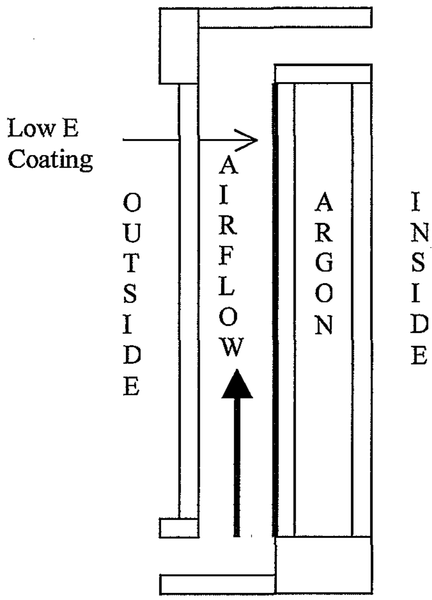



Figure 4. Diagram of Best Design

Finally, different designs of window are simulated with cavities of 10mm. The best design tested is shown in Figure 4. It is a triple paned window with an argon filled gap and the ventilated layer on the outside with a hard low e coating facing the ventilated layer. This has a predicted U-Value of 0.3, which is a very low value for a window. The U-Value for a similarly designed window of similar cost, without ventilation, is approximate 1.2.

**DISCUSSION**

The Optimum cavity width for the window is 10mm, and very low U-Values are possible using this system which could significantly reduce the heating demand of building, while providing healthy levels of ventilation. Testing of these designs in a more realistic situation is however required to accurately determine the window performance. The theoretical analysis shown here, although providing a good fit to experimental data, has made some assumptions that may affect the predictions for other designs. These assumptions include the removal of the differential equations, and the fact that it does not allow a temperature gradient across the air flow , which exists in a real situation. A CFD analysis is therefore required, which will be the next task in this work programme.

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