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Air Distribution in Rooms, (ROOMVENT 2000)
Editor: H.B. Awbi

13369

RESULTS FROM A VALIDATED CFD SIMULATION OF A 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. This utilises an airflow between panes to pre-heat ventilation air to the building, and to reduce thermal convection losses, thus reducing the window Ue-Value.

A 2D Computational Fluid Dynamics (CFD) model has been built and validated to analyse the performance of the window under various conditions, including different glass types, configurations and ventilation. The simulated behaviour of the window under these conditions is shown, including it's thermal insulation properties and ability to pre-heat ventilation air to the building, and the factors affecting it's performance discussed. The results show that a very low Ue-Values of the order of 0.2 are possible with even simplistic double paned designs. Finally the simulation is used to optimise the design of window, with cost considerations included.

KEYWORDS

Ventilation, U-Value, Supply Air Windows, Computational Fluid Dynamics.

INTRODUCTION

The need to reduce energy consumption has, in the last few years, become clear. With 42% of the UK's end use energy going into the heating of domestic and commercial properties, Boyle (1996), improved building thermal insulation should be a priority.

A Supply Air 'Ventilated' window has been shown to be effective in reducing window Ue-Value, Yuill (1987), Barakat (1987) and Tjelflaat & Bergesen (1985), 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, Roaf & Mancock (1982). 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 Ue-Value. At times of high incident solar irradiation this method can be used to deliver warm airflow to the building instead of highly localised radiative heat fluxes, which can lead to thermal discomfort for the occupants. A 2D CFD simulation has been built using the Flovent™ software package, and validated from experimental data taken from a test rig at the University of Westminster.

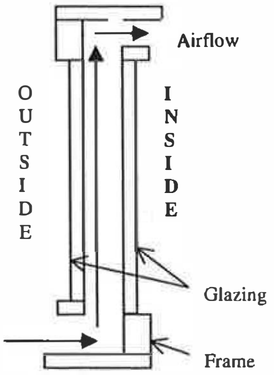


Figure 1. Principle of Supply Air Window Design

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. We therefore use the term Effective U-Value (Ue) which denotes the heat loss coefficient to the exterior from the outer pane in Watts/m^2.K, and is the same as the U-Value for an unventilated window.

CFD SIMULATION

CFD is a method of solving the physical laws of conservation for heat and mass transfer. The conservation laws of mass, momentum, and energy must be solved for a situation such as ours which involves both fluid flow and heat transfer. All CFD solutions are based on the same basic principles, Versteeg & Malalasekera (1995).

- Approximation of the unknown flow variables by means of simple functions
- Discretisation by substitution of the approximation into the governing flow equation, and subsequent mathematical manipulations.
- Solution of the algebraic equations.

Various methods, Spectral, Finite Difference, Finite Element and Finite Volume are used to complete the first two steps. The Finite Volume method is the most common and well-validated technique, which forms the basis for most commercially available CFD codes. Flovent™ software employs the finite volume method for solution of the governing equations. The Finite Volume method is distinct from the others as the integration of the governing equations takes place over finite control volumes within the solution domain. This process expresses the conservation of relevant properties for each finite cell size. It is easy to relate the concept of the conservation laws with a finite volume or box, and this is one of the main reasons why Finite Volume methods have proved so popular as the underlying concepts are easier to understand than Spectral or Finite Element methods.

The turbulence model employed by Flovent is the κ-ε model. Two extra differential equations now need to be solved, for the turbulence kinetic energy (κ) and it's rate of dissipation (ε). This is again the most widely validated method, and shows excellent performance for most industrial applications. However poor performance is reported in non-circular ducts, Versteeg & Malalasekera (1995), which is the case in the window cavity.

The model has been used to simulate unventilated window designs, which have been compared to ASHRAE standard U-Values. Agreement was excellent. Also, a supply air window experiment at the University of Westminster has been modelled and agreement was again very good.

The window has been initially modelled two dimensionally as this cuts down considerably on computational time, and should not effect the centre of glazing U-Value. We are also modelling in the steady state, as the input of weather data is not allowed in our software version. To simulate the indoor and outdoor environment, the solution domain is split into two. Boundary walls with high U-Value then surround the outdoor domain, and a constant outdoor temperature (0°C) set on the outer sides of these boundary walls. The internal environment is also surrounded by boundary walls with a U-Value representative of building fabrics of 0.6, and an internal temperature of 20 °C. The U-Value of the wall between the two domains is set to 0.6. The thermal conductivities, densities, specific heat capacities and emissivities of the materials used in a typical window construction are taken from ASHRAE Fundamentals (1995).

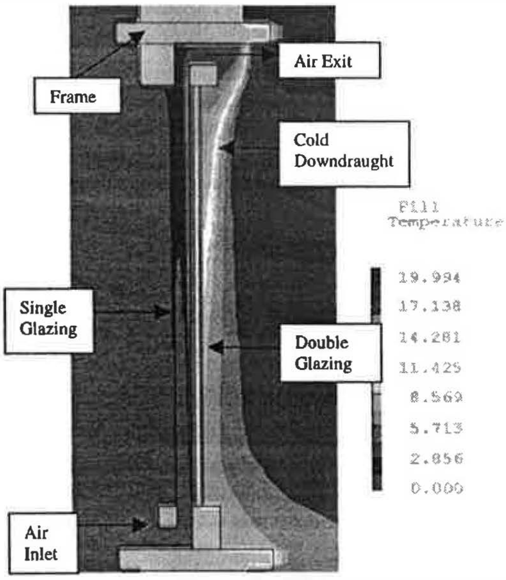


Figure 2.
Example Temperature Distribution.

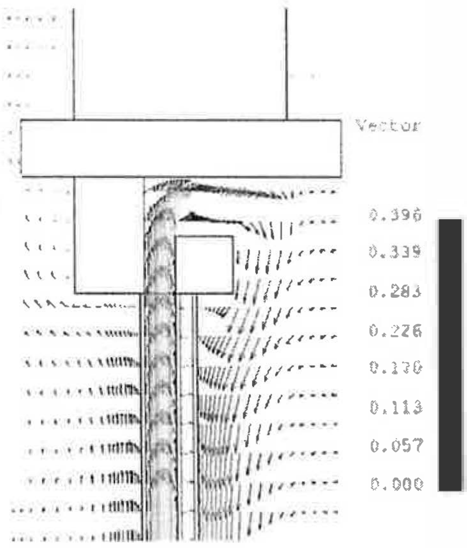
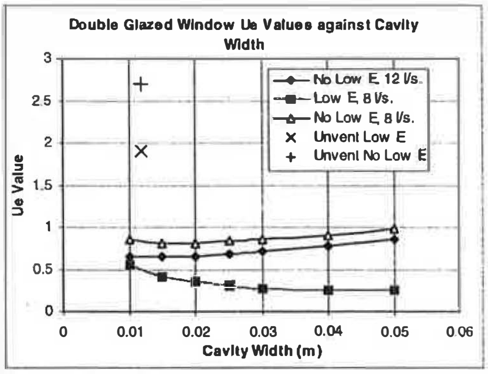


Figure 3
Velocity Vectors Over Window Outlet.

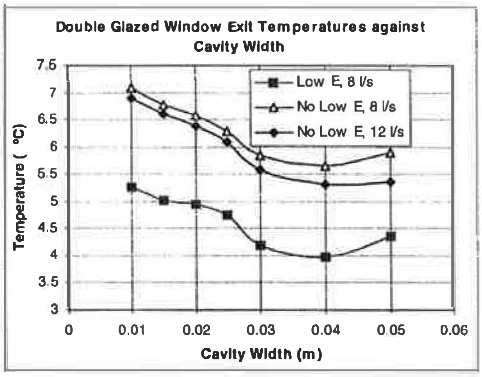
Grid cell size within the cavity is kept to a maximum of 2mm as anything large begins to have a significant effect on the results. Standard logarithmic wall functions are used within the κ-ε model to simulate flow next to the window surfaces. Inter-pane, internal and external radiative exchange is modelled. In the case of the latter two by panels placed on each end of the domain, facing the window. Solar irradiation cannot however be modelled in conducting surfaces with this software version. An extract is placed in the internal domain to provide ventilation and an opening in the external domain for air supply. Model outputs for temperature and velocity vector are shown in figures 2 and 3.

The aim of our work program is to find the optimum design of Supply Air 'Ventilated" window. We have therefore simulated various designs with different glass types, cavity widths and ventilation rates. We shall first look at the double glazed case.

The double glazed window is modelled with two ventilation rates of 8 l/s, UK Building Regulations (1994), and 12l/s for comparison. Cavity widths of 10 to 50 mm are modelled. Cavities of less than 10 mm were not modelled because if a Passive Stack Ventilation (PSV) system is required to supply the building ventilation demand, then the size of system required becomes prohibitive at cavity widths below 10mm. This was calculated with equations from Awbi (1991). 50 mm was considered to be the upper limit for standard window constructions. The window is also modelled with and without a low E (emissivity 0.17) coating on the inner pane. The results for Ue-Value and air exit temperature are shown below in graphs 1 and 2. The simulated values of two unventilated double glazed windows (12-mm cavity), with and without low E coatings are also shown in Graph 1 for comparison.



Graph 1. Ue-Values



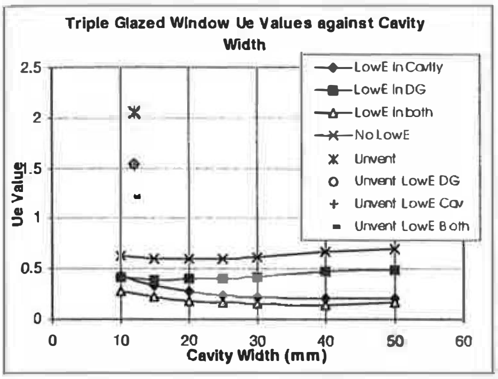
Graph 2. Air Exit Temperatures.

It is first worth noting that these are extremely low Ue-Values for a double glazes window. Typical values for a double glazed window without a Low E coating, and with, are 2.9 and 1.8 respectively [4]. Higher ventilation rates do bring about a reduction in Ue-Value, but it is relatively minor over the 50% increase shown here, and one should be aware that an increase in ventilation rate would increase the ventilation heating demand. The best cavity widths for a window without a low E coating is 15 to 20mm. This is however not the case for a window with one, and a cavity width of 30 to 50 mm provides the best results. On analysis of the temperature profile within the cavity, the low E coating reduces the outer pane temperature, and therefore the dominant effect on this pane temperature is how close it is to the warmer pane. With no Low E coating this outer pane is warmed slightly by radiative heat transfer, and is therefore also cooled by the higher air speeds at low cavity widths. It is not until 10 mm that the proximity of the warmer pane begins to increase the Ue-Value. The Ue-Value reduction at higher cavity widths is, however, impressive for this scenario.

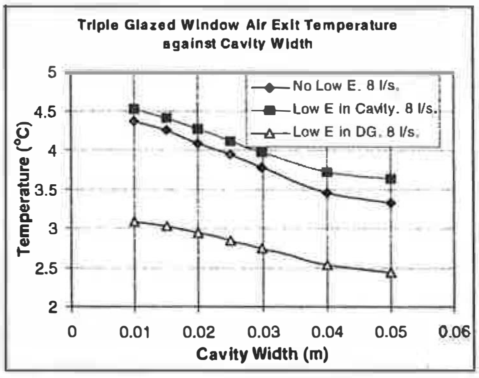
Graph 2 of the air exit temperatures is relevant in terms of the ventilation heating demand on the building, and the thermal comfort in the proximity of the window. The highest temperatures are associated with the non-Low E coated window as the outer pane is at a relatively high temperature.

This is slightly reduced with the higher air speeds associated with the increased ventilation rate. With this window we can also achieve the ideal scenario of low Ue-Value and high exit temperature, with the window providing approximately 35% of the ventilation heating demand at 15mm cavity width. With the Low E coated window at the ideal cavity width we are providing only 20%, and bringing air in at only 4°C. Also the inner pane temperature is lower. Both will have a detrimental impact on thermal comfort.

A triple glazed window has also been modelled with a sealed double glazed window with internal air space on the interior side. The low E coating now has two potential positions, on the internal and external surfaces of the middle pane. The results are shown below in graphs 3 and 4. With simulated values for an unventilated triple glazed shown in graph 3 for comparison.



Graph 3. Ue-Values



Graph 4. Air Exit Temperatures

Lower Ue-Values are achieved as expected. In terms of Low E coating it is interesting to note that its positioning is significant. Lower Ue-Values can be achieved with the Low E coating in the ventilated cavity as opposed to the double-glazing. This is probably due to the fact that when the coating is in the ventilated layer all three heat transfer types, conduction, convection and radiation are inhibited at the same point i.e. between the mid and outer panes. It also has the effect of making the middle pane warmer, which is why when the cavity width reduces, the Ue-Value eventually becomes greater than with the coating in the double-glazing. This also explains why the air exit temperature is warmer for the coating in the cavity, so we have an ideal scenario of low Ue-Value and high air exit temperature.

We have calculated payback times in terms of the cost of glazing and relative to a single glazed window. Glazing costs were taken from Pilkington UK. We have taken the average yearly outdoor temperature in Glasgow [last] of 8.9 °C, and indoor of 20°C. Some comparisons between ventilated and unventilated windows are shown below in table 1.

Table 1.
PAYBACK TIMES ON GLAZING COSTS FOR VENTILATED AND UNVENTILATED WINDOWS

Window Type	Unventilated	Ventilated
Double Glazed	1	0.52
Double Glazed Low E	1.37	0.77
Triple Glazes with Air Fill	1.47	0.92
Triple Glazed with Air Fill and Low E	1.63	1.25

A good balance of cost against performance is the triple pane window with Low E coating in the ventilated cavity. Although this is not the shortest payback time, the long-term performance of the window will justify the initial expense.

CONCLUSIONS

The Supply Air "Ventilated" window shows great potential for reducing window Ue-Value. When considering a design with a Low E coating within the ventilated layer a cavity width of 30 mm or above should be chosen. If not a cavity width of between 15 and 20 mm is the best. If a Low E coating is to be used it is recommended that it be placed in the ventilated cavity as lower Ue-Values are then attainable.

These windows however make a central ventilation intake plant unfeasible, and no mechanical pre-heating of the ventilation can economically occur. Thermal comfort is therefore an important factor in very cold climates. From this point of view it is likely that a triple glazed window with a low E coating in the cavity will be more suitable because of the higher temperature of the inner pane, and the relatively high air exit temperature. Thermal comfort and solar irradiation effects will be modelled in detail with a new version of the software.

Payback times are significantly shorter for ventilated windows and shortest for the double glazed window, although over the long term the triple glazed windows will give better returns. This does not take into account however

A ventilation rate that is recommended for the space for the purposes of adequate indoor air quality should be used, and no higher, as this would lead to a heating penalty and no great improvement in Ue-Value.

REFERENCES

ASHRAE Fundamentals. (1995).

Awbi H. B. (1991). *Ventilation of Buildings*. E & FN SPON.

Barakat S A. (1987). Thermal Performance of a Supply Air Window. *Proceedings of the 12th Annual Passive Solar Conference* **12**, 152-158.

Boyle G. (1996). *Renewable Energy*. Oxford University Press.
Roaf S. and Hancock M. (1992). *Energy Efficient Building*. Blackwell.

Tjelflaat P O. and Bergesen B. (1985). *Improved Thermal Insulation in Windows by Laminar Airflows*. Thermal Performance of the Exterior Envelopes of Buildings **3**, 992-1003.
UK Building Regulations. (1995).

Versteeg H. K. and Malalasekera W. (1995). *An Introduction to Computational Fluid Dynamics*. Longman Scientific and Technical.

Yuill, G K. (1987). *Laminar Airflow Super Window*. Renewable Energy Branch, Energy Mines and Resources. Canada.