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Programme of Testing for a Low-Energy Whole House Ventilation System

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Synopsis

This paper is an overview of the work carried out during a 3year EPSRC funded project investigating the important factors in Supply Air window design. The structure and some of the main conclusions of this work are presented here. The project consisted of alternating experimental and simulation phases; the experimental results contributed to the model validation, and the simulation outputs provided design guidance for the following experiments. The project has shown that the window can reliably produce U-Values in the order of 0.45 W/m^2K under semi-laboratory conditions, that the ventilation pre-heat attained was between 10 and 15% of the ventilation heat load at night, and 40 to 70% on sunny south facing facades. This was achieved with a glazing configuration optimised for thermal insulation. Both Computational Fluid Dynamics (CFD) and thermal mass network simulations have proved excellent at predicting window performance.

This work has been preparatory to an EU funded project into a complete low energy ventilation system which couples the supply air windows with pressure controlled vents, and a Passive Stack Ventilation (PSV) system. The methodology of the project will be described and the main objectives discussed.

Background

The basic concept behind the supply air ventilated window is a simple one, instead of using conventional trickle vents, the air space between the outer and inner panes of a window is used as a supply air plenum. Air is drawn through vents at the bottom of the outer pane and into the room at the top of the inner pane. The passage of air, especially if the flow is laminar, reduces heat loss since heat escaping from the room is entrained in the air path and returned to the room. If facing in the right direction the window also acts as a passive solar device. In this way increased volumes of pre-heated background ventilation can be delivered in winter without incurring draughts. The system is an energy efficient way of resolving the conflicting demands for increased background ventilation rates to dispel indoor pollution, despite ongoing pressures for energy conservation. Figure 1 shows a simple schematic of the window along with the heat flows associated with its operation. It is worth noting that in the case of the supply air window we are concerned with Q_3, the $U_{effective}$ or U_e-Value to quantify heat insulation performance as opposed to the usual U-Value employed for standard designs.

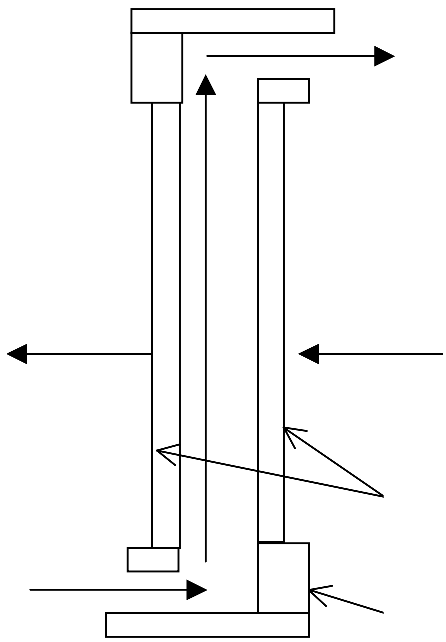


Figure 1. Simple Schematic of a supply air ventilated window.

Although the idea is not new (notable work has been done by Yuill et al [1], and Wright et al [2] in Canada and Tjelflaat et al in Finland) interest in the idea has waned in the last 15 years. In 1996 McEvoy [3] began again to look at this idea of which this is a follow on study. Since then however, improvements in glazing technology and computer simulation techniques, have allowed more scope for the optimisation of the window.

Methodology and main results

The project consisted of experimental work providing validation data for simulations that fed design parameters into a subsequent experiment. Here we will be discussing the latter simulation phases utilising Computational Fluid Dynamics (CFD) and the ESP-r thermal network software. Previous stages of the project have been described in [4], [5], [6] and [7].

Computational Fluid Dynamics (CFD) models were constructed of the two previous experimental rigs. The first experiment dealt with the analysis of the effect of cavity width and air flow characteristics on the performance of the window [4], and the second was a test cell based experiment at the Building Research Establishment's Scottish laboratory [5]. CFD is currently the most powerful technique available for modelling heat and mass transfer, and was ideally suited to modelling the processes at work within, and around, the 'supply air' window. A commercial software package Flovent was used for the task. Flovent uses the finite volume method to solve the heat and mass conservation laws that lie at the heart of CFD code. The finite volume is the most common and validated of the solution methods, and is especially well suited to analysis of the predominantly cuboidal components in this window system.

Models of the initial (figure 2) and Scotlab experiments (figure 3) were built, as well as a generic model for the testing of additional features. Once the CFD model was validated with data from these two experiments, investigations were undertaken into the effects of additional parameter changes not undertaken in the experiment. These included: glazing tilt, glazing solar absorption, redirection of output air flow, and positioning of heat sources within the room for maximum comfort. The post-processing abilities of the software allowed detailed analysis of the changing thermal comfort within the test cells (which was below the sensitivity of the experimental regime). The model was then applied to the optimisation of design for the next experiment, which varied the parameters already identified as influential on performance.

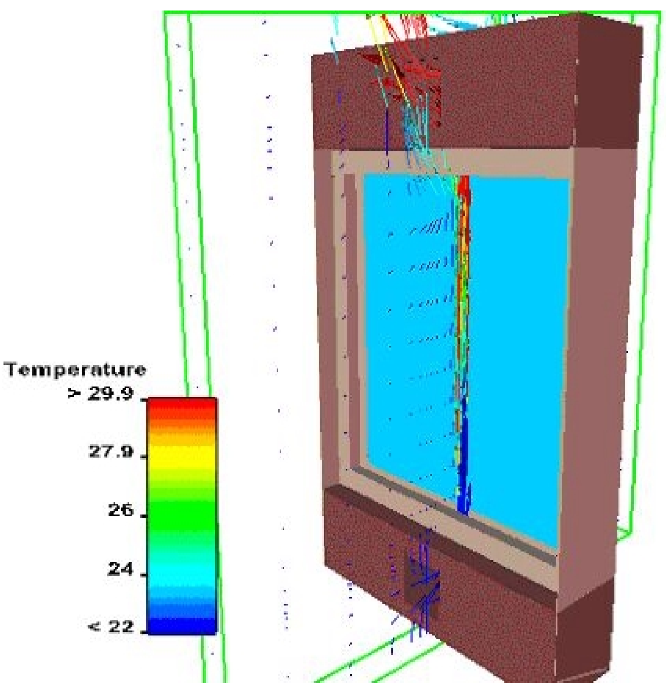


Figure 2. CFD model of the initial test rig velocity vectors within the cavity.

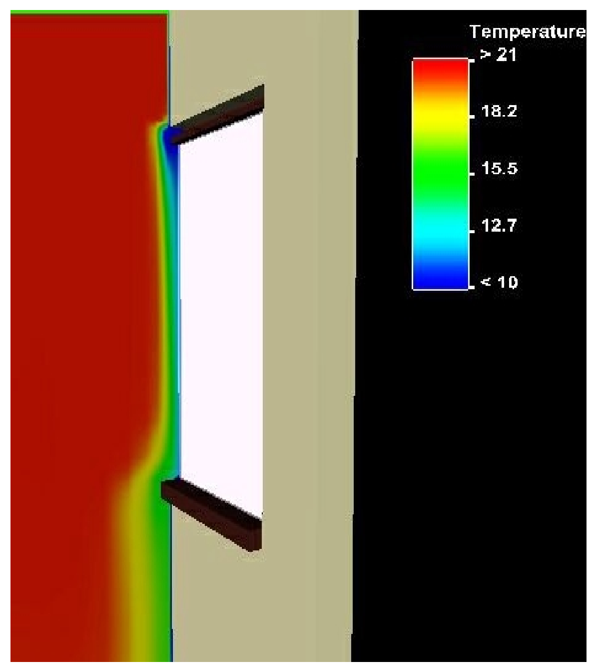


Figure 3. CFD model of the Scotlab test showing cell and window with cool downdraught

The CFD model agreed well with initial experiments that predicted the influence of cavity width on U-Value, and the temperatures at the window outlet (figure 4 and 5). The only significant discrepancy was due to the underestimation, by the CFD software, of the natural convection flows within the window.

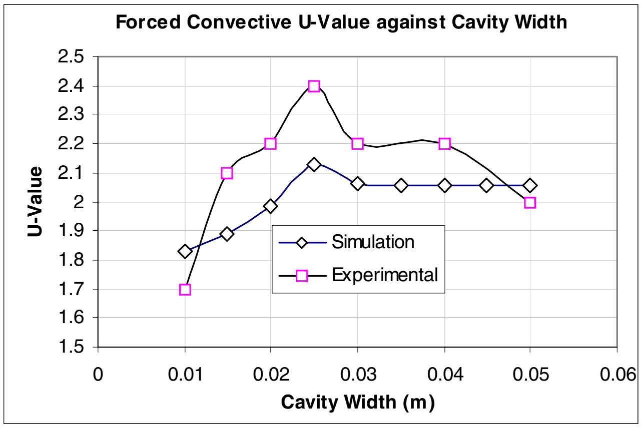


Figure 4. Graph of U-Values from experiment and CFD simulations.

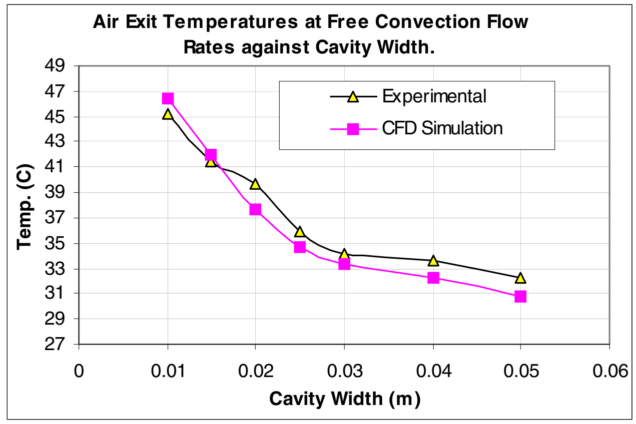
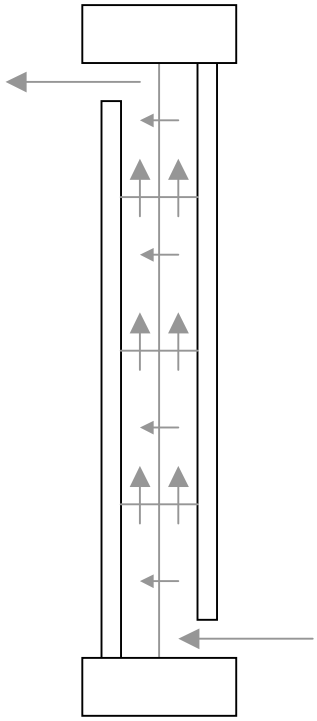


Figure 5. Graph of exit temperatures from experiment and CFD.

The CFD model also matches closely with the Scotlab data, predicting a U-Value of 0.43 and an air exit temperature of 2.6, compared to experimental values of 0.44 and 2.0. CFD confirmed the 30mm gap width as the best overall, and the position of the low-e coating within the ventilated cavity, was also confirmed to be the best.

The isolated performance of the window has been well characterised in the previous stages, and the last modelling phase analysed the benefits of this performance in the wider context of a complete building. Experimental work was again used for validation and now included a second test cell study carried out at the Energy Monitoring Company's facilities in Milton Keynes [7]. This required the construction of an ESP-r model of the test cells for validation, and the modelling of the window under generic circumstances, to calculate potential energy savings and payback times.

ESP-r is a heat and mass network model which can be applied to whole buildings, under realistic circumstances, by importing real climate data to supply the boundary conditions. A drawback of this technique is that any one zone within the network is considered to be well mixed and therefore isothermal, which does not predict with enough accuracy, the stratified conditions within the window cavity. To overcome this difficulty the cavity was modelled with eight zones, four vertical and two lateral (figure 6), to provide a rudimentary CFD system. This was found to be far more effective than a single or 4 cell high technique. A model of the BRE's and EMC's test cell facilities, incorporating the windows was built, and climate data was taken from the experiment's weather station to provide the boundary conditions.



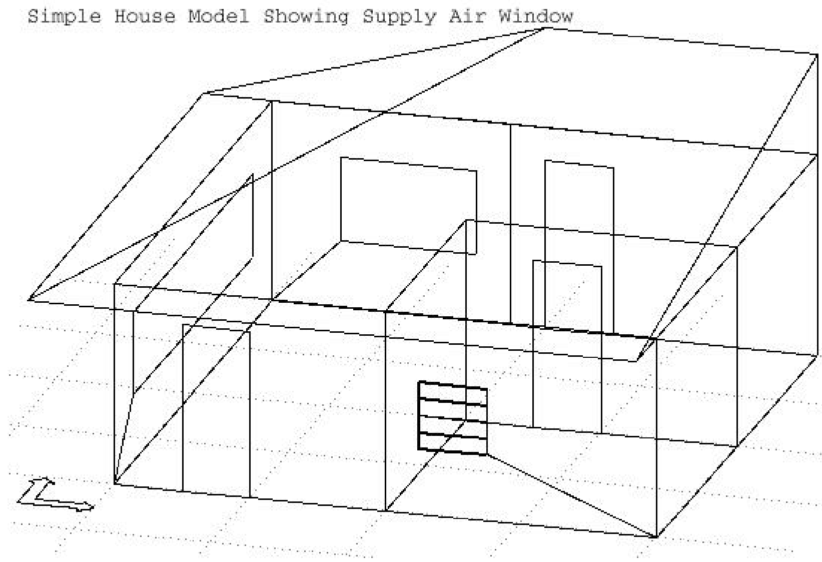


Figure 6. Schematic of ESP-r zones. Figure 7. ESP-r model with installed SAW.

Having demonstrated the accuracy of this technique when predicting performance of the window, the model was imported into an example test house supplied with ESP-r (figure 7). Yearly tests were carried out with climate data for the North and South of the UK, compared to an identical house without supply air window installation. Heating demand, thermal comfort, ventilation levels and occurrences of overheating were all analysed. This allowed prediction of national energy usage reduction, CO_2 emissions reduction, and payback times for the window itself. The model is shown in figure 14.

The model results were in good agreement with the test cell measurements in terms of both ventilation pre-heat and U- value. The average U-Value over time was calculated as approximately 0.5. Temperature comparisons with the EMC data are shown in figure 8. The U-Value may be slightly higher than the experimental findings due to the coarseness of the grid within the window cavity. Modelling of the cavity as a single zone led to high U-Values, the four-zone model was an improvement, but still an overestimation. An 8 zone model, whilst maybe still too course, was a compromise between length of modelling time, and the level of accuracy that could be achieved. It was concluded that the extra time it would take to build a 12 or 16 zone model in ESP-r would not be justified by only small improvements in accuracy.

Applying this data to the generic house, the predicted cost savings over the year are significant. In a London climate, with a standard domestic heating regime, 158 kWh per year can be saved using a triple glazed supply air window as compared to a similar unventilated design, resulting in an estimated payback time of 7-10 years for an electric heating system. In the more common case of gas heating this figure will be longer as the energy saved will total only £4 or so per year.

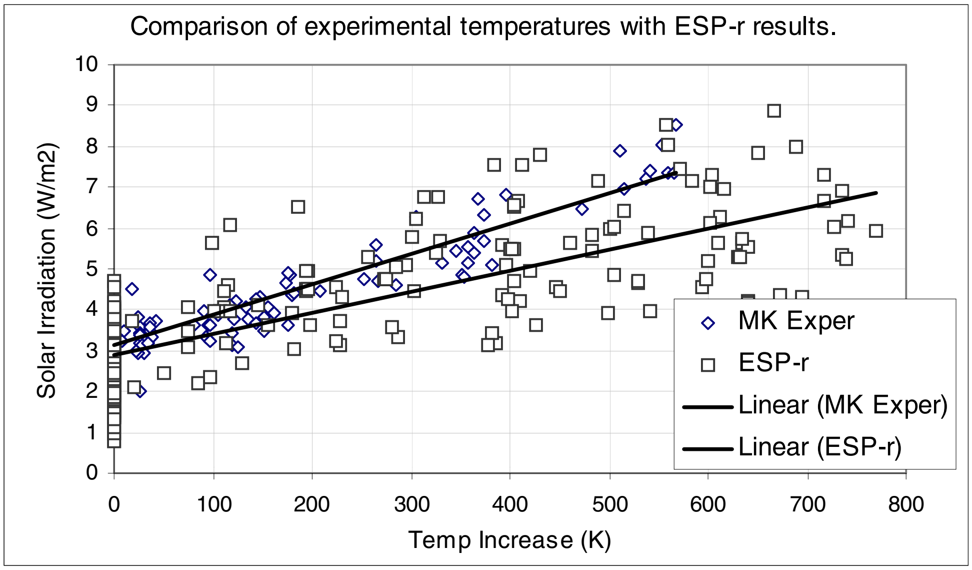


Figure 8. Temperature comparisons between experiment and ESP-r simulation

The project has shown by a variety of methods, both experimental and simulation, that a triple glazed supply air window can attain U-Values in the region of 0.45, night-time ventilation pre-heat achieving 10-15% of the ventilation heat load. The presence of strong sunlight further improves this figure to between 40-70%. These results represent a significant improvement compared with the performance of an equivalent unventilated design where one would expect a U-Value in the region of 1.8. It would however be difficult to justify the installation of the window purely on financial grounds; the payback time (as is true for many energy efficiency systems) is too long.

EU Project

This work has formed the basis of a successful EU proposal to install Supply Air windows into houses in Denmark and Ireland, and flats in Poland coupled with a PSV system and pressure controlled vents to offer a completely passive method to improve ventilation and heat insulation. Denmark and Ireland will receive test installations investigating the effectiveness of additional next generation pressure controlled vents and compact noise attenuation technology. The Polish installations will be fitted out with the basic window design as described here as a demonstration. Denmark and Ireland will each consist of a test and control house with the control house possessing typical ventilation strategies for the two countries i.e. mechanically ventilated heat recovery system in Denmark, and kitchen/bathroom extract fans in Ireland. The aim of the project is to analyse the performance of the innovative features incorporated into the window and to demonstrate the effectiveness of the whole passive ventilation system at delivering a low cost solution to the problem of improving thermal insulation whilst maintaining good indoor air quality and comfort.

Acknowledgements

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