AIVC 11116

DISPLACEMENT VENTILATION APPLICATIONS - AN ALTERNATIVE VIEW

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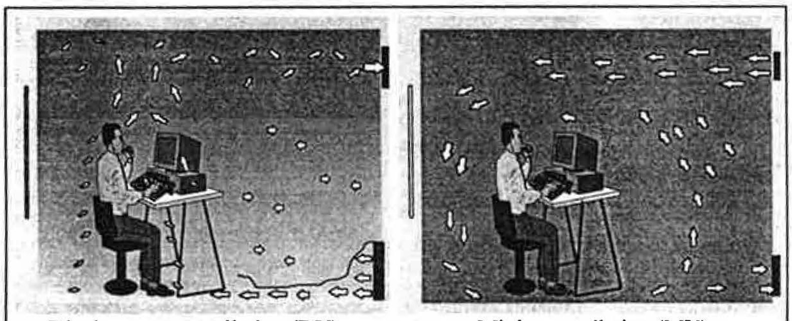
This paper critically reviews current and previous research into the use of displacement ventilation in commercial offices with and without supplementary static cooling devices. It also reports the findings of a preliminary study of a displacement ventilation technique that may increase the scope of application for displacement ventilation systems without the need for supplementary static cooling.

1. Introduction

Buoyancy driven displacement ventilation, involves the introduction of fresh air into a space at low level, at a temperature slightly lower than the room air temperature (Fig.1). The cooler air tends to spread across the floor until local heat sources cause convective plumes to rise. Claims that displacement ventilation provides better air quality in the breathing zone, with a reduced energy requirement when compared with a mixed dilution ventilation system are well documented.[1][2][3] A displacement system can achieve a high ventilation effectiveness when the internal sources produce both heat and contaminants, as is the case with people and some office equipment. The benefits available if these principles can be delivered in practice, are improved indoor air quality and also lower energy consumption due to lower flow rates and more free cooling, with supply temperature typically 19-21°C. The vertical temperature gradient produced by displacement flow, results in higher temperatures at ceiling level than with a dilution or "mixing" system. The main limitation of displacement ventilation in offices is the ability to remove high internal heat loads while maintaining an acceptable temperature gradient within the occupied zone.



Displacement ventilation (DV) Mixing ventilation (MV)

Fig.1. The Principle of Displacement Ventilation

In the belief that a better understanding of the mechanisms of displacement ventilation will reduce the level of uncertainty in the design of such systems, a wide range of research activity is being undertaken across Europe and in the Far East. This paper describes developments to date, and identifies areas where further research may be required. Three broad categories of research have been identified:

- to develop underlying theory with the aim of providing guidance for designers
- to establish the limitations of application, and the effects of cold surfaces and obstructions on displacement ventilation
- to investigate the merit of combining displacement ventilation with static cooling systems to bring offices with high cooling loads the benefits of displacement ventilation without overheating problems.

2 DEVELOPMENT OF UNDERLYING THEORY

The approach to this area of work is varied. Some teams have concentrated their activity in one field of the model shown in Fig. 2, whereas some have worked holistically towards offering design advice. Single focus research has contributed some useful findings as described below:

Sandberg[4] has investigated the effect of movement of a heat source within the space, (i.e. a person walking across the office), and concluded that movement lowers the stratification height and causes oscillations of the interface. This was predicted by mathematical modelling, and confirmed by conducting tests on a scale model.

This work identifies a possible problem although a view is put forward by Wyatt[5] that a thin "personalised" boundary layer of fresh air is maintained in the breathing zone despite the lowering of the interface.

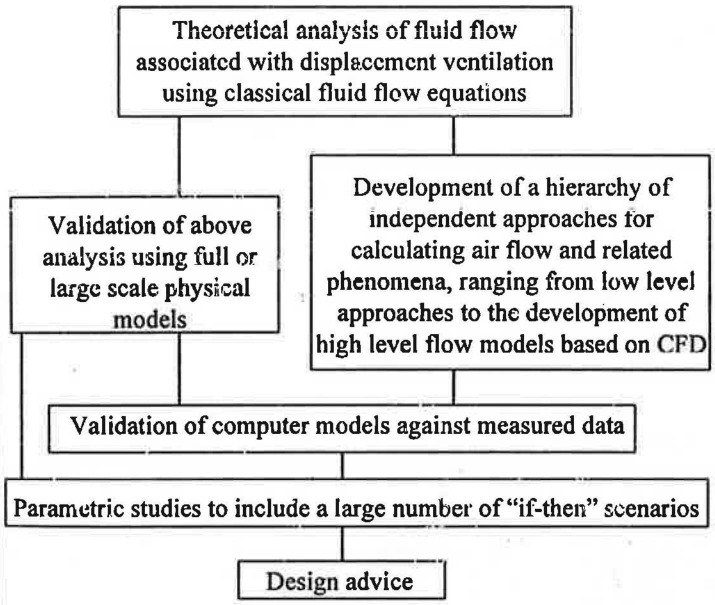


Fig.2. Research Model

Examples of the "total concept" approach to research generally include the verification of a CFD package as a design aid.

Alamdari[2] has used a combination of site measurements and computer modelling to confirm the variation of room air temperature with height for displacement ventilation systems. Confidence is expressed in the CFD modelling to investigate further the problems of floor level obstructions and down flow from cold surfaces.

As the air velocities in the test room experimental work were too low to measure, Holmberg[6] turned to computer modelling to demonstrate that a horizontal displacement effect could be achieved without help from thermal forces. A similar conclusion was made by Alamdari[2].

3 LIMITATIONS OF APPLICATION

A number of claims are made about the amount of cooling that can be handled by a displacement ventilation system. Values of 70 - 100 W/m^2, M Koganei[7] 40 - 50 W/m^2 C Twinn[8] are examples that show that there are conflicting views. This may be the reason that designers are looking for additional cooling via "static" devices.

There are also conflicting claims over the real air quality benefits associated with displacement ventilation. Cox[9] measured a ventilation effectiveness of 1 in a test room, no better apparently than a good dilution system. Guntermann[10] identified an improved air quality at a height of 1 - 1.4 m near heat sources. Lauriken[11] states that with displacement ventilation, air quality may be 3 times better than with a dilution system with the same air flow rate. Breun[12] links relative improved air quality with increasing air charge rates when comparing displacement with dilution systems.

Although the findings of all four researchers may be accurate and correct, the apparent conflict may simply be due to the fact that they are reporting on different situations, Sateri[13] identifies the need to measure air quality in the breathing zone. With a mixing system (assuming perfect mixing), the measurement of contaminants can be taken anywhere in the room to calculate ventilation effectiveness, whereas with a displacement system the level of contaminant is very variable with location in the room, and if the effectiveness is to reflect the experience of the occupant, it is only the breathing zone that is relevant.

4 PREVIOUS WORK ON DISPLACEMENT WITH STATIC COOLING

A number of researchers[1][2][7] have suggested that downward convection due to cold surfaces such as windows or cold external walls will seriously disrupt the buoyancy driven displacement flow. This is considered a sufficient disturbance to break down the stratification boundary, mixing air from the contaminated upper zone with the clean lower zone, negating the main benefit of the displacement system.

Krohne[14] has concluded that displacement ventilation in combination with cooled ceilings, does not always have an advantage over mixing ventilation where air quality is concerned, but that thermal comfort conditions are achieved. Recent physical tests carried out at BSRIA support this finding. Using a model room facility incorporating a displacement ventilation system with a chilled panel ceiling, smoke visualisation tests were carried out, releasing test smoke above the false ceiling. It was observed that the room rapidly became contaminated by the smoke. On inspection, it was evident that smoke was falling through every extract grille and unsealed joint in the ceiling. This indicates that air in the ceiling void is being cooled by the reverse side of the chilled panels, and there is insufficient pressure difference between the room and ceiling void to overcome the resulting negative buoyancy.

Although this re-circulation effect enhances the heat exchange from the chilled panel, it is destroying the air quality characteristic of the displacement ventilation system. The work at BSRIA concludes that where static cooling devices are used in conjunction with displacement ventilation systems, care should be exercised in the specification and construction of the ceiling, (i.e. sealed joints), to ensure positive air flow from room to ceiling void.[15] Further, in the case of chilled panels, the insulation on the back of the panel within the ceiling void must be in place.

Additionally, work carried out by Taki(16) indicates that the temperature of the chilled water is influencing the displacement flow increasingly as it reduces from 21°C, and that with a ceiling temperature of 14°C, displacement flow is completely destroyed.

Despite this concern, there is significant research activity into the use of static cooling with displacement ventilation to counter the risk of thermal discomfort due to high heat gains, and also considerable commercial exploitation of the technique.[2][5][17][18] This activity seems to be driven by the over-riding need to reduce design risk of overheating which is easily perceived by the building occupants at the expense of air quality which is less tangible. This could arguably be overlooking current design philosophy in two major respects in addition to the air quality concerns. The positioning of static cooling at ceiling height introduces a false or lowered ceiling with the following consequences:

* the creation of a barrier to building fabric thermal storage by the ceiling slab.
* the depression of the high temperature zone towards the occupied zone.

An alternative method of applying static cooling to the displacement ventilation system is proposed by Ma[19], who suggests supplying chilled water to the heating system radiators. This will provide some cooling effect without the disadvantages identified above, and as the radiators are located low in the pool of clean air, their downward convection should not significantly reduce air quality and may in fact assist the displacement flow. This system also has cost benefits over a chilled ceiling, but further work is required as there is little information of the cooling performance of radiators, or the ratio of radiant to convective output.

5 RECENT WORK

One element of the recent work at BSRIA has been to establish the limitations of displacement ventilation in dealing with heat loads. It has been recognised that the primary limitation is the amount of air that can be provided through conventional wall or floor mounted displacement diffusers without causing discomfort due to draughts. Preliminary studies carried out at BSRIA using fabric diffusers indicate that it may be possible to deal with higher heat loads without causing draughts(20). Studies investigating the interaction of chilled ceilings with semi-cylindrical wall mounted displacement diffusers had already been carried out in a test room measuring 10m x 6m with a floor to ceiling height of 2.7m, as shown in Fig.3. Although it proved difficult to match the room heat load exactly, the results from these studies would provide the reference for the tests with the fabric diffusers, with respect to their ability to limit the temperature rise in the room.

Air speed and air temperature measurements in the space were carried out using two arrays of six Dantech 54R10 probes incorporating spherical omni-directional hot film anemometers and thermistors. The probes were mounted on mobile stands, which could then be positioned on the grid points in the test room. The 4 semi-cylindrical diffusers were replaced by 2 polyester/cotton fabric diffusers, installed in 10m lengths on opposite walls of the room. These diffusers, normally used in the food preparation industry, were custom made in a "D" section for this experiment.

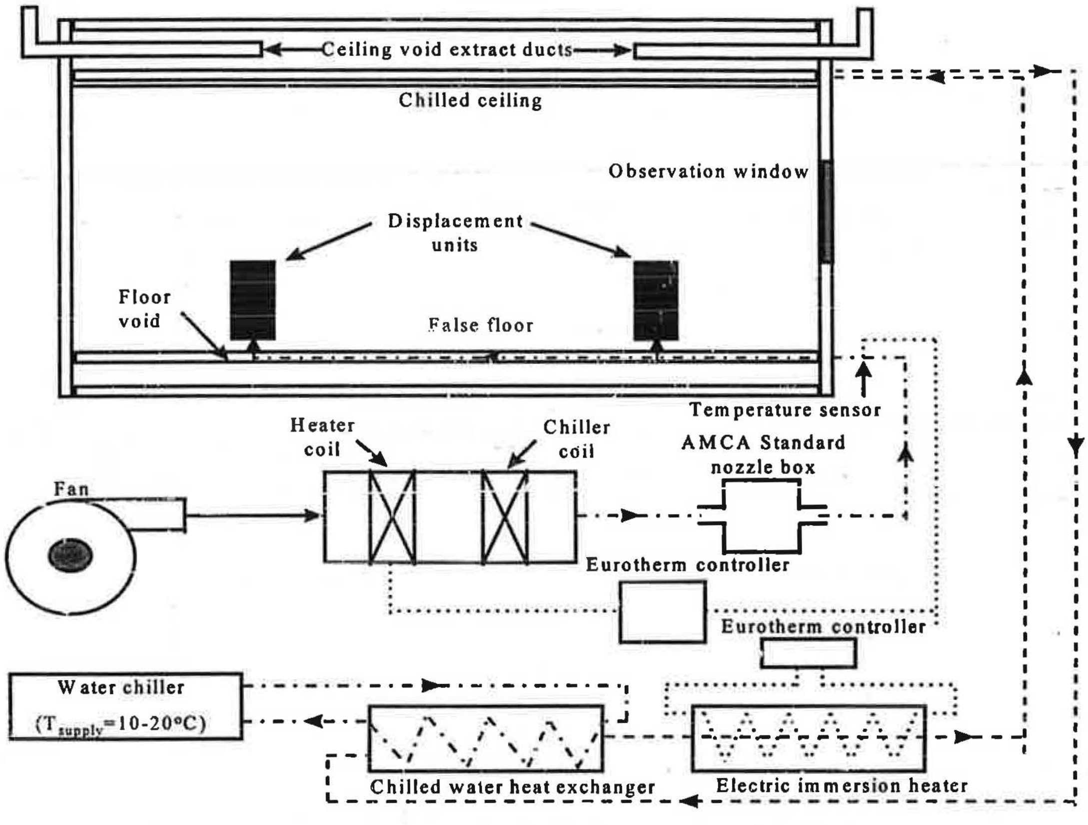


Fig.3. Original Test Room

With a heat load of 50W/m^2 provided by PCs, 100W heaters simulating people, and a photocopier, arranged as shown in Fig. 4, and an air change rate of 9.3 per hour, the maximum output of the fan, conditions were monitored in the test room. These were compared with earlier results from the same room using standard semi-cylindrical metal diffusers when the heat load was 40 W/m^2 and the air change rate 3.5 per hour.

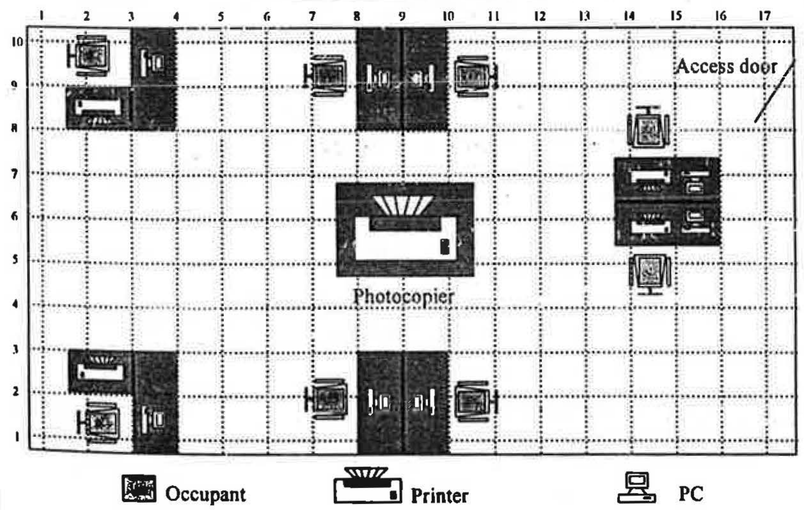
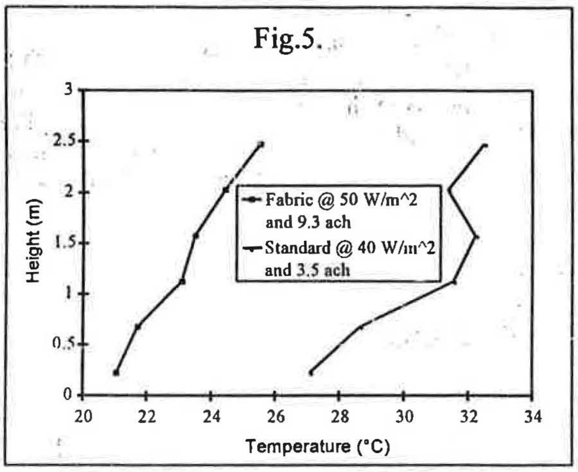
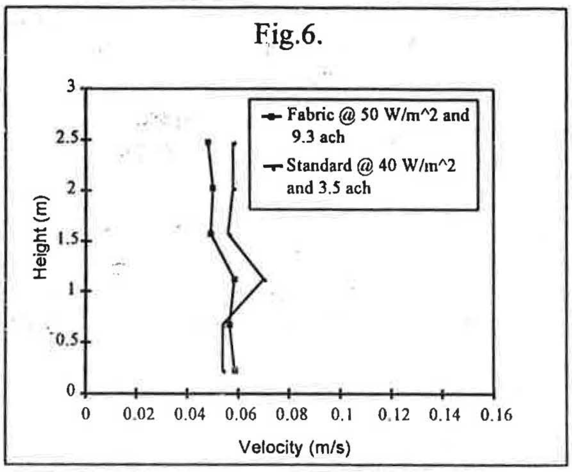


Fig.4. Floor plan of original test room showing test grid points

Fig. 5 shows that despite the slightly higher load the average air temperatures in the room were significantly lower using the fabric diffusers with the higher air change rate, as would be expected. However, Fig 5 shows that the average velocities produced by the fabric diffusers were very similar to those produced by the bin diffusers. Encouraged by these preliminary findings, further tests were carried out to directly compare the performance of the fabric diffuser with and without a chilled ceiling panel.





A number of shortcomings were identified with the original test room, the most significant being the difficulties in maintaining steady state conditions for the length of time involved in logging the conditions. As these shortcomings reduced confidence in the results, the experiment was repeated under more controlled conditions. A smaller test room 4.5m x 4.5m was constructed within the original room, resulting in a reduction in measuring time, and giving more stable conditions around the room. The modified arrangement is shown in Figs 7 and 8.

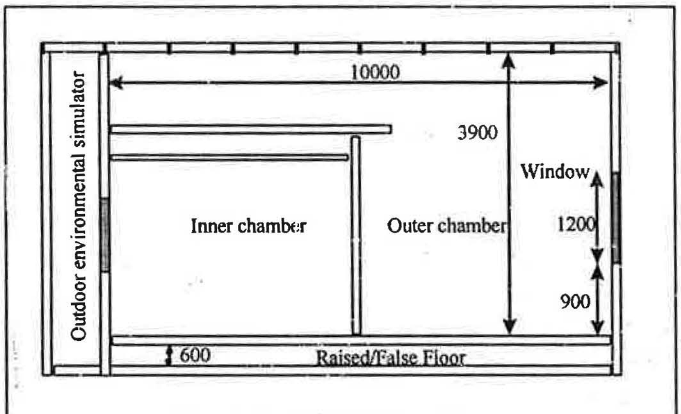


Fig.7. Modified Test Room

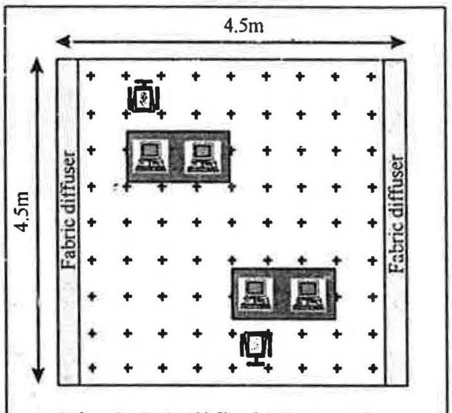


Fig.8. Modified Floor Plan

With a room load of approximately 60 W/m^2, (57 W/m^2), the performance of the fabric diffuser supplying 3,6, and 9 air changes/hour was compared with the performance of the fabric diffuser supplying 3.5 air changes/hour assisted by a chilled ceiling panel. With the panel operating, the water supply temperature was 14.5°C, providing 950W of cooling, and the ventilation air, 200W. The load and panel assisted air supply rate were selected to match tests already conducted as part of the BSRIA Code of Practice programme, and the maximum air change rate for displacement ventilation only was selected close to the rate that had been successfully established in the previous test facility. Only the results at 9 air changes have been shown for clarity. Temperature, velocity, PPD and PMV are used as performance indicators. ISO 7730[21] recommends the following:

* vertical temperature gradient of 3K from ankle to head (approx 3K/m seated)
* velocity less than 0.15 m/s in winter, 0.25 m/s in summer
* PPD less than 10
* PMV between -0.5 and +0.5

Fig.9

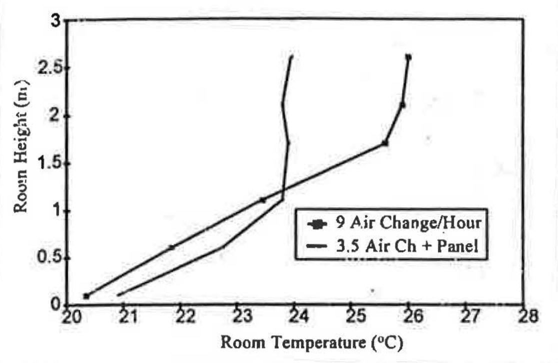


Fig.10

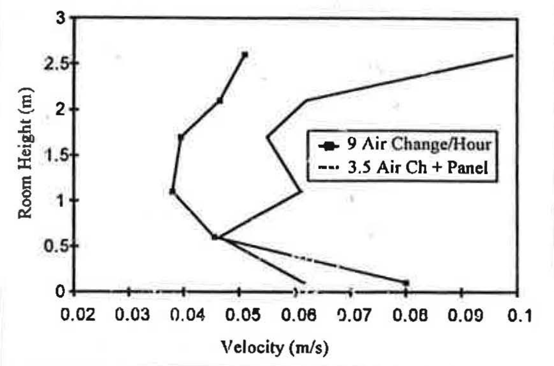


Fig.11

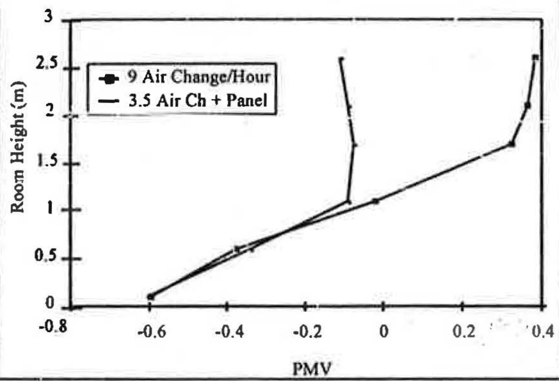


Fig.12

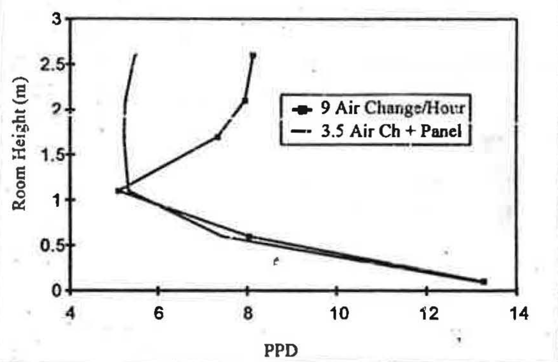


Fig. 9 shows that the fabric diffuser at 9 air changes produces a uniform temperature gradient to a height of 1.7m, indicating a good displacement flow to this height. For seated occupants, the temperature gradient is acceptable. It is possible that without the suspended ceiling, this situation would be improved as the maximum temperature would be reduced. Fig 10 indicates that there are no velocity problems when using the fabric diffusers at 9 air changes per hour. Figs 11 and 12 indicate that acceptable PMV and PPD limits are exceeded at low level with the fabric diffusers. This is where velocities are known to be highest and the temperatures are lowest. Adopting the same measurement grid configuration as for the standard semi-cylindrical metal diffusers, 18 low level readings were taken with the probes actually pushed into the fabric diffusers. If these readings were to be excluded from the analysis, the fabric diffusers could be expected to provide better comfort conditions.

6 CONCLUSIONS

In the field of research into Displacement Ventilation examples have been found of contradictory research findings. This can be explained at least in part, because the objectives, the parameters considered, and the assumptions made, were different. There appears to be some merit in attempting to standardise this. For example, when establishing the ventilation effectiveness of displacement systems, a standard measuring point for level of contaminant should be stated.

Particular problems that require further research to reduce the design risk in applying displacement ventilation systems more widely are:

i) environmental performance assessment and comparison of displacement ventilation with chilled ceiling devices and displacement ventilation with low level wall mounted systems (such as radiators).

ii) consistency of input data for CFD analysis, particularly in representation of air terminal devices, heat sources, moving objects and also in appropriate mathematical modelling of radiation heat transfer.

iii) the problem of dealing with higher cooling loads, without resorting to static cooling with the associated problems identified in 4 above, should be addressed. The findings described in 5 above present the hypothesis that the number of applications for displacement ventilation without static cooling could be increased if larger air volumes could be supplied without causing draughts at low level, or causing noise problems. Additionally, given the higher ventilation efficiency, it is likely to be advantageous to use fabric diffusers where contaminant control rather than temperature control is the over-riding factor, such as where smoker/non-smoker segregation is an issue. Comfort limits in terms of velocity are not challenged at all with these diffusers at 9 air changes per hour. These preliminary tests with a fabric diffuser are very promising and further physical tests and CFD modelling are proposed.

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