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The Effect on Ventilation Parameters of Various Ventilation Strategies

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1 Synopsis

The work described in this paper is aimed at predicting the local values of the ventilation effectiveness parameters of large industrial buildings by a technique which involves the use of computational fluid dynamics and multizonal modelling.

A modelling technique is described and applied to a typical modern industrial building equipped with both, mixing and displacement ventilation systems. The results of modelling each of the above systems are presented and discussed. They provide an interesting insight into magnitude and spatial variations in of local air change index that occur in the occupied space. The results also demonstrate how differences in ventilation strategy can result in distinctly different variations of ventilation effectiveness parameters.

It is concluded that the modelling technique described may be used to provide important information about the air movement characteristics of buildings in terms of local air change index and also that it could prove to be a very useful design aid.

2 List of Symbols

Symbol		**Units**
ε_p	local air change index at point p	
$\bar{\tau}_p$	local mean age of air at point p	s
τ_n	nominal time constant	s

3 Introduction

Ventilation effectiveness parameters provide a valuable insight into the air movement characteristics of enclosures. They are of particular importance in the case of buildings which contain large undivided internal spaces since the characteristics of such buildings are particularly difficult to predict. In addition, effective ventilation strategies to remove the contaminants associated with the industrial processes frequently carried out in such buildings are essential if risks to health are to be avoided. However, the measurement of ventilation effectiveness parameters is restricted to the relatively small number of points at which tracer gas can be sampled. It is therefore of value to be able to model the behaviour of air within large buildings in order to predict the magnitude and variation of the parameters. This work represents a development of that reported by M W Simons et al [1] which because of computational constraints was restricted to buildings subdivided, for the purpose of CFD analysis, into a small number of zones

4 Ventilation Effectiveness Parameters

Ventilation effectiveness parameters which have been devised to allow the variability of the air movement within a space to be studied may be subdivided into the categories of **air change efficiency** and **contaminant removal efficiency**. Air change Efficiency parameters have been devised to establish how effectively the air within an enclosure is replaced by fresh ventilating air which is the purpose of the present study. The most commonly used are:

i Local mean Age of Air, $\bar{\tau}_p$

This is defined as the average time taken for air to travel from the inlet to any point p in the room and may be written as:

$$\bar{\tau}_p = \int_0^\infty t.A_p(t).dt$$

where $A_p(t)$ represents the age distribution curve for air arriving at point p. The local mean age of the air is different at each point, p within the room.

ii Local Air Change Index (LACI), ε_p

This index provides a measure of the age of the air at a point relative to the overall supply rate being defined as:

$$\varepsilon_p = \frac{\tau_n}{\bar{\tau}_p}$$

where τ_n is the nominal time constant of the room. The nominal time constant is the reciprocal of the ventilation air change rate.

It will be observed that a value of LACI greater than 1 indicates that a point is receiving air more efficiently than the average and that the higher the index, the better the ventilation. The opposite applies to values less than 1. The result of the current study have been expressed in terms of LACI.

5 Experimental Procedure

5.1 The approach adopted has been to first undertake a CFD analysis of the internal space in order to establish intercellular flows. The CFD software used for this work was 'Flovent' by Flomerics. The intercellular flows were then post processed by inputting them as interzonal flows into software developed at Coventry University to undertake a multizonal analysis and hence establish the relevant ventilation effectiveness parameters.

A significant difference in the post processing software used here and that reported previously is that it has been necessary to replace the standard matrix inversion routines with a customised solver specially designed to handle the very large sparse matrices involved.

Software has been made available from 'Flomerics' to return the computed ventilation effectiveness parameters to Flovent for the purposes of presentation.

5.2 Investigation of several buildings has been undertaken, one of which has been selected for presentation here as an example of the information that can be derived.

The building chosen, which is shown in Figure 1, is representative of the type of modern building that could be used for engineering manufacture in a location where extremes of climatic conditions may be expected. The building was selected to closely resemble a Finnish factory unit which has been used as a case study for the International Energy Agency Annex 26 Project "energy Efficient Ventilation of Large Enclosures" by the Finnish Institute of Occupational Health [2].

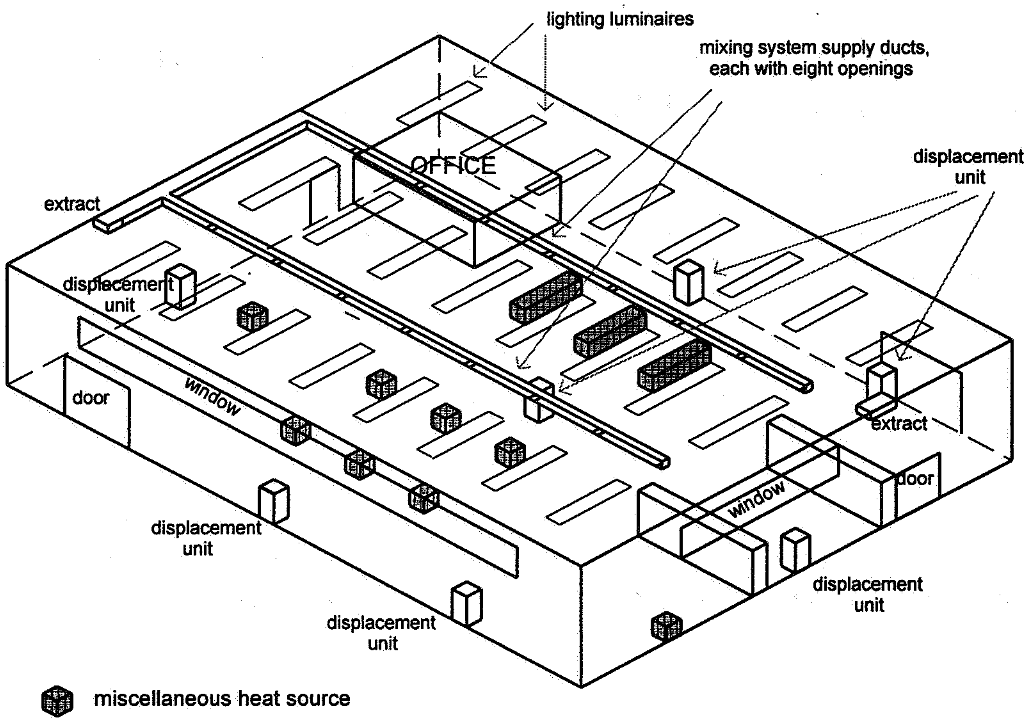

Figure 1 Factory with mixing and displacement ventilation systems

The model is of a factory 40m by 30m in plan and 8m high with wall, roof and window thermal transmittances of 0.45, 0.25 and 2.8 $Wm^{-2}K^{-1}$ respectively. Various incidental heat sources are present within the building as indicated in Figure 1.

Mixing and **Displacement** ventilation systems have been modelled assuming the environmental conditions described below:

i Mixing Ventilation System

An ambient temperature of 5^0C is assumed and air is supplied through 16 roof mounted duct openings each supplying 0.44kgs^{-1} (0.37m^3s^{-1}) at 18^0C. This gives an overall air change rate of 2 per hour and corresponds to winter heating in the UK.

ii Displacement Ventilation System

An ambient temperature of 22^0C is assumed and air is supplied through 7 floor mounted displacement flow diffusers at a velocity of 0.3ms^{-1} and a temperature of 14^0C. The data used for the performance of the diffusers is typical of currently manufactured products. This gives an overall air change rate of 2.2 per hour and corresponds to a low level, low turbulence displacement supply suitable for providing summer cooling in the UK.

6 Consideration of results

6.1 Mixing Ventilation System

Figure 2 illustrates the air velocity vectors and temperature gradients 1.5 m above floor level with the mixing ventilation system operational. This shows an acceptable velocity distribution and uniform temperature of between 18.5^0C and 19^0C, the temperatures above 19^0C corresponding to positions immediately above the heat sources.

If the mixing system was working perfectly, the value of the LACI would be unity throughout the space. However, Figure 3 clearly shows that despite the apparently satisfactory airflow patterns, the values of LACI at head height range from values in excess of 1.10 close to the supply openings down to values below 0.90 over a significant proportion of the working space. The areas with low values of LACI correspond to those areas where air movement is least. The variability of the LACI is also shown in Figure 4 where inspection reveals that on vertical planes remote from the supply openings, the value of the index follows a similar range, from 0.85 to 1.15.

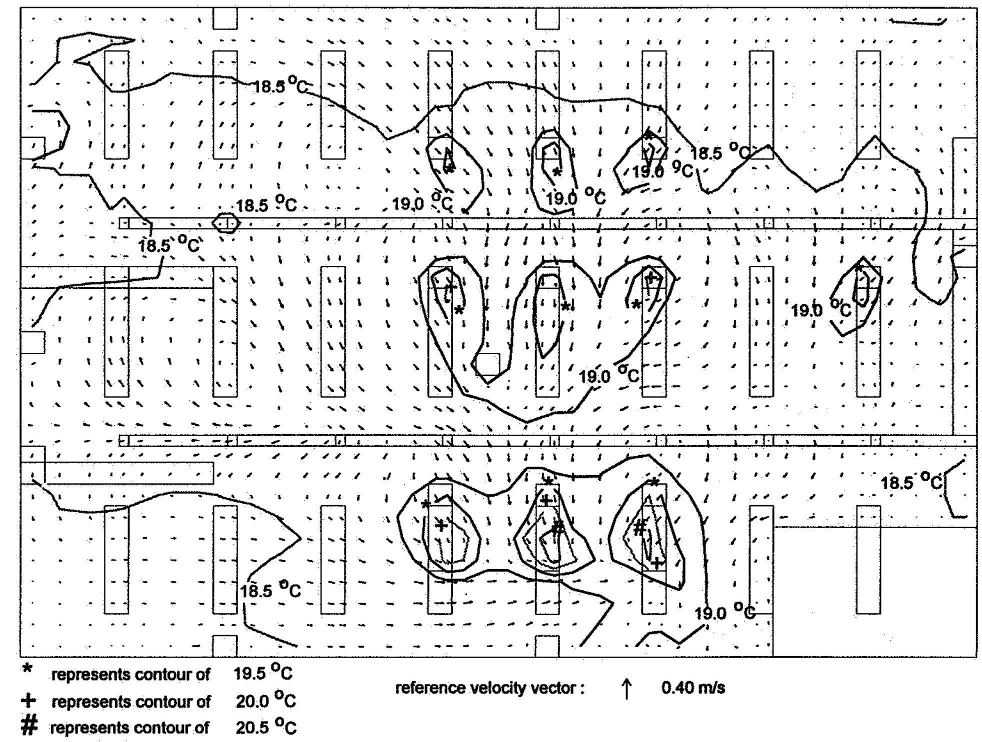

Figure 2
Mixing Ventilation Velocity Vectors and Temperature 1.5m Above Floor Level

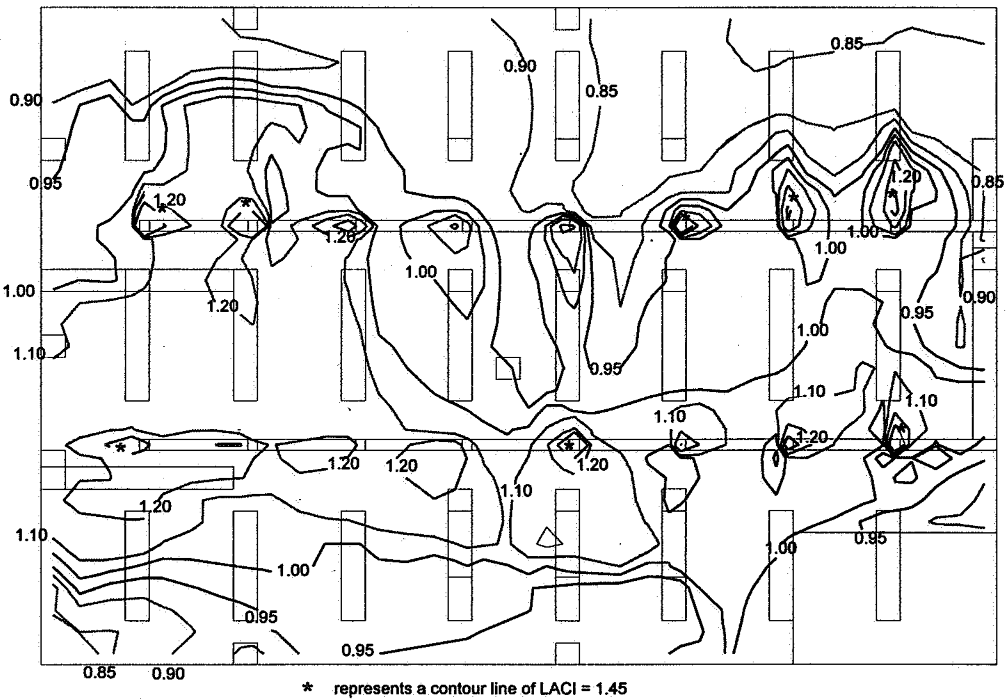

Figure 3
Mixing Ventilation LACI Contours on Plane 1.5m Above Floor Level

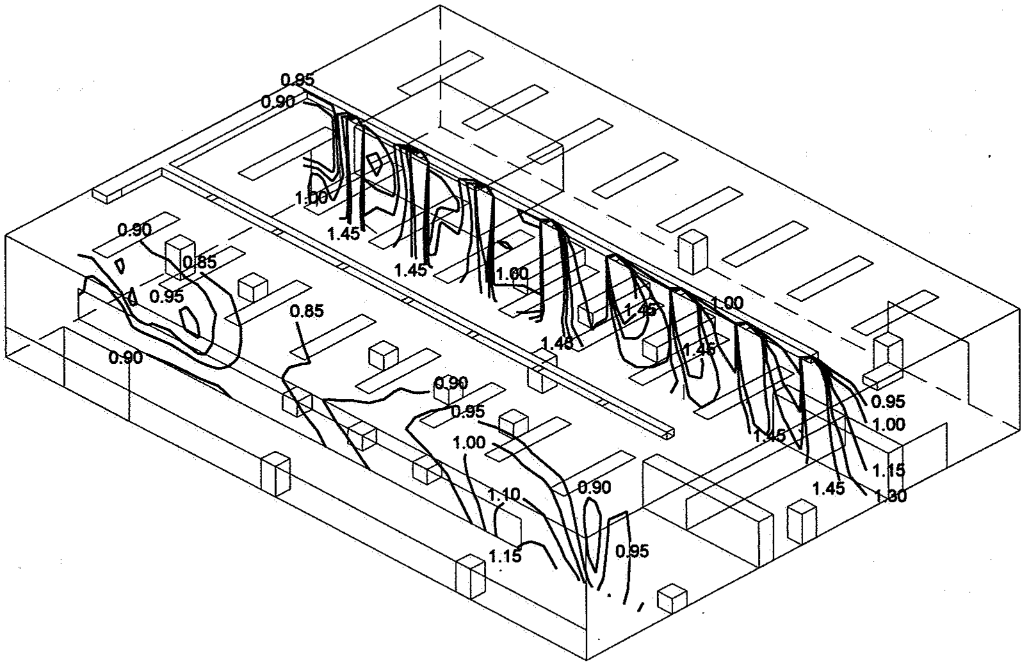

Figure 4 Mixing Ventilation
Contour diagrams of LACI on vertical planes

Figure 5 illustrates the magnitude of LACI close to the mixing ventilation supply outlets. It is interesting to observe how rapidly the index reduces in close proximity to the supply outlets and that values of less than unity are present within 2m of them, showing that high values of LACI are restricted to the immediate vicinity of the outlets

The overall conclusion is that the mixing system is behaving satisfactorily.

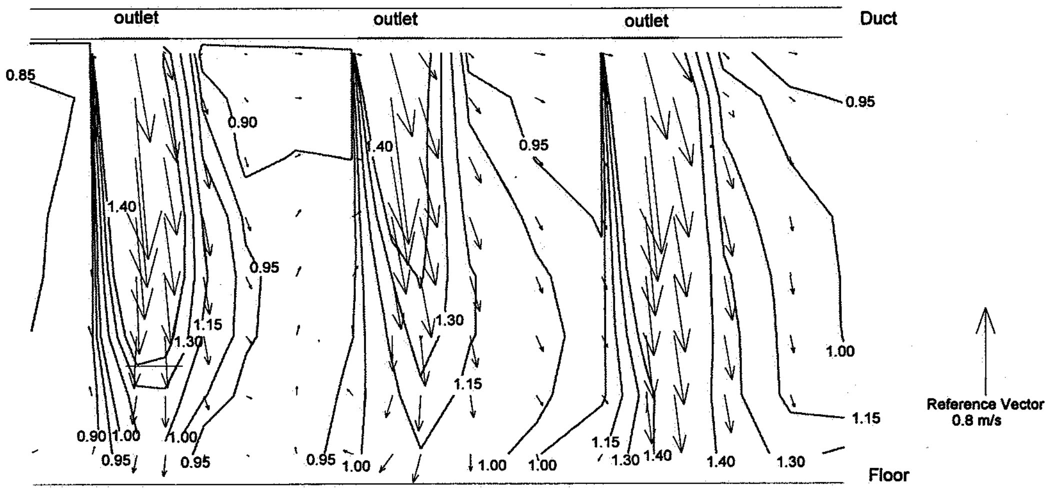

Figure 5 LACI Contours and Velocity Vectors in Vicinity of Mixing System Outlets

6.2 Displacement Ventilation System

Figures 6, 7 and 8 illustrate the LACI contours, at heights of 0.5m, 2.5m and 5.5m respectively above floor level, resulting from operation of the displacement system. These figures clearly show that the values of the LACI are high at the low level and decrease with height above floor level. However they also show a considerable variation across these horizontal planes, i.e.:-

Height(m)	Range of LACI	
	from less than	to greater than
0.5	1.3	1.9
2.5	0.8	1.3
5.5	0.7	1.3

with the proportion of the area at a high value decreasing with height. The variability of the LACI in the vertical plane is also clearly shown in Figure 9.

The interpretation of these contour diagrams is that whereas the displacement system is **on average** behaving as expected, there are notable variations, with a significant area at a height of 2.5m with an LACI of less than 1. It appears that in addition to the upward movement of air caused by the displacement units, there is a circulatory motion with air rising in some regions (high values of LACI) and falling in others (low values of LACI). The contours in Figure 8 show this particularly well.

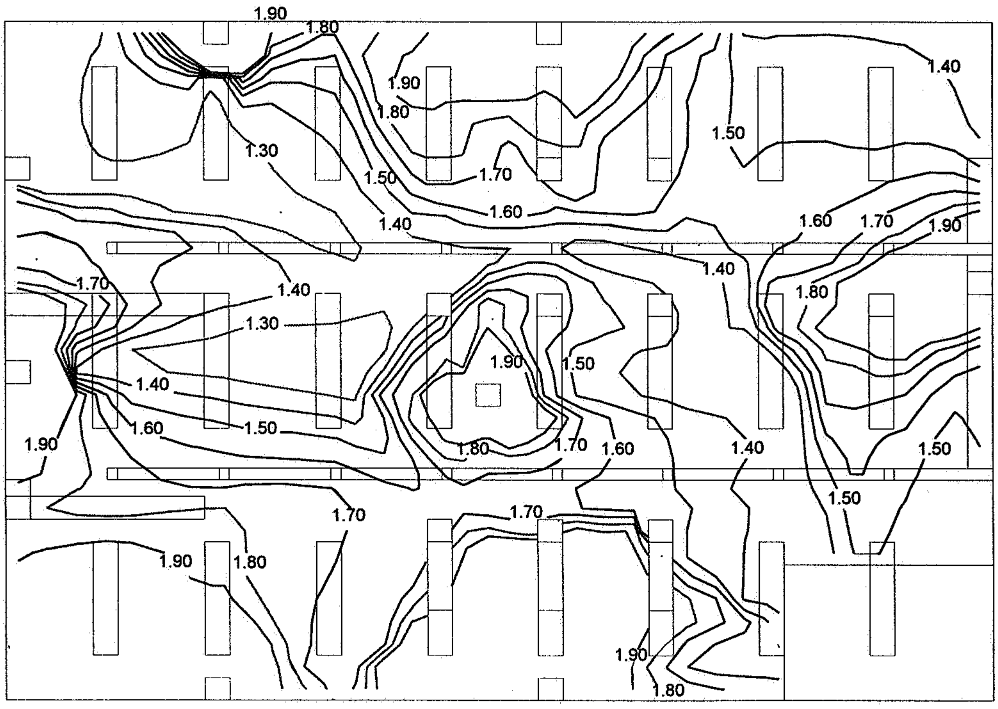

Figure 6
Displacement Ventilation LACI Contours on Plane 0.5m Above Floor Level

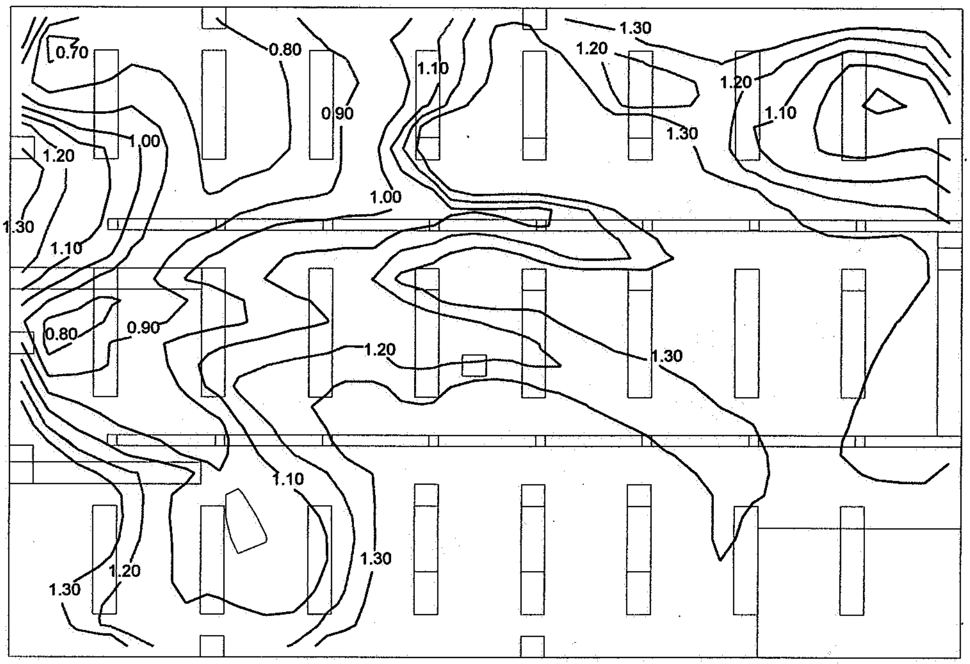

Figure 7
Displacement Ventilation LACI Contours on Plane 2.5m Above Floor Level

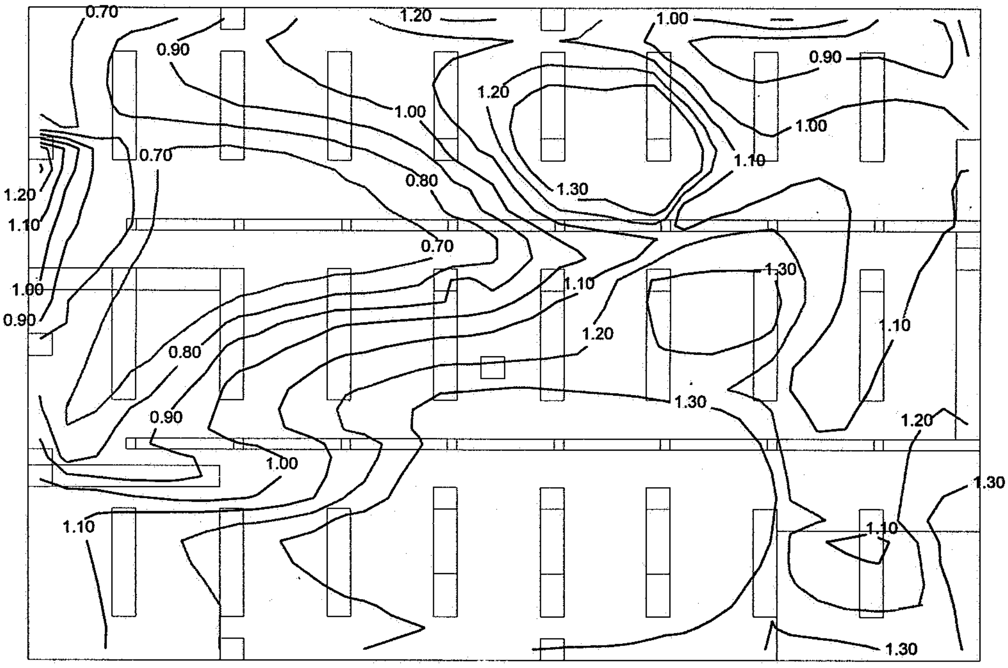

Figure 8
Displacement Ventilation LACI Contours on Plane 5.5m Above Floor Level

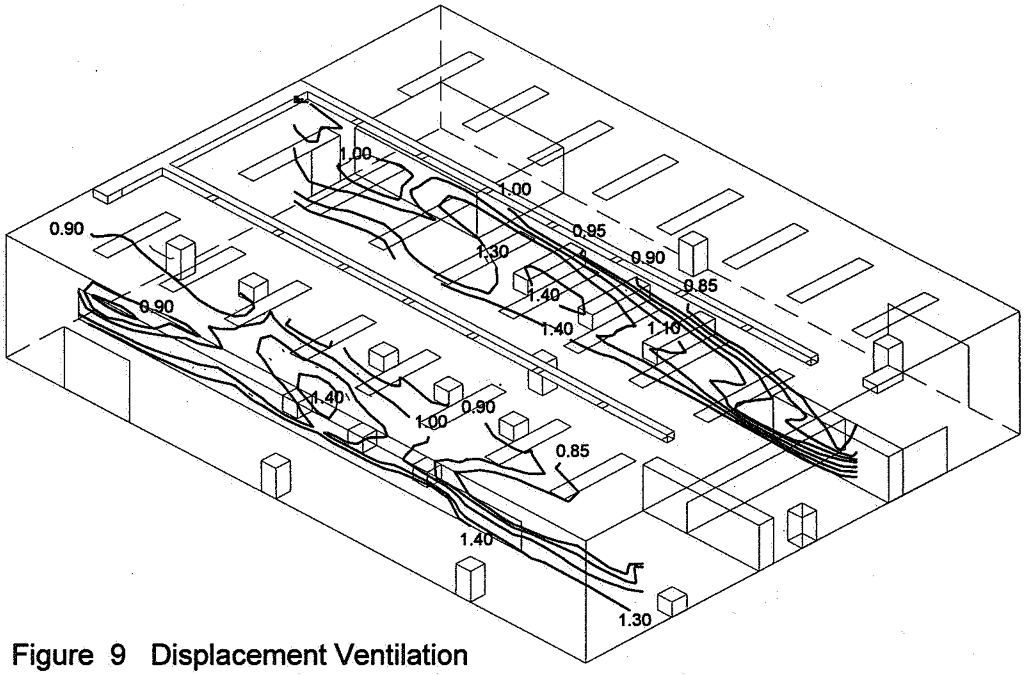

Figure 9 Displacement Ventilation
Contour Ddiagrams of LACI on Vertical Planes

7 Conclusions

The output from CFD analysis has been successfully analysed by the multizonal modelling technique to provide local values of ventilation effectiveness parameters. It has been applied to two distinctly different mechanical ventilation systems thereby demonstrating the usefulness of the technique as a design tool and the value of air change efficiency parameters in assessing the performance of buildings.

The results show that the two ventilation systems are working generally as expected. However the LACI contour diagrams for the displacement system show that the air distribution patterns are more complex than a simple analysis would suggest.

8 References

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