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CHILLED CEILINGS AND DISPLACEMENT VENTILATION

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ABSTRACT

Displacement ventilation and chilled ceiling systems have been promoted as being 'greener' alternatives to other common forms of air conditioning system. They have been viewed by some of the building services industry as a welcome departure from the traditional 'North American' systems of air conditioning most frequently adopted to date, and could be viewed as a more suitable alternative for use in the moderate climatic conditions of the UK.

This paper reviews some of the authors' recent and current work on the performance of these systems in office environments. © 1998 Published by Elsevier Science Ltd. All rights reserved.

KEYWORDS

Chilled ceilings; chilled beams; displacement ventilation

INTRODUCTION

There is currently an upsurge of interest in the application of displacement ventilation systems and chilled ceiling devices in office spaces within the UK ventilation and air conditioning industry. Although these systems, individually, have been in use on the continent for many years, their combined performance and effectiveness has been in doubt.

Displacement ventilation systems have gained popularity amongst designers because of the potential benefits they can provide in creating thermally comfortable environments with high ventilation effectiveness. Although these systems have some cooling capability, their prime function is to provide the fresh air requirements of occupants. The additional cooling requirement, however, may be provided by the adoption of appropriate 'static' cooling techniques such as chilled ceilings, whilst preserving the displacement upward flow concept.

Chilled ceiling and displacement ventilation systems have been promoted as being 'greener' alternatives to other common forms of air conditioning system such as variable-air-volume and fan-coil systems. Further, since chilled ceilings operate with relatively high chilled water temperatures, usually around 14°C to 16°C, they may make use of one of a number of low energy or free cooling alternatives to mechanical refrigeration which have the potential to reduce the energy consumption and CO_2 emissions associated with the building cooling system.

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ENVIRONMENTAL PERFORMANCE

To examine the environmental performance of combined displacement ventilation and chilled ceiling systems a combination of physical and computer modelling techniques was used by Alamdari and Eagles (1996). The main objective of their study was to determine whether the combination of these systems could maintain adequate levels of thermal comfort and a predominant upward displacement airflow within the office environment.

Alamdari and Eagles introduced air at 3.5 ach^{-1} and 19°C at low level via wall mounted displacement air terminals to the space (Figure 1). The selection of the flow rate and temperature was based on thermal comfort rather than air quality requirements (Jackman, 1990). In this way the overall room heat load and the vertical temperature gradient (2 K/m) determined the overall temperature difference and the airflow rate.

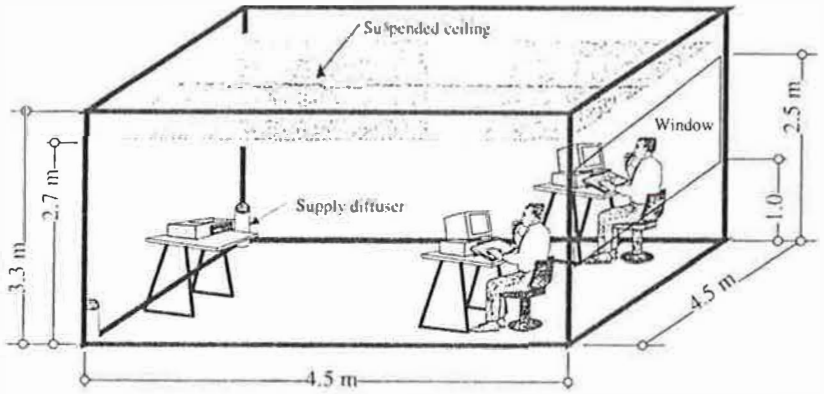

Figure 1 Schematic diagram of the space considered

Initially, the displacement ventilation flow field was characterised for an internal heat load of 20 W/m^2. Internal gains were then increased in increments of 20 W/m^2 up to a maximum load of 80 W/m^2. At load settings of 40 W/m^2 and above, chilled beams or chilled panels were operated to provide the additional cooling necessary.

Figure 2 shows the predicted velocity vectors and air temperatures within the office with displacement ventilation. The predictions indicated that displacement airflow patterns were established when the thermal loads were matched to the cooling capacity of the displacement ventilation system. The warm mixed airflow region extends from the top of the seated people to the ceiling. Although the depth of this mixed-flow region can be reduced by adopting a higher ventilation rate, based on air quality calculation methodology (Jackman 1990), this will increase the air flow rate to almost double the one considered here. However, to achieve the same comfort level higher supply air temperatures will then be required (≈ 21-22°C). It is important to note that the quality of the air, which would be breathed by an occupant, differs from that at breathing height in the room, as the convection currents created by the person draws it from below.

When displacement ventilation with chilled ceilings were considered, the predicted airflow patterns indicated more downward convection than in the pure displacement ventilation case (see Figure 3). However, upward convection was dominant in the vicinity of the occupants. The plane-averaged vertical variation of environmental (ie air temperature and air speed) and thermal comfort parameters (predicted percentage dissatisfaction and predicted mean vote) are shown in Figure 4. The predicted mean vote and the percentage of occupants' dissatisfaction were well within the recommended ranges specified by ISO 7730 (1984). Indeed, in all of the cases considered, thermal comfort was of a very high order, ie better than or equal to 90% occupant satisfaction.

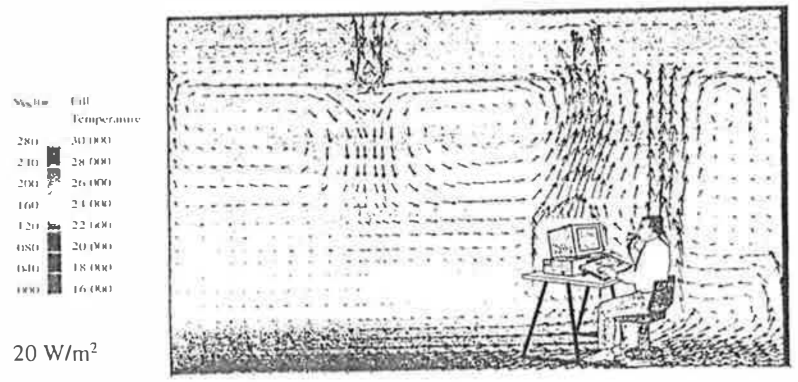

Figure 2 Airflow and thermal field [source, Alamdari et al (1996)]

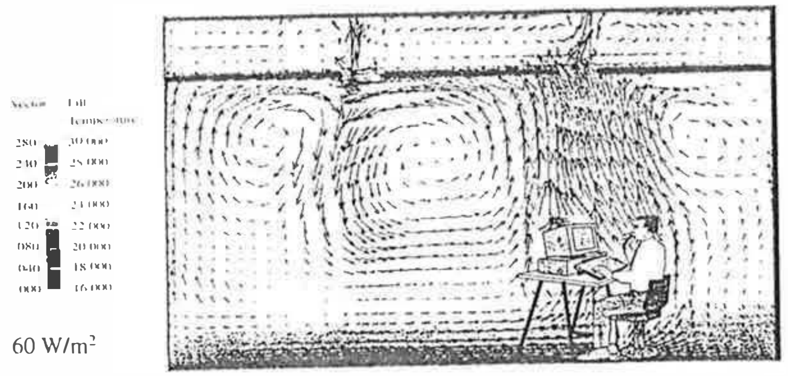

Figure 3 Airflow and thermal field [source, Alamdari *et al*., 1996]

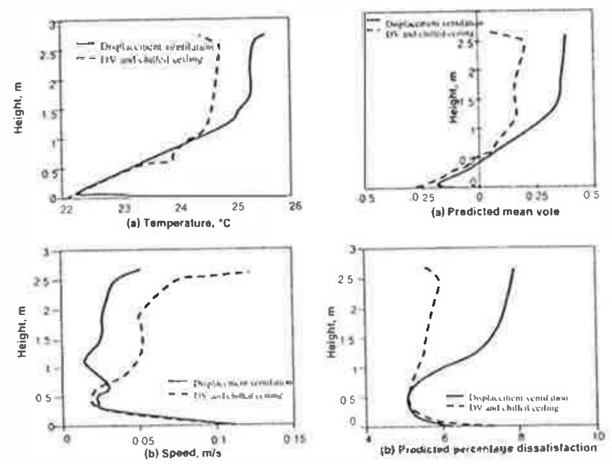

Figure 4 Variation of environmental and comfort parameters [Alamdari *et al*., 1996]

LOW ENERGY COOLING

Low energy cooling alternatives to mechanical refrigeration, such as evaporative cooling, ground water cooling, thermosyphon cooling, and dry coolers, have the potential to reduce energy consumption and CO_2 emissions of building cooling systems. Chilled ceilings operate with relatively high chilled water temperatures, usually around 14°C to 16°C, which can improve the viability of these low energy cooling systems.

Ground water cooling

Around 50% of the UK land surface is estimated to have suitable underlying geological conditions for ground water. Ground water cooling usually involves the abstraction of cool ground water from a well to perform a cooling process (usually via a heat exchanger to prevent contamination of the building chilled water system) before being returned to the ground via a second well. The temperature of ground water in the UK is usually between 9°C and 12°C all year round and could, therefore, be used with chilled ceiling systems operating with a chilled water flow temperature as low as 14°C without the need for any supplementary mechanical refrigeration. In recent years, ground water cooling systems have been used in several new prestige buildings in the UK, notably BRE Environmental Building (Building Services Journal, 1995), New Parliament building (Evans, 1994) and office development for Hertz (Glackin M, 1997).

Although ground water cooling appears to have considerable potential for chilled ceiling systems, factors such as hydrological and size characteristics of the site, and the costs associated with well-drilling and maintenance may limit its application in practice. In any case, designers of chilled ceiling cooling systems often specify dehumidification of the fresh air supply to prevent any risk of surface condensation (the so called "office rain" effect). Therefore a separate low-temperature refrigeration system would be required for the dehumidification coil. Alternatively, a desiccant dehumidification system could be used.

Thermosyphon cooling

Thermosyphon cooling involves the natural circulation of refrigerant in a specially designed vapour compression chiller without being pumped by the compressor. Thermosyphoning can only occur when the condensing temperature is lower than the evaporating temperature; at other times the compressor is operated as normal. Thermosysphon systems, therefore, are best suited to buildings that have all year round cooling requirements, such as computer and data processing centres, and systems that employ evaporative condensers or cooling towers. Chilled ceilings allow a higher than normal evaporating temperature and can therefore extend the operating time of thermosyphoning.

Dry coolers

Although the use of dry coolers is limited because the leaving chilled water temperature is usually 5°C to 10°C above the ambient air dry bulb temperature, they could provide some free cooling to buildings with a year round cooling need. However, this would be less than is possible with thermosyphon chillers or evaporative cooling towers alone.

Evaporative cooling

Evaporative cooling exploits the wet bulb depression that normally exists, especially during the daytime in summer when the ambient relative humidity is relatively low. The typical summer weather design values for London are a dry bulb temperature of 29°C and a corresponding wet bulb temperature of 20°C, giving a wet bulb depression of 9°C.

Evaporative cooling towers have been widely used for rejecting heat from vapour compression chillers at a lower temperature than is possible with air-cooled systems, and could be used directly for producing chilled water for chilled ceilings and beams for part of the summer. BRE has recently assessed the potential benefit of using evaporative cooling towers with chilled ceilings (CIBSE, 1998).

Practical and economic cooling towers have a wet bulb approach of around 3°C which would result in an overall system temperature difference of 4.5°C between the wet bulb temperature and the secondary chilled water temperature (allowing a 1.5 °C temperature difference across a plate heat exchanger to separate the cooling tower water from the chilled ceiling chilled water system). Chilled ceiling and beam systems normally operate with a chilled water flow temperature between 14°C and 16°C which would require a wet bulb temperature of 11.5°C or lower. Temporary excursions to higher water temperatures might be acceptable during hot weather, if a reduction in cooling capacity and an increase in internal temperature could be tolerated. Alternatively the active area of chilled ceiling or chilled beam could be increased, although this would raise capital costs and would be limited by the available free ceiling area. Either measure would increase the length of time that chilled water could be provided by the evaporative cooling tower alone.

Recent tests at BRE using a realistic chilled ceiling and beam office mock up demonstrated that chilled water temperatures as high as 18°C could still allow reasonable thermal comfort conditions to be achieved. Sensible internal heat gains were 60 W/m^2, and solar gains appropriate for a SW facing room (for July in SE England), with a 3m^2 window, were provided by solar simulator lamps. A maximum internal dry bulb temperature of 25.2 °C occurred between 1600 and 1700 hours on a high solar gain day. However, the predicted comfort mean vote (PMV) was 0.8, indicating conditions were slightly warmer than the recommended ranges specified by ISO 7730.

Table 1 shows the proportion of the cooling season in that a cooling tower system could supply chilled water at or below the temperatures indicated. A chilled water temperature of 15.5°C is typical for conventional chilled ceiling systems and 18.5°C may be considered to be the higher limit using extended surface areas. Table 1 shows that the cooling tower could meet the cooling load for between 32% and 43% of the time for conventional chilled ceiling cooling, and between 59% and 78% of the time for high chilled water temperature systems. It is clear that cooling towers alone cannot meet the entire cooling load and that conventional chillers would be required during hot weather.

Table 1 Percentage of year (April to September) that evaporative cooling alone is viable.

	Percentage of year (April to September, hours 0700 to 1800)		
chilled water temperature	1976-80	1976 (a hot year)	1977 (a cool year)
15.5°C or below	38%	32%	43%
18.5°C or below	70%	59%	78%

ENERGY PERFORMANCE IN PRACTICE

Much of the market in the UK still perceives more 'traditional' forms of air conditioning as less expensive on a first cost basis and are more confident that they will provide the internal environments they require. The market can only be convinced whether or not displacement and chilled ceiling/beam systems can provide worthwhile energy and running cost savings when there is a body of supporting evidence. To enable both designers and building owners to make an informed decision, there is a need for impartial practical information on which to base realistic performance, life cycle cost or CO_2 comparisons. To address this, the BRE has begun on a new study of the practical performance and economic implications of chilled ceilings and beams. The project aims to enhance the information available to industry and for policy purposes, providing a more detailed picture of energy use in air conditioned buildings served by the three most common central plant systems. The inclusion in the study of surveys of building occupants' satisfaction with the environments provided by the different forms of air conditioning will provide further information to support the choice of air conditioning system, by introducing factors related to employee productivity.

CONCLUSIONS

Predictions of air flow and thermal energy have shown that displacement airflow patterns will be established when the thermal loads are matched to the cooling capacity of the displacement ventilation system. However, for thermal loads higher than 25 W/m^2 there would be a risk of occupant thermal discomfort at low levels in the room.

Additional cooling can be provided by chilled ceiling panels to offset higher thermal gains. However, the addition of these devices affects the air distribution characteristics of displacement ventilation systems. Chilled ceiling panels change the air temperature near the ceiling, which creates downward convection, and hence increases the depth of the mixed warm and contaminated upper region. Furthermore, radiation heat transfer between the chilled panels and walls reduces the room surface temperatures below the room air temperature, which causes downwards convection near the wall. This may therefore transport pollutants from the mixing region into the supply air and occupation area. The predictions, however, have indicated very high environmental thermal comfort conditions within the spaces studied.

The relatively high chilled water temperature requirements of chilled ceilings improves the case for using low energy cooling technologies instead of conventional vapour compression refrigeration. However, many of these technologies, including thermosyphon cooling, evaporative cooling, and dry coolers, would still require the use of conventional chillers during hot weather. For this reason they are probably best suited to buildings with a year round cooling requirement. However, ground water cooling would appear to be ideally suited to the chilled water temperature range required by chilled ceilings and could provide cooling all the year round, although a separate low temperature refrigeration system may be required if dehumidification of the fresh air supply were required (dehumidification is often specified with chilled ceilings to minimise the risk of condensation or "office rain"). Although ground water cooling appears to have considerable potential it has only just begun to be used in a few buildings in the UK.

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