COMPUTATIONAL ANALYSIS OF INDOOR AIR AND TEMPERATURE DISTRIBUTION IN AN OFFICE SPACE

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ABSTRACT

There is a growing demand for buildings to have a high indoor air quality environment. Two of the main elements that contribute to this quality are temperature and air distribution within the occupied space. In modern office buildings particularly in hot climates, care must be taken to design the most economical air distribution system that provides comfort for the occupants.

There are many techniques available to predict the air distribution patterns in the space at design stage, but these are often not very accurate. In one of the techniques, scaled models are used to collect data on air distribution patterns but this is expensive, time consuming and it is not possible to include all the room parameters. There are also problems associated with scaling.
Recent innovations in air modelling are more wide-ranging in their analysis and are also more cost effective. These include computer simulation modelling in two or three dimensional form so that spatial factors such as air temperature, velocity and pollutant concentration distribution can be predicted with a reasonable degree of accuracy.

In this paper a Computational Fluid Dynamics (CFD) model was used to predict air velocities, temperatures and air distribution patterns in an office building in a hot climate. Experimental data was collected in an office space in Dhahran, Saudi Arabia and the space was then modelled in a CFD code. Measured data was compared with that predicted by the software to gain confidence in the technique. Once confidence had been gained, the office air supply and extract system were re-designed to improve the quality of the indoor air in the space.
The paper reports on the technique and shows how computer modelling can be used successfully at design stage to predict and consequently improve the final air quality parameters in an occupied space.

INTRODUCTION

The design of many buildings constructed in hot climates are inappropriate and so do not provide the desired internal comfort conditions. The quality of the internal environment depends on many factors such as materials, construction, form, orientation, as well as the specification of the services installed to mechanically ventilate the building.

In the past, traditional buildings have been more successful than modern ones in providing a comfortable interior. Their simple forms and appropriate construction techniques have evolved as a result of a long process of trial and error and the resulting designs are sympathetic to the local climate. Over the past three decades it has become possible with the advent of electricity, to overcome the effect of climate on the construction of a building. This has been achieved by using mechanical aids, which are successful up to a limit, in controlling the internal environment. Unfortunately the equipment required to do the controlling is entirely dependent upon the use of large quantities of energy and with today's high-energy costs, this will inevitably impose a restriction on their future application and development.

In a country such as Saudi Arabia, a comfortable internal environment can only be achieved in a modern building by using a mechanical air cooling system. A problem then arises. If the cool air supply is not designed and configured properly then this often leads to uncomfortable conditions that include amongst other things comfortable temperatures on the sun side of the building and over-cooling on the shade side. This problem is common in nearly all the office buildings in the eastern province of Saudi Arabia and results from the fact that the technology of many of the buildings was transferred direct from western countries, without modification despite their moderate climate and differing building standards. Consequent to this, most of the designs are not suitable for a hot climate like that of Saudi Arabia and therefore need more cooling energy to control overheating. The main problems with the buildings are that most of them utilise low thermal capacity materials and have high thermal transmission glazed envelopes. Such buildings need a huge amount of air-conditioning to compensate for the excessive heat gains.

Thermal conditions in the perimeter zones of office buildings are influenced by the outdoor climate, particularly on the eastern and western sides where radiation transfer through the envelope causes problems. Under such conditions, the cooling air system is adjusted to provide a large volume airflow to compensate for the radiation transfer and this often causes a risk of draught, temperature gradients and increased energy consumption.

Thermal problems are also experienced when the air-conditioning system is turned-off over night after working hours. The next morning, the building fabric needs time to be cooled before occupancy and the temperature will not be reduced sufficiently unless cold air is supplied at a maximum. Under this sort of supply a new problem arises, the building becomes divided into two zones, the one on the sun side will have an acceptable comfort condition but the other zone on the shade side, will be over-cooled and not acceptable. This means that in an office building with an open-floor layout, some work places may be over-ventilated and over-cooled while others will have an inadequate supply of ventilation and cooling even though the total cold air supplied to the space is adequate.

Having arrived at the problem, this study concentrates mainly on the effect of cold air distribution systems on the comfort performance of office building in a hot climate to provide optimum satisfaction to the users. It aims to provide designers and engineers with up to date information for use during the process of design selection.

METHODOLOGY

A modern office building in Dammam, Saudi Arabia that had a history of poor thermal comfort provision was selected for the study. An office space on its upper floor was instrumented to measure internal air temperatures, relative humidities, radiant temperatures and air speeds. The outside of the building was instrumented to measure air temperatures, solar radiation, wind speed and direction. The test room inside the building comprised of three exterior walls-north, east and west, that were made from 150 mm thick precast concrete panels. The south wall that was not exposed to external conditions, was constructed from

150mm thick concrete blocks. The roof of the test room consisted of steel girders, supporting 120 mm thick reinforced concrete topped by 100 mm foam concrete, 20 mm water-proof (PVC) membrane, 50 mm polystyrene insulation and a water proof protection layer.
Installation and calibration of the experimental equipment took place just prior to a summer period and actual comfort measurements were recorded over the summer months. The purpose was to measure the thermal performance of the internal space in order to assess the level of comfort being provided for the occupants and also to validate a CFD code by comparing measured values with those predicted by the code.

Once validation of the CFD code had been completed the code was then used to simulate the cooling performance of various inlet and outlet air configurations and also to evaluate any improvement that could be made to the provision of thermal comfort in the office space.

It has been reported by many researchers, Gulf Report [1], Olgyay [2], ISO (International Standard Organisation) [3], Auliciems [4] and Konya [5] that comfort conditions exist in an office space when the temperature is between 25°C to 27°C and air speed between 0.1 to 0.25 m/s. Samples of air temperatures and air speeds measured in the office space are given in Table 1 from where it can be seen that comfort conditions were not being provided.

Table 1. Measured air temperatures and air speeds

Location	Air temperature (°C)	Air speed (m/s)
East side of space	21	0.23
Centre of space	24.3	0.64
West side of space	29.5	0.41

Figure 1 gives a more detailed analysis of the temperatures recorded at the centre of the space and clearly shows the variation in the indoor temperature caused by the external climate even when the mechanical cooling system is in operation. For comparison purposes the comfort temperature range is also shown.

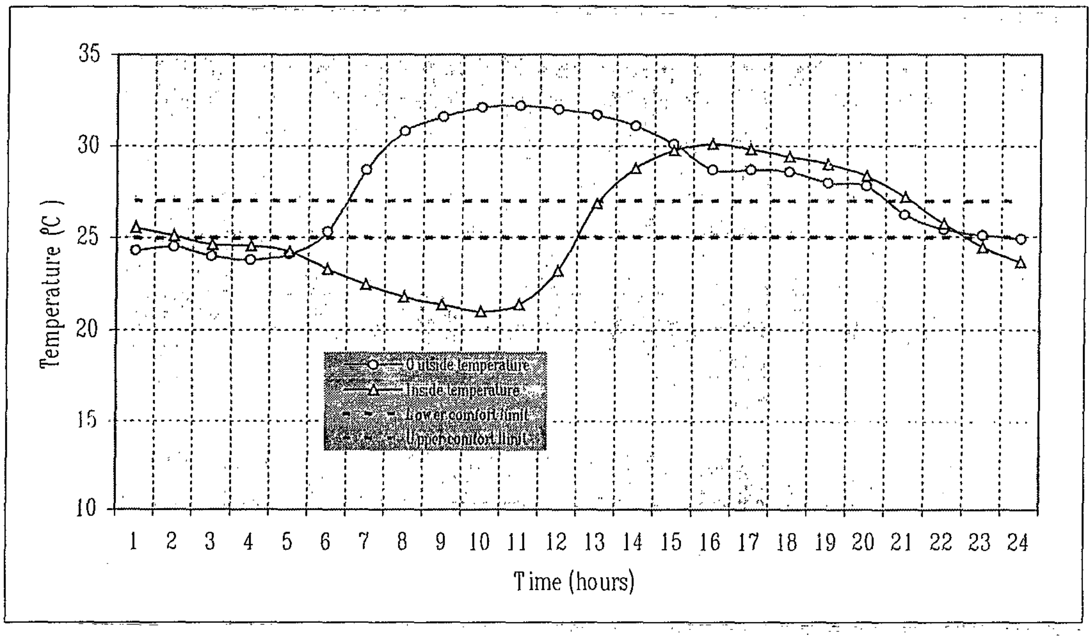

Figure1. Variations between measured outside air temperature and inside air temperature at the centre of the office space under mechanical cooling.

As mentioned previously, the measured results were also used to validate a CFD simulation code. This was completed by entering the office space into the computer program and analysing the room's performance under the same climatic conditions that were prevailing at the time of taking the measured values. The results obtained from the CFD simulation showed very close agreement with the experimental measurements and this gave confidence to use the computer simulation for further analysis work.

In the simulation that followed, six mechanical air distribution layouts were proposed and then simulated. Due to the space limitations, only the layout that provided the best comfort conditions has been included in this paper.

The six proposed layouts that were simulated had air distribution systems that jetted air into the space at ceiling level to provide air change rates equivalent to about 3 per hour. The reason for using ceiling level inlets was to ensure that the cold supply air mixed thoroughly before it reached the occupied zone. In the layout presented in this paper (see figure 2) an air diffuser was allocated to every 25 to 35 m^2 of floor area, as determined from separate simulation tests. The layout discharged air along the ceiling except for a central inlet which discharged air directly downward towards the floor. The layout extracted air at ceiling level at positions again shown in figure 2. Floor and low level wall inlets were avoided.

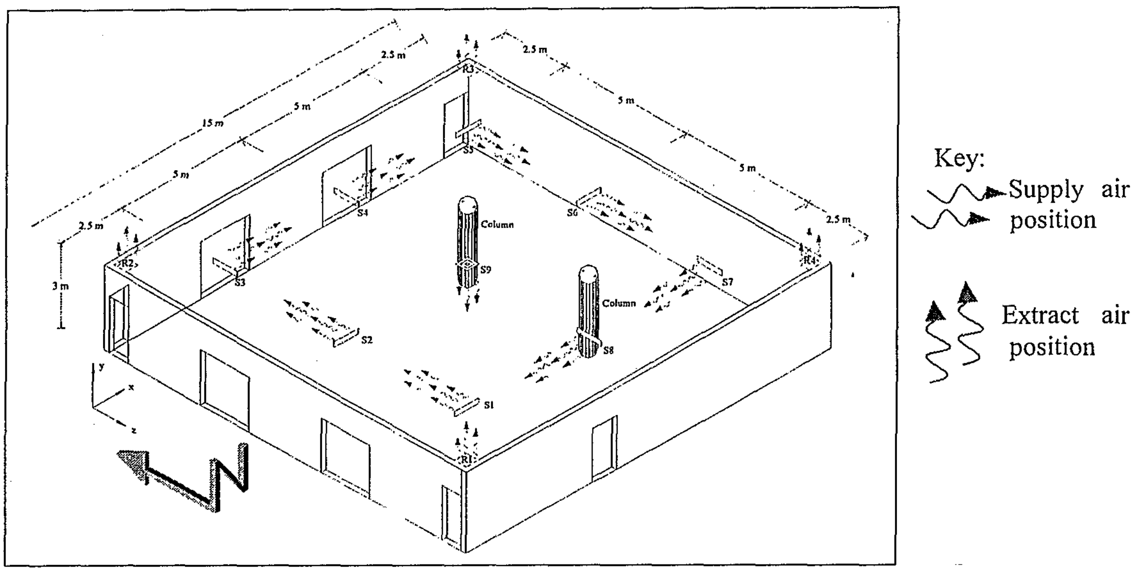

Figure 2. Air distribution layout used in the simulation.

RESULTS AND DISCUSSIONS

The comfort temperatures and air speeds provided by the layouts tested were all different and most of them did not show any improvement on the original distribution. The layout presented above in figure 2 however showed excellent results where the air mixed well under acceptable air speeds and temperature gradients were very low. Figure 3 shows a plan view of the air distribution and temperature variation obtained at a height of 1.8m above floor level. The air flows and space temperatures were then analysed on vertical sections at 3m, 7m and 12m distances into the room. Results are presented in figures 4, 5 and 6 respectively from which it can be seen that the air distribution system provided very good air quality provision with all the air speeds in the occupied zone being in the comfort range of 0.1 to 0.25 m/s and air temperatures between 25 to 27 °C.

From these results it can be suggested that a beneficial way of supplying air to an occupied zone in a hot climate is to inlet the air at high level along the ceiling line in a clockwise or anti-clockwise direction and to extract at the same level. Using this techniques, acceptable air speeds and room temperatures are obtained.

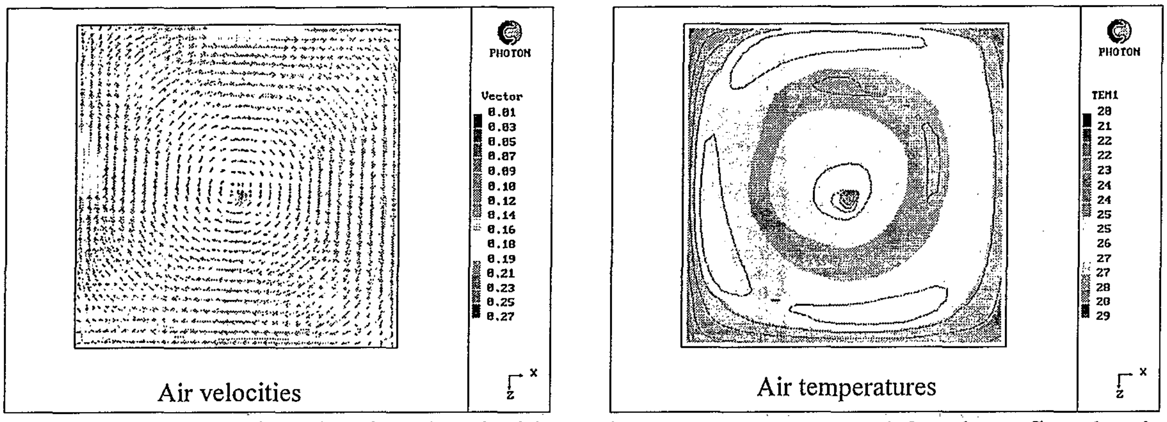

Figure 3. Plan view showing air velocities and temperature contours 1.8m above floor level

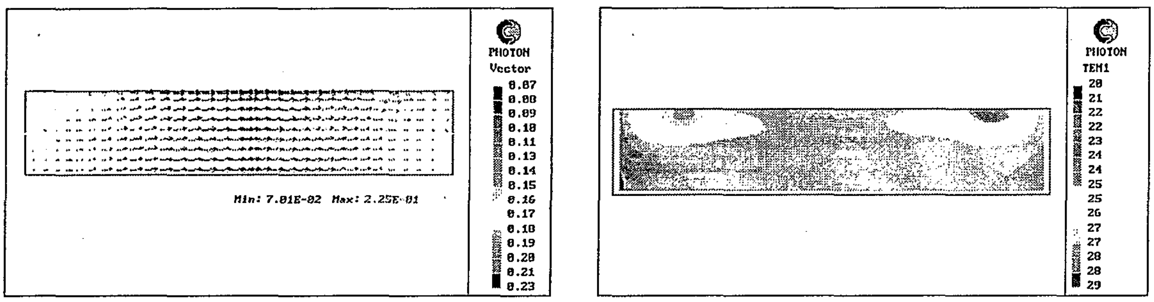

Figure 4. Vertical section showing air velocities and temperature contours at 3m into the room

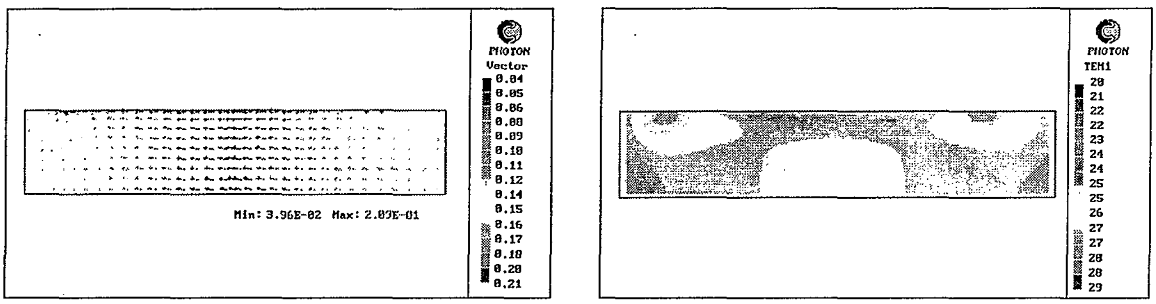

Figure 5. Vertical section showing air velocities and temperature contours at 7m into the room

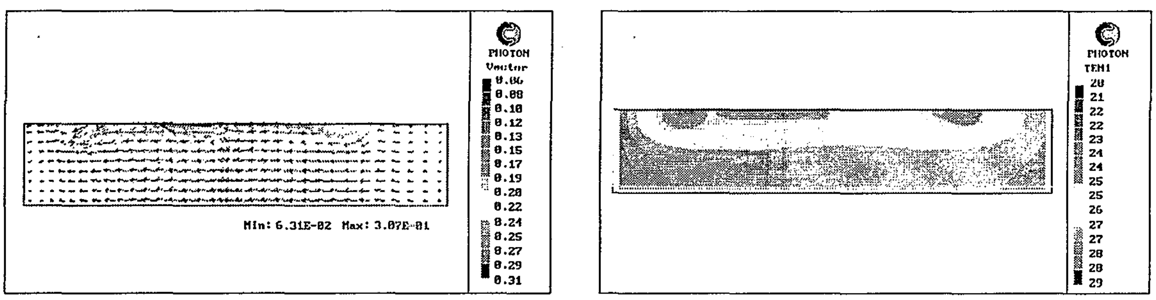

Figure 6. Vertical section showing air velocities and temperature contours at 12m into the room

CONCLUSIONS

Air distribution and temperature profiles of several air layout systems have been assessed. The layout that performed the best has been reported in this paper. CFD computer simulation has shown that thermal comfort can be provided in an open plan space in a building exposed to a hot climate by using an air inlet configuration that directs air in a circular motion at ceiling level.

The system reported provides a high degree of air mixing that reduces temperature gradients and draughts due to high air speeds and stagnation zones. This was achieved by using low air velocities and low air change rates compared to those currently used in office buildings in Saudi Arabia.

Other air inlet configurations do not perform so well as the system proposed because they produce unacceptable air speeds and temperature gradients across a space.

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