Theoretical assessment of the indoor environmental conditions in an office

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Abstract: - The purpose of this work is to study numerically the indoor environmental conditions of an office. The indoor air quality status has already been studied experimentally under different indoor and outdoor conditions and it was found that indoor originated pollutants' concentrations (CO_2, PM_{10} and TVOCs) were elevated when smoking was taking place and windows were closed. In order to investigate the mechanisms that affect the indoor environmental conditions the CFD model PHOENICS was applied based on input data obtained during the experiment. The indoor air velocity, temperature and CO_2 concentration fields established indicated low air velocities and a relatively non-uniform flow field due to the presence of the geometrical objects.

Key-Words: - Indoor environment, CFD model, indoor air quality, measurements

1 Introduction

In the last decades indoor air quality has become a public health concern since people spend more than 80% of their time indoors. Studies have concentrated on the measurement of pollutants concentrations in indoor environments, such as residences, offices, shopping malls and restaurants, giving a comparison of their pollution status and identifying indoor pollutants sources [1]. Computational Fluid Dynamics (CFD) codes have become an important tool in the research field of indoor air quality. They are currently applied for investigations of indoor airflow fields for building design and optimum ventilation purposes [2] and for pollutants dispersion in working areas for health and safety reasons [3].

Within that frame the main objective of this work is to study numerically the indoor environmental conditions that prevail in an office while fully occupied under natural ventilation conditions with the aid of a CFD model. The input data necessary for the applications were obtained during an extensive experimental campaign.

2 Experimental Methodology

The office is located on the first floor of the 5th Physics building at the University Campus, which is a suburban area not close to heavy traffic roads. The office is equipped with computers, printers and furniture, while a wall-to-wall carpet covers the floor. The surface area is 70 m^2 and the office is daily occupied by at least 7 people. Measurements were taken under different scenarios including occupation conditions, opening of windows, operation of the air conditioning system and smoking. For the needs of the current study the following measurements were taken:

- TVOCs and CO_2 concentrations, using portable indoor air quality monitors (IAQRAE and ppbRAE of RAE systems).
- Spot mean air velocity, temperature and turbulence intensity values, at 1-min sets, at several indoor locations (including the inflow and outflow points), using DANTEC FlowMasters.
- Surface temperature of indoor materials (walls, desks, cupboards etc.) using an infrared thermometer.

3 CFD Model – Initial and Boundary Conditions

The PHOENICS CFD code (Version 3.5, 2003, CHAM Ltd.) solves the time-averaged conservation equations of mass, momentum, energy and chemical species in steady three-dimensional flows. The discretization of the domain is followed by the reduction of the previous equations to their finite domain form using the "hybrid formulation of the coefficients" and the solution technique employs the SIMPLEST algorithm. The standard k-ε turbulence model is applied, while buoyancy effects are considered. To improve convergence, under-relaxation was used.

A 3-D rectangular enclosure was considered in a Cartesian coordinate system (Fig. 1). The domain size is 7m x 10m x 3.5m and it includes 3 windows, 1 door, 7 desks, 11 partition walls, 2 tables, 6 cupboards and 1 refrigerator. The dimensions of the modelled objects are real and the domain geometry is as detailed as possible, taking into account computational efficiency. The boundary and initial conditions based on the experimental measurements are: (a) Fresh air comes in the office through the partly open windows and it is taken out of the office through the open door (see also Table 1). The surface temperatures of indoor materials range between 22.5ºC and 27.7ºC. (b) People are modelled as heat and scalar sources emitting metabolic CO_2. One student corresponds to one desk. The reference value given for the interpretation of the model results regarding CO_2 concentration was based on measurements (position A of Fig.1) and corresponds to the value calculated very close to the students working (2346 mg/m^3).

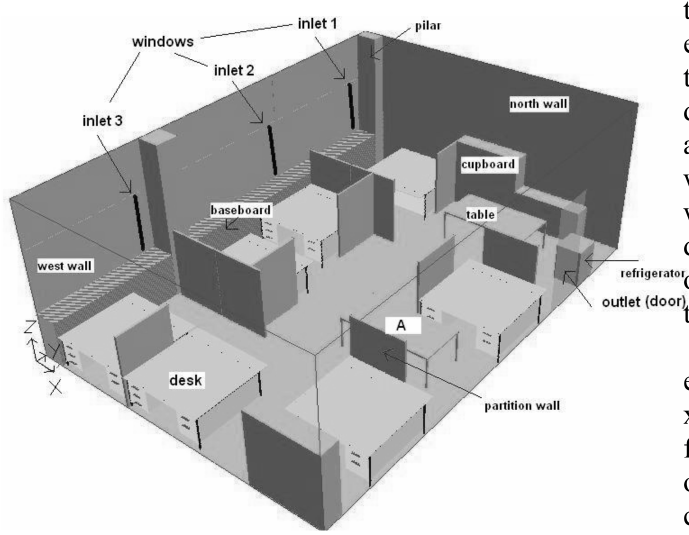

Figure 1. Computational domain.

Table 1. Experimentally measured air inlet data.

Air inlet	Measurement height (m)	Velocity (m/s)	Turbulence intensity (%)	Temperature (^{0}C)
1	z=1.5	1.6	46	22.3
1	z=2	1.36	50	22.4
1	z=2.5	2.26	47	22.2
2	z=1.5	1.8	33	22.6
2	z=2	1.79	22	21.9
2	z=2.5	1.36	63	23.2
3	z=1.5	2.86	47	22.5
3	z=2	4.25	12	21.2
3	z=2.5	2.31	44	21.6

The cases studied are the following: a) Basic Case: The office is empty, the door is open and the windows are partly open. Grid cells employed are 67x75x40 and the minimum cell size is 0.1x0.13x0.09m. b) Working-day Case I: The office is fully occupied (7 students) on a typical working day and ventilation conditions are the same as previously. Grid cells employed are 77x87x41 and the minimum cell size is 0.09x0.12x0.09m. c) Working-day Case II: The office is double-fully occupied (14 persons) and other conditions are the same as previously.

4 Results

Simulated results of *Basic Case* exhibited satisfactory agreement with experimental data, given also that the indoor airflow is characterized by very low velocities of the order of 0.15 to 0.8 m/s (not shown here for brevity). The wind field established on the y-z plane (from the north wall to the south wall) is presented in Fig. 2. It can be seen that three distinct vortex-like patterns are established characterized by low velocities in the centre and areas of acceleration near the obstacles of the room. The flow between the two successive vortices (from the right) seems to be downwards. The flow established is quite different on the x-z plane (from the windows to the door), since it seems to be divided into two "layers" (Fig. 3). Above a height of approximately 1.5 m the air coming in from the windows reaches the opposite side of the room, while at lower heights distinct vortices are developed due to the existence of the furniture and other obstacles. The wind speed remains very low of the order of 0.5 m/s.

It is interesting to observe the flow field established in the office at a height of 1.5m (on the x-y plane). It is clearly seen that the air coming in from the three windows, with a velocity of the order of 2 m/s reaches the other end of the room in one case, but from the two windows on the right it does not due to the presence of partition walls. On the left side of the room a distinct vortex structure is seen whose boundaries are set by the partition walls and the same at various locations in the room. Furthermore, a large part of the room close to the door is characterised by very weak and almost uniform flow, of the order of 0.2m/s, driven by the draught towards the door (Fig. 4).

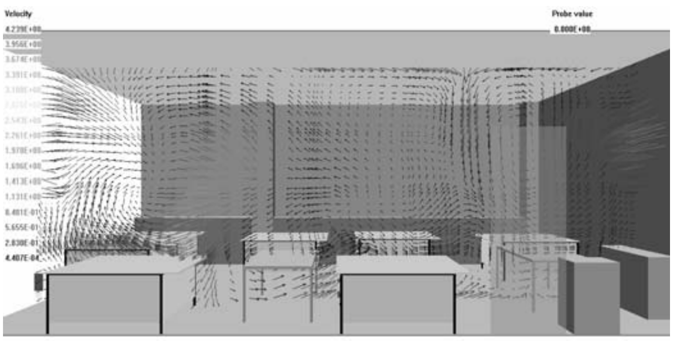

Figure 2. Y-Z plane view of airflow at x=5m (Basic)

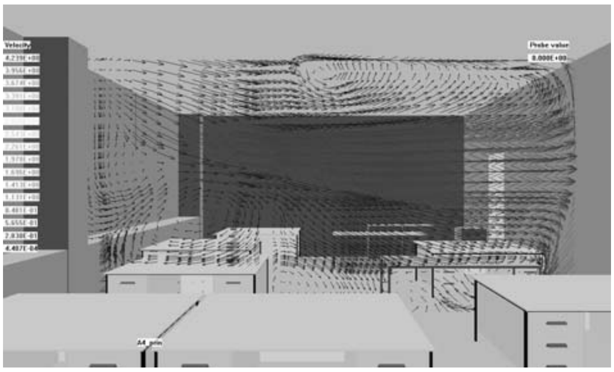

Figure 3. X-Z plane view of air flow at y=3.8m (Basic)

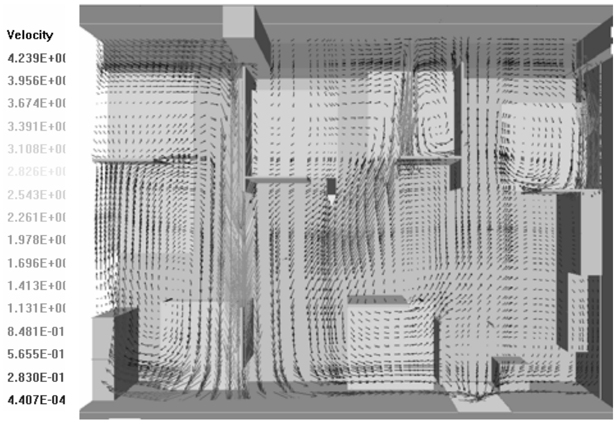

Figure 4. Plan view of airflow at z=1.5m (Basic)

The temperature field established does not present any distinct features besides the fact that air temperatures are higher close to objects and decrease moving away from them along the room (Fig. 5). The room temperature is on average approximately 22.5 ºC.

Working-day Case I: When the office is occupied by all 7 people working at their desks they are assumed to be motionless since this is a steady state case and hence their presence does not have an effect on the flow field developed (not shown).

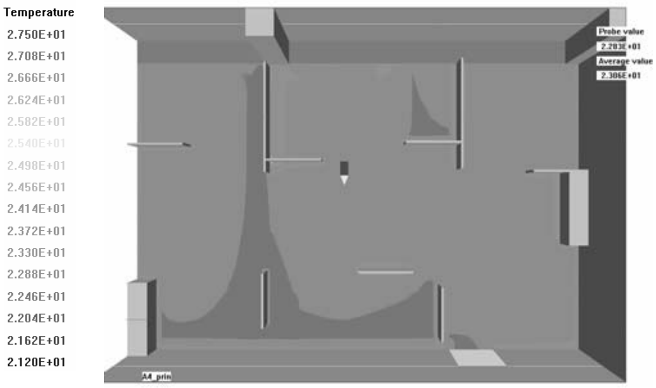

Figure 5. Plan view of temperature at z=1.5m (Basic)

However, regarding the temperature field computed by the model it can be seen that the presence of people consists of a heat source since the average room temperature has increased by about 1ºC. In figure 6, a plan view of the temperature field computed at a height of z=1m (approximately the height at which people work) is given. It is notable that the people working close to the windows (i.e. those within the distinct vortices formed between the partition walls) are the most important heat sources, the temperature close to them being approximately 27ºC and decreasing to the background value at a distance of 0.5 to 1m away from them depending on the air flow. At points of the domain where the flow is very weak (i.e. close to the door) the temperature contours originated by the people are not distinct.

Computed results of the CO_2 dispersion pattern are given in Fig. 7. As expected each person consists of a source emitting CO_2, which is then transported by the flow field developed in the room. The maximum CO_2 concentration found in the close vicinity of each person reaches 2346mgm^{-3}. Concentration contours indicate higher concentration levels at the left side of the office because of local trapping, giving values of the order of 1079mgm-3 which is close to the limit set for indoor air quality. Better conditions prevail at the centre and the right side of the room. The average concentration at z=1m is 798mgm^{-3}.

Working-Day Case II: When the office is occupied by 14 people while ventilation conditions remain the same as before, it is observed that still the wind field developed is not affected by their presence which may be attributed not only to the fact that they are motionless but also to the fact that other objects such as partition walls are bigger. The addition of people brings a further increase in the room temperature which due to the wind field developed is higher on the left side of the room (approximately 26ºC) and lower on the centre and right sides reaching 24ºC (Fig. 8).

The current ventilation scheme seems to be inadequate in this case since the CO_2 concentrations exceed the specified limits for acceptable indoor air quality. They reach 1550 mgm^{-3} on the left side of the room, as expected and approximately 1200mgm^{-3} at the centre and left sides (Fig.9). In the vicinity of the people working the concentrations are much higher, while close to the windows and door the concentrations drop significantly.

Figure 6. Plan view of temperature at z=1m (Working-day I)

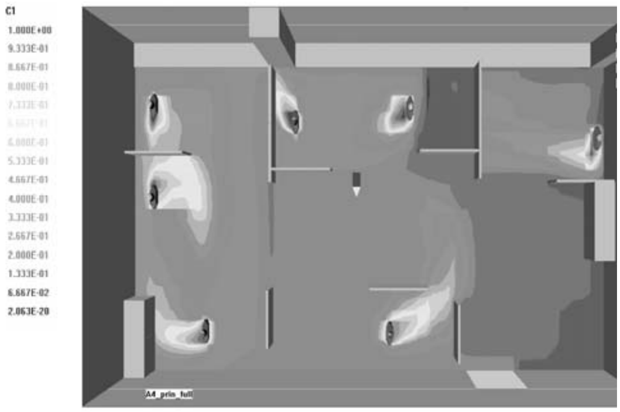

Figure 7. Plan view of CO_2 concentration at z=1m (C1 is % relative to 2346mgm^{-3}) (Working-day I)

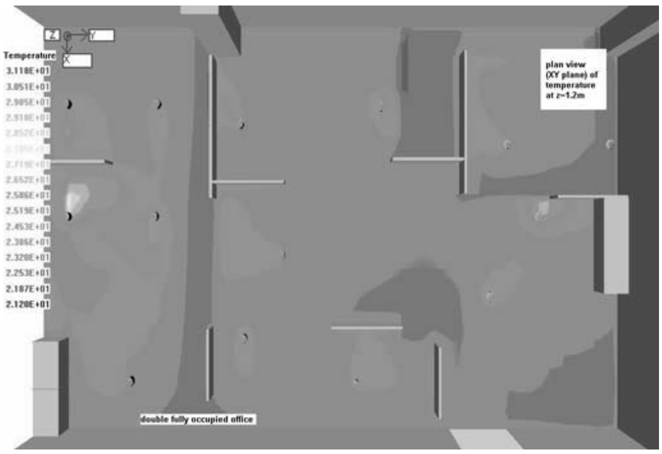

Figure 8. Plan view of temperature at z=1.2m (Working-day II)

5 Concluding Remarks

The indoor environmental conditions that prevail in a naturally ventilated occupied office were studied theoretically with the aid of experimental measurements. Results presented here revealed the following: a) Comparison of computed versus experimental results revealed that the model performed in a satisfactory manner. b) The flow field developed is characterised by areas of uniform flow and isolated vortices depending on the presence of objects (offices etc.), and by very low velocities. However, the presence of people does not seem to have an effect on the patterns established. c) People consist of an important source of pollution and heat. Intense contours of temperature and pollutant concentrations are formed around each person. Their dispersal is dominated by the general flow field, leading to areas of higher temperature and pollution. Regarding indoor CO_2 levels it seems that according to computational results the guideline limit is exceeded depending on the number of people present.

Further work is currently taking place in order to include more ventilation and occupation/use scenarios.

Figure 9. Plan view of CO_2 concentration at z=1.2m (Working-day II)

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