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A case study on the application of measurements and computer simulation to the ventilation and airborne contaminants control within a workshop

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SYNOPSIS

This paper discusses the results from measurements and **Computational Fluid Dynamic (CFD)** simulations for the airflow within a workshop carried out with the view of examining the performance of its current ventilation system as required under the Health and Safety Regulations (**COSHH**). Results from measurements indicated that the existing ventilation system performs unsatisfactorily with regards the possible removal of contaminants being released within the workshop.

The effects upon the room airflow of a number of proposed modifications to the ventilation system were then examined by means of CFD. This resulted in a specific set of proposals for the modification of the existing ventilation system which once implemented, would enhance its performance and thus lead to a reduction in the contamination levels within the workshop.

INTRODUCTION

The objective of a ventilation system for offices and other such commercial sector buildings is to promote comfort and to suppress odours due to human occupancy, with additional consideration given to temperature control and effective air distribution and motion in the buildings.

In an industrial plant, the ventilation system carries an additional function which is to control airborne dusts, vapours and gaseous contaminants. The purpose being to prevent the potential exposure of workers to harmful contaminants.

For health effects on workers within the workplace, the Health and Safety Executive issues a list of Occupational Exposure Limits (1) for both short and long term exposure to a wide range of industrial substances.

Site tests performed on a daily basis by the Health Physics Department of the Company indicate high ambient levels of air contaminants, exceeding the working limits as required by the COSHH law.

In order to bring the concentration levels of air contamination within the working levels as required by the COSHH regulations, the company commissioned A & K Associates to carry out an extensive survey of the airflows within the workshop and proposed a practical solution to the current ventilation system which would lead to a reduction in the levels of air contamination within the workshop.

A & K Associates recognised that the airflow pattern within the workshop is fairly complex and in order to achieve the desired improvements in air quality, it was deemed necessary to conduct measurements, smoke flow visualisation and computer modelling of the air movement within the room.

DESCRIPTION OF THE WORKSHOP AND ITS VENTILATION SYSTEM

The main room is part of the workshop complex having principal dimensions of 9m long x 7m wide and 4.5m high and its ante-room having dimensions of 8m long x 2m wide x 2.5m high. It includes three identical furnaces with their respective control units, lathe booth, drill booth, fettling booth, local exhaust hoods and a number of work benches as shown in Figure 1.

The room ventilation system comprises of the extract and the supply sides. The extraction side comprises of three local exhaust hoods on the three furnaces with added extraction on the three aforementioned booths, a local grinder hood and two general room extracts located on the wall. The input side comprises of six supply registers with added input air from an opening on the main entrance door (**Door B**) and another opening situated on a door (**Door A**) connecting an adjacent room.

AIRFLOW MEASUREMENTS

The intent of the measurements was to assess the effectiveness of the current ventilation system and to use the data as input to the computer modelling of the airflow. To this extent, measurements of input and output sections of the existing ventilation system were carried out using hot wire anemometry and a pitot static pressure tube. Also for the purpose of computer simulation, both surface and airflow temperatures were measured.

SMOKE FLOW VISUALISATION

Smoke flow visualisation was used in order to give a better understanding of the existing airflow pattern within the workshop and to aid in the interpretation of the computer simulated airflow pattern. For this, non toxic smoke pellets were energised and released at various locations in the workshop. The smoke used has the same density as air so that it was possible to observe the true air movement within the workshop.

DISCUSSION OF RESULTS FROM MEASUREMENTS AND SMOKE FLOW VISUALISATION

Results from both the velocity and pressure measurements taken at various locations within the workshop and the smoke flow visualisation indicated that the mass flow rate contribution from the supply registers is considerably lower to that from door openings A and B and less than the recommended mechanical ventilation rates by A.E.C.P. (2) and C.I.B.S.E. (3) guides. In principle, such a difference will not matter. In this case, however, the incoming air from the door openings may already contain contaminants and thus increase the contamination levels in the workshop. It is therefore desirable to have a greater proportion of the supply air coming through the supply registers in order of 80-90% of the total mass flow rate. It was also seen that one of the six supply registers, a number of the local extract hoods and the two general room extracts require either redesigning and/or considerable upgrade.

In summary, the airflow measurements and the smoke flow visualisation indicated that the airflow pattern within the workshop was dominated by two large flow regions. Region 1 at the working level is dominated by the strong air jets from the openings on Doors A and B, whilst the other region is dominated by a large area of weak recirculation situated at the upper layer of the workshop.

With regards to the small ante-room, it was observed that some smoke reached the area but once there, it remained for a considerable time.

COMPUTER MODELLING OF AIRFLOW

From the measurements and smoke flow visualisation, it became apparent that the airflow within the workshop is highly complex and three dimensional. It was thus felt that to propose a solution to the contamination problem based solely on the smoke flow visualisation and the limit number of local airflow measurements would not be prudent since many important flow features might be overlooked.

It was thus decided to take positive steps to investigate this problem. This step consisted of utilizing the Computational Fluid Dynamic (**CFD**) technique to initially simulate the airflow as currently exists within the workshop and then examine the effects of possible alterations. The computer simulations were performed on the HARWELL CRAY-2 super computer system using the HARWELL-FLOW 3D software which has been developed to simulate laminar and turbulent flow problems for a wide variety of applications (4) including ventilation flows. The mathematical modelling and computational details of the simulations by the HARWELL-FLOW 3D are not discussed in this paper but details of the software may be found in reference (5).

DISCUSSION OF RESULTS FROM COMPUTER SIMULATION

Due to the large amount of data generated by the modelling and the short nature of this paper, only a few results are presented here. In particular, Figures 2 and 3 show 2-D velocity vector and temperature contour diagrams across specific cross-sections of the workshop for the existing ventilation system. These clearly show the influence of both the strong air jet (2.5m/s) emanating from the opening on Door B and of the recirculation zone near the ceiling. Also seen is the relatively large amount of air flowing from the main workshop to the adjacent ante-room. This is undesirable since any contaminants present would remain in the ante-room for long periods of time (see Figure 4) since it is impractical to install a general room extraction system in that area.

Having established that results from the computer modelling of the airflow are in good agreement with those observed from the measurements and the smoke flow visualisation, the effects of a number of proposed modifications upon the airflow pattern within the workshop were investigated. Before any specific proposals for improvement were put forward, it was necessary to review the basic requirements for the desirable ventilation system for the workshop. These requirements include the following:-

1. Efficient local exhaust hoods and booths.

2. Sufficient number of general room extracts placed at optimal to the flow field locations.

3. The supply system should provide adequate mass flow rates to satisfy the demands of the extraction system without causing outflow of air from the workshop to the adjacent areas.

4. It should strive to maintain a comfortable working environment for the personnel.

5. Avoid large stationary recirculation zones within the room.

6. Avoid strong air currents which are capable of carrying contaminants into the ante room.

7. The modified ventilation system must be easy to implement and affordable.

A number of proposed modifications to the system was then examined by means of CFD. This resulted in the selection of a proposed ventilation system which met all the above requirements and once implemented, would result in the efficient removal of all airborne contaminants from the workshop. Examples of the simulated airflow patterns within the room resulting from the implementation of the proposed ventilation system are shown in Figures 5, 6 and 7. A comparison with Figures 2, 3 and 4 clearly shows the reduced influence of the jet from the opening on Door B, the removal of the large recirculation zone near the ceiling and the reduction of the amount of air flowing to the ante-room.

CONCLUSIONS

(1) Airflow measurements and smoke flow visualisation within the workshop indicated that:

- The performance of the current ventilation system is unsatisfactory, resulting in large infiltration of air from adjacent areas.
- Some of the local exhaust hoods and booths perform satisfactorily within their respective capture zones.
- Absence of general room extracts resulting in contaminants remaining within the room for a considerable time.
- It is necessary to upgrade both the supply and the extract sides of the existing ventilation system.

(2) The complex airflow patterns within the workshop were satisfactorily simulated by the use of CFD.

(3) Simulations of a number of possible modifications to the existing ventilation system were successful in identifying a practical and an acceptable solution to the workshop ventilation and contamination problems.

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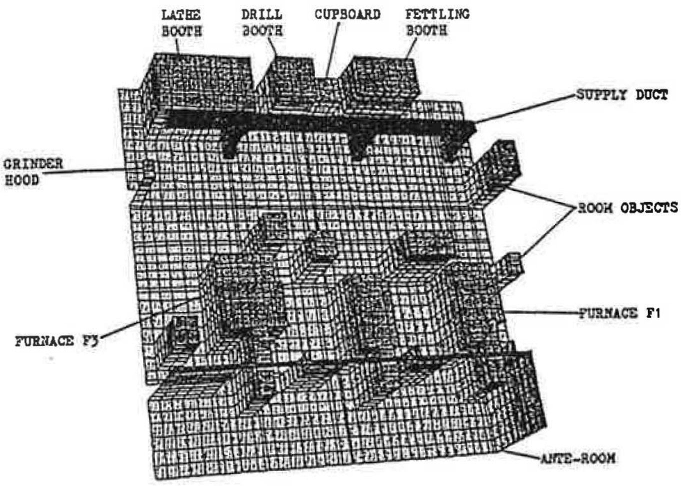

Fig 1. The workshop showing the ante-room, supply and extract systems

CURRENT SYSTEM

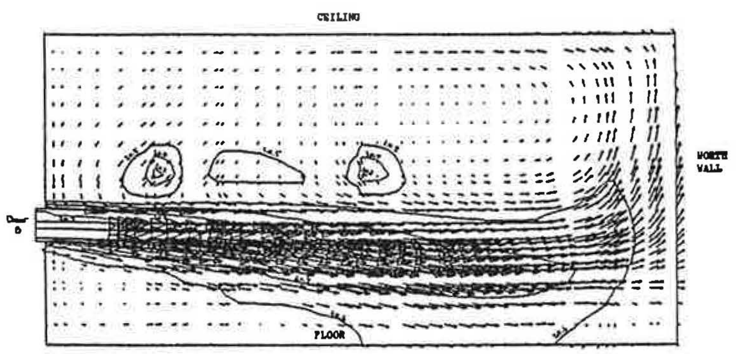

Fig 2. 2D velocity vector and temperature contours along the plane through door B (existing system)

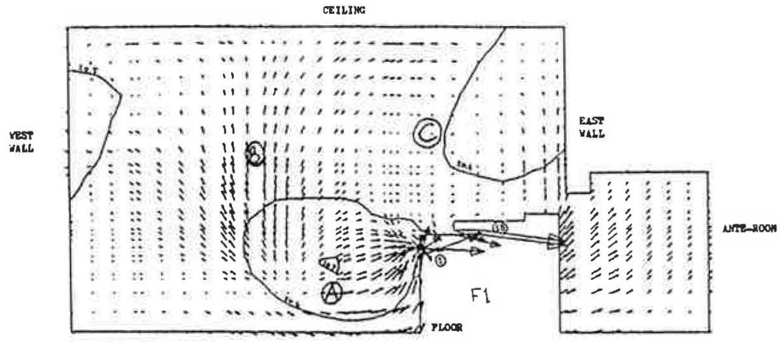

Fig 3. 2D velocity vector and temperature contours along the plane through furnace hood (existing system)

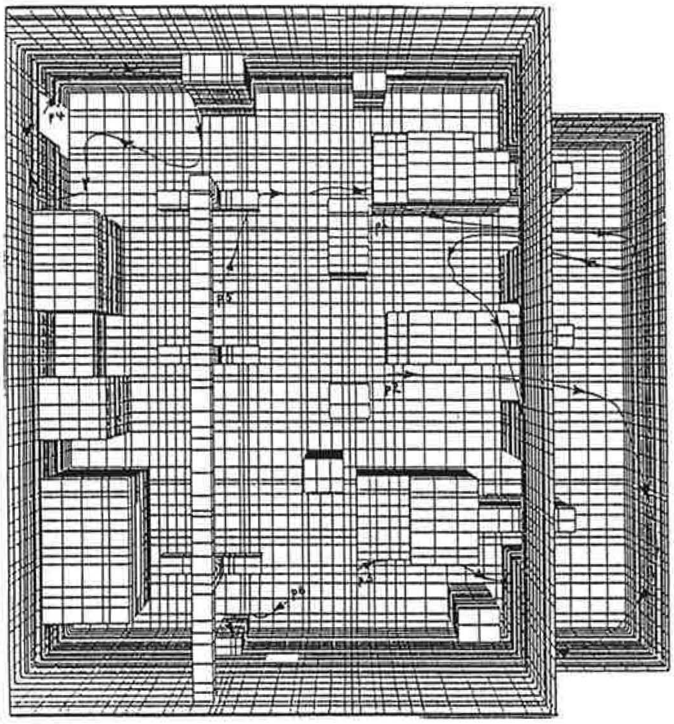

Fig 4. Existing system: airborne particle tracks

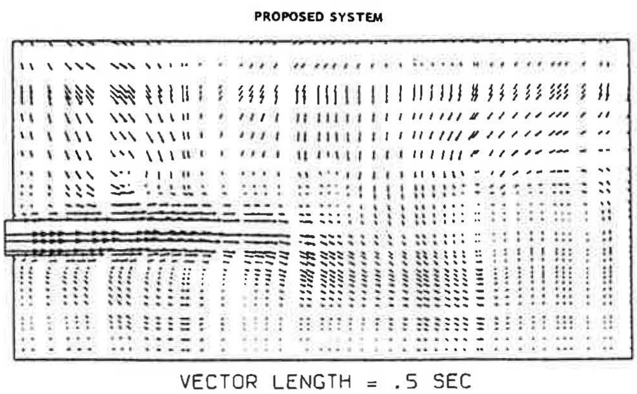

Fig 5. 2D velocity vector along the plane through door B (proposed system)

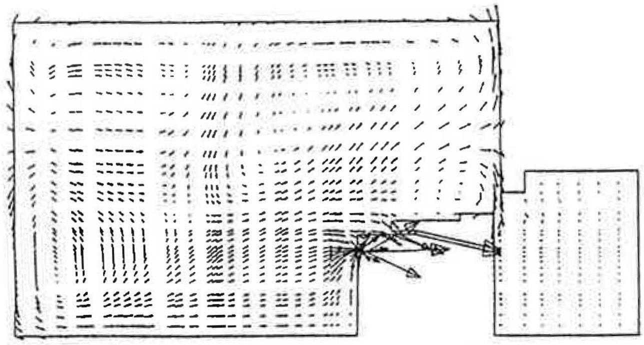

Fig 6. 2D velocity vector along the plane through furnace hood (proposed system)

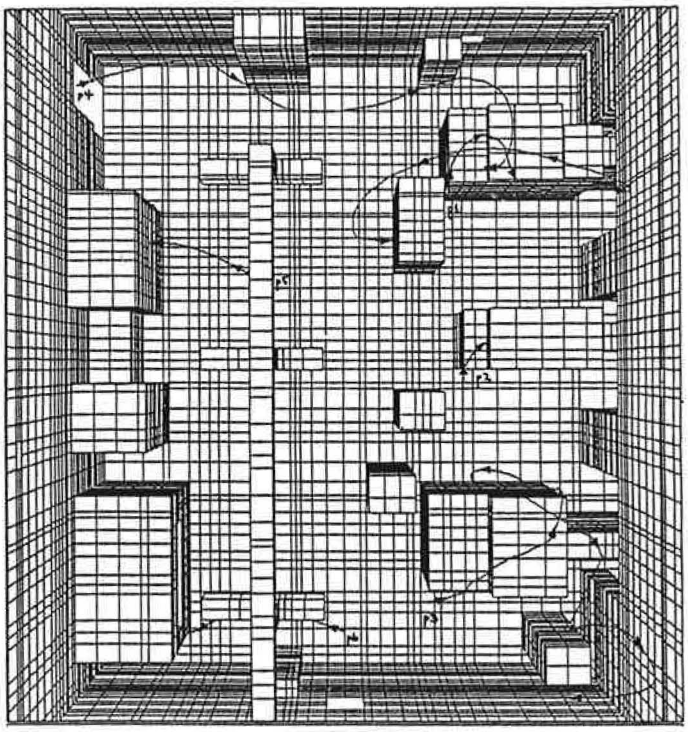

Fig 7. Proposed system: airborne particle tracks