Energy Impact of Ventilation and Air Infiltration
14th AIVC Conference, Copenhagen, Denmark
21-23 September 1993

Efficient "Horizontal Flow" Ventilation: Influence of Supply Inlet Designs

Y-Q Tang, S Holmberg

Ventilation Division, National Institute of Occupational Health, S-171 84 Solna, Sweden

Efficient "Horizontal Flow" Ventilation: Influence of Supply Inlet Designs

Yan-Qiu Tang and Sture Holmberg
Ventilation Division, National Institute of Occupational Health
S-171 84 Solna, Sweden

Abstract

An even distribution of room air can improve indoor air quality, lower energy costs, and create thermally comfortable environments. This paper investigates the influence of the design of plaque diffusers on the efficiency of supply air.

For better comfort and more accurate observations, the isothermal flow investigation was made in a small scale chamber with the air supply and exhaust on opposite walls. The supply air was spread radially and symmetrically over the vertical inlet wall. Plaques of different sizes, both solid and perforated were tested. The diameter of the plaques and the distance to the inlet wall were important parameters. They both influenced the general flow pattern in the room and the flow pattern close to the inlet region. Promising results regarding air change efficiency were reached by perforated plaques. The experimental results are compared to the results from numerical simulations on a fine grid where the plaque perforation degree has also been taken into consideration. An acceptable agreement was reached between experimental and numerical results.

Introduction

Previous investigations of horizontal flow ventilation experiments, in a full-scale laboratory environment with diffusers for radial air spread, have shown efficient in terms of air change efficiency, Tang and Holmberg (1992). In the present study, simple plaque diffusers for radial air spread are tested in a small- scale chamber. The flow pattern and the air change efficiency are reported.

Isothermal tests with three plaque diffusers were conducted in the reduced-scale model. An air supply opening, 125 mm in diameter, is placed in the center of a side wall. The plaques used are 100, 125 and 150 mm in diameter. This means that one is smaller than the inlet, one is of the same size as the inlet and one is bigger than the inlet. The main purpose of this study is to investigate how plaque size and distance to the inlet wall will influence the flow pattern in the chamber. Differences in the resulting flow patterns from solid and perforated plaques have also been observed. Experimental results are compared to numerical simulations. Simulations are made with a TEACH program and a k-ε turbulence model.

The scale model where the experiments are carried out has dimensions of 1*1*0.8 m^3. Before each test, a plaque diffuser is mounted centrally in front of the air inlet at a fixed distance (slit) from the inlet wall. The plaques distance from the wall can be mechanically controlled from outside the chamber by moving the plaque supporting pins. The exhaust opening is on the opposite wall, facing the plaque. Exhaust and inlet are on the same axis, in the center of the walls, Figure 1. What is presented here is part of a more extensive work for improved indoor air quality, lower energy costs and thermally comfortable environments.

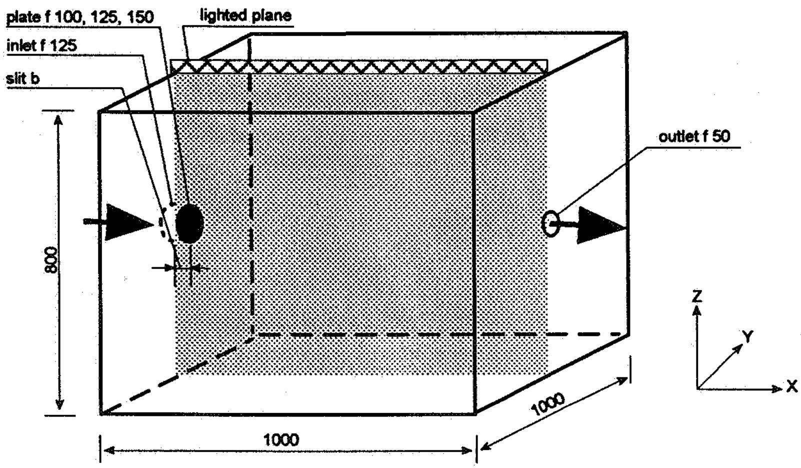


Fig. 1 The small-scale test chamber with coordinates.

Measured, observed and calculated flow characteristics

Smoke visualization, velocity measurements, computer simulations and measurements of air change efficiency have been used to study the flow characteristics in the chamber. While using a fixed flow rate (all experiments and simulations are done with a flow rate of 40 m^3/h), the distance between the plaque and the inlet wall, the so called impinging distance b (or slit b), is altered. Warm smoke from a Jem Fogger smoke generator is cooled down in a long tube before being mixed with air in the supply pipe, and discharged into the chamber. The scale model is constructed with two plexiglass walls for observation. A sheet of light is used to visualize the air movements in different two-dimensional plane cuts. In this study, the symmetrical x-z plane is visualized by the light sheet. The general flow pattern in the chamber is observed and studied by smoke visualizations and computer simulations. Both simulations and measurements have been used to find differences in the flow pattern after altering the impinging distance. A slit width which gives low recirculation and mixing is of interest. The same concept has been used for the critical diameter of the plaque. This diameter is found when the flow through the chamber is as parabolic (one-way) as possible.

For a very small plaque, a free-jet-like flow is expected, Figure 2. For a bigger plaque, a wall-jet-like flow is expected, Figure 3. There must be a critical diameter somewhere in between where a sudden change in the flow pattern occurs. The flow is discharged directly into the chamber as a merged free-jet-like flow when the diameter is smaller than the critical one. For plaques bigger than the critical size, a wall-jet-like flow with entrainment appears in the test chamber.

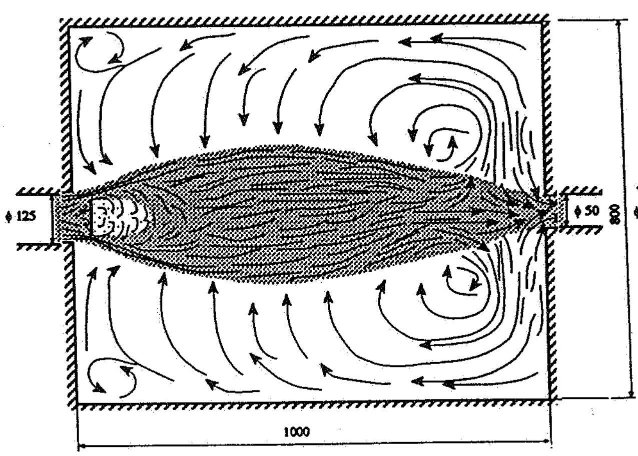


Fig. 2 Free-jet like flow.

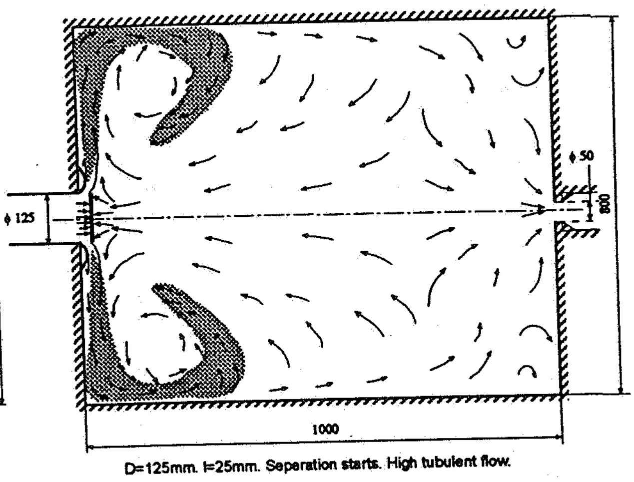


Fig. 3 Wall-jet like flow.

The experiments are started with the 125 mm plaque and an impinging distance of approximately 20 mm from the inlet wall, Figure 4. When b is less than 20 mm, a strong radial wall-jet flow is formed over the inlet wall. The wall-jet flow region increases because of entrainment. The radial wall-jet flows farther downstream with decreased momentum. When reaches the ceiling, the floor and the side walls, it turns around and moves along the new bounding surfaces as a wall-jet. In the central x-z plane, these wall-jets have a limited chance of entering further into the room. They turn into a reverse flow at 0.2 m from the inlet wall, Figure 6-A. The central x-y plane is similar but not identical. Here wall-jets along the x coordinate can enter the room and recirculate in the outlet region, Figure 6-C. Because of the entrainment and a low pressure area behind the plaque, the retarded wall-jets recirculate from the bounding surfaces. Instead of wall-jet-flow, through the chamber, recirculation dominates most of the occupied region. Close to the outlet, potential flow is observed. When the slit width b is more than 20 mm, the attaching point moves farther downstream with increased b (because of the Coanda effect). When b is around 40 mm or more, no direct attaching to the inlet wall occurs any longer. The flow hits the neighboring walls in a second impinge. (The first impinge is on the plaque diffuser). A flow separation takes place. Part of the flow recirculates back to the inlet wall and part of it enters in x-z direction, Figure 5. With an increased b, the attaching points of the neighboring surfaces move farther away from the inlet wall. For normal diffuser plaque distances (greater than 40 mm), the attaching to the neighboring surfaces is always observed with the 125 mm plaque. Ordinary free-jet-like flow over the plaque, Figure 2, was not observed. Another characteristic of the flow is that when the impinging distance b is increased, the potential flow region around the outlet increases as well.

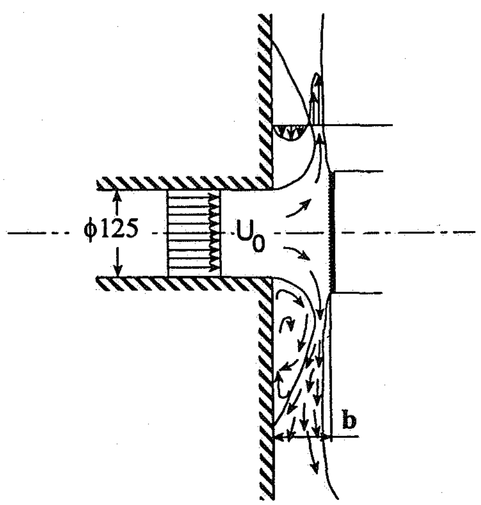


Fig. 4 Illustration of velocity profile around air inlet.

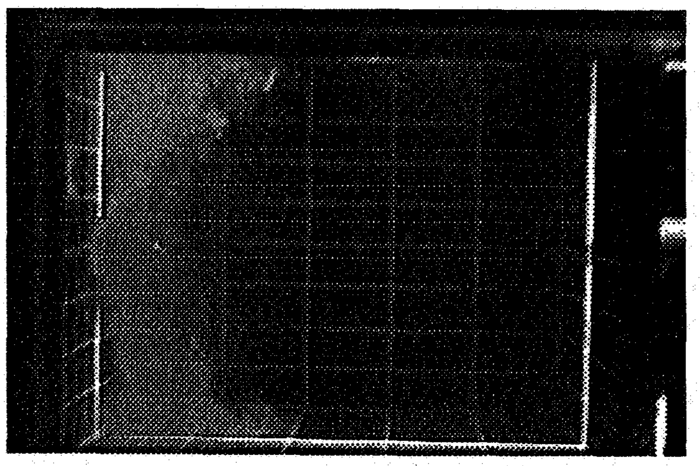
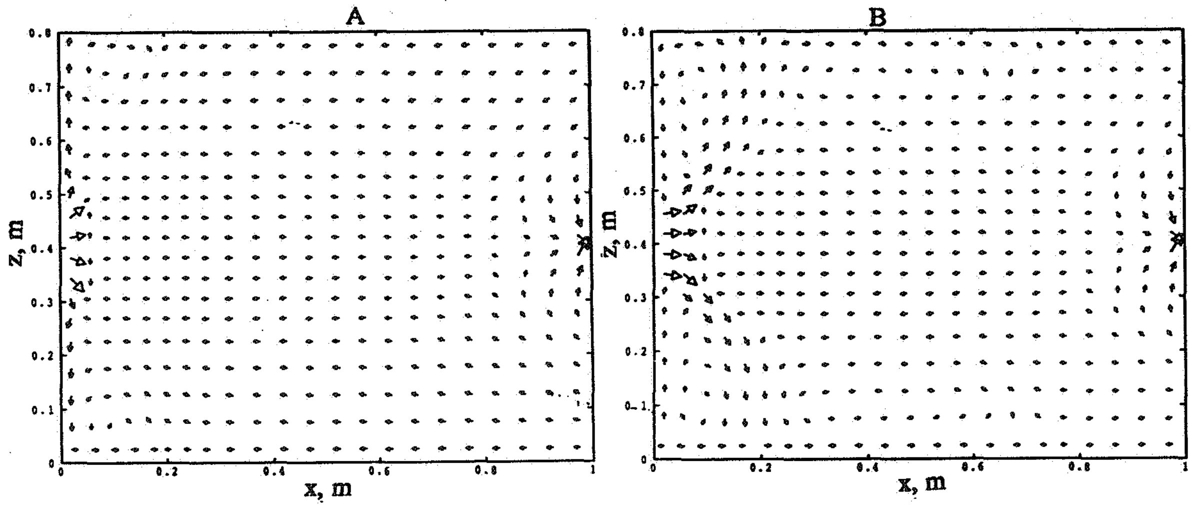


Fig. 5 Experimental flow pattern from a 125 mm plaque diffuser, x-z plane at y = 0.5 m, slit width b = 40 mm.



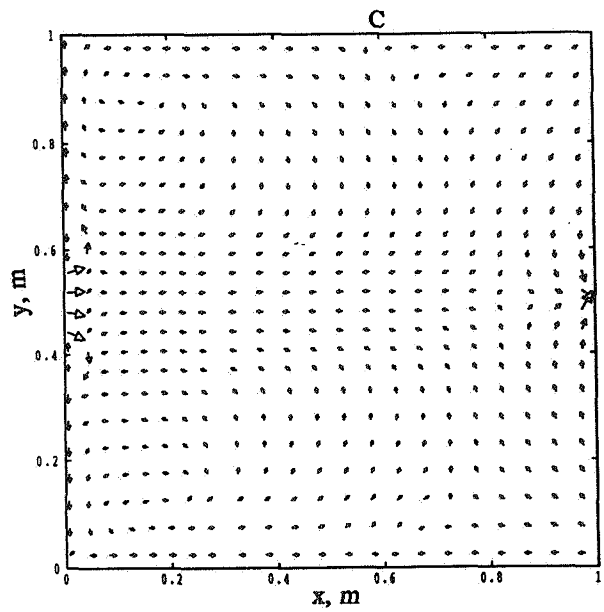


Fig. 6 Simulated three-dimensional flow pattern from a 125 mm plaque diffuser,
A) x-z cut at y = 0.5 m, slit width b = 43 mm
B) x-z cut at y = 0.5 m, slit width b = 81 mm
C) x-y cut at z = 0.4 m, slit width b = 43 mm.

Fig. 7 Experimental flow pattern from a 150 mm plaque diffuser, x-z plane at y = 0.5 m, slit width b = 60 mm.

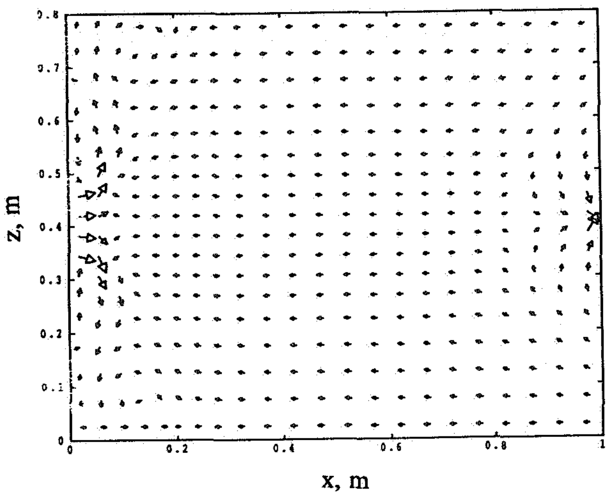


Fig. 8 Simulated three-dimensional flow pattern from a 150 mm plaque diffuser, x-z cut at y = 0.5 m, slit width b = 68 mm.

With the 150 mm plaque, the critical experimental separation distance is about 45 mm. When b is about 60 mm, the attachment to the ceiling appears. Recirculation and wall-jet, however, still dominate the general flow pattern, Figure 6. Figure 7 shows the calculated velocity flow field at slit width b = 68 mm. The direct attaching to the ceiling has not yet occurred here in the simulation.

When comparing the observed and the simulated flow patterns, one can see that there are similarities, but also differences between them. Generally speaking, the simulated critical slit values are larger than the observed ones. For the 125 mm plaque, the experimental attaching to the ceiling starts from a slit width b around 40 mm, which is smaller than the simulated value around 70 mm.

If the plaque diameter is 100 mm, the flow pattern will be totally different from what has been observed in Figures 4-8. With the 100 mm plaques, the flow-spread capacity is lost and the flow is similar to a free jet. The main flow goes through the chamber, and part of it directly to the exhaust. The rest recirculates along the bounding surfaces, Figures 9 and 10

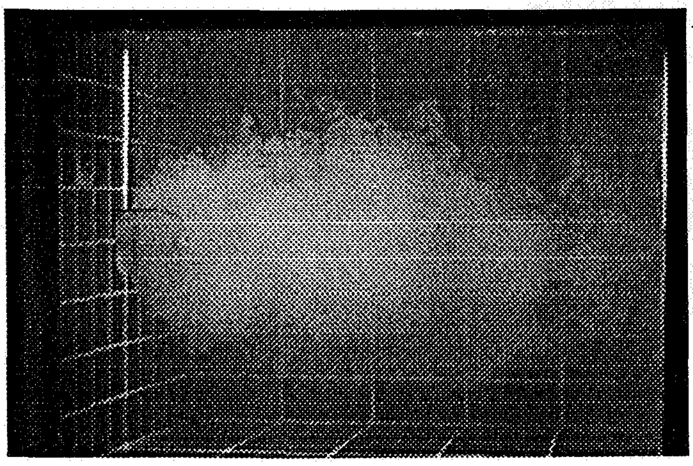


Fig. 9 Experimental flow pattern from a 100 mm plaque diffuser, x-z plane at y = 0.5 m, slit width b = 40 mm.

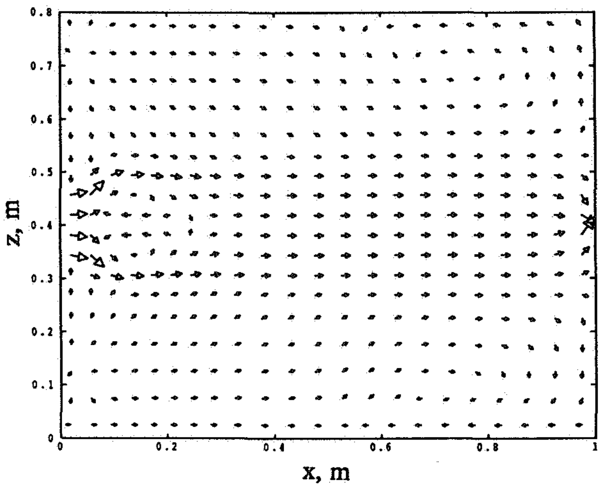


Fig. 10 Simulated three-dimensional flow pattern from a 100 mm plaque diffuser, x-z cut at y = 0.5 m, slit width b = 68 mm.

The critical diameter

The tests have shown that the impinging distance has less influence on the flow pattern than the plaque size. The 125 mm plaque creates a wall-jet-flow within the practical design impinging distances of b. The 100 mm plaque always creates a free jet like flow.

When the plaque diameter is 114 mm, the flow pattern is very sensitive to small changes of the plaque diameter. The flow changes from wall-jet-like to a much more forward flow when the plaque diameter is slightly changed, e.g. 1 mm smaller. Again, when the plaque diameter is 1 mm bigger, the flow pattern is characterized by wall-jet-like flow. The impinge distance has more influence on wall-jet-like flows than on free-jet-like flows.

Air change efficiency

Air change efficiency is measured by a step-down tracer gas technique. Perforated plaque diffusers are used in comparison with solid ones. Perforated plaques are used to eliminate the characteristic back-flow behind plaques, in order to diminish recirculation and improve forward directed flow movements. The age-of-air concept is employed, which means the age of air $<\bar{\tau}>$ is calculated from measured tracer-gas concentrations:

$$<\bar{\tau}> = \frac{\sum_{i=0}^{t_{co}} t_i c_i(t)\,\delta t}{\sum_{i=0}^{t_{co}} c_i(t)\,\delta t} \qquad (1)$$

where t_{co} = cut-off point, s.
c_i = instantaneous concentration of tracer gas in the exhaust opening, ppm.

The following relation is applied to calculated the air change efficiency:

$$\varepsilon = \frac{\tau_n}{2<\bar{\tau}>} \qquad (2)$$

where ε =air change efficiency
τ_n = nominal time constant, s.

Results from air change efficiency tests with a perforated plaque give an air change efficiency around 52%. The flow in the chamber is turbulent and thus mixed. The nominal time constant in our tests here is 25 times less than previous full-scale tests, Tang and Holmberg (1992).

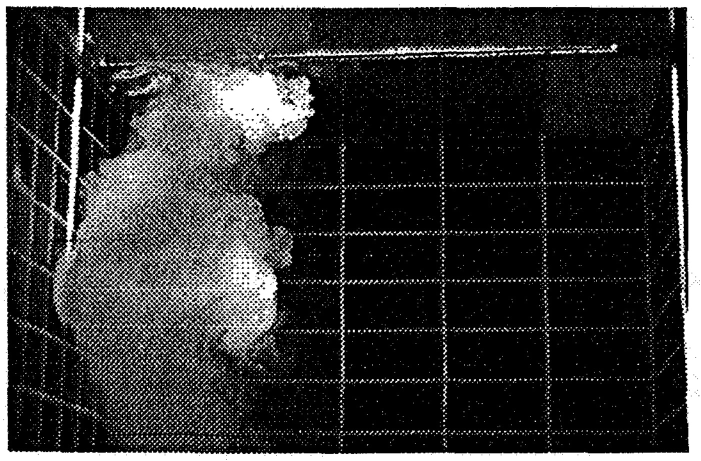


Fig. 11 Experimental flow pattern from a 150 mm plaque with a perforation degree of 33%, slit width b = 35 mm.

In the simulations, the plaque consists of many blocked Cartesian grid cells arranged in a circular formation. The plaque is perforated by unblocking (opening) every second grid cell. Flow through the perforations is altered by an extra pressure source term in the upper-stream grid cells. This is an indirect way of making the holes of perforation smaller than the grid cells.

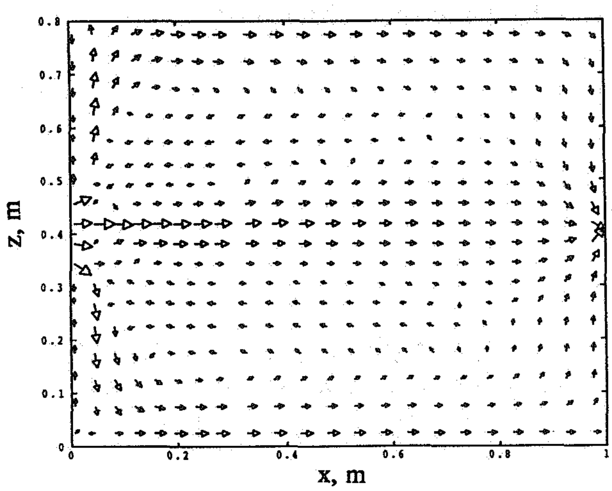


Fig. 12 Simulated two-dimensional flow pattern from a 150 mm plaque with perforation degree of 35%, slit width b = 43 mm.

Conclusions

Results from this investigation shows that plaque diffusers can be used for isothermal horizontal applications. The plaque dimensions are important for the flow structure. The slit width also influences the flow pattern in the chamber but is a less important parameter than the size of the plaque. Perforated plaques show much forward-directed flow movement. Air change efficiencies of just over 50% are achieved.

Acknowledgements

The authors are greatful to Björn Nilsson, Andrzej Paprocki, Sten Lundström and Tyrrell Burt for their help with this paper. The work was financially supported by The Swedish Work Environment Fund.

References

1. Waschke, G.
"Über die Lüftung mittels isothermer, turbulenter, radialer Deckenstrahlen"
Ki Klima+Kälte-Ingenieur 7-8/76, 1976, pp277-284.

2. Pattie, D. R. and Milne, W. R.
"Ventilation air-flow patterns by use of models", ASAE Trans. 9(5), 1966, pp646-649.

3. Timmons, M. B.
"Use of physical models to predict the fluid motion in slot-ventilated livestock structure", ASAE Trans. 27(5), 1984, pp1514-1517.

4. Zhang, J. S.
"A fundamental study of two dimensional room ventilation flows under isothermal and non-isothermal conditions", Ph. D. thesis, University of Illinois, Urbana, Illinois, 1991.

5. Reinartz, A. and Renz, U.
"Calculations of the temperature and flow field in a room ventilated by a radial air distributor", International J. of Refrigeration, Vol. 7, No. 5, 1984, pp308-312.

6. Tang, Y.Q. and Holmberg, S.
"An experimental investigation of a horizontal displacement ventilation system"′, Undersökningsrapport 1992:2, National Institute of Occupational Health, S-171 84 Solna, Sweden.