CONVECTIVE FLOWS AND VERTICAL TEMPERATURE GRADIENT WITH THE ACTIVE DISPLACEMENT AIR DISTRIBUTION

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ABSTRACT

The active displacement air distribution method is a combination of displacing and mixing. It is a low impulse system based on special nozzle ducts, which are usually placed above the occupied zone. Depending on nozzle spacing in the duct and duct position related with heat sources, it is possible to get a more displacing or more mixing system.

A study called *Convective Flows and Vertical Temperature Gradient with the Active Displacement Air Distribution* was started in September 1996 and it will end in December 1998. The main aim of the study is to determine the guidelines for air flow rate dimensioning of the system. The focus is in cases where thermal loads and need of cooling are dominating and dimensioning is possible by using vertical temperature gradient. The performance of supply air flow patterns together with convective air flows is studied experimentally by carrying out measurements in a test room and in field plants This paper presents the aim of the study and the two-zone calculation method developed for modelling the temperature stratification in the test room. Some experimental results of the test room measurements are compared with the results of the calculation model.

The results show that with uniform heat load / floor area and with high air velocities through the nozzles the air distribution behaves near fully mixing. When the heat sources create relatively strong plumes, they are able to control the room flows and higher vertical temperature gradients and contaminant gradients are achieved. Thus dimensioning with lower airflow rates is possible.

Two other papers named *Behaviour of Convective Plumes with the Active Displacement Air Flow Patterns* and *Test room and Measurement system for Active Displacement Air Distribution* regarding this study are also submitted to be presented at this conference.

KEYWORDS

Convection flows, displacement ventilation, modelling, plumes, temperature gradient.

INTRODUCTION

The active displacement air distribution method is a combination of displacing and mixing. It is a low impulse system based on special nozzle ducts (Figure 1), which are usually placed above the occupied zone

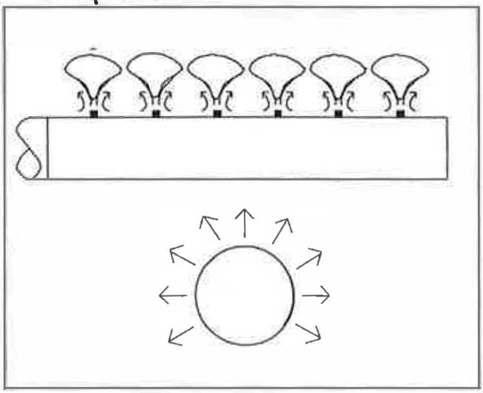


Figure 1 Principle of the nozzle duct.

along the whole length of the duct and on full or a part of circular surface (nozzle sector 0 - 360 degrees). Air velocity in the nozzle is high, but the supply air mixes quickly with the room air in the near zone of the duct. Thus the air velocity is quickly reduced and the air distribution can be considered as a low impulse system and can be used for displacement. Depending on the nozzle sector and the direction of the supply air it is possible to produce four different types of air flow patterns (Figure2).

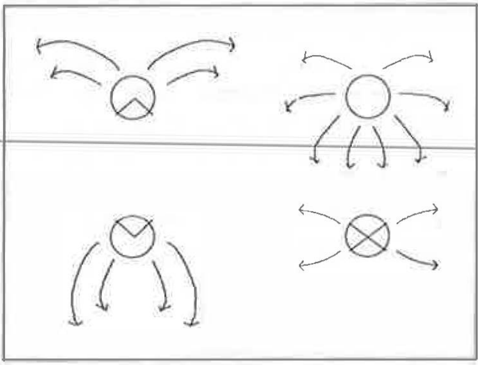


Figure 2 Air distribution upwards, full circular, downwards and two sides.

carried out by using two types of the air flow patterns, air distribution upwards and full circular distribution. The most common type is air distribution upwards. It is used in industrial and comfort ventilation and can be used for a large range of cooling effects and air flow rates. Even temperature in the occupied zone is also characteristic for this method. The full circular distribution is used mostly for displacement purposes in industrial ventilation.

The air velocity level in the whole room with the active displacement air distribution is relatively low. It means that strong thermal plumes created by heat sources are able to break through the supply air flow pattern, whereas thermal plumes with low buoyancy are mixed with the room air (Figure 3).

The aim of the experiments is to determine the vertical temperature gradient in the room by varying the placing and the strength of heat sources.

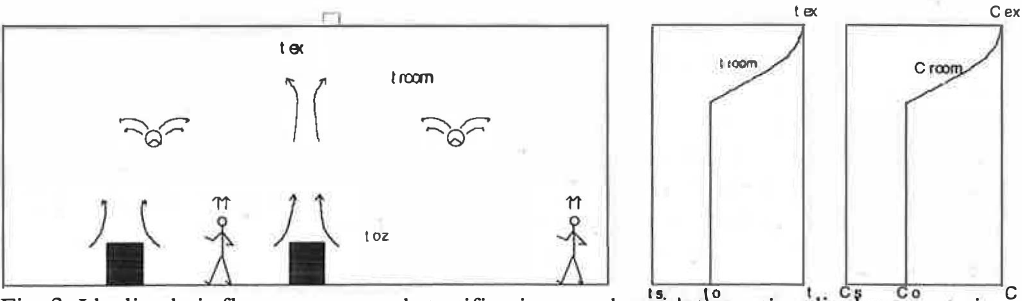


Fig. 3. Idealized air flow patterns and stratification graphs with the active displacement air distribution.

Similarly the contaminant gradient in the room is measured by using tracer gas injection both into the heat sources and outside the heat sources (contaminant source without thermal buoyancy). The temperature effectiveness, local and general contaminant removal effectiveness and air exchange efficiency will be determined from the measurements (Ethridge 1996, Mundt 1996). The experiments are carried out in a test room in the laboratory of Finnish Institute of Occupational Health in Turku. Furthermore field experiments are carried out in three test plants in Finland and Sweden.

Finally the guidelines for air flow rate dimensioning of the system are determined (VDI 3802 1997, Zhivov 1997). The focus is in cases where thermal loads and need of cooling are dominating and dimensioning is possible by using the vertical temperature gradient, Equation 1.

$$q_s = \frac{Q_{cool}}{\rho C_p (t_s - t_{ex})} = \frac{Q_{cool}}{\rho C_p \varepsilon_t (t_s - t_{oz})} \quad (1)$$

where Q_{cool} = need of cooling effect

METHODS

Two zone calculation method

A two zone calculation method has been developed for modelling the temperature stratification in the test room. The method can also be used in practical cases in the general formula (Equations 2...8). Nomenclature for the equations is at the end of the presentation.

When the temperature of the exhaust air T_{ex} is assumed to be known, the temperature of the supply air T_s (Equation 18), the temperatures of the wall surfaces T_{wlz} and T_{wuz} (Equations 14...16) and the air temperature in the lower zone T_{lz} (Equation 11) can be calculated.

The concentration stratification has been modelled similarly (Equations 19...20). When the contaminant flow from the source is known, the concentration in the upper and the lower zone can be calculated.

Plume air flow rates

The plume air flow rates q_{cbm} have been measured for three types of heat sources by Hautalampi (1998).

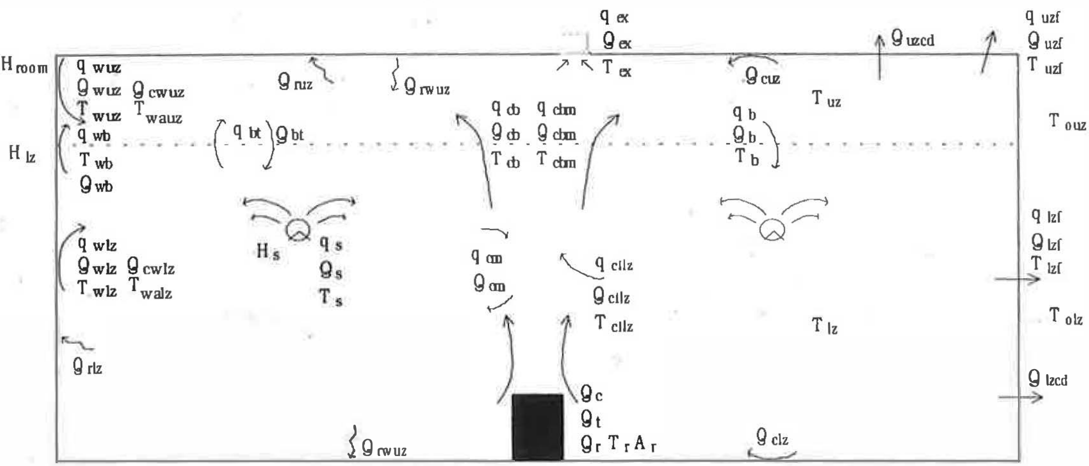


Figure 4 Two zone model for the calculation of temperature stratification with the active displacement air distribution.

Temperature model

<u>Air mass flow balance</u>

Lower zone

$$\rho q_s + \rho q_b - \rho q_{wb} - \rho q_{lzf} - \rho q_{cbm} = 0 \quad (2)$$

Upper zone

$$\rho q_{cbm} - \rho q_{ex} - \rho q_b + \rho q_{wb} - \rho q_{uzf} = 0 \quad (3)$$

<u>Heat flow balance</u>

Lower zone

$$Q_s + Q_c + Q_{clz} + Q_{wlz} + Q_b + Q_{bt} - Q_{wb} - Q_{lzf} - Q_{cbm} = 0 \quad (4)$$

Upper zonc

$$Q_{cbm} - Q_{cuz} - Q_{wuz} - Q_b - Q_{ex} - Q_{bt} + Q_{wb} - Q_{uzf} = 0 \quad (5)$$

$$-Q_{clz}-Q_{cwlz}+Q_{rvuz}+Q_{rlz}-Q_{lzcd}=0 \quad (6)$$

Walls, upper zone

$$Q_{cuz}+Q_{cwuz}-Q_{rvuz}+Q_{ruz}-Q_{uzcd}=0 \quad (7)$$

In the test room it is assumed

- air density will stay constant
- outside temperatures = inside temperatures
- $q_{uzf}=0$, $q_{lzf}=0$

Equations become with assumptions

Air mass flow balance

Lower zone

$$q_s+q_b-q_{cbm}-q_{wb}=0 \quad (8)$$

Upper zone

$$q_{cbm}-q_{ex}-q_b+q_{wb}=0, \quad (9)$$

where q_{cbm} is a measurement result for different kinds of heat sources

The whole room

$$q_s-q_{ex}=0 \quad (10)$$

Heat flow balance

Lower zone

$$Q_s+Q_c+Q_{clz}+Q_{wlz}+Q_b+Q_{bt}-Q_{wb}-Q_{cbm}=0, \quad (11)$$

where $Q_s=\rho C_p q_s T_s$

$Q_c=Q_t-Q_{rlz}-Q_{ruz}$

$Q_{rlz}=F_{rlz}A_r\varepsilon_r\sigma(T_r^4-T_{wlz}^4)$

$Q_{ruz}=F_{ruz}A_r\varepsilon_r\sigma(T_r^4-T_{wuz}^4)$

$Q_{clz}=h_{cf}A_f(T_{wlz}-T_{lz})$

$Q_{wlz}=(q_{wuz}/q_{wlz})Q_{cwlz}$ (when $q_{wlz}>q_{wuz}$, and $q_{wuz}>=0$ and $q_{wlz}>0$)

$Q_{wlz}=Q_{cwlz}$ (when $q_{wlz}<q_{wuz}$, and $q_{wuz}>=0$ and $q_{wlz}>=0$; or $q_{wlz}<0$ and $q_{wuz}>=0$)

$Q_{wlz}=0$ (when $q_{wlz}>=0$ and $q_{wuz}<0$)

$Q_{cwlz}=h_{cwlz}A_{wlz}(T_{wlz}-T_{lz})$

$Q_b=\rho C_p q_b T_{uz}=\rho C_p T_{uz}(q_{cbm}+q_{wb}-q_s)$ (when $q_{cbm}+q_{wb}>q_s$)

$Q_b=\rho C_p q_b T_{lz}=\rho C_p T_{lz}(q_{cbm}+q_{wb}-q_s)$ (when $q_{cbm}+q_{wb}<q_s$)

$Q_{bt}=\rho C_p q_{bt}(T_{uz}-T_{lz})$

$Q_{cbm}=\rho C_p q_{cbm} T_{cbm}=\rho C_p(1-q_{cm}/q_{cb})q_{cb}T_{cbm}$

$Q_{wb}=(1-q_{wuz}/q_{wlz})Q_{cwlz}+\rho C_p q_{wb} T_{lz}$ (when $q_{wlz}>q_{wuz}$, and $q_{wuz}>=0$ and $q_{wlz}>0$)

$Q_{wb}=(q_{wlz}/q_{wuz}-1)Q_{cwuz}+\rho C_p q_{wb} T_{uz}$ (when $q_{wlz}<q_{wuz}$, and $q_{wuz}>=0$ and $q_{wlz}>=0$)

$Q_{wb}=Q_{cwlz}+\rho C_p q_{wb} T_{lz}$ (when $q_{wlz}>=0$ and $q_{wuz}<0$)

$Q_{wb}=-Q_{cwuz}+\rho C_p q_{wb} T_{uz}$ (when $q_{wlz}<0$ and $q_{wuz}>=0$)

$Q_{cwuz}=h_{cwuz}A_{wuz}(T_{uz}-T_{wuz})$

Upper zone

$$Q_{cbm}-Q_{cuz}-Q_{wuz}-Q_b-Q_{ex}-Q_{bt}+Q_{wb}=0 \quad (12)$$

where $Q_{cuz}=h_{cc}A_c(T_{uz}-T_{wuz})$

$Q_{wuz}=Q_{cwuz}$ (when $q_{wlz}>q_{wuz}$, and $q_{wuz}>=0$ and $q_{wlz}>0$; or when $q_{wlz}>=0$ and $q_{wuz}<0$)

$Q_{wuz}=(q_{wlz}/q_{wuz})Q_{cwuz}$ (when $q_{wlz}<q_{wuz}$, and $q_{wuz}>=0$ and $q_{wlz}>=0$)

In the equations of the mass flows it can be seen that the air flow rates of the convective plumes dominate the mass balance if there are not any buoyancy flows on the walls. When the flow rate of the plume increases higher than the supply air flow rate, the return flow from the upper zone to the lower zone will increase and the temperature of the room air will become more even.

The results of the calculation, temperature effectiveness and local contaminant removal effectiveness, can be now presented by varying parameters such as type, power, placing and number of the heat sources, supply air flow rate, mixing air flow rate through the zone boundary, reduction of the plume air flow rate by the supply air flow.

The calculation results are compared with some experimental results. The measurement system of test room is presented by Koskela (1998).

RESULTS

The results of the calculation model are shown in the Figures 7...12. The temperature effectiveness ε_t and local contaminant removal effectiveness ε_c are presented as a function of several parameters. All the cases except Figure 8 are calculated using convective heat sources (Hautalampi 1998).

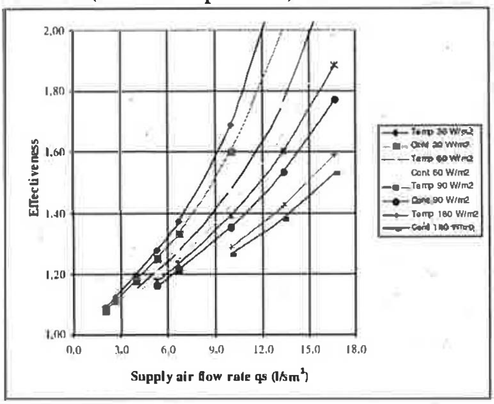


Figure 7 Effectiveness ε_t and ε_c as functions of supply air flow rate and power of the heat source

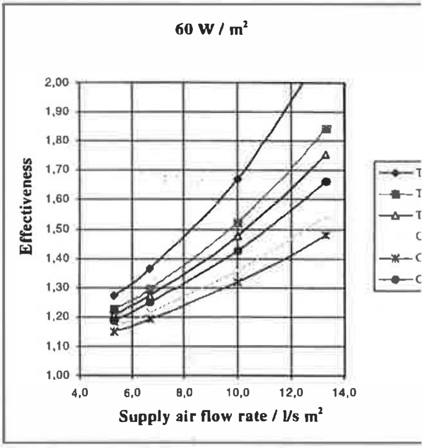


Figure 8 Effectiveness ε_t and ε functions of supply air flow rate an type of the heat source.

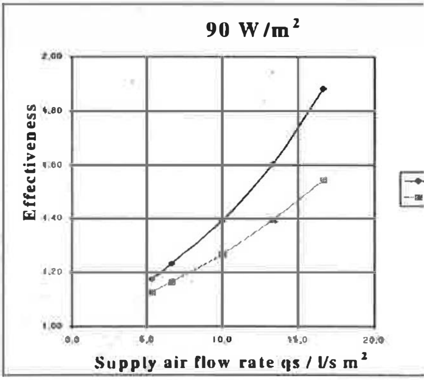


Figure 9 Effectiveness ε_t as a functi supply air flow rate and the number o sources.

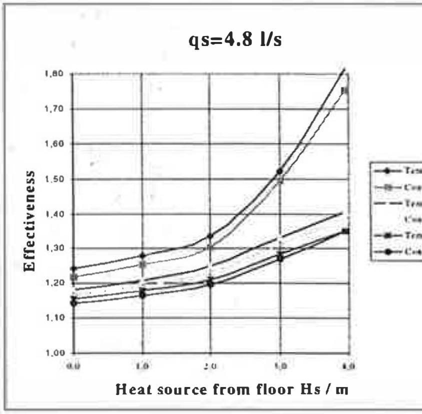


Figure 10 Effectiveness ε_t and ε functions of the location of the heat so

$Q_{wuz} = 0$ (when q_{wlz}<0 and q_{wuz}>=0)

$Q_{cwuz} = h_{cwuz} A_{wuz} (T_{uz} - T_{wuz})$

$Q_{ex} = \rho C_p q_{ex} T_{ex}$, $T_{ex} = T_{uz}$

whole room

$$Q_s + Q_t - Q_{ex} - Q_{lzcd} - Q_{uzcd} = 0 , \quad (13)$$

where $Q_{lzcd} = (1/(s/\lambda + 1/h_{walz})) A_{wuz} (T_{wuz} - T_{olz})$, $T_{olz}=T_{lz}$

$Q_{uzcd} = (1/(s/\lambda + 1/h_{wauz})) A_{wuz} (T_{wuz} - T_{ouz})$, $T_{ouz}=T_{uz}$

lls, lower zone

$$- Q_{clz} - Q_{cwlz} + Q_{rwuz} + Q_{rlz} - Q_{lzcd} = 0 \quad (14)$$

where $Q_{rwuz} = F_{rulz} A_{cuz} \varepsilon_w \sigma (T_{wuz}^4 - T_{wlz}^4)$

lls, upper zone

$$Q_{cuz} + Q_{cwuz} - Q_{rwuz} + Q_{ruz} - Q_{uzcd} = 0 \quad (15)$$

lls, the whole room

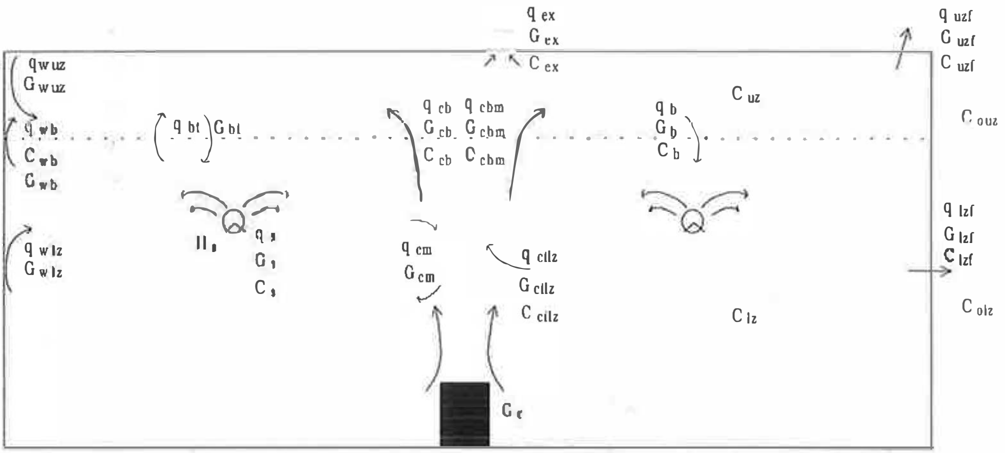
$$Q_{cuz} - Q_{clz} + Q_{cwuz} - Q_{cwlz} + Q_{rlz} + Q_{ruz} - Q_{lzcd} - Q_{uzcd} = 0 \quad (16)$$

ation (13) becomes

$$\rho C_p q_s (T_s - T_{uz}) + Q_t - Q_{lzcd} - Q_{uzcd} = 0 \quad (17)$$

ression of supply air temperature T_s

$$= T_{uz} - \frac{Q_t - Q_{lzcd} - Q_{uzcd}}{\rho C_p q_s} \quad (18)$$



ure 5 Two zone model for the calculation of concentration stratification with the active lacement air distribution.

ncentration model

mass flow balance

ations 2-3.

taminant flow balance

ver zone

$$G_s + G_c + G_b + G_{bt} - G_{wb} - G_{lzf} - G_{cbm} = 0 \quad (19)$$

per zone

$$G_{cbm} - G_b - G_{ex} - G_{bt} + G_{wb} - G_{uzf} = 0 \quad (20)$$