Temperature and Contaminant Stratifications in the Active Displacement Air Distribution Method

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Introduction

In the applications of zoning and stratification room air conditioning strategies (1) the calculation of the needed air flow rate in a space is based on the utilization of the temperature and contaminant stratifications. The basic calculation is presented in Figure 1 and Equations 1 and 2, which are determined from the air mass, heat and contaminant mass flow balances of the space. The utilization of the stratifications leads to energy and cost efficient air conditioning systems, but all the flow elements in the space and their effect on the stratifications must be known and taken into account.

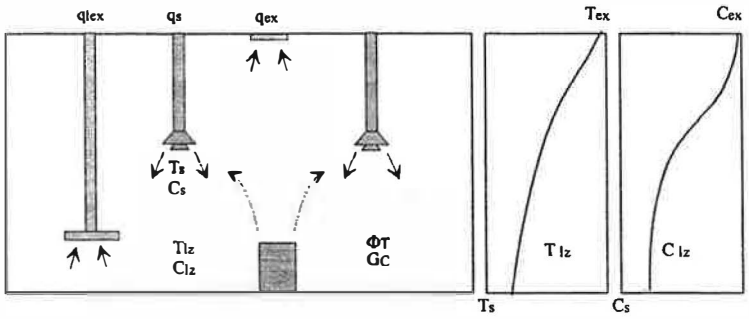

Figure 1. The influencing factors in the supply air flow rate calculation

$$q_s = \frac{\Phi_T}{\rho c_p (T_{ex} - T_s)} + \frac{T_{ex} - T_{lz}}{T_{ex} - T_s} q_{lex} \quad (1)$$

$$q_s = \frac{G_C}{C_{ex} - C_s} + \frac{C_{ex} - C_{lz}}{C_{ex} - C_s} q_{lex} \quad (2)$$

The main objective of this study was to determine a calculation model and a computing program for the calculation of the dimensioning air flow rate in the active displacement air distribution method. The model was to be developed especially for practical cases and based on the temperature and contaminant stratifications. The active displacement (replacement) (1) is an application of the zoning strategy and a combination of mixing and displacing air distribution methods. It is based on special nozzle ducts, which are usually placed above the occupied zone (2, 3).

Methods

The study consisted of six tasks:

A. Flow models. The effecting phenomena and existing theoretical models for flow elements were studied.

B. Test room measurements. In the test room built for this study the flow element measurements were carried out (2, 4, 5). In the stratification measurements variable parameters were the type and air flow rate of the supply air device and the type, power and location of the heat sources (6). Also two key flow elements were determined: the turbulent mixing flow rate between the lower and upper part of the room and the plume air flow rate from the heat sources effected by supply air flow patterns. In all the measurements smoke visualisation videos were recorded.

C. Calculation model for the test room. Calculation models were developed for determining the temperature and contaminant stratifications and the effect of the flow elements in test room (2).

D. Field measurements. The measurements of temperature stratification were carried out in thirteen field cases. In four of the cases the air and heat flow rate balances were determined in Scandinavian winter conditions based on the measurements during two weeks. In nine of the cases the temperature stratification was measured in summer conditions during two afternoon hours.

E. Calculation model for field cases. A calculation model was developed for field cases including local exhaust air flows. The model was based on the test room model and improved by some simplifications of wall temperatures and wall flows. The model was tested with the results of the four winter case measurements and with the examination of the effects of different parameters.

F. Computing program. A computing program was developed based on the calculation model of field cases.

Results

An air distribution method as itself does not determine temperature or contaminant stratification in a space, because other flow elements affect significantly on the stratification. During the project, a proposal for the classification of room air conditioning strategies was determined (1). The active displacement was considered as an application of the zoning strategy. The calculation model for the test room was developed as a two zone model, which is suitable for the zoning strategy. The model has been presented earlier (2).

A part of the stratification measurements in the test room has been reported separately in another paper (6). The turbulent mixing between the zones was shown to be a function of the vertical temperature gradient and the momentum flux of the supply air flow. The plume penetration coefficient ψ describes how much of plume air flow rate flows from lower zone into the upper zone compared to the case of an undisturbed plume. It was shown to be a function of several parameters, as described in Equation 3.

$$\psi = a\Phi_c^{2/3} + b, \qquad 0 \le \psi \le 1 \tag{3}$$

where Φ_c is the convection heat power of the source and a and b are functions the sizes and locations of supply air units and heat sources, vertical temperature gradient and the momentum flux of supply air flow.

The field measurements showed relatively high temperature values for effectiveness $\varepsilon_T = (T_{ex}-T_s)/(T_{lz}-T_s)$. In winter cases, the average was 1,31 and in summer cases 1,39. The summary of the measurement results of temperature stratifications is presented in Figure 2. The dimensionless temperature difference at height H, $\Delta T_D=(T_H-T_{lm})/(T_{ex}-T_{lm})$, is in x-axis and the dimensionless height $H_D=H/H_{supply\ unit}$ is in y-axis.

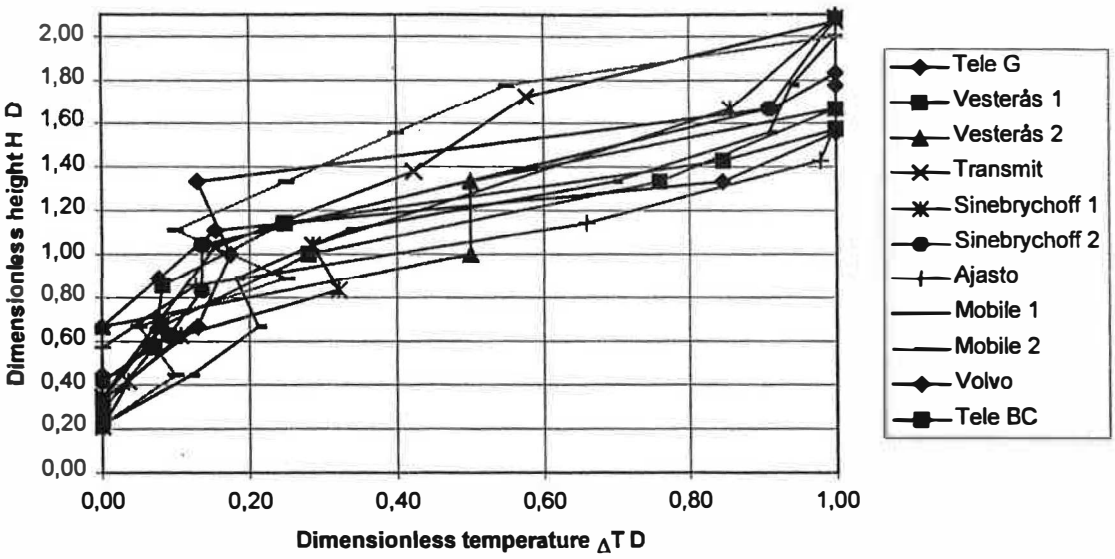

Figure 2. Summary of the field measurement results.

The two zone model for the field cases is based on the calculation model, which is presented separately in another paper (7). It is a steady state model, where the inside surface temperatures of all the wall structures are calculated from the outdoor temperature $T_{wall}=T_{room}-(U_{wall}/h_{wall})(T_{room}-T_{out})$.

The computing program has three alternatives for the calculation depending on what starting values are known:

A. The calculation of the supply air flow rate and the temperature of the upper zone air, when the temperatures of supply air and lower zone air are known.
B. The calculation the temperatures of the supply air and upper zone air, when the supply air flow rate and the temperature of lower zone air are known.
C. The calculation the temperatures of the lower and upper zone air, when the supply air flow rate and the temperature of supply air are known.

Discussion

In this study, a two zone model was developed for active displacement air distribution. It is based on the calculation of all influencing flow elements, which is not found in earlier computing programs used in ventilation design. The model can be used for analysing the system performance in different outdoor conditions, heat source power and location, etc. The wall flows are very important for analysing differences in summer and winter conditions especially when the concentration is dominating the dimensioning of the needed supply air flow rate.

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