Modelling of Air Distribution Methods for Zoning Strategy

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Introduction

Zonal models are often used in analytical calculation of temperature, concentration or humidity conditions in ventilated spaces. The space is divided in two or several zones (1). The zoning of the space is based on the assumption of constant temperature, concentration and humidity in each separate zone. The balances for air mass flow, contaminant mass flow, water vapour mass flow and heat flow are determined between zones and between zone and outer boundaries.

The two zone models are especially useful for stratification and zoning strategies because of the typical vertical stratification of heat, contaminants or water vapour within these strategies. The aim of the zoning strategy is to have control of temperature, concentration or humidity over a certain volume of the room, while the rest of the room is left with less attention (2). The objective of this paper is to determine a practical two zone model for the air distribution methods of the zoning strategy.

Methods

The calculation of the two zone model is based on the steady state balance equations for air mass flow, contaminant mass flow and heat flow of both zones. The level of the boundary between the lower/controlled and the upper/uncontrolled zone is determined on the level by the highest temperature or/and concentration gradient and with the criteria of the air distribution method and devices. The lower zone is defined high enough to get nearly all the induction air of the supply air devices from the controlled zone, i.e. the turbulent mixing between the zones is low. This is presented in Figure 1.

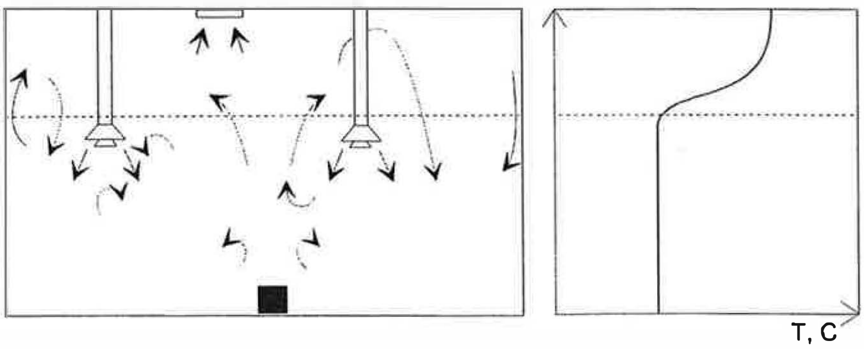

Figure 1. The height of the lower zone boundary in zoning strategy.

Results

The developed model is presented in Figures 2 and 3 and Equations 1–6. The balance equations have the basic form Σ Flow in + Σ Flow sources - Σ Flow out = 0. First the air flows and air temperatures and then the concentrations in the both zones are solved by iteration towards a steady state. The air and contaminant mass flow elements in outer boundaries and between the zones are created by

1. Supply air
2. Extract air
3. Heat and contaminant sources
4. Local ventilation
5. Plumes of the buoyancy sources through the zone boundary
6. Possible return air from upper zone into lower zone
7. Flows along wall surfaces due to temperature differences
8. Infiltration and exfiltration
9. Mixing between zones due to turbulence and disturbances

The heat flow elements are created by

10. Radiation from heat sources
11. Radiation between room surfaces

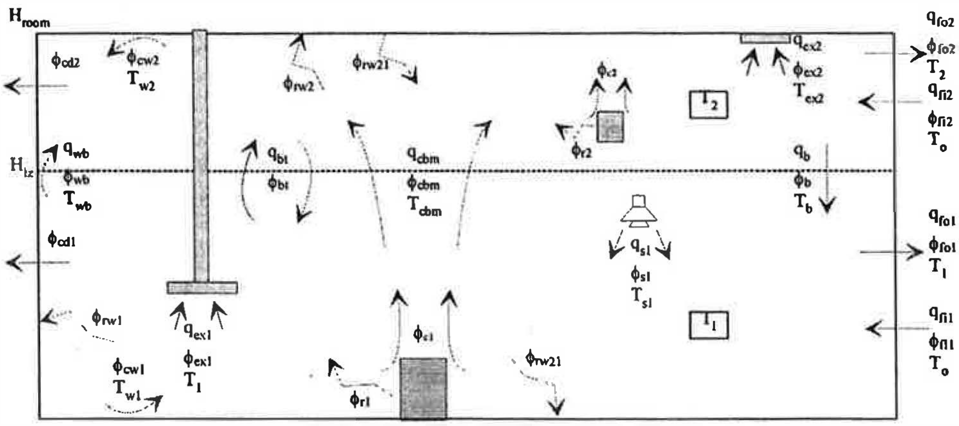

Figure 2. Two zone air mass and heat flow model

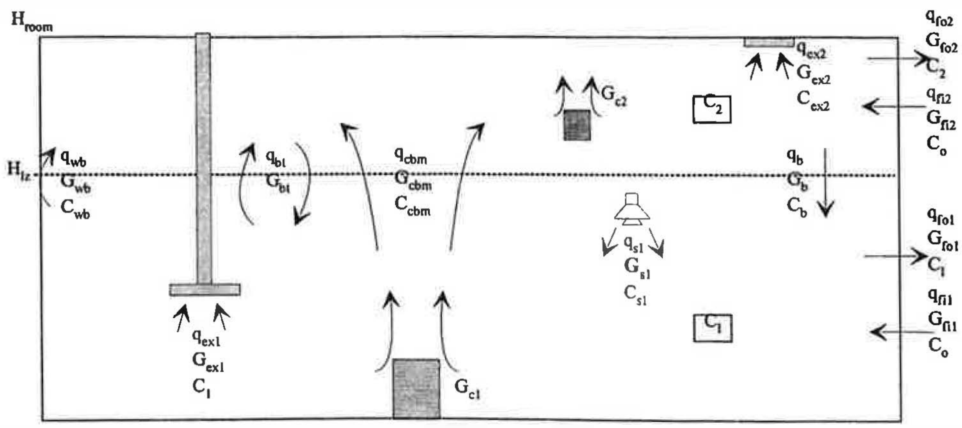

Figure 3. Two zone air and contaminant mass flow model

Nomenclature for Figures 2-3 and Equations 1-6:

C =	concentration [mg.m^{-3}]	H =	height [m]
G =	contaminant flow rate [mg.s^{-1}]	q =	air flow rate [dm^{3}s^{-1}]
Φ =	heat flow rate [W]	T =	temperature [K]
Subscripts			
1 =	upper zone	2 =	lower zone
b =	boundary, through the boundary	c =	convection
cd =	conduction	ex =	exhaust, extract
f =	filtration	i =	in
m =	mixing, mixed	o =	out, outside
r=	radiation	s =	supply
t=	turbulent mixing	w =	wall

The model equations are determined by writing the balance equations based on the conservation of mass and energy.

Air mass flow balance for the lower zone

$$\rho_{s1}q_{s1} - \Sigma\rho_{ex1}q_{ex1} + \rho_b q_b - \Sigma\rho_{wb}q_{wb} - \rho_1 q_{fo1} + \rho_o q_{fi1} - \Sigma\rho_{cbm}q_{cbm} = 0 \qquad (1)$$

Air mass flow balance for the upper zone

$$-\Sigma\rho_{ex2}q_{ex2} - \rho_b q_b + \Sigma\rho_{wb}q_{wb} - \rho_2 q_{fo2} + \rho_o q_{fi2} + \Sigma\rho_{cbm}q_{cbm} = 0 \qquad (2)$$

Heat flow balance for the lower zone air

$$\Phi_{s1} - \Sigma\Phi_{ex1} + \Phi_b - \Sigma\Phi_{wb} - \Phi_{fo1} + \Phi_{fi1} - \Sigma\Phi_{cbm} + \Sigma\Phi_{c1} + \Sigma\Phi_{rw1} + \Sigma\Phi_{rw21} - \Sigma\Phi_{cd1} + \Phi_{bt} = 0 \qquad (3)$$

Heat flow balance for the upper zone air

$$-\Sigma\Phi_{ex2} - \Phi_b + \Sigma\Phi_{wb} - \Phi_{fo2} + \Phi_{fi2} + \Sigma\Phi_{cbm} + \Sigma\Phi_{c2} + \Sigma\Phi_{rw2} - \Sigma\Phi_{rw21} - \Sigma\Phi_{cd2} - \Phi_{bt} = 0 \qquad (4)$$

Contaminant mass flow balance for the lower zone

$$G_{s1} - \Sigma G_{ex1} + G_b - \Sigma G_{wb} - G_{fo1} + G_{fi1} - \Sigma G_{cbm} + \Sigma G_{c1} + G_{bt} = 0 \qquad (5)$$

Contaminant mass flow balance for the upper zone

$$-\Sigma G_{ex2} - G_b + \Sigma G_{wb} - G_{fo2} + G_{fi2} + \Sigma G_{cbm} + \Sigma G_{c2} - G_{bt} = 0 \qquad (6)$$

In heat balance equations 3 and 4, the radiation heat flows $\Sigma\Phi_{rw1}$ and $\Sigma\Phi_{rw2}$ from the heat sources (machines, lamps, people and sun) and $\Sigma\Phi_{rw21}$ from upper zone wall surfaces to lower zone wall surfaces, are not supposed to increase the temperatures of the walls but the air temperatures. The wall surface temperatures T_{w1} and T_{w2} are calculated separately for each wall and window surface by means of heat transfer through the wall: $T_{w1}=T_1-(U_1/h_1)(T_1-T_o)$ and $T_{w2}=T_2-(U_2/h_2)(T_2-T_o)$, where h is the heat transfer coefficient on the surface and U is the overall heat transfer coefficient. The air flows along the wall surfaces through the zone boundary q_{wb} are calculated separately for each wall and window surface.

The convection flows from the heat sources $\Sigma\Phi_{c1}$ and $\Sigma\Phi_{c2}$ as well as contaminant flows from contaminant sources are flows loading the room. There may be also additional heat and pollutant flows, which are exhausted directly out by local ventilation and are not included in the balance calculation.

The flow rate of the plume through the zone boundary depends on the plume strength and the air distribution method and device because of the interaction between the plume and the supply air (3). The turbulent mixing between the zones is dependent on the air distribution method and device (3).

Discussion

The stratifications of temperature and contaminants depend on several parameters, which all should be included in calculations when designing the system combination of the room air conditioning methods e.g. the differences of wall flows in summer and winter conditions. The air distribution method and dimensioning of the air supply devices are important factors in determining the accumulation of heat and contaminants. The presented model has been applied to the so called active displacement method, which is a typical example of an air distribution method and device in the zoning strategy (3).

References

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