

A METHOD FOR PREDICTION OF ROOM TEMPERATURE DISTRIBUTION

Hong-zuo zhao, An-gui Li

Xi'an University of Architecture & Technology, Xi'an ,P.R .China

ABSTRACT

The heat sources in a room with upward air supply, can be ideally decomposed into some basic models. Based on searching of the solution of the basic models, then solving the varieties of practical problems, a simplified method for predicting vertical temperature distribution of room air is submitted in this paper. Calculated values of some practical examples agree satisfactorily with experiment results.

KEYWORDS

Temperature distribution, Displacement ventilation, Mixing ventilation.

INTRODUCTION

On account of meeting with different needs, not only simulation or modeling methods, but also simplified methods are useful for prediction of temperature distribution. However the simplified methods ordinarily can be used only for specified problems. In view of the manifold conditions of engineering, the purpose of this paper is to find a simplified method that is easier to deal with complicated conditions.

Experimental analysis shows that the primary factors to effect the air temperature of rooms with upward air supply are mean air velocity, status of heat source distribution, as well as the mode of heat exchange. The status of heat source distribution in engineering may be classified as three basic models: A. uniformly distributed heat sources in space, B. uniformly distributed heat sources on the floor, C. concentrated heat source at bottom of the room. If the effects of these typical heat source distributions on air temperature can be determined one by one, then the actual engineering problems consisting of the different combinations of typical heat source models will be solved quantitatively.

METHOD

The basic models A, B, C and two composite models AB and BC are shown in Fig. 1. Models AB and BC are formed of combining A with B and B with C. In Fig 1, the heat source distribution is shown in upside and the temperature distribution is shown in lower part. And so on and so forth, composite models such as ACB etc also can be indicated and solved.

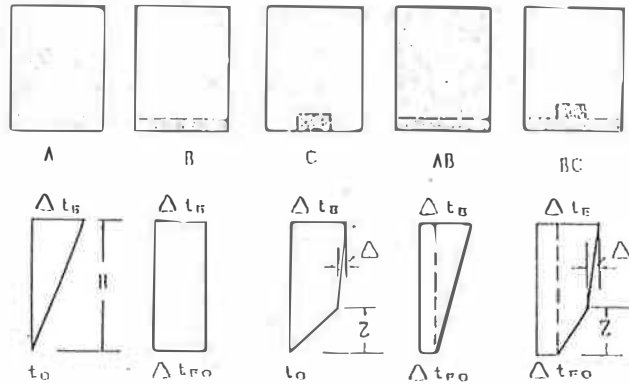


Figure 1 Heat source models and temperature distribution

Basically, the prediction of room temperature can be concluded as the determination of the respective temperature distribution of the basic heat source models. Authors have illustrated temperature patterns respective to the three basic heat source models in a prior work^[7], the main conclusion being as follows:

(A) Uniformly distributed heat sources in space

As seen in Fig.1 mode A, gives

$$\Delta t_E = t_E - t_0 = \frac{q_v F H}{\rho C_p G} \quad (1)$$

$$\text{thus } \frac{dt}{dh} = \frac{q_v F}{\rho C_p G} \quad (2)$$

where t_E =exhaust air temperature (°C)
 T_R =supply air temperature (°C)
 q_v =volumetric intensity of heat load (W/m³)
 F =floor area (m²)
 H =room height (m)
 ρ =air density (kg/m³)
 C_p =specific heat at constant pressure (J/kg.K)
 G =volumetric flow rate (m³/s)

Though in engineering practice, the actual condition always can not be accord with the uniformly distributed hypothesis completely, however [1] movement of objects and air flow are helpful for heat diffusion, [2] radiant heat transfer acting as a secondary heat source is another uniformization mechanism, [3] vertical temperature distribution stands for the temperature on different levels, so it is only related to vertical distribution of heat and has nothing to do with horizontal distribution of heat. In fact imperfectly uniformly distributed of heat sources will result in the approximate solution as a uniform one. For example, if there are some dispersed and same quality of heat sources on the different levels in a room, the temperature distribution of the room can be estimated according to the heat source model A. As example No.1 in Fig.2, there are five measured temperatures in different heights of the room with heat sources containing: ceiling lights, window, person,

desk lamp and computer.^[1] All those measured and calculated values agree within 1°C.

(B) Uniformly distributed heat sources on the floor

There is heat emission only directly from floor panel heating or from floor surface heated by radiant heat Q_r .

$$\begin{aligned} \text{Then} \quad & \therefore q_r = 0 \\ & \therefore \frac{dt}{dh} = 0 \end{aligned} \quad (3)$$

$$\text{and} \quad \Delta t_{Fo} = t_{Fo} - t_o = \Delta t_E = \frac{Q_r}{\rho C_p G} \quad (4)$$

where t_{Fo} = air temperature at the floor

Thus the temperature distribution becomes a vertical line as shown in Fig.1 model B. It means on this occasion, prediction method is not only fitting for displacement ventilation but also applicable to mixing ventilation. Temperature data of three model experiments^{[4][6]} with different air supply systems in the main floor of a hydropower station are shown in Fig.2 example Nos. 2~4. And for each experiment, the air temperatures at ceiling, floor and middle height of the room are shown to be approximately same.

In a special case, if the ceiling temperature t_E is higher than that of the floor as usually seen in model A. Radiant heat transfer between these two horizontal planes takes place and the air temperature at floor increases. So Δt_{Fo} is given by^[3]

$$\Delta t_{Fo} = \frac{t_E - t_o}{\frac{\rho C_p G}{F} \left(\frac{1}{\alpha_c} + \frac{1}{\alpha_r} \right) + 1} \quad (5)$$

where α_c = convective heat transfer coefficient (w/m² k)

α_r = radiant heat transfer coefficient (w/m² k)

Eq.(2) becomes

$$\frac{dt}{dh} = \frac{\Delta t_E - \Delta t_{Fo}}{H} \quad (6)$$

So if radiant heat transfer is considered, temperature pattern of model A changes to model AB automatically.

(C) Concentrated heat source at bottom of the room

The fundamental parameters of a heat source at bottom of the room are as follows:

Q_s = total heat emission of source (w)

P_r = radiant heat transfer ratio of source (%)

f = horizontal projecting area of source (m²)

h_s = source height (m)

Similar to Eg.(1) and Eq.(4), gives

$$\Delta t_E = \frac{Q_s}{\rho C_p G} \quad (6)$$

Convective heat transfer from source is

$$Q_c = Q_s(1 - P_r) \quad (7)$$

$$\text{and } \Delta = \Delta t_e - \frac{Q_c}{\rho C_p G} = \frac{Q_s P_s}{\rho C_p G} = P_s \Delta t_e \quad (8)$$

From Fig.1, Z is the thermal stratification height of a room. Two empiric formula given by Ergilman^[9] can be used to calculate Z.

$$\text{for plate source } h_s=0 \quad Z = 25G^{1/3} Q_c^{-1/3} - \frac{2ab}{a+b} \quad (9)$$

$$\text{for } h_s > 0 \quad Z = 23G^{1/3} Q_c^{-1/3} - \left(\frac{3.4ab}{a+b} - h_s \right) \quad (10)$$

where a=length of a plate source (m) (m)

b=width of a plate source (m) (m)

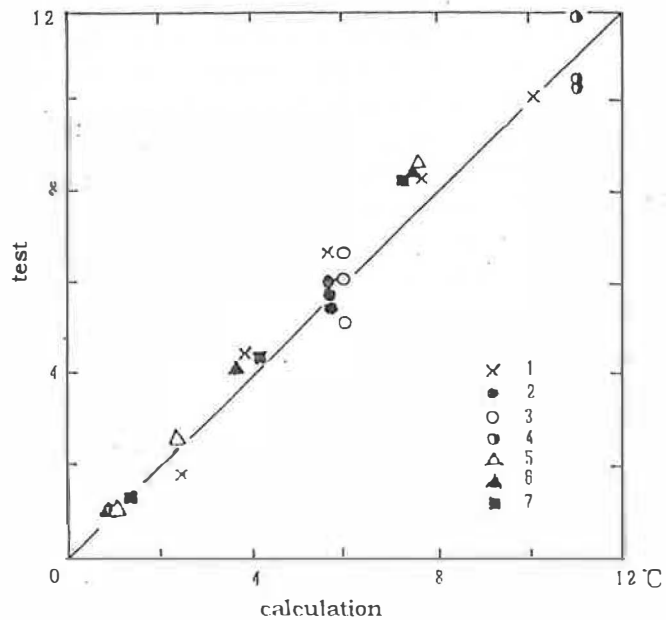


Figure 2 Calculation method in comparison with test.

Table 1 Experiment conditions of examples in Fig.2

Example No.	heat source model	air supply condition	heat load (kw)	flow rate (m ³ /s)	room volume (m ³)	test point height (m)
1	AB	U ₀ =0.2(m/s)	0.685	0.057	40	0.1,0.6,1.2,1.8,2.6
2	B	U ₀ >4(m/s)	216.4	32.14	18500	0,10.9,21.8
3		air inlet height =3.5(m)	228.4	32.14		
4			282.7	21.43		
5	BC	Perforated plate	1.845	0.167	50.75	1.0
				0.386		
				0.613		
				0.162		
6		swirl diffuser		0.251		
				0.594		
				0.174		
7		slot diffuser		0.270		
				0.510		

As radiant heat transfers both from the source and ceiling to floor are considered, the radiant heat from the source to floor is

$$Q_F = Q_s P_r \phi \quad (11)$$

where ϕ = configuration factor (%)

and

$$\Delta t_{Fo} = \left\{ \frac{Q_F}{Q_s} + \left[\frac{1}{\frac{\epsilon_r G}{F} \left(\frac{1}{\alpha_c} + \frac{1}{\alpha_r} \right) + 1} \right] \left(1 - \frac{Q_F}{Q_s} \right) \right\} \Delta t_E \quad (12)$$

$$\Delta = (1 - \Phi) P_r \Delta t_E \quad (13)$$

Eq.(12) is the representation of Δt_{Fo} in composite model BC as shown in Fig.1. When $\Delta t_{Fo}=0$, model BC retrogrades to model C. When $Q_F=0$, Eq.(12) retrogrades to Eq.(5) and model BC changes to another composite model ACB.

In examples Nos.5~7 of Fig.2, from experiments^[2] in regard to a displacement ventilation system with three types of air inlet and a $V_s=0.15(\text{m}^3)$ solid source in the centre of room, mean temperatures of occupied zone are measured. Following Eq.(6),(8),(10),(11) and (12) using $P_r=0.2$, $\phi=0.4$, mean temperatures can be calculated also. As supplementary explanation of Fig.2, some important information are listed in table 1.

For all 23 temperature samples of examples, the mean value of differences between test and this method is equal to 0.51°C with a standard deviation of 0.38°C . And the maximum difference is shown to be limited within 1.2°C .

REFERENCES

1. Holmberg, R.B, Folkesson, K., Stenberg, L-G and Jansson, G. Experimental analysis of office room climate using various air distribution methods. *proceedings ROOMVENT 87*. Stockholm, Sweden
2. Ma, R.M. (1985) Studies on the air distribution factors of upward ventilation from floor. *J. Hv & AC*, 3. (in Chinese)
3. Mundt, E. Convection flows above common heat sources in rooms with displacement ventilation. *Proceedings ROOMVENT 90*. Oslo, Norway
4. Sang, H.L (1991) Airflow Organization in Main Floor of Longtan Hydro Power Station. Msc. thesis of XUAT, P.R. China (in Chinese)
5. Sheetlombearg, Y.A. (1968) Natural ventilation in a hot shop with unbalanced arrangement of heat sources. *J. Water Supply and Sanitary Engineering*, 2. (in Russian)
6. Wang, X. J. (1990) Sidewall Air Supply for Upward Ventilation System in a Tall Hall. Msc. thesis of XUAT, P.R. China (in Chinese)
7. Zhao, H.Z. and Li, A.G. Prediction on the air temperature distribution of a upward ventilated room. *J. HV & AC*, (unpublished) (in Chinese)

