International Symposium on Room Air Convection and Ventilation Effectiveness
University of Tokyo, July 22 – 24, 1992

STUDY ON PERFORMANCE OF AIR CURTAIN ENCLOSURE FOR LOCAL COOLING OR AIR—CONDITIONING

Ma Ren Min Yian ShuQion
Xian Institute of Mettalurgy and Construction Engineering

ABSTRACT

This paper proposed a type of surrounding air curtain instrument being used in local space of rooms or workshops, to maintain a certain cooling and air conditioning environment without solid enclosure. The Author surveyed that a series of factors afferting its velocity and temperature fields, the flow regularity and performance of heat isolation of the surrounding curtain have been studied. the regresson formulas of velocity and temperature decay of air curtain flow were given, found out the relation between diathermancy Coefficient of air curtain and some main factors. The mean air temperature in the partial space can be lower 5～7℃ than that of ambient air.

Keywords: Surrounding air curtain; Heat isolation; athermancy coefficent; Efficiency of heat isolation;

INTRODUCTION

Using air curtain enclosure to Maintain the air parameter in a local zone has been studied and applied in some countries such as Britain, japan[3], switzerland[1] and china, they are all by aimed at keeping a clean working place. It is certificated that the surrounding air curtain with inner laminar flow instrument the efficency of dust particule obstruction is affirmed. However the possibility for maintaining a partial space to prevent heat gain is clear as mud. Certainly as we know, a factory in northeast in china , it is said that this type of local air conditioning instrument has been applied for heat isolation, But no reference has been issued. A little about surrounding air curtain for heat isolation is introduced in reference[5], however the calculation method and design data are not given. For this reason, we conducted prilliminary research work on it to investigate the performance of heat isolation and the practical possibility of technique and economics.

Of course, using air curtain to prevent a little space from heat gain is not as good as solid protective screen and it can only reduse the heat gain caused by ambient air infilfration and convective heat exchange.

METHDOLOGY AND TEST DESIGN

Considering the research work of forefathers and the requirment in practise, the authors defined the space enclosed by the air curtain instrument as 1m × 2m × 2.5m and the plane of the instrument is 1m wide and 2m long, the test were performed in a testing room with the size 3m × 4.95m × 3.4m. In oroer to keep the air curtain flow being free jet, we adopted the reduce scale of instrument. and let the geometric scale be 1 : 2, the Ar of model equal to the Ar of prototype, Then let the ratio of the temperature of model and the temperature of prototype be $C_t = 1$ and air temperature different ratio $C_{\Delta t} = 1$, thus;

we can obtain; velocity scale; $C_v = C_l^{\frac{1}{2}} = 0.707$ flow rate scale; $C_Q = C_l^{\frac{5}{2}} = 0.177$

The sketch of surrounding air curtain model is shown in figue 1 and a sketch of experimental facialty is shown in figure 2. The width of slot outlet is adopted 53mm, 76mm and 100mm in each test. The height of slot is 70mm. The flow rate of air curtain is 280m³/n, 450m3/h, 580m3/h and 750m³/h respectively. The ambient air temperature (at outlet) is 20℃, 22℃, 25℃ respectively. At the minimum air flow rate and maximum bo, the $Re = 5500 \geqslant 2400$, and Pr, $Gr = 12.37 \times 10^7 \geqslant 2 \times 10^7$, thus the velocty and temperature field are all in a state of turbulent Self - modeling zone.

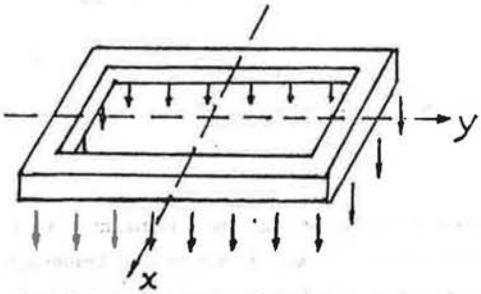


Fig 1 sketch of Annular air Curtain

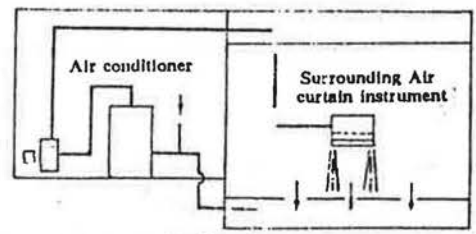


Fig2 Skecth of experimental facialty

AIR FLOW PATTERN OF SURROUNDING AIR CURTAIN

The reqularity of cold air jet flow spurted from the slot outlet follows the plane jet, During the first step, oweing to air curtains from four slots encloses the space inside the surrounding air curtain, the outside air can' t come into the inside, So that the static pressure in the enclosed space is lower than the atmosphere' s. Thus the four plane jets will curved inward during its ascending period in the begining, and then unite into a single synthtic jet by mixing each other, the pressure inside is equal to the outside. Afterwards, the synthitic jet begin to spread, but it only spreads obviously along the x axis, and not along y axis. There for we consider that the synthitic flow is somewhat similar to plane jet after mixing. See Figure (3) and Figure (4).

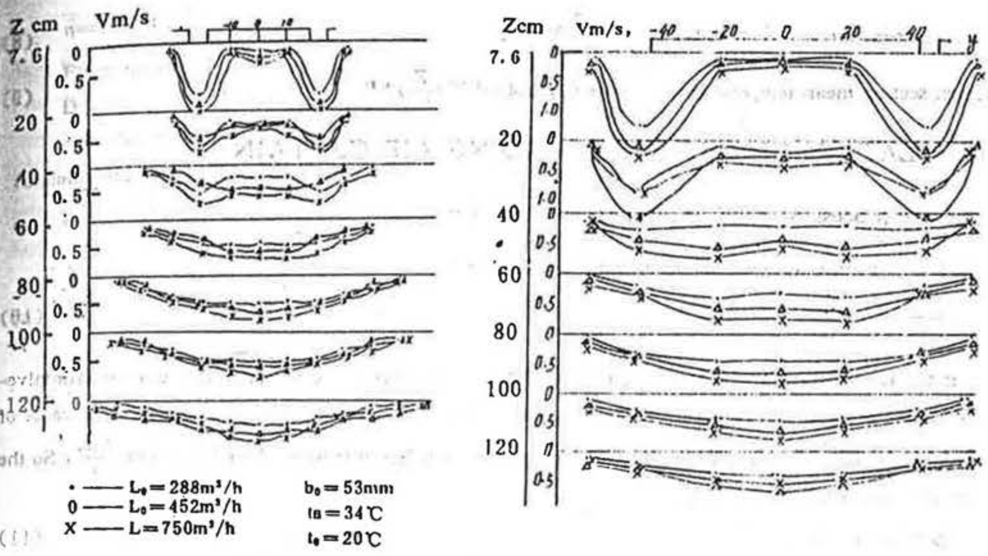
The Velocity and Temperature Distribution of Plane Jet

On the basis of turbulent mechanics[4], Through a series deducting procedur, the theoitical formulas have been deduced for velocity and temperature distrubution of plane jet.

$$\frac{V}{V_0} = a_0 Ar^{a_1} \left(\frac{Z}{b_0}\right)^{a_2} \exp\left[a^3 \left(\frac{X}{Z}\right)^2\right] \tag{1}$$

$$\frac{\theta}{\theta_0} = C_0 A_r^{C_1} \left(\frac{Z}{b_0}\right)^{C_2} \exp\left[C^3 \left(\frac{x}{Z}\right)^2\right] \tag{2}$$

Where; bo is the breadth of the slot outlet, v_0 is the velocity spurted form the outlet, θ_0 is the temperature difference between ambient sir and supply air, Z is the jet throw, and $Ar = gb_0\theta / v_0^2 T_a$ To and Ta are the temperature of supply air and ambient air; x is a perpendicular distance between point of air jet and the jet axis; a_0, a_1, a_2, a_3, c_0, c_1, c_3 are all coefficient.



(a) x axis section (b) γ axis section

Fig 3 The velocity field of Annular air curtain for downward

The velocity and Temperature Distribution formulas of Synthitical Air Flow

As mentioned above, charasteristics of the synthitic flow is simular to the requlartiy of plane jet, and the length of the four slots are fixed, except bo. So the formulas 3, 4 may be suitable, too, for the synthitical folw field, with experiment data, a series of regression formulas of velocity and temperature decay of synthitic flow has been found out, all of the formulas (for downward air supply) are as follows:

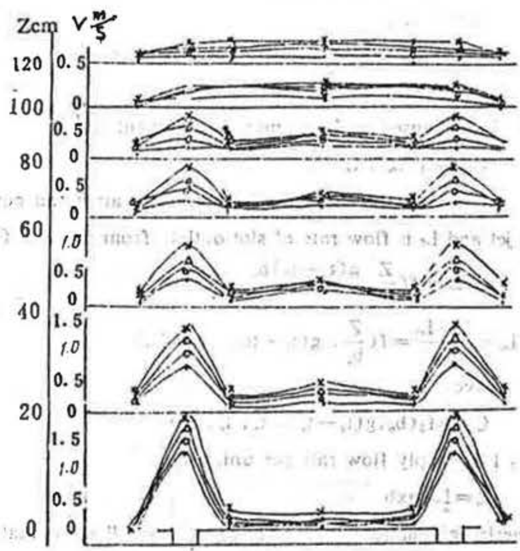


Fig. 4 The y axis sectional velocity field for upwards

1) Any point velocity

$$\frac{v}{v_0}=6.057Ar^{-0.117}(\frac{Z}{bo})^{-0.791}e^{-8.71(\frac{x}{Z})^2} \quad (3)$$

2) Axis velocty $$\frac{v_0}{v_D}=6.057Ar^{-0.117}(\frac{Z}{b_0})^{-0.791} \quad (4)$$

3) cross sectional mean veloctiy $$\frac{v_m}{v_0}=0.3029Ar^{0.117}(\frac{Z}{bo})^{0.791} \quad (5)$$

4) Cross Sectional mean flow rate: $$\frac{L}{L_0}=0.748Ar^{-0.117}(\frac{Z}{bo})^{0.209} \quad (6)$$

5) any point temperature $$\frac{\theta}{\theta_0}=1.668Ar^{0.137}(\frac{Z}{bo})^{-0.58}e^{-0.337}(\frac{x}{Z})^2 \quad (7)$$

6) axis temperature $\frac{\theta_z}{\theta_0}=1.668Ar^{0.137}(\frac{Z}{b_0})^{-0.58}$ (8)

7) Cross section mean temperature $\frac{\theta_p}{\theta_0}=0.0834Ar^{0.137}(\frac{Z}{b_0})^{-0.58}$ (9)

HEAT ISOLATION OF THE SURROUNDING AIR CURTAIN

Heat exchange process of Air Curtain and Ambient Air

1. Heat gain getting Into the enclosed space by Eddy Diffusion

$$\bar{\upsilon}=\frac{\partial\bar{\theta}}{\partial Z}=\varepsilon_0\frac{\partial^2\bar{\theta}}{\partial x^2} \qquad (10)$$

Where: θ is the temperature of the flour, ε_0 is Eddy diffusion coeffcient, $\varepsilon_0=\sqrt{\bar{\upsilon}_x^2}\cdot Ll$; υ_x is horizontalvelocity, Ll is large scale of turbulent length, it is a constant in general. In tarbulent jet, the more the value of Re, the more the value of $\bar{\upsilon}_x$, and the more the heat gain by turbulent diffusion. Dueing to $Re=\frac{\upsilon_0 d_e}{\upsilon}$, So the 1. Turbulent diffusion heat gain may be:

$$Q_{dif}=f_1(\upsilon_0,\ de) \qquad (11)$$

Where The V_o is outlet air velocity, de is equivalent diameter, we defined de as $\frac{2F_0}{a+b}$, in which F_0 is the total area of slot outlet and a、b are the length and width of the plane of the enclosed space.

2. Convective heat exchange is:

$$Q_c=\alpha(t_a-t_0)$$

Where α is convective coefficient, it is related with Re, bo, so we have:

$$Q_c=f_2(\upsilon_0,\ de,\ bo,\ ta-t0) \qquad (12)$$

3. Heat Gain Caused by Entralment of Ambient Air

$$Q_{en}=f_3(L_{en},\ t_a-t_o) \qquad (13)$$

Where L_{en} is air volume entrained from embient air by air curtain. $L_{en}=L-L_0$, in which L is flow rate of air curtain jet and L_0 is flow rate of slot outlet. from formule (6), we have

$$L/L_0=f(\frac{Z}{b_0},\frac{g(t_a-t_0)b_0}{\upsilon_0^2 Ta}$$

So $L_{en}/L_o=\frac{L-L_0}{L_0}=f(\frac{Z}{b_o},\ g(t_a-to),\ \upsilon_o,\ Ta)$

Thus we have:

$$Q_{en}=f_3(b_o, g(t_a-t_o),\ t_a,\ l_o,\ \upsilon_o) \qquad (14)$$

WHere: l_o is supply flow rate per unit area

$$l_o=L_o/axb$$

4. Sumerizing equations (11), (12), (14), we'll know that the factors which affect the total heat gain Q_o in enclosed space may be written:

$$Q_0=Q_{dif}+Q_c+Q_{en}$$
$$=f(v_0,\ d_e,\ T_a,\ \theta_0, b_o,\ g\theta_o,\ l_o) \qquad (15)$$

Diathermanycy Coeffieient D and Heat Isolation effectioness

The variation in amount of heat gain getting into the enclosed space can be expressed by the following definition formala.

$$D=\frac{t_m-t_o}{t_a-t_o} \qquad (16)$$

Where D is defined Diathermancey coefficient and t_m is air temperature in enclosed space.

Obviously, the heat isolation effectivness η is:

$$\eta=1-D=\frac{t_a-t_m}{t_a-t_0} \tag{17}$$

From equation (15), the factor affect the diathermancy coefficient can be expressed;

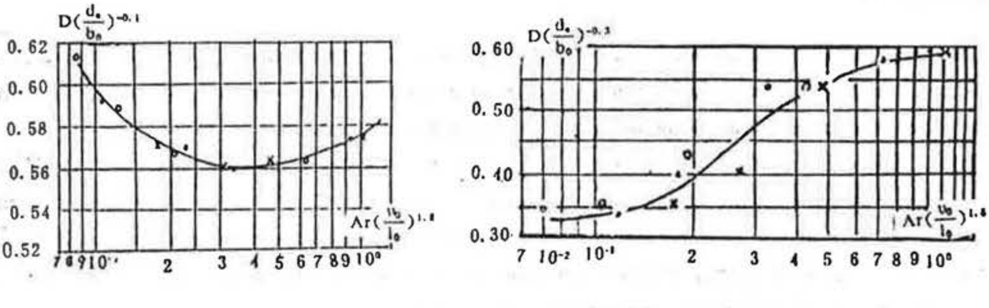
$$D=f(\upsilon_0,\ d_e,\ T_a,\ \theta_0,\ b_0,\ g\theta_0,\ l_0) \tag{18}$$

Applying the Pi — theorem, we proceed dimmsional analysis and use υ_0, b_0, T_0 in equation (18) as fundamental quantities, we abtain non—dimensional expressions as follows;

$$D=f\left(\frac{\theta}{T_a},\ \frac{d_e}{b_0},\ \frac{g\theta_0 b_0}{\upsilon_0^2 T_a},\ \frac{l_0}{\upsilon_0}\right),$$

$$=f\left(\frac{\theta}{T_a},\ \frac{de}{bo},\ Ar,\ \frac{l_0}{\upsilon_0}\right) \tag{19}$$

Fig 5 gives the relationship between D and Ar. b_0



a Dawnward Condition　　　b upwards condition

Fig 5 The relationship among D. bo and Ar

When t_a and t_0 are fixed, the term θ_0/Ta can be canceled,

Considering the regularity of distribution in Fig 5, and by least square method to regress the experiment data, the empirical formulars can be obtained.

For downward

$$D=\left\{1-\exp\left[-0.153-0.3097\ln Ar\left(\frac{\upsilon_0}{l_0}\right)^{1.8}-0.1137\left[\ln Ar\left(\frac{\upsilon_0}{l_0}\right)^{1.8}\right]^2\right]\right\}\left(\frac{de}{bo}\right)^{0.1} \tag{20}$$

For upward;

$$D=\left\{1-\exp\left[-0.893-0.268\ln Ar\left(\frac{\upsilon_0}{l_0}\right)^{1.5}-0.0253\left[\ln Ar\left(\frac{\upsilon_0}{l_0}\right)^{1.5}\right]^2\right]\right\}\left(\frac{de}{bo}\right)^{0.3} \tag{21}$$

Analysis of heat isolation performance

In order to analyze the heat isolation performance feather directly perceived through the senses. We give out the difference between the ambient air temperature and the mean temperature of enclosed space air which is shown in Fig(6). It is obviously that the temperature difference is varing with some factors. For Downward condition, when at the same flow rate, the more the value bo, the higher the efficiency of heat isolation.

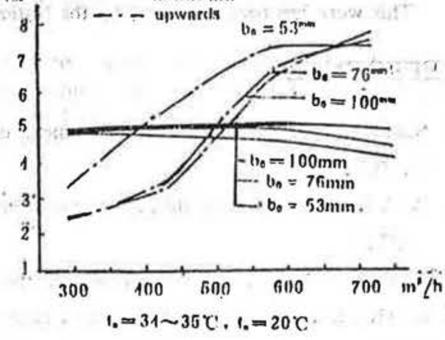


Fig 6 Temperature reducing

When at the same bo, bo=53mm, the more the air flow rate is the lower the efficiency of heat isolation will be. Thus while bo=76,100mm, however the efficiency of heat isolation is going to raise as the flow rate with increas, certainly, when the flow rate come up to its muximum, the efficiency of heat isolation will come down to sum up. Fopwards conditionThe performance of screen effect is different from downward condition, at the same flow rate, bo=53mm is better than bo=76 or 100mm, while the width bo is constant, the heat isolation effect will raising when flow rate increasing. As we know, the cold air sports upwards, it is retarded by the gravitation, after its initial ascend impulse exhausts, the cold flow retraces downward, so the screen effect is depended on the initial formed by outlet velocity υ_0, which provids the air curtain flow reaching to the needed acsending height, this is the main reason why the bo should be smalar and the flow rate be much more large, when the performance of heat isolation is better.

DISCUSSION

1. The broad slot outlet is somewhat better than the narrow slot for heat isolation using in downward air curtain. But if the flow rate in the small range. both are approximatle. On the contrary, the narrow slot is obviously better than the broad slot while using it in the upwards condition.
2. In the downward condition the mean temperature inside the enclosed space is lower 4. 18℃～5. 13℃ (Fig6) than ambient air temperature. In upwards contition, it is 2. 4～7. 8℃ lower than ambient air temperature. from Fig 6 we have, while supply air rate in the low range, downward air curtain is benifit for heat isolation; while supply air rate in the low range, downward air curtain is benifit for heat isolation; while supply air flow rate in the high range, upwards air curtain is benifit.
3 . From experiment data we know that tha air temperature distribution in the enclosed space is not uniform.

CONCLUSSION

1. This article investigated priliminary the regularity of surrounding air curtain flowage, give out the regression formulas for velocity and temperature . distribution
2. investigated priliminary the regularity of surrouunding air curtain has been discusse, experiment data shows that this kind of local air conditioning instrument posses a certain degree of heat isolation function to reduce the local space temperature.
3. Proposed a diathermancy coefficient D and defined its definition formula, surveyed a regression formulas expressin D.

ACKNOWLEDGMENTS

This work has been supported by the National Nature science Foundation of china.

REFERENCES

1. Naokihiqi transtate:《Combined instrumemt of vertical laminar and Air curtain》, Air clean, V17, Nol,47～49, 1979.
2. A. A Field, 《Operating theater air conditioning》, Heating piping Air conditioning, V. 45, No11,91～93, 1973.
3. Shen jin ming, 《A study on the performance of Air curtain shed》, thesis of master degree, 1981.
4. Do Guo Ren,《Turbulant Mechanics》, High education publishing house of china, 1981.
5. 《Air conditioning design hand book 》, Architectural engineering publising house of china, 554～556, 1983.