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ANALYSIS OF DRAFT QUANTITY THROUGH VENTILATED AIR SPACE

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ABSTRACT A draft quantity through a ventilated air space is analyzed by numerical calculation and model experiment, and a correlation between the draft quantity and buoyancy, following a temperature difference between the ventilated air space and circumference, is discussed. At first, a dimensionless theoretical analysis method for the draft quantity is shown, and a relation between a dimensionless draft quantity and dimensionless height $\ell/(bG_r)$ of ventilated air space is defined. Next, the relation between both values is experimentally verified. As the results, it is made clear that the draft quantity shows a proportional relationship with the temperature difference in case a thickness of the ventilated air space is the same, and the dimensionless draft quantity can be expressed as a function of the dimensionless number $(b/\ell)G_rP_r$ (modified Rayleigh number).

1. INTRODUCTION

In an exterior wall of recent residences, a ventilated air space is generally constructed for the purpose of air ventilation. However a draft quantity of the ventilated air space is hardly researched. The present report therefore aims at quantitatively explaining a correlation between the draft quantity and buoyancy, following a temperature difference between the ventilated air space and circumference, and at theoretically obtaining the draft quantity in response to any different condition in temperature difference, thickness and height of ventilated air space and opening area of air vent.

2. NUMERICAL CALCULATION METHOD OF DRAFT QUANTITY THROUGH VENTILATED AIR SPACE

A draft quantity through a ventilated air space, which is constructed between a heating and adiabatic surface as in Fig.1, can be estimated by equations (1)～(3) of continuity, energy and motion.

$$\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}=0 \qquad (1)$$

$$\rho c_p u\frac{\partial T}{\partial x}+\rho c_p v\frac{\partial T}{\partial y}=\lambda\frac{\partial^2 T}{\partial y^2} \qquad (2)$$

$$u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}=\upsilon\frac{\partial^2 u}{\partial y^2}-\frac{1}{\rho}\frac{\partial p_d}{\partial x}+\beta g\left(T-T_o\right) \qquad (3)$$

$$\left(\because p_d=p-p_o, \beta=\frac{\rho_o-\rho}{\rho\left(T-T_o\right)}\right)$$

Boundary conditions are expressed by equations (4)~(8).

$$x=0, 0<y<b: u=\bar{u}, v=0, T=T_o \qquad (4)$$

$$y=0, x\geq 0: u=0, v=0, T=T_w \qquad (5)$$

$$y=b, x\geq 0: u=0, v=0, \partial T/\partial y=0 \qquad (6)$$

$$x=0: p_d=0 \qquad (7)$$

$$x=l: p_d=0 \qquad (8)$$

The equations as described above can be rearranged by introducing dimensionless numbers defined by following equations (9)~(16)

$$U=\frac{bu}{\upsilon G_r},\quad V=\frac{bv}{\upsilon} \qquad (9),(10)$$

$$X=\frac{x}{bG_r},\quad Y=\frac{y}{b} \qquad (11),(12)$$

$$P=\frac{p_d b^2}{\rho\upsilon^2 G_r^2},\quad \Theta=\frac{T-T_o}{T_w-T_o} \qquad (13),(14)$$

$$G_r=\frac{g\beta\left(T_w-T_o\right)b^3}{\upsilon^2},\quad P_r=\frac{\mu c_p}{\lambda} \qquad (15),(16)$$

Continuity, energy and motion equations are rewritten as follows:

$$\frac{\partial U}{\partial X}+\frac{\partial V}{\partial Y}=0 \qquad (17)$$

$$U\frac{\partial\Theta}{\partial X}+V\frac{\partial\Theta}{\partial Y}=\frac{1}{P_r}\frac{\partial^2\Theta}{\partial Y^2} \qquad (18)$$

$$U\frac{\partial U}{\partial X}+V\frac{\partial U}{\partial Y}=\frac{\partial^2 U}{\partial Y^2}-\frac{\partial P}{\partial X}+\Theta \qquad (19)$$

Boundary conditions are represented as follows:

$$X=0, 0<Y<1: U=Q, V=0, \Theta=0 \qquad (20)$$

$$Y=0, X\geq 0: U=0, V=0, \Theta=1 \qquad (21)$$

$$Y=1, X\geq 0: U=0, V=0, \partial\Theta/\partial Y=0 \qquad (22)$$

$$X=0: P=0 \qquad (23)$$

$$X=L: P=0 \qquad (24)$$

Then Q (dimensionless draft quantity) and L (dimensionless height of ventilated air space) are defined on referring to the dimensionless numbers.

$$Q=\frac{b\bar{u}}{\upsilon G_r}=\int_0^1 U\,dY \qquad (25)$$

$$L=\frac{l}{bG_r} \qquad (26)$$

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$$Q=\frac{\Delta Y}{3}\left(4\sum_{j=1}^{(K-1)/2}U_{m+1,2}\right.$$

If the values of Q and P_r
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In case difference coordinates are decided as in Fig.2, the value of Q is obtained from equation (27) by use of Simpson's low, because the draft quantity is equal in every height level of the ventilated air space.

$$Q = \frac{\Delta Y}{3}\left(4\sum_{j=1}^{(K-1)/2} U_{m+1,2j} + 2\sum_{j=1}^{(K-3)/2} U_{m+1,2j+1}\right) = \text{Constant draft quantity} \qquad (27)$$

If the values of Q and P_r are given as the initial calculation conditions, the values of U, V, Θ and P can be solved from the equations (17)~(19) in every height level on basis of the boundary conditions by convergence calculation concerning the value of Q, which is obtained from the right side term of equation (27). If the value of L is found out (the value of P becomes 0 in this height), the corresponding value of Q is obtained.

3. EXPERIMENTAL MEASUREMENT METHOD OF DRAFT QUANTITY THROUGH VENTILATED AIR SPACE

Fig.3 shows an experimental model of a ventilated air space, thickness of its space can be arbitrarily changed. One side of ventilated air space is constructed by plywood and an transparent acrylic board, another side is constructed by an aluminum plate, of which temperature can be controlled freely by a flat calorific material put on outside of this plate. Fig.4 shows an experimental measurement system. We measured draft quantities (velocity of flow) through the ventilated air space with smoke wire method, as the visible method of a moving smoke. The acrylic board is a window to observe a locus of smoke. A camera is set up in front of the acrylic board. We generated smoke in the ventilated air space by passage of an electric current through a nichrome wire, which was stretched on under level of the acrylic board and to which paraffin oil was applied. Then we took photographs of the loci of smoke through the acrylic board, in a state of opening a stop, by periodically emitting strobe light into the ventilated air space from the side, and we obtained the velocity of flow from the distance of photographed loci in the regular intervals of a time (We read the distance of the loci at the middle part of the ventilated air space).
In the upper part of the ventilated air space (a temperature of adiabatic surface approaches that of heating surface), velocity distribution of flow describe a parabola between both surfaces as in Fig.5. Therefore we calculated the draft quantities on the assumption that the measured velocity of flow is the maximum value of the parabola. The draft quantities were measured under different experimental conditions in thickness (10, 15, 20, 25, 30mm) of the ventilated air space, temperature differences (5, 10, 15K) between the ventilated air space and circumference, and a joint framework of air vent is attached or not at lower part of the ventilated air space.

4. ANALYSIS OF MEASURED AND CALCULATED DRAFT QUANTITY

Photo.1 and Fig.6 show examples of the loci of smoke and its tracing, for the case that the thickness of the ventilated air space is 20mm, the temperature difference between the ventilated air space and circumference is 15K, the interval of emitting strobe light is 0.5sec, and there is not the joint framework of air vent at lower part of the ventilated air space. The locus of smoke moves at regular distance.
Fig.7 and 8 (results without or with the joint framework of air vent) show a correlation between the draft quantities and the temperature differences. The draft

quantities indicate a proportional relationship with the temperature differences, irrespectively without or with the joint framework, in case the thickness of the ventilated air space is the same. Fig.9 and 10 show the correlations between the draft quantities or the dimensionless draft quantities Q and dimensionless number $(b/\ell)G_rP_r$ (modified Rayleigh number: P_r times the reciprocal of L). The solid lines in the figures represent the calculated values, provided that modified Rayleigh number is revised by using a correction value A'/A in the case with the joint framework. The values of Q and $(b/\ell)G_rP_r$ show one-to-one correspondence. The calculated values agree well with the measured values, whether there is a joint framework of air vent or not, namely the draft quantities can be expressed as the function of modified Rayleigh number.

5. CONCLUSION

We showed a dimensionless theoretical analysis method, on the basis of equations of continuity, energy and motion, to obtain a draft quantity through a ventilated air space, which is constructed between a heating and adiabatic surface, and defined a relation between a dimensionless draft quantity and dimensionless height $\ell/(bG_r)$ of ventilated air space. Furthermore, a correlation between the draft quantity and buoyancy, following a temperature difference between the ventilated air space and circumference, is explained by a visible experiment (smoke wire method).

The summary of the results is: The draft quantity indicates a proportional relationship with the temperature difference in case a thickness of the ventilated air space is the same. The dimensionless draft quantity and dimensionless number $(b/\ell)G_rP_r$ (modified Rayleigh number) show one-to-one correspondence, and the values of calculated draft quantities agree well with that of measured values. In case a joint framework of air vent is attached at lower part of the ventilated air space, the calculated values agree with the measured one by making revision for the modified Rayleigh number by a correction value A'/A. The draft quantity can be expressed as the function of modified Rayleigh number.

NOTATION

A: sectional area of ventilated air space, A': opening area of air vent, b: thickness of ventilated air space [m], c_p: specific heat of air [J/(kg·K)], G_r: Grashof number [-], g: gravitational acceleration [m/s^2], K: horizontal grid number [-], L: dimensionless height [-], ℓ: height of ventilated air space [m], P: dimensionless differential pressure between ventilated air space and circumference [-], P_r: Prandtl number [-], p_s: differential pressure between ventilated air space and circumference [Pa], Q: dimensionless draft quantity [-], q: draft quantity [m^3/s], T: absolute temperature [K], U: dimensionless velocity of vertical direction [-], u: velocity of vertical direction [m/s], V: dimensionless velocity of horizontal direction [-], v: velocity of horizontal direction [m/s], X: dimensionless coordinates of vertical direction [-], x: coordinates of vertical direction [m], Y: dimensionless coordinates of horizontal direction [-], y: coordinates of horizontal direction [m], β: coefficient of volume expansion [1/K], Δ X: grid interval of vertical direction [-], Δ Y: grid interval of horizontal direction [-], Θ: dimensionless air temperature [-], λ: thermal conductivity [W/(m·K)], μ: viscosity [Pa·s], υ: kinematic viscosity [m^2/s], ρ: specific weight of air [kg/m^3]

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2) Akihito OZAKI, Takashi SUGAI, Toshiyuki WATANABE et al.: "Analysis of Heat and Moisture Transfer through Ventilated Air Space", Research Report of 35th session, Kyushu Branch, Architectural Institute of Japan, pp.105-108, 1996

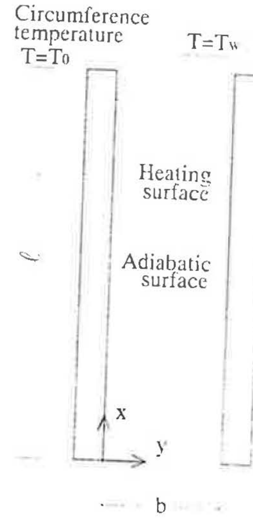

Fig.1 Analytical model

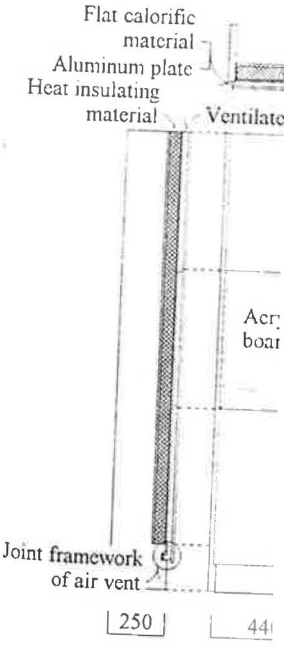

Fig.3 Experimental mod
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ction [m/s], X: dimensionless
rection [m], Y: dimensionless
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Δ Y: grid interval of horizontal
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air [kg/m^3]

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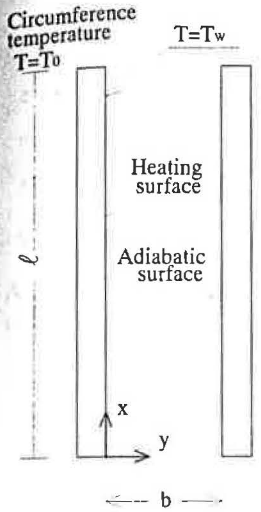

Fig.1 Analytical model

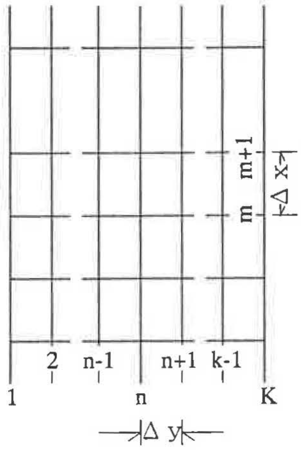

Fig.2 Difference coordinates

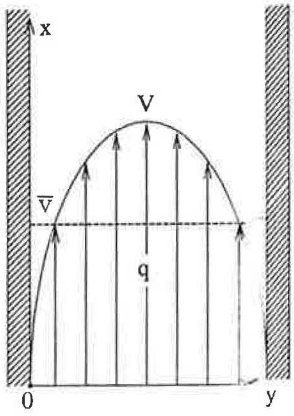

Fig.5 Velocity distribution of flow

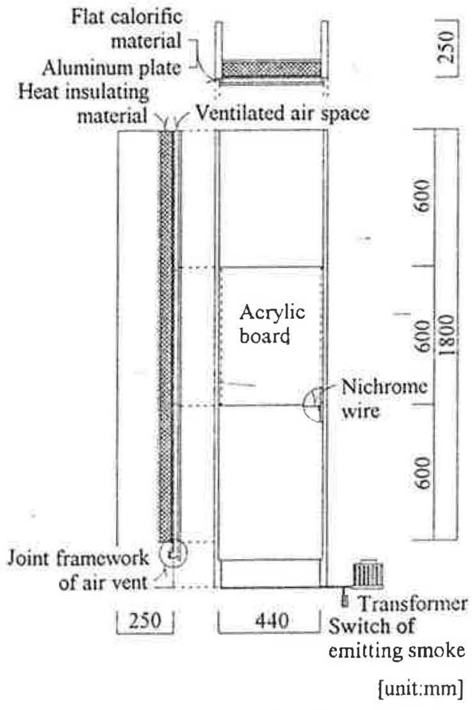

Fig.3 Experimental model of ventilated air space

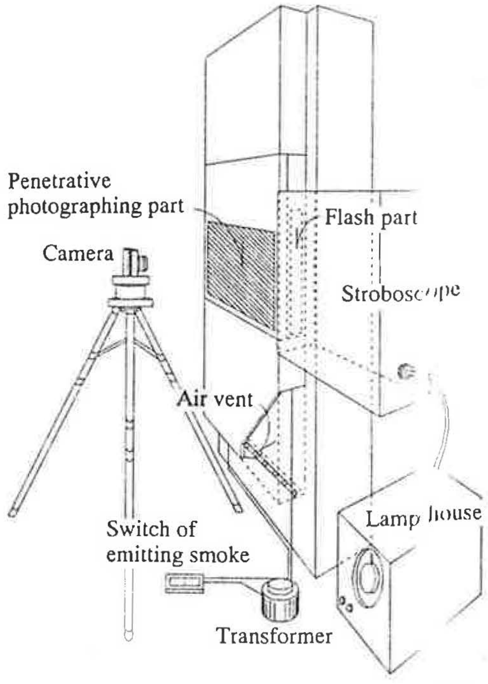

Fig.4 Experimental measurement system

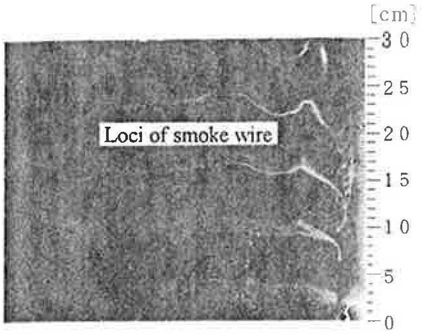

Photo.1 Photograph of smoke wire

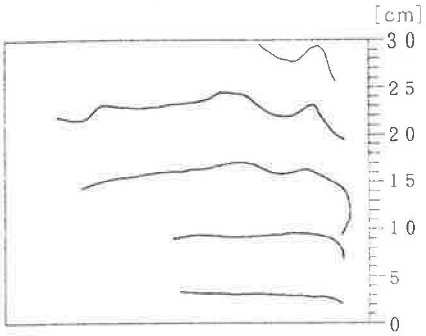

Fig.6 Tracing of loci of smoke wire

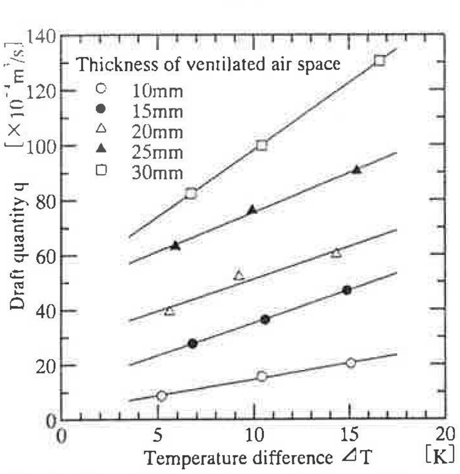

Fig.7 Correlation between draft quantity and temperature difference without a joint framework of air vent(sectional area of ventilated air space:$1\sim3\times10^2$cm^2/m)

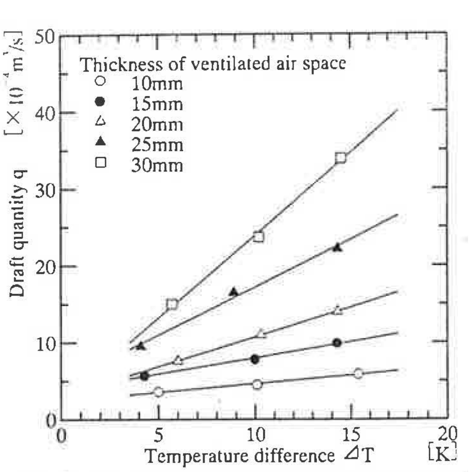

Fig.8 Correlation between draft quantity and temperature difference with a joint framework of air vent(opening area of air vent:7.31cm^2/m)

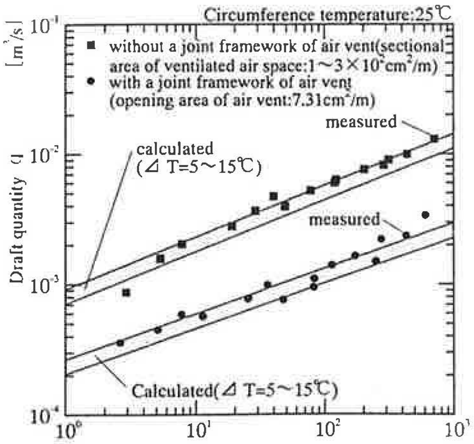

Fig.9 Correlation between draft quantity and dimensionless number

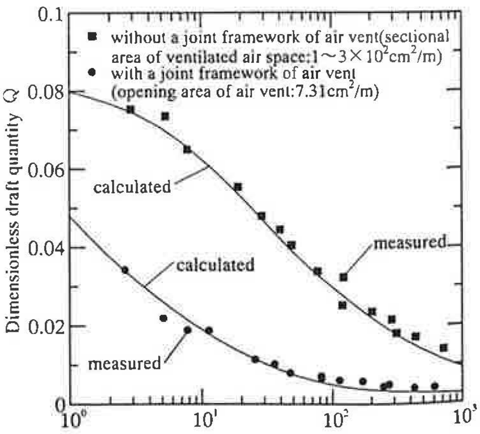

Fig.10 Correlation between dimensionless draft quantity and dimensionless number

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STUDY ON S

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Dept. of Architecture, S
Takaharu
Nikken Sekke

ABSTRACT A solar sh
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blinds in the cavity betwee
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solar radiation, air tempera
was carried out in the atriun
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proved the possibility of pr
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developed and adopted.

1. INTRODUCTION

Because an atrium has a large
conditions, the concern is th
solar radiation and an increas
example where a double skin
of the atrium in order to contr
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2. SUMMARY OF ATRIUM

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