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Natural Ventilation of High-Rise Buildings with Large Light Wells

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ABSTRACT

In this paper, the effectiveness of natural ventilation in high-rise building is studied by the network theory of ventilation. Firstly, the relation between the building shape and the natural ventilation efficiency during mild seasons is studied. The results show that the building with a light well is suitable for keeping stable ventilation and indoor thermal comfort. Next, the effect of nighttime ventilation during the summer is studied. The results show that the nighttime ventilation can be used to precool the building structure during the summer night. The paper also shows the results of field measurement .

KEYWORDS Natural Ventilation, Large Light Well, High-Rise Building

INTRODUCTION

Natural ventilation can save energy by reducing building heat loads and can ensure comfortable habitability during the mild seasons even without air conditioning. In this paper, the following two cooling effects of natural ventilation are considered.

1) the energy-conserving effect (the reduction of air-conditioning period) during mild seasons (spring and autumn) .
2) the precooling effect of building structures during the summer night.

Although natural ventilation is generally applied to dwelling houses and low-rise

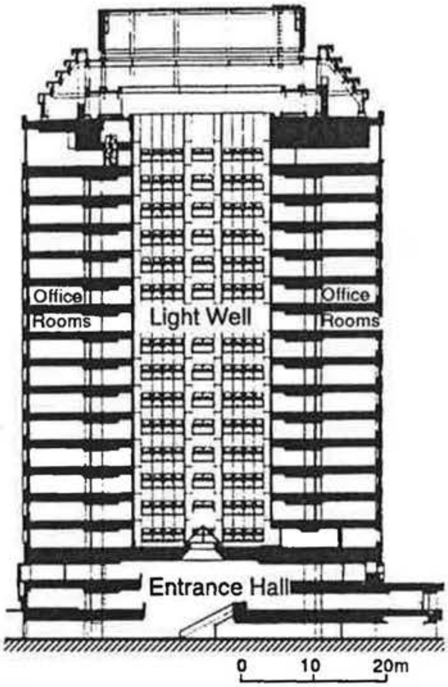


Fig. 1 High-Rise Building with Large Light Well (Niigata Prefectural Office)

- Location: Niigata, Japan
- Total floor areas: 45,500 m²
- Number of floors: 18 floors, 1 basement
- Scale of light well: 16m × 16m × 60m

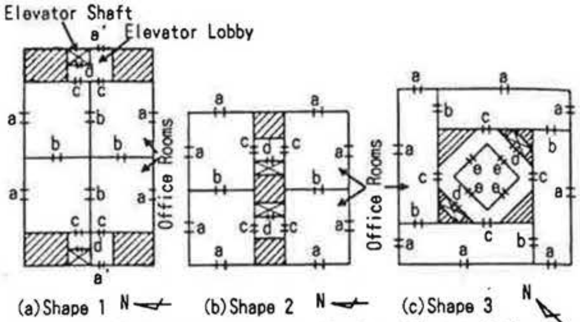
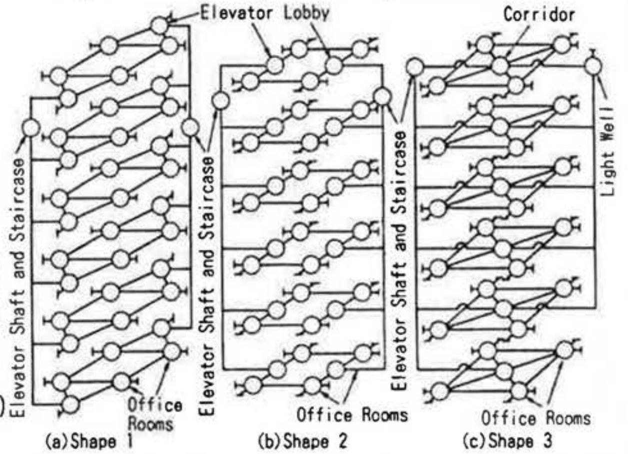


Fig. 2 Building Shapes for Study of Natural Ventilatic



○ Room (Zone) —Opening ⊢Opening connecting indoor and outdoor

Fig. 3 Ventilation and Thermal Models of the Buildings reperesented by Network

buildings in Japan, most high-rise buildings do not have openable windows through which natural wind can blow into office rooms. This is because the available natural wind is greatly affected by the wind direction, velocity and the building shape; therefore, high-rise buildings often cannot expect to get stabilized airflow from natural wind. In order to keep stable natural ventilation effects in the two high-rise buildings introduced in this paper, i.e., Niigata Prefectural Office (Fig. 1) and Bunkyo Ward Office, use of large light wells was proposed. With the installation of a light well, stack effects of the light well and negative pressure coefficient at the upper opening of the well were expected.

1. NATURAL VENTILATION IN MILD SEASONS

1.1. Comparison of Natural Ventilation Efficiency for Different Building Shapes.

As shown in Fig. 2, three plan shapes were considered for the 18 story Niigata Prefectural Office building : two without a light well and one with a light well. According to the ventilation network calculation theory for multi-zone space (ASH-

Nomenclature	
M_i : airflow rate through i-opening [m³/s]	C_{pi} : wind pressure coefficient at i-opening [−]
C_{di} : discharge coefficient for i-opening [−]	V_i : external wind velocity [m/s]
A_i : area of i-opening [m²]	cp : specific heat of air [J/kg·℃]
ΔP_i : pressure difference at i-opening [Pa]	K_j : thermal transmittance [W/m²·℃]
ρ_i : air density flowing through i-opening [kg/m³]	A_{wj} : area of j-wall [m²]
P_k : static pressure at floor level of k-room [Pa]	t_k : temperature of k-room [℃]
h_{ik} : height of i-opening from k-room level [m]	t_{kj} : room temperature connected by j-wall [℃]
ρ_k : air density in k-room [kg/m³]	Q_k : internal heat generation in k-room [W]
P_{wi} : wind pressure at i-opening [Pa]	n_{ok} : number of openings in k-room
	n_{wk} : number of walls in k-room

Table 1 The Ventilation and Thermal Network Theory for Multi-Room

[Mass Flow] $M_i = C_{di} \cdot A_i \cdot \sqrt{2 \cdot \Delta P_i / \rho_i}$

[Pressure Difference]

$$\Delta P_i = (P_k - h_{ik} \cdot \rho_k) - (P_{k'} - h_{ik'} \cdot \rho_{k'}) + P_{wi}$$

[Outdoor Wind Pressure] $P_{wi} = C_{pi} \cdot \rho_o \cdot V_i^2$

[Mass Valance in Room] $\sum_{i=1}^{n_{ok}} M_i \,|_{in\ k\text{-}room} = 0$

[Heat Valance in Room] $\sum_{i=1}^{n_{ok}} M_i \cdot cp \cdot \rho_i \cdot t_{ki} \,|_{in\ k\text{-}room} + \sum_{j=1}^{n_{wk}} K_j \cdot A_{wj} \cdot (t_k - t_{kj}) \,|_{in\ k\text{-}room} + Q_k = 0$

Table 2 Simulation Cases

Case No.	Outdoor Wind Velocity [m/s]	Outdoor Wind Direction	Indoor Heat Generation [W/m²] (kcal/m²·H)
1	2	South	29.1(25)
2	1	South	29.1(25)
3	4	South	29.1(25)
4	2	South-West	29.1(25)
5	2	West	29.1(25)
6	2	South	58.1(50)

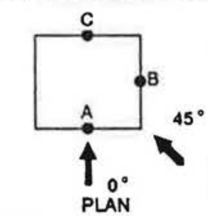
* In all cases, the simulation is performed under the condition that the outdoor temperature is 20 ℃.

Table 3 C_d-Values and Areas of Openings

Symbol of Opening*	C_d	Area [m²] Type 1	Type 2	Type 3
a	0.4 (0.2)**	29.25	20.0	25.0
a'	0.4 (0.2)**	0.75	10.0	5.0
b	0.7	6.0	6.0	6.0
c	0.7	8.7	8.7	8.7
d	0.7	0.105	0.105	0.105
e	0.4	−	−	2.0
f***	0.7	−	−	245.0

* These symbols are same as in Fig. 2.
** (0.2) means the value when the opening angle is 15°.
*** The "f" is the opening at the top of light well.

Table 4 C_p-Values for Each Wall

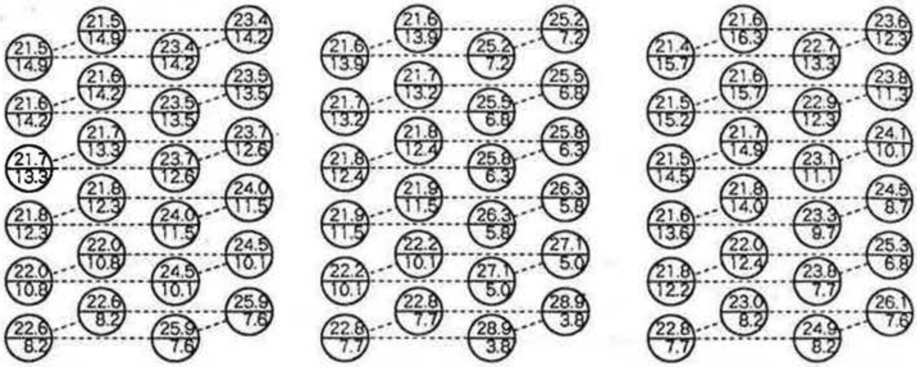


		Wind Direction 0°	45°
Position of Wall	A	0.7	0.4
	B	-0.4	0.4
	C	-0.4	-0.5

* The C_p-Value at the top of light Well is assumed to be -0.4
** Outdoor wind profile is assumed according to the Power Law : $V_H = V_{ref}(H/H_{ref})^{0.25}$ where V_H is the mean wind velocity at a heigt H, and V_{ref} is the mean wind velocity at refference level H_{ref}.

RAE Fundamentals 1989, Okuyama 1983), these buildings can be represented by the network shown in Fig. 3 and the temperatures of office rooms are calculated by the method shown in Table 1. The six cases in Table 2 are considered by using the calculation conditions given in Tables 3 and 4. The results of Case 1 are as shown in Fig. 4.

With the increase in the outdoor wind velocity, the room temperature obviously drop in all the building shapes as shown in Fig. 5, but the relationship between the room temperature and the wind velocity differs depending on the building shapes. With respect to the effects of outdoor wind direction, Fig. 6 shows that the building shape 3 which has a light well is less affected by the wind direction than other building shapes. The daytime room temperature in June is calculated based on the



(a) Building Shape 1 (b) Building Shape 2 (c) Building Shape 3(with light well)

Fig. 4 Calculation Results of Case 1

22.0 ----▸ Temperature of Room [℃]
10.0 ----▸ Ventilation Rate [h⁻¹]

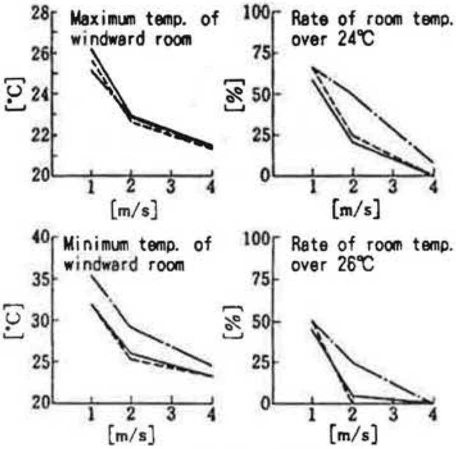


Fig. 5 Effects of Outdoor Wind Velocity on Natural Ventilation

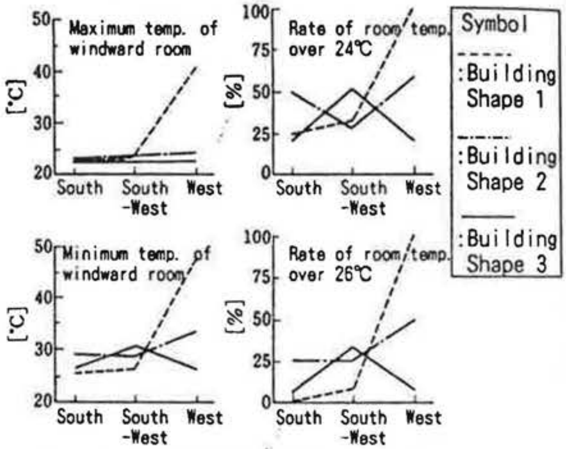
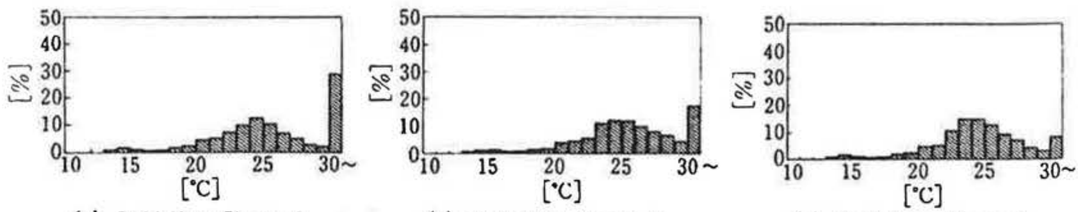


Fig. 6 Effects of Outdoor Wind Direction on Natural Ventilation



(a) Building Shape 1 (b) Building Shape 2 (c) Building Shape 3

Fig. 7 Histogram of Room Temperature based on Network Simulation Results and Weather data from 9:00 A.M. to 17:00 P.M. in June

network simulation results and weather data. As seen in Fig. 7, the occurrence rate of room temperature over 26 ℃ in Shape 3 is much smaller than those in Shapes 1 and 2.

1.2. Air Flow Distribution.

The air flow distribution created by natural ventilation is different from that caused by mechanical air conditioning. Numerical analyses were conducted in order

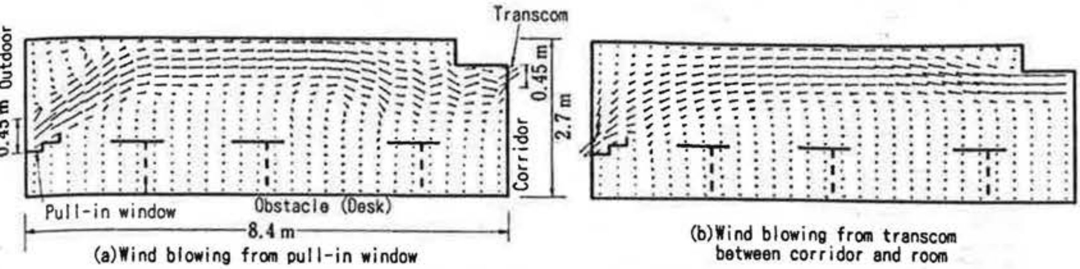


Fig. 8 Airflow Distribution in Naturally Ventilated Room

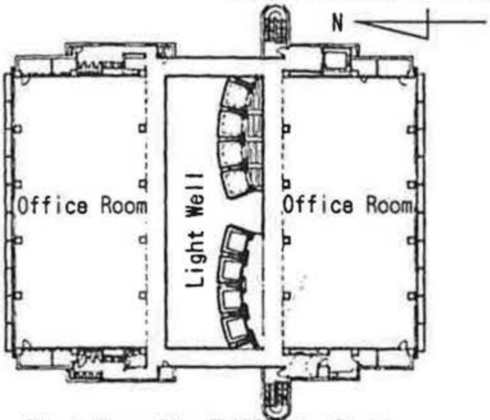


Fig. 9 Plan of the Building for Study on Nighttime Ventilation

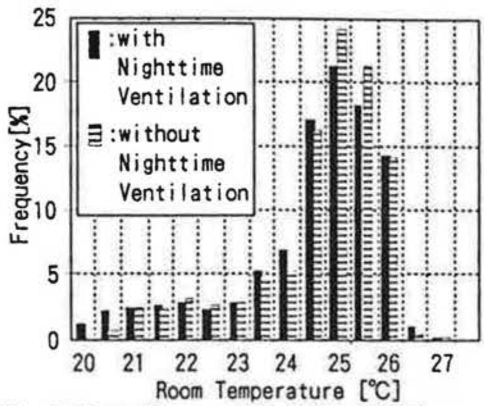


Fig. 10 Room Temperature during Nighttime (19:00P.M.~8:00A.M., in July)

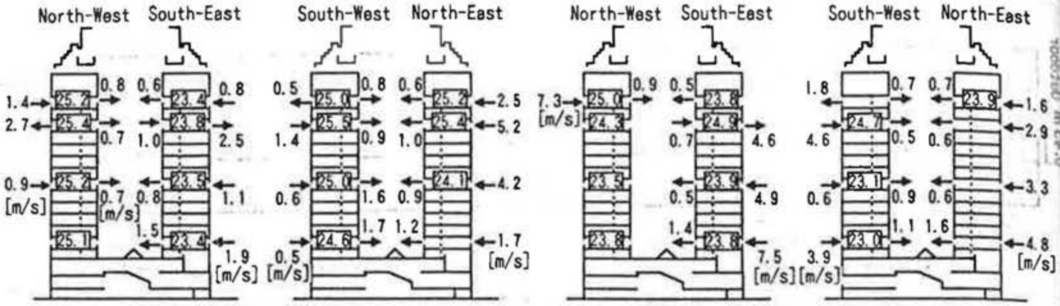
to predict the air flow distribution at the cross section through the office room. In the calculations, the two-dimensional k-ε two equation model (Nomura et al. 1975) was utilized. According to the calculation results given in Fig. 8, the wind velocity in the upper region was large and that in the lower region was small. It thus became possible to introduce outside wind into rooms while eliminating the direct wind effects on the occupants.

2. NATURAL VENTILATION AT NIGHTTIME

In case of Bunkyo Ward Office (Fig. 9), an attempt was made to reduce the cooling load at the outset of the cooling process by introducing outside air during the summer nights. In the case of nighttime ventilation, the effect of thermal storage of the structure was large so that the effect of nighttime ventilation was evaluated by using the dynamic heating/cooling load calculations (HASP ACLD/8501, Matsuo 1985) and circuit network ventilation calculation theory. Fig. 10 shows the temperature drop in office rooms at the start of air conditioning was confirmed.

3. FIELD MEASUREMENT OF NATURAL VENTILATION

Actual room temperature, and the wind direction and velocity at various points in the building were roughly measured during the natural ventilation. The following



(a)Wind Direction:NNE, Wind Speed:6m/s
Outdoor Temperature:23.8℃,
15:06P.M. ~16:45P.M., 5. June. 1986

(b)Wind Direction:SSE, Wind Speed:2m/s
Outdoor Temperature:23.8℃,
11:15A.M. ~12:22P.M., 6. June. 1986

←: Airflow Direction 25.2 : Room Temperature 0.9 [m/s] : Airflow Velocity

Fig. 11 The Room Temperature and Airflow Measured in Naturally Ventilated Building (Niigata Prefectural Office, June.1986)

points were confirmed from the measurements shown in Fig. 11. (1) regardless of the space locations, (windward or leeward), wind was introduced from the outside into the office rooms and the light well. and (2) the room temperature was generally satisfactory being in a range of 23 ~25℃.

4. CONCLUSION

From the foregoing study by simulation and measurement, the effectiveness of natural ventilation in high- rise building has been confirmed as follows:

(1) The building having a large light well can expect very satisfactory ventilating effects due to the natural wind and the stack effect.

(2) Nighttime ventilation can be effective for precooling building structure.

(3) By the measurement, the anticipation of airflow and room temperature given by simulated for the building with a light well has been roughly confirmed.

REFERENCES

ASHRAE handbook-1989 fundamentals, chapter 23. Atlanta: American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc.

Matsuo, Y., 1985. Manual of HASP/ACLD/8501, Japan Building Mechanical and Electrical Engineers Association(in Japanese).

MAKIMURA, I., and KONDO, Y. 1986. "Environmental Feature in and around the Light Well in the High-rise Building, -A Study in Designing of Niigata Prefectural Office" KUUKICHOUWA EISEIKOUGAKU, Vol.60, No.9, The Society of Heating, Air-Conditioning and Sanitary Engineers of Japan(in Japanese).

NIWA, K., and KONDO, Y. 1991. "Study on Natural Ventilation for Energy Conservation in the Public Building with Light Well", Summaries of Technical Papers of Annual Meeting the Society of Heating, Air-Conditioning and Sanitary Engineers of Japan(in Japanese).

OKUYAMA, H. 1983. "Theory and Application of Circuit Network Simulation", Summaries of Technical Papers of Annual Meeting the Society of Heating, Air-Conditioning and Sanitary Engineers of Japan(in Japanese).

Nomura, T., Matsuo, Y., Kaizuka, M., Sakamoto, Y. and Endo, K. 1975. "Numerical Study of Room Air Distribution 3 -Numerical Solution of Three Dimensional Turbulent Flow by Two -Equation Model -", Transaction of The Architectural Institute of Japan, No.238