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Simulation and Evaluation of the Environment of a Large Scale Atrium

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Abstract

We hereby present the results of a study which compares a numerical simulation of the atrium of a hotel undertaken during the design stage with a subsequent evaluation of its environment after completion. This atrium is surrounded by guest rooms and measures 102m × 47m with aheight of 37 m and 120,000m^3 of air space. During the design stage, therewas concern that the summer sun coming through the glass roof would adversely affect the indoor environment of the atrium. However, a numerical simulation of three dimensional non-isothermal tur-bulence flow employing finite dif-ference method was able to approximate the environment. We then decided to attach a hanging curtain from the lower part of the glass roof as a means of air-conditioning in the atrium only. The atrium was completed in March 1990. In August 1990, a survey was made of the indoor environment under summer weather conditions. The conclusions of the numerical simulation and the actual results were then compared. This comparison clearly corroborated the validity of the projections arrived at by numerical simulation.

KEYWORDS Numerical Simulation, Design, Air-Conditioning System

1. INTRODUCTION

Recently, the buildings with an atrium have been increasing, so that the data about the living environment of that buildings is required to be collected. On the other hand, due to advanced environment simulation method, the living environment has been estimated on design stage so as to reflect the simulation result to design stage in more and more cases. We estimated living environment by numerical simulation from design stage and compared the design value and estimation result with an actually measured value on completion stage.

2. OUTLINE OF BUILDING

2.1 Overview

The building which we took as objective for our study is 50 m in width, 90 m in length and 35.7 m in height, having 4,300 m^2 floor area. The atrium is enclosed by the corridor running along guest rooms of this hotel. The roof is covered with glass, which is 70% wired glass to reduce direct sunlight in the summer season and further awning curtain is used.

2.2 Overview of air conditioner system

This atrium serves for air conditioning of the living zone and the air port is provided at the fourth floor, so that air is spouted via nozzle and ventilated on the floor level. The air port can automatically change spouting direction up and down depending on the hot wind and cool wind. With the atrium divided to four zones, eight temperature sensors are used to control the temperature of spouted air. Additionally, the temperature of the cold water in the pond and fall is 15℃ to reduce the load for cooling. The top of the atrium collects heat and if the temperature rises, the electric damper exhausts air.

3. OUTLINE OF NUMERIC SIMULATION

3.1 Calculation method

Three-dimensional non-isothermal turbulence analytic program, called Marker and Cell Method (MAC) was used to calculate numeric data.

3.2 Condition for calculation

(1) Setting of the case

Table 1 shows the calculation condition set for each case. For all cases, it was assumed that the season was summer, the outside temperature was 33℃ and the set temperature inside the atrium was 26℃. Additionally, it was assumed that the roof did not open and the atrium was separated from the corridor along the guest rooms. No air flow through the clearance was not taken into account for this measurement.

For the cases 1 to 4, with a restaurant built in the atrium, heat reflecting glass or float sheet glass was used for the roof glass, and the reflectance of the shade blind was 70% and 100%, and these factors were combined for each case. The case 5 is that the atrium was constructed completely flat and the total air volume was assumed to be double. For the cases 6 and 7, with the air volume calculated as ΔT = 10℃, the roof opening factor was 70% at average, and on the other hand, 70% only at the center while the circumferential value was 0% so that the average value was 50%. The case 8 is the same condition as the case 7 except that the water temperature of the pond was 15°C and the air volume was smaller.

(2) Calculation model

Fig.1 shows an example of the mesh model of the plan considering the shape and scale of the atrium. The cases 6 to 8 were, 54 X 19 X 20 totaling 24,624 cells. From the transmission factor of the roof glass and reflectance of the shade blind, the amount of solar radiation to the inside floor and wall of the atrium was calculated and the temperature at each surface of the atrium was set as the boundary condition.

(3) Calculation of the solar radiation load

The amount of direct solar radiation was assumed to be 700 kcal/ $m^2 \cdot h$. The solar radiation which passes a glass and is reflected by the curtain, then entering the atrium is assumed to be diffused equally over the wall and floor. Then, of this solar radiation amount, the area which air conditioning covers is assumed to be the floor and wall up to FL +4m.

(4) Amount of supplied air

The wind speed at each air port is smaller than the actual value because it is regulated for the cell area for which a certain spouting area is set.

4. DESCRIPTION OF ACTUAL MEASUREMENT

4.1 Measuring Method

Table 2 shows measuring items, measuring method and the number of measuring points, and Fig.2 shows the measuring points on vertical temperature distribution and in the living zone. The measurement was carried out mainly in the living zone inside the atrium, and concretely, the vertical temperature distribution was measured at four points and further the temperature at the 6th floor corridor whose windows facing the atrium were open were measured. The temperature and humidity of the living zone were measured by the person who moved a measuring sensor placed on a carrier at each specified time. The vertical temperature distribution was measured by hanging a thermocouple from the cat walk. This measurement was carried out on August 1, 1990.

4.2 Outside Condition on Measuring Day

Fig.3 shows the changes of the outside temperature and amount of solar radiation on the measuring day. Both the amount of solar radiation and outside temperature on this day were low because it was thinly cloudy. In the afternoon, the highest temperature was 30.9℃ and the amount of solar radiation was 2.6 MJ/H because it became fine. These values were a little lower than the set value (outside temperature: 32℃, amount of solar radiation: 2.9 MJ/H)

5. COMPARISON OF SIMULATION RESULT AND MEASURING RESULT

5.1 Vertical Temperature Distribution

Fig. 4 shows the temperature and humidity of the corridor and Figs. 5,6 show a measured vertical temperature distribution and simulation result (Case 8). This simulation was carried out on the assumption of 12 o'clock. According to this measurement, heat was collected at the floors over the 10th story at every time interval of daytime so that the temperature reached 56.6℃ max. So this measurement recognizes that heat collection occurs on the top section of the atrium. In the morning and evening, the temperature of the top section was partly lower than that of the bottom section. Comparing the simulation result at 12 o'clock with measuring result indicated that the distribution of collected heat over the 10th story deviates slightly. From general viewpoint, the estimation of heat collection by simulation coincides with the measuring result relatively well although those conditions were different.

In the living zone of the atrium on the bottom, the temperature distribution was around 26℃ both at each point and time. On the floors below the 6th story, the windows facing the atrium are open. As for the vertical temperature distribution, the temperature near the 6th floor was over 30℃, however the corridor was little affected by this fact, so that the temperature was from 25 to 27℃.

5.2 Living Zone Environment

Figs. 7, 8 show temperature distribution simulation and the measuring result at 12:30. In the living zone, generally the temperature was from 25 to 27℃ to assure comfortable environment. Although the simulation result indicates a slightly higher point on the south side, this can be considered to the point where heat is collected. On the other hand, the measuring result indicates that there was an area near 27℃ to the north east section. This is because the sun shone on the living zone through the gap of the shade blind.

Figs. 9, 10 show the simulation of wind direction and speed and measuring result at 12:30. Although the wind speed in the living zone was over 0.4 m/s near the suction port, it was mostly 0.1 to 0.3 m/s. Ascending current of air arose to the north east because the sun shone on it, and the air flow at the half of the north side directed to the north east. The half of the south side see a flow toward the center because it is affected by spout from the nozzle and suction port.

6. CONCLUSION

Concerning the temperature environment inside the atrium, the comparison of the simulation result in summer season with actually measuring result is described above. Although the temperature of the living zone was 24 to 26℃ and heat collection was noticed at the top section about vertical temperature distribution, the reason can be considered to be due to the effect of the shade blind and air conditioning of the living zone which were estimated on design stage. In conclusion, we have recognized that the simulation result coincides with the measuring result well.

ACKNOWLEDGEMENTS

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Table 1 List of Simulation Condition for Atrium

	CASE 1	CASE 2	CASE 3	CASE 4	CASE 5	CASE 6	CASE 7	CASE 8
Number of calculation meshes	DX=DY=DZ=2m:55×17×25=23.375					54×19×24=24.624		
Shade blind:reflectance (Complete diffusion): absorption factor	70% 30%	100% 0%	70% 30%	100% 0%	70% 30%	←	←	←
Roof glass	Heat reflection glass (transmission factor:0.164)	←	Float sheet glass (transmission factor:0.726)	←	←	← Averaged opening factor:70%	← center:70%, circumferrnce: 0%	←
Roof shape	Flat	←	←	←	←	Slanted	←	←
Atrium internal shape	Restaurant theater with roof	←	←	←	No restaurant, flat	restaurant with roof	←	←
Supply air outlet	Atrium wall	←	←	←	←	wall, restaurant roof	←	←
Return intake	Column inside atrium	←	←	←	Atrium floor slit	←	←	←
Water temperature of pond inside atrium	10℃	←	←	←	←	25℃	←	15℃
Solar radiation to wall and floor (kcal/m²·h)	21.1	30.1	93.4	133.4	93.4	65.4	46.7	←

Table 2 Measuring Items and Method

Measuring item	Measuring point	Measuring device	Measuring method	Measuring time
Outside temperature	a point outdoor (see Fig. 3.2)	thermo/ hygrometer	Continuous	0:00-24:00 per day
Room temperature	3F FL+1,100 18points(Fig. 3.1)	Thermocouple	Intermittent	10:30-17:30 per day (an hour)
Air verocity		RION air speedometer		
Air direction		Smoke tester		
Vertical temperature distribution	At each floor: FL+1,000 × 4points (see Fig. 3.2-3)	Thermocouple	Continuous measurement using data logger	10:30-17:30 per day

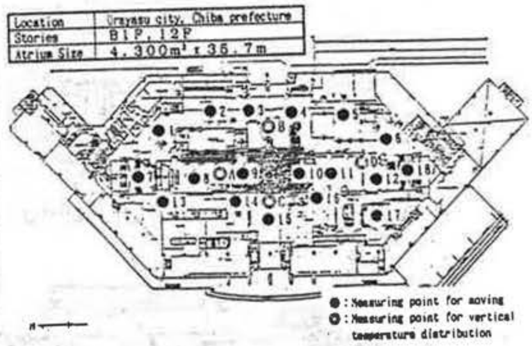
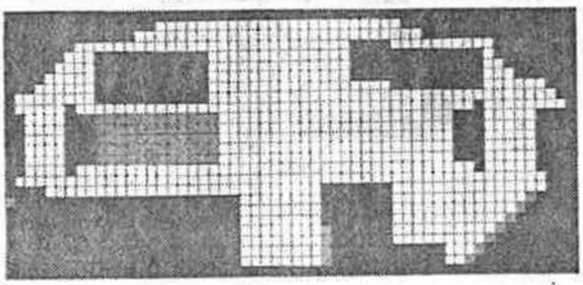


Fig. 2 Measuring Points of Living Zone (3F)



← Fig. 1 Mesh Model for Simulation

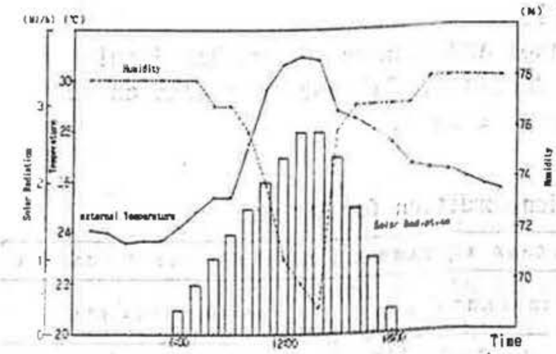


Fig. 3 Changes of External Temperature, Humidity and Amount of Solar Radiation by Time

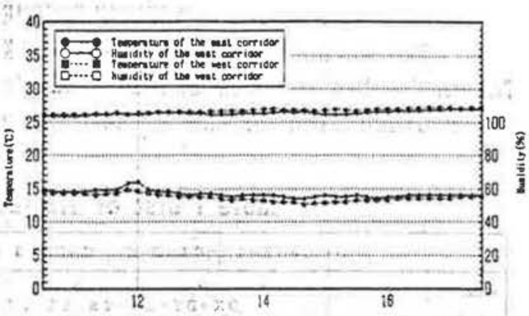


Fig. 4 Changes of Temperature and Humidity at the Corridor of 6th Floor

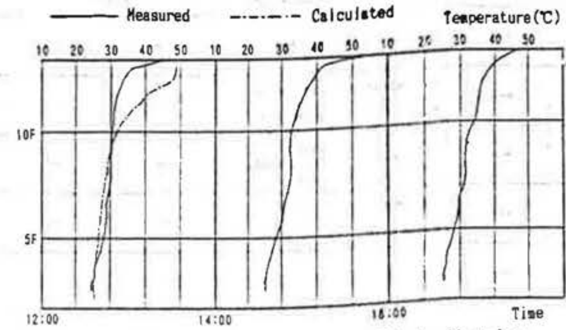


Fig. 5 Vertical Temperature Distribution (Measured, Point A)

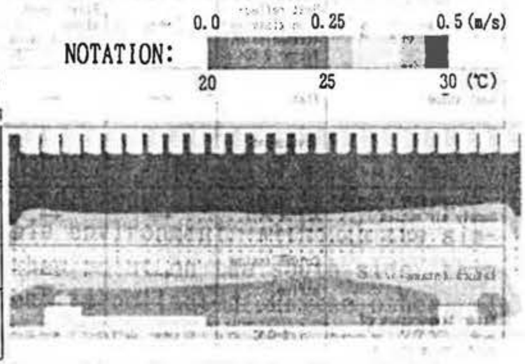


Fig. 6 Vertical Temperature Distribution (Calculated)

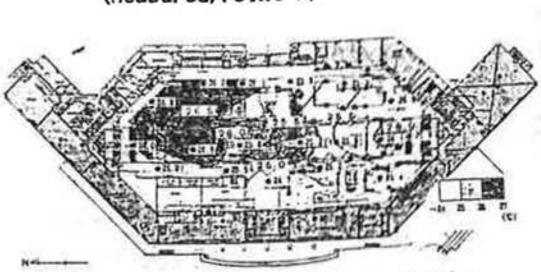


Fig. 7 Room Temperature Distribution (Measured)

Fig. 8 Room Temperature Distribution (Calculated)

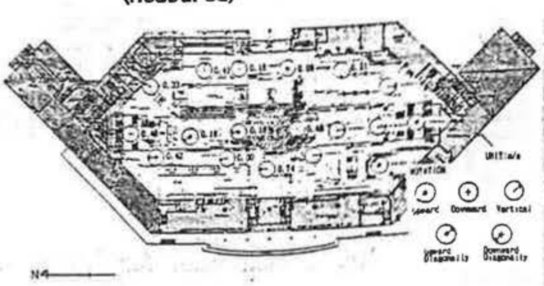


Fig. 9 Air Flow Speed Distribution (Measured)

Fig. 10 Air Flow Speed Distribution (Calculated)