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# SIMULATION ON TEMPERATURE AND FLOW FIELD IN THE ATRIUM (PART2. COMPARISON BETWEEN RESULTS FROM EXPERIMENTS AND NUMERICAL ANALYSIS, AND APPLICATIONS FOR ACTUAL DESIGN OF ATRIUM)

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## ABSTRACT

In order to verify accuracy of the numerical method mentioned in the previous paper(Part1), comparison between results from experiments and numerical analysis was made. As a result of comparison, it became obvious that results of numerical analysis agreed with those of experiments by coupling the calculation of radiative heat transfer and that of convective heat transport. Still more,the numerical method was applied to the actual design of atrium having very complicated shape. Ability of adaptation to complicated shape is one of special features of this numerical method.

KEYWORDS Atrium, Measurements of temperature, Coupled analysis

## 1 INTRODUCTION

In the previous paper (Part1), the numerical method for solar radiation, radiative heat transfer and temperature and flow field calculation has been mentioned, because these calculations are needed for the analysis on temperature and flow field in the atrium. One of purposes of this paper is to verify the accuracy of this numerical method by comparison between results from experiments and numerical analysis. Using the test atrium[1], the experiments were carried out without air-conditioning. Outline of the test atrium will be mentioned in the following paragraph. A shape of the test atrium for experiments is very simple, but actual atrium has complicated shape generally. It is required for numerical analysis to be well adapted to complicated shape in actual design of atrium. It will be mentioned some applications with this numerical method to actual design of atrium having very complicated shape.

## 2 OUTLINE OF THE TEST ATRIUM

An outward appearance of the test atrium for experiments is shown in Fig.1, and a size of this atrium is shown in Fig.2. As shown in Fig.2, this atrium is 7.0m wide, 4.3m deep, and 4.5m high. All four walls are consisted of glass, and this atrium is facing south. The north wall and the floor consists of building materials whose thermal characteristic is well known, such as autoclaved aerated concrete, extruded foamed polystyrene.

## 3 ITEMS OF EXPERIMENTS

Items of experiments are 1)solar radiation to horizontal surface, 2)outside air temperature, 3)inside temperature, 4)surface temperature, 5)air flow velocity. Temperature was measured by thermocouples whose radius is 0.2mm, and air flow velocity was measured by the three dimensional supersonic measuring instrument. The positions of measuring instruments are shown in Fig.3 and Fig.4.

## 4 EXPERIMENTS CONDITIONS

The experiments was carried out during 13:30 ~ 14:30 in February 26th, 1992. Then solar radiation to horizontal surface was 423kcal/m$^2$h, and altitude was 37.4°.

## 5 CALCULATION CONDITIONS

According to the numerical method mentioned in the previous paper (Part1), temperature and flow field in the test atrium was analyzed. There are three kinds of the numerical method. The method(0) is not considering radiative heat transfer at all, and other methods (the method(1) and the method(2)) are considering it. The difference between the method(1) and the method(2) is whether calculation of radiative heat transfer and that of convective heat transport are coupled or not. The mesh for finite element method is shown in Fig.5. Boundary conditions are shown in Table 1. In the solar radiation calculation, permeability of atmosphere was used the value which was calculated back from experimental data. In the radiative heat transfer calculation[2], it was assumed that heat transfer coefficient was 6kcal/m$^2$h°C.

## 6 RESULTS OF BOTH EXPERIMENTS AND ANALYSIS

The distribution of inside temperature measured in experiments is shown in Fig.6, and that of surface temperature measured in experiments is shown in Fig.7. Concerning inside temperature and surface temperature, comparison between results of experiments and numerical analysis is shown in Fig.8.

### 6.1 DISTRIBUTION OF INSIDE TEMPERATURE

As shown in Fig.6, the distribution of inside temperature by experiments is nearly uniform, between 41~44°C. By considering radiative heat transfer, results of the numerical method approach those of experiments. Furthermore, it is obvious that the results of the numerical method agree with those of experiments extremely by coupling radiation and convection in the calculation process.

### 6.2 DISTRIBUTION OF SURFACE TEMPERATURE

In the numerical analysis without considering radiative heat transfer (the method(0)), the surface temperature of the north wall and the floor is very high, more than 75°C. Similar to the distribution of inside temperature, results obtained from the method(2) show best agreement with those of experiments.

### 6.3 DISTRIBUTION OF FLOW VELOCITY

The air flow was breeze. So the maximum of air flow velocity was about 0.1m/s in both experiments and numerical analysis.

## 7 COMPARISON BETWEEN EXPERIMENTS AND ANALYSIS

Judging from the above, there is no doubt about importance of radiative heat transfer in the process of numerical analysis. Still more, it seems reasonable to suppose that results of numerical analysis approach those of experiments extremely by coupling calculation of radiative heat transfer and that of convective heat transport. The reason for good agreement is assumed that the amount of convective heat transport can be calculated accurately by coupled analysis. For reference, heat balance on the north wall is shown in Fig.9, and those on the south glass wall is shown in Fig.10. Then a direction of heat transfer from atrium space to wall is positive. As these figures indicate, the amount of radiative heat transfer is equal to or higher than that of convective heat transport, and the amount of radiative heat transfer can not be ignored to that of solar radiation. It can be foreseen that the surface temperature of the wall is affected by heat transfer coefficient of convection very much. Throughout the future experiments, it will be expected to put forward a suggestion of well-suited heat transfer coefficient of convection.

## 8 OUTLINE OF ACTUAL ATRIUM

Secondly, some applications of the numerical analysis to actual design of atrium having very complicated shape will be mentioned. Before everything an outline of this atrium is explained. The atrium for analysis is a part of I-project (in Osaka, Japan), and it has cylindrical shape. The atrium is connected with 1st.~3rd.floor office room. The form of the atrium is shown in Fig.11, and the measurements of the atrium is shown in Fig.12. Still more, the mesh for finite element method is shown in Fig.13. The size of elements are 0.2m(minimum)~ 2.8m(maximum), and the number of elements is 36,237. The roof of the atrium and the north wall are consisted of glass. So at 13:00, July 21th, direct solar radiation comes to the 1st. and 2nd. floor. In summer air-conditioner is run at lower space of atrium to keep comfortable climate in the atrium.

## 9 BOUNDARY CONDITIONS

According to the previous paper(Part1), K',Tref, and Q are set up, as boundary conditions. In this place Q is solar radiation absorption to each wall considering radiative heat transfer. The concrete value of these boundary conditions are shown in Table 2. Boundary conditions about air-conditioning such as amount of air flow supplied or exhausted and temperature of air flow from air-conditioner are shown in Table 3.

## 10 ANALYSIS

The analysis was carried out according to the numerical method mentioned in the previous method(Part1). It took 3,000 minutes for the radiative heat transfer calculation with IBM3090/20J, and 180 minutes for temperature and flow calculation with HITAC S820/80. The radiative heat transfer calculation was executed for only setting the boundary conditions, so calculation of radiative heat transfer and that of convective heat transport were not coupled. It was assumed that the heat transfer coefficient of inside convection was 6.0kcal/m$^2$h°C on each wall.

## 11 RESULTS OF ANALYSIS

The circumstances of direct solar radiation reaching the floor is shown in Fig.14. The maximum absorbed direct solar radiation is 460~470kcal/m$^2$h. The distribution of radiative heat transfer is shown in Fig.15. It is considered that about 130~140kcal/m$^2$h quantity of heat is transferred to other walls by radiative heat transfer, and an influence of radiative heat transfer can not be ignored in the numerical analysis. As a result of the temperature and flow field analysis, the distribution of temperature and flow velocity on Y-Y' section are shown in Fig.16 and Fig.17, those on the 1st. floor (1.5m high) are shown in Fig.18 and Fig.19. Still more, the distribution of surface temperature on the 1st. floor is shown in Fig.20. As shown in Fig.17, in the upper space of atrium, circulation flow appears. Concerning the distribution of temperature, it can be seen that the thermal stratification is formed in the atrium space, and lower space of atrium is well air-conditioned (22~26°C), so it is in the comfortable condition.

## 12 CONCLUSION

In order to verify accuracy of the numerical method, we made comparison between results from experiments and numerical analysis. As a result, it became obvious that not only considering radiative heat transfer but also coupling calculation of radiative heat transfer and that of convective heat transport is very effective on improvement of accuracy. In the future, the effect of some factors to indoor climate such as transmittance of glass, absorption of glass, emissivity of walls, air-condition, ventilation, and so on, will be studied. It will be coming subject to improve the accuracy of experiments, too.

In the last part of this paper, applications to actual design of atrium having very complicated shape were mentioned. Solar radiation, radiative heat transfer, temperature and flow calculation was applied to this atrium. In this application, results of analysis have not been compared with results of experiment, and calculation of radiative heat transfer and that of convective heat transport were not coupled, so these are future subject.

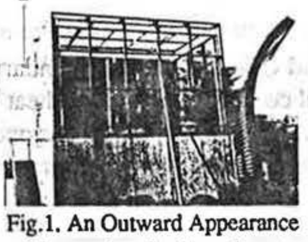


Fig.1. An Outward Appearance of Test atrium for Experiments

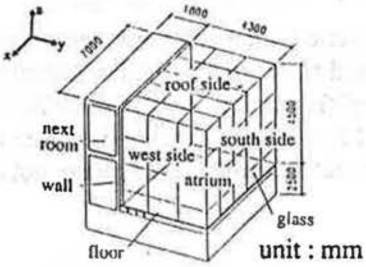



Fig.2. A Size of Test Atrium

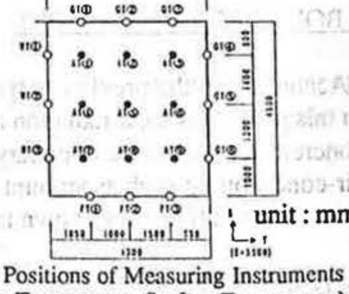



Fig.3. Positions of Measuring Instruments (Inside Temperature, Surface Temperature)

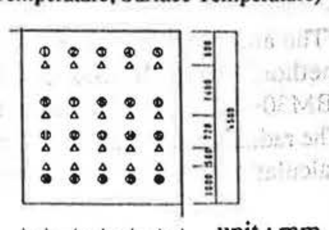



Fig.4. Positions of Measuring Instruments (Flow Velocity)

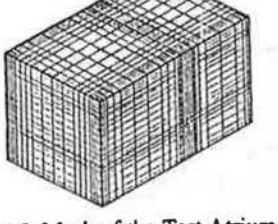


Fig.5. Mesh of the Test Atrium for Finite Element Method

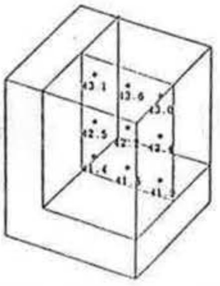


Fig.6. The Distribution of Inside Temperature in Experiments

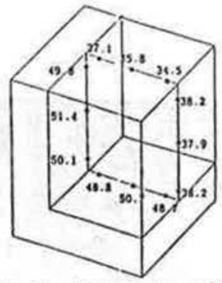


Fig.7. The Distribution of Surface Temperature in Experiments

Table 1. Thermal Boundary Conditions

| parts | absoptivity | transmittance | emissivity | K' | Tref |
|---|---|---|---|---|---|
| roof glass | 0.47 | 0.37 | 0.30 | 8.80 | 12.0 |
| south side glass | 0.47 | 0.37 | 0.30 | 8.80 | 12.0 |
| east west side glass | 0.47 | 0.37 | 0.30 | 8.80 | 12.0 |
| wall surface | 0.91 | 0.0 | 0.95 | 0.24 | 25.3 |
| floor surface | 0.98 | 0.0 | 0.95 | 0.25 | 9.5 |

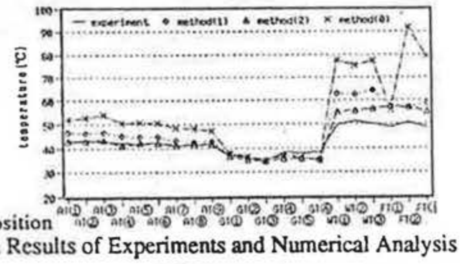



Fig.8 Comparison Between Results of Experiments and Numerical Analysis

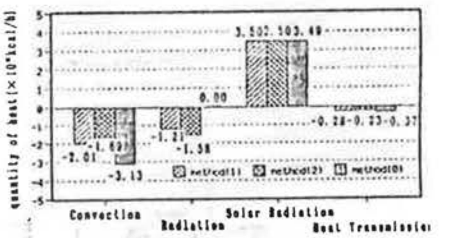



Fig.9 Heat Balance on the North Wall

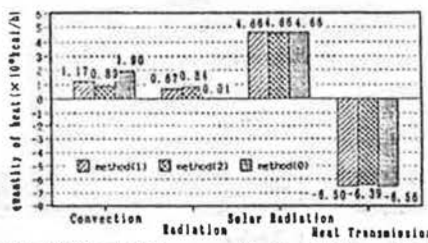



Fig.10 Heat Balance on the South Glass Wall

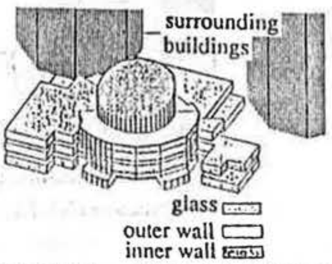



Fig.11. Form of the Actual Atrium

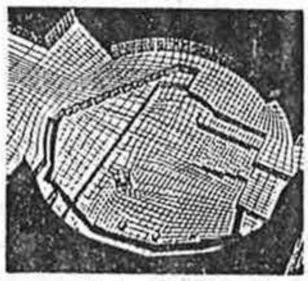
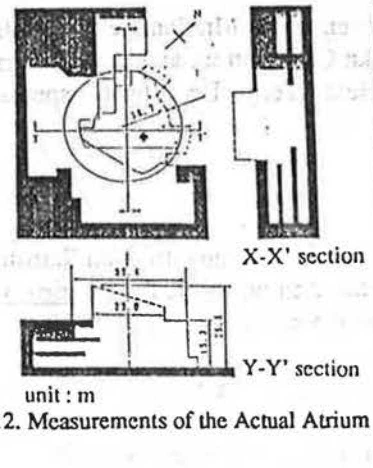


Fig.13. Mesh of the Actual Atrium for Finite Element Method

Table 2. Thermal Boundary Conditions of the Actual Atrium

| position of air-conditioner | amount of supply CMH | num. | total supply CMH | velocity m/s | temp. ℃ |
|---|---|---|---|---|---|
| supply from wall of atrium | 1,455 | 8 | 11,640 | 10.1 | 16.0 |
| supply from tower | 3,880 | 2 | 7,760 | 2.3 | 16.0 |
| supply from tower | 1,500 | 7 | 10,500 | 1.1 | 16.0 |
| total amount of supply (atrium) | —— | 17 | 29,900 | —— | — |
| exhaust from atrium | —— | 11 | 35,926 | —— | — |
| supply from ceiling of office | —— | — | 142,965 | —— | 16.0 |
| exhaust from office | —— | — | 136,939 | —— | — |




unit : m

Fig.12. Measurements of the Actual Atrium

Table 3. Boundary Conditions about Air-Conditioning.

| parts | absorption | K kcal/h·m²·℃ | K' kcal/h·m²·℃ | Tref ℃ | Q kcal/h·m² |
|---|---|---|---|---|---|
| roof glass | 0.23 | 6.45 | 18.18 | 34.0 | 0.0 |
| wall glass | 0.21 | 4.65 | 12.20 | 34.0 | 0.0 |
| floor of atrium | 0.90 | 1.02 | 1.14 | 32.0 | 5.4 |
| ceiling of atrium | 0.90 | 1.52 | 1.80 | 34.0 | 34.9 |
| floor of office | 0.90 | 2.33 | 3.04 | 26.0 | 11~62 |
| ceiling of office | 0.80 | 1.87 | 2.29 | 26.0 | 29~116 |
| wall of office | 0.90 | 2.44 | 3.51 | 34.0 | 0.0 |
| partition of office | 0.90 | 1.81 | 2.34 | 26.0 | 0.0 |

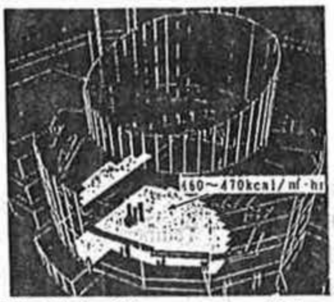


Fig.14.The Circumstances of Direct Solar Radiation Reaching the Floor

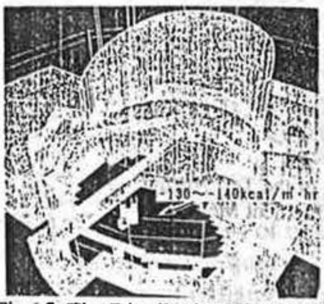


Fig.15. The Distribution of Radiative Heat transfer from the Floor.

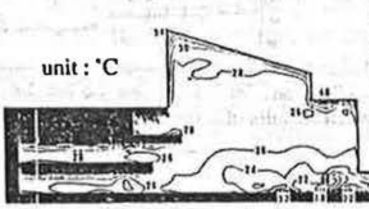



Fig.16. The Distribution of Inside Temperature (Y-Y' Section)

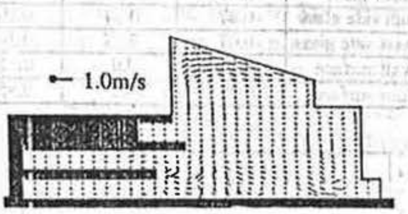



Fig.17. The Distribution of Flow Velocity (Y-Y' Section)


Fig.18. Inside Temperature Distribution (1st. Floor)

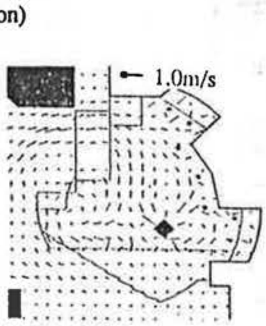



Fig.19. Flow Velocity Distribution (1st. Floor)

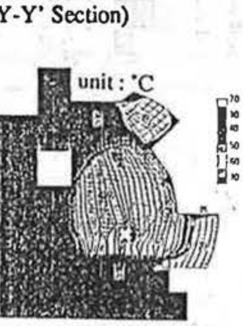



Fig.20. Surface Temperature Distribution (1st. Floor)

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## REFERENCES

[1] Tunehiro Saito : Yoshiyuki Sonda : Yoshiichi Ozeki : Masafumi Yamamoto : and Satoshi Ohgaki. 1991. Analysis on Temperature and Flow Field in the Atrium Part1. Summaries of Technical Papers of Annual Meeting, Architectural Institute of Japan, D,1991, pp.521-522.

[2] Yoshiichi Ozeki : Masafumi Yamamoto : Satoshi Ohgaki : Tunehiro Saito : and Yoshiyuki Sonda. 1991. Analysis on Temperature and Flow Field in the Atrium Part3. Summaries of Technical Papers of Annual Meeting, Architectural Institute of Japan, D, 1991,pp.525-526.