#6220

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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SUMMARY

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. In this paper, comparison of results obtained from the test atrium for experiments and from this numerical method will be mentioned, and applications of this numerical method for the actual design of atrium will appear. One of special feature of this study is that solar radiation, radiative heat transfer, temperature and flow field calculation could be applied to the atrium having very complicated shape.

1 INTRODUCTION

In order to verify accuracy of the numerical method mentioned in the previous paper (Part1), this paper presents comparison of results obtained from the test atrium[1] for experiments and from the numerical method. Using the test atrium, the experiments was carried out without air-conditioning. Outline of the test atrium was mentioned in the following paragraph.

The test atrium for experiments is having simple shape, but actual atrium has complicated shape generally. So it is required for numerical analysis to be well adapted to complicated shape in actual design of atrium. In this paper, it will be mentioned some applications with the 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 long, and 4.5m high. All four walls are glasses, 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.

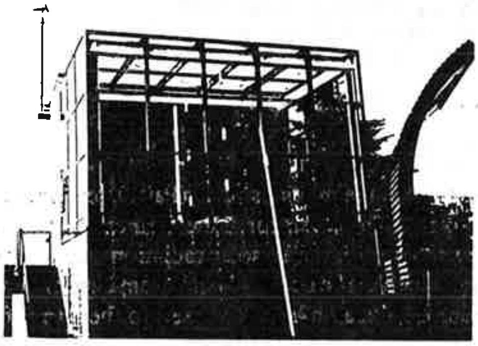


Fig.1. An outward appearance of test atrium for experiments.

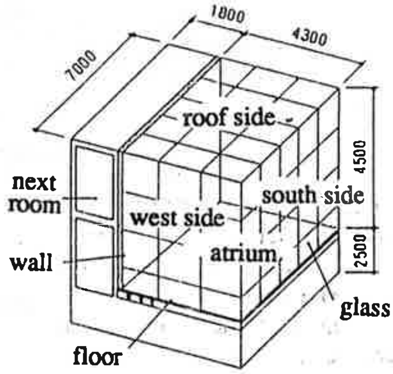
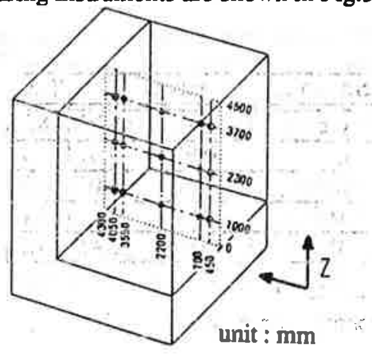


Fig.2. A size of test atrium.

3 ITEMS OF EXPERIMENTS

Items of experiments are 1)all solar radiation to horizontal surface, 2)reference temperature, 3)inner 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 3-dimensional supersonic measuring instrument. The positions of measuring instruments are shown in Fig.3 and Fig.4.



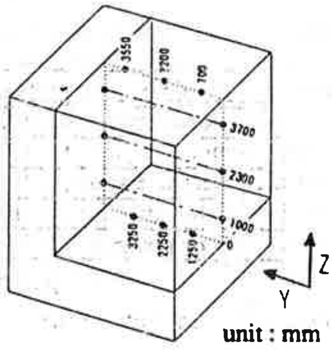


Fig.3. Positions of measuring instruments. (Inner temperature, flow velocity)

Fig.4. Positions of measuring instruments. (Surface temperature)

4 EXPERIMENTS CONDITIONS

The experiments was carried out when the sun came in the south direction in March 26th. 1991. Then all solar radiation to horizontal surface was 645kcal/m^{2}h, and altitude was 56.4°.

5 CALCULATION CONDITIONS

According to the numerical method mentioned in the previous paper(Part1), temperature and flow field in the test atrium was analyzed. The mesh for finite element method is shown in Fig.5. Boundary conditions are shown in Fig.6. In solar radiation calculation, permeability of atmosphere was used value which was calculated back from experimental data. In the radiative heat transfer calculation[2], 6kcal/m^{2}h°C was used for heat transfer coefficient.

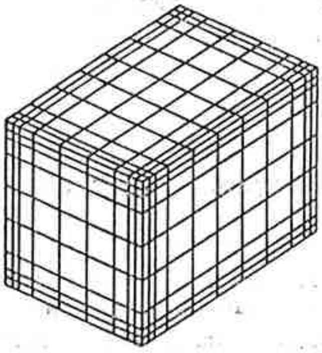


Fig.5. Mesh of the test atrium for finite element method.

parts	absoptivity	permiability	emissivity	K'	Tref
roof glass	0.27	0.65	0.90	9.01	18.7
south side glass	0.27	0.61	0.90	9.01	18.7
east west side glass	0.27	0.59	0.90	9.01	18.7
wall surface	0.91	0.0	0.95	0.24	17.8
floor surface	0.98	0.0	0.95	0.45	14.2

unit : K'(kcal/m2h°C), Tref(°C)

K':Over-all heat transfer coefficient without contribution of inner convective heat transfer

Fig.6. Thermal boundary conditions.

6 RESULTS OF BOTH EXPERIMENTS AND ANALYSIS

6.1 DISTRIBUTION OF INNER TEMPERATURE

The distribution of inner temperature measured in the experiments is shown in Fig.7. The distribution of inner temperature calculated by the numerical method is shown in Fig.8 and Fig.9. The difference of Fig.8 and Fig.9 is whether the radiative heat transfer is considered or not in the calculation process. As shown in Fig.7, the distribution of inner temperature by experiments is nearly uniform, between 51~53°C. It is obvious that results of the numerical analysis agree with that of experiments by considering radiative heat transfer.

6.2 DISTRIBUTION OF SURFACE TEMPERATURE

As well as inner temperature, the distribution of surface temperature is shown in Fig.10~12. In the numerical analysis without considering radiative heat transfer, the surface temperature both of the north wall and the floor is very high, more than 100°C. If radiative heat transfer is considered in the numerical analysis, results approach experimental data. But the surface temperature of the numerical analysis is still 10°C higher than that of experiments.

6.3 DISTRIBUTION OF FLOW VELOCITY

The distribution of flow velocity by experiments is shown in Fig.13, and that of the numerical analysis is shown in Fig.14. In experiments, the updraft along the north wall and the downdraft along the glass wall were surveyed. The velocity of downdraft was about 0.2m/s. This tendency is appeared in the numerical analysis.

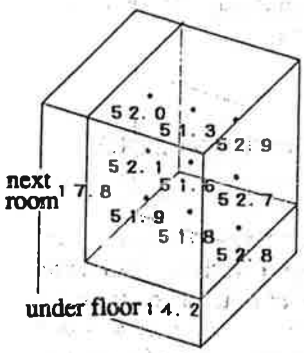


Fig.7. Inner temperature. (Experiments)

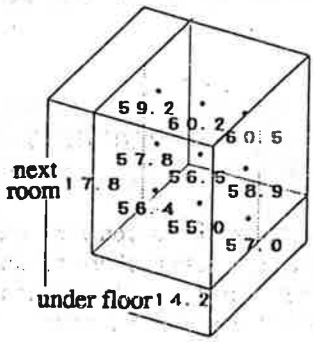


Fig.8. Inner temperature. (Analysis without considering radiative heat transfer)

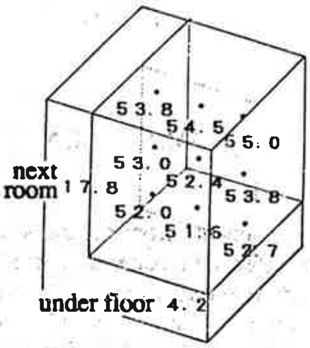


Fig.9. Inner temperature. (Analysis with considering radiative heat transfer)

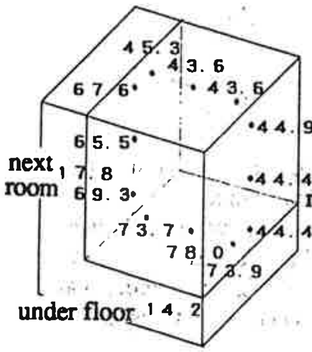


Fig.10. Surface temperature. (Experiments)

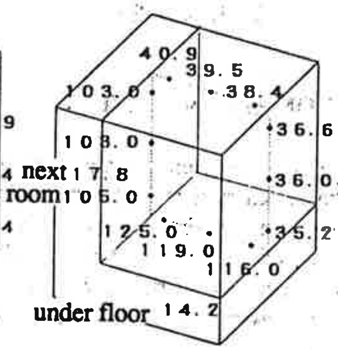


Fig.11. Surface temperature. (Analysis without considering radiative heat transfer)

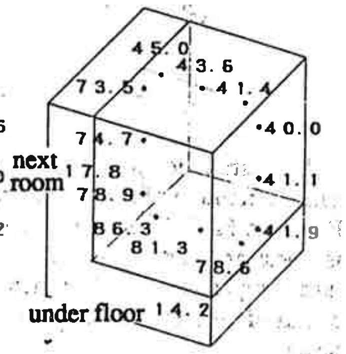


Fig.12. Surface temperature. (Analysis with considering radiative heat transfer)

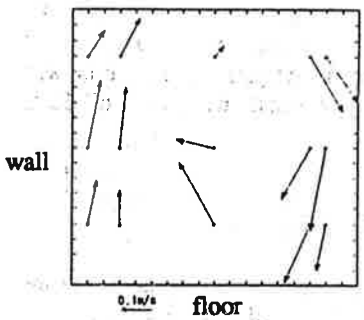


Fig.13. The distribution of flow velocity. (Experiments)

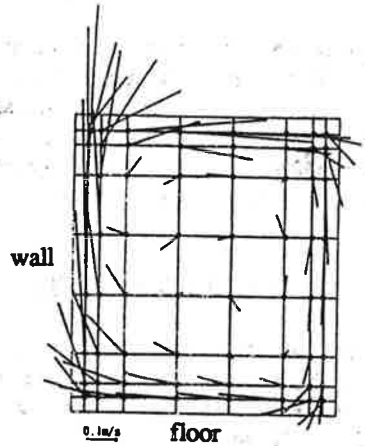


Fig.14. The distribution of flow velocity. (Analysis)

7 COMPARISON BETWEEN EXPERIMENTS AND ANALYSIS

The results from the numerical analysis with considering the effect of radiative heat transfer have better agreement than the results of another analysis without considering radiative heat transfer. For reference, income and expenditure of heat flax on the north wall is shown in Fig.15. Then a direction of heat transfer from atrium space to wall is positive. The amount of radiative heat transfer is equal to or higher than that of convective heat transfer, and the amount of radiative heat transfer cannot be by-passed 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.

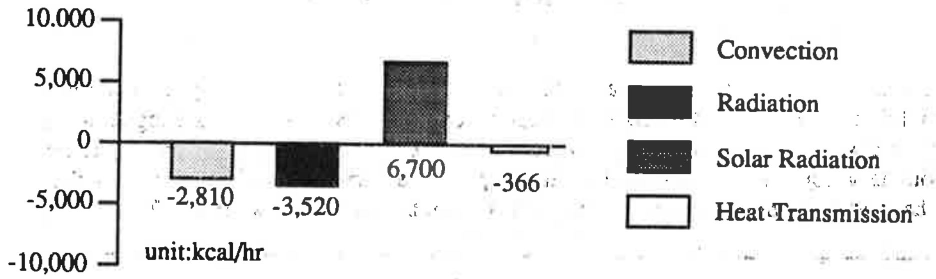


Fig.15. Income and expenditure of heat flax on the north wall.

8 OUTLINE OF ACTUAL ATRIUM

Secondly, some applications of the numerical analysis to actual design of atrium having a 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.16, and the measurements of the atrium is shown in Fig.17. Still more, the mesh for finite element method is shown in Fig.18. 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 glasses. So at 13:00 21th. July, direct solar radiation comes to the 1st. and 2nd. floor. In summer air-conditioner is run at lower space of atrium to keep climate in the atrium.

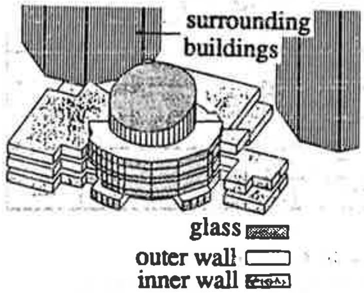


Fig.16. Form of the actual atrium.

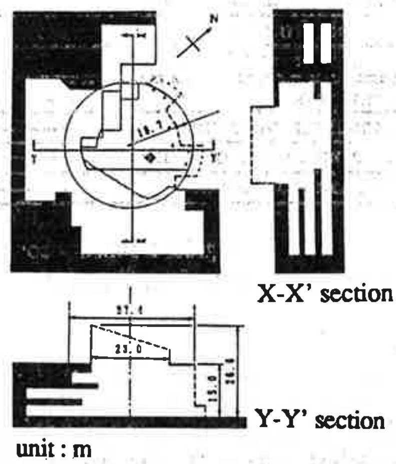


Fig.17. Measurements of the actual atrium.

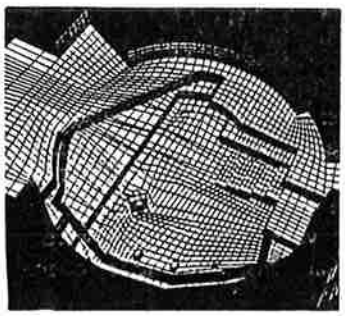


Fig.18. Mesh of the actual atrium for finite element method.

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 Fig.19. 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 Fig.20.

parts	absorption	K kcal/h·m²·°C	K' kcal/h·m²·°C	Tref °C	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.19. Thermal boundary conditions of the actual atrium.

position of air-conditioner	amount of supply CMH	num.	total supply CMH	velocity m/s	temp. °C
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	—	—

Fig.20. Boundary conditions about air-conditioning.

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 radiative heat transfer and convective heat transfer were not calculated simultaneously. It was assumed that the heat transfer coefficient of inner convection was 6.0kcal/m²h°C on each wall.

11 RESULTS OF ANALYSIS

The circumstances of direct solar radiation reaching the floor is shown in Fig.21. The maximum of direct solar radiation absorption is 460~470kcal/m^{2}h. The distribution of radiative heat transfer is shown in Fig.22. 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 cannot 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.23 and Fig.24, those on the 1st. floor (1.5m high) are shown in Fig.25 and Fig.26. Still more, the distribution of surface temperature on the 1st. floor is shown in Fig.27. As shown in Fig.24 in the upper space of atrium, circulation flow appears. About 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.

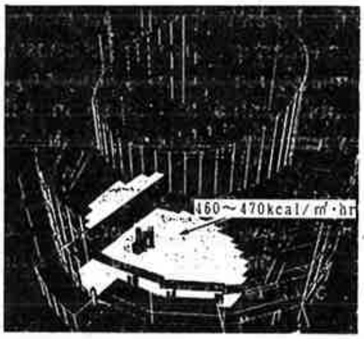


Fig.21.The circumstances of direct solar radiation reaching the floor.

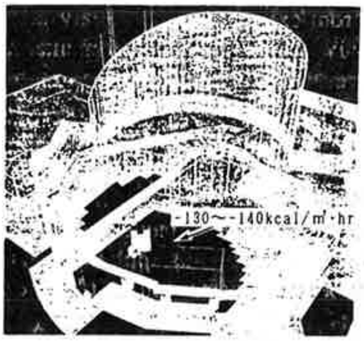


Fig.22. The distribution of radiative heat transfer from the floor.

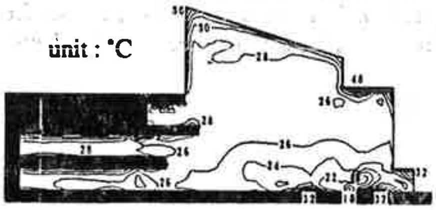


Fig.23. The distribution of inner temperature.(Y-Y' section)

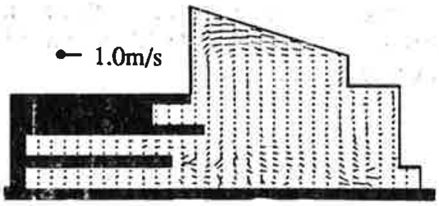


Fig.24. The distribution of flow velocity.(Y-Y' section)

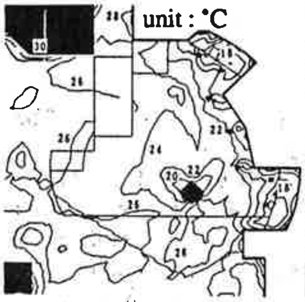


Fig.25. Inner temperature distribution.(1st.floor)

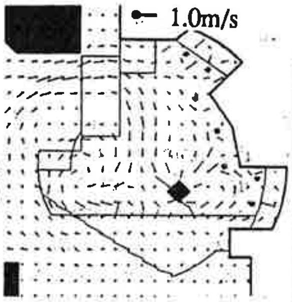


Fig.26. Flow velocity distribution.(1st.floor)

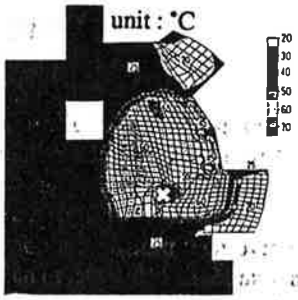


Fig.27. Surface temperature distribution.(1st. floor)

12 CONCLUSION

In order to verify accuracy of the numerical method, we made comparison between results from experiments and analysis. As a result, it became obvious that the results from analysis approached experimental results by considering radiative heat transfer. In the future, the effect of some factors to indoor climate such as permeability of glass, absorption of glass, emissivity of walls, air-condition, ventilation, and so on, will be studied. The improvement of accuracy of both experiments and analysis will be the coming subject, 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, so it is future subject.

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