ANALYSIS OF THE EFFECTS OF ENERGY SAVING METHODS ON THE THERMAL ENVIRONMENT INSIDE AN ATRIUM IN A TEMPERATE REGION

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ABSTRACT With respect to a glass-enclosed atrium space which it is intended to construct in a temperate region, such space involving the cooling of the occupied space, on the assumption of the buoyant ventilation being conducted by discharging the stagnant mass of heat in the upper stratum by operating openings facing the outside air, an attempt was made to predict the effects of such ventilation by numerical calculations. The results obtained ascertained that removal of the stagnant mass of heat was effective in improving the radiation environment of the occupied space and also in reducing the cooling load (sensible heat) both in all-day cooling and at peak times of cooling. That is, it was possible to predict a reduction in both cooling energy (sensible heat) consumption and cooling-system capacity. This indicates that passive "opened cooling*",which assumes that heat stratification occurs in a large space, has the potential to be very effective in a temperate region as well as a cold region.

1. INTRODUCTION

An atrium space, which has come into increasingly wide use in architectural plans regardless of the region and use of a building in recent years, sufficiently retains its function as a semi-outdoor space, as is, in cold regions. Whereas, in temperate regions, due to higher outdoor temperatures, particularly during spring and summer (or during summer and autumn), an atrium space is generally converted into an outdoor space on the assumption of full-space cooling.[1] Actual measurements show that a large space forms a distinctively horizontal contour (heat stratification) of dry-bulb temperatures[2], indicative of the concept of localized cooling of the occupied space in the lower stratum alone, rather than full-space cooling. In other words, the effect of high-temperature radiation from the wall face of the mass of stagnant heat in the upper stratum is to increase the cooling load and cause discomfort in the occupied space. Improving the radiation environment of the occupied space[3]by an efficient discharge of this mass of stagnant heat[4], thus avoiding wasteful energy consumption, is the essential point in the thermal environmental plan for an atrium.

This paper attempts to predict the resulting improvements in the internal thermal environment when the buoyant ventilation by the operation of openings to the outside air is adopted, using as a model an atrium being planned for a new airport project in Kyushu. That is, the influence of high-temperature radiation from the wall faces in the upper stratum of the cooling space is lessened by the lowering of the wall-face temperatures in that stratum by means of discharging the mass of stagnant heat in the upper stratum through the openings provided in that stratum. In this state, reduction of energy (sensible heat) consumption and improvement of the level of comfort can be attempted by the localized cooling of the occupied space. The effect of this attempt is analyzed by simple simulation, for the purpose of evaluation.

*opened cooling : Localized cooling of the occupied space, with some of its upper portion being left open.

2. METHOD OF SIMULATION

2.1 Successive integration method

- Language used and program software : Successive integration method by N88-BASIC.
- Method of analysis : Separation of convection heat transfer from radiation heat transfer with respect to the constituent walls of the subject space for analysis, and analysis of changes in temperature and thermal load in the imaginary zones representing the subject space divided into upper, middle and lower zones (3 temperature zones).

2.2 Modeling for simulation

- Set region and use of the building, etc. : The waiting lobby (atrium) of the planned airport terminal building is used as a model. (Figure-1)
- Setting of the imaginary zones : It has been clarified from actual measurements that in a large space, a horizontal contour of dry-bulb temperatures is formed, particularly in the summer. Thus, on the assumption of heat stratification occurring, the space is divided into the upper, middle and lower (occupied space) zones or imaginary zones. Then, the subject space is made to serve as both a Space-I and a Space-II, these spaces being joined together. (Figure-2) In the interface between the two spaces constituting the atrium (Space-I and Space-II), a virtual party wall is provided so that no heat exchange by convection between the two spaces is permitted, while permitting heat exchanges by radiation. This is because the use of the buoyant ventilation is believed to greatly affect radiation from the wall faces in the upper stratum to each of the imaginary zones, and also because radiation is expected to be a determinant substantially affecting the thermal environment of each imaginary zone.
- Opening for discharging the heated air and introducing the outside air : Slit-shaped openings are provided in the top portion and the middle portion of Space-I and in the top portion of Space-II, along the longitudinal direction of the building, to perform the buoyant ventilation by the stack effect (temperature differences between the inside and outside).

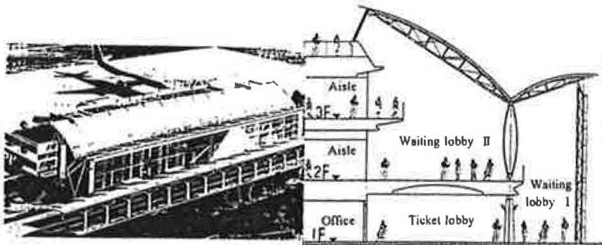

Figure 1. External appearance and sectional plan

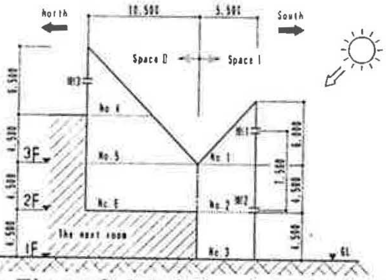

Figure 2. Modeling for simulation

Exp. No. 1 ~ No. 6 : Number of zones
#1 ~ #3 : Number of openings

2.3 Outdoor conditions

Using the data on HASP1988 (Fukuoka), an analysis is made for every hour of a typical spring day and a typical summer day (May 1 and August 1).

2.4 Indoor conditions

Cooling of the occupied space of the atrium is assumed to be for 24 hours, that is, continual. Also, in the room adjoining the atrium, dry-bulb temperatures are assumed to be maintained at a constant 26℃ (summer) or 24℃ (spring).

3. SPECIFICATION OF NUMERICAL ANALYSIS

In order to ascertain the effect of the buoyant ventilation on the thermal environment inside the atrium, the respective results of the effects of such ventilation in the summer and the spring (Table-1) are compared for the purpose of predicting the energy-s

3.1 Operation in summer

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3.2 Operation in spring or

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Case No.	Occupied Space Cooling	Summer: Opening 1 opening in top stratum
1-1	○	-
1-2	○	○
1-3	○	-
1-4	-	-

Note :

4. RESULTS

4.1 Air temperature and

Air temperatures operative temperatures Space-II are shown in

In Space-I, Case 1- compared to Case 1-1 both the day's maximu particularly in the upp markedly manifest in being open, those in th shows a slight reducti removal of the stagna buoyant ventilation ha tegration method by

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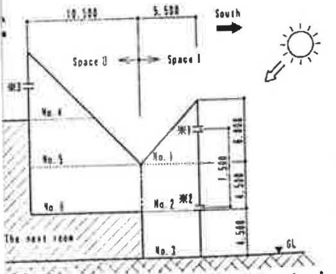

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3.1 Operation in summer

Based on the assumption of "cooling of the occupied space", three different cases are assumed: namely, "all the openings to the outside air are kept shut", "one opening in the top zone is open", and "openings in the upper and lower strata are open". Also, in order to explore the possibility of "non-cooling of the occupied space", an additional case is assumed. "Cooling of the occupied space" means that respective lower stratums in Space-I and Space-II (i.e., Stratum No.3 and 6 in Figure-2) are cooled to maintain temperatures uniformly at 26 ℃. "One opening in the top zone is open" means that the openings in the top stratum of Space-I and Space- II are open. "Openings in the upper and lower strata are open" means that the opening in the top and middle strata in Space-I and one in the top stratum in Space-II are open.

Cooling of the occupied space assumes the occurrence of localized cooling using heat stratification. Thus, heat generated internally, such as that from human bodies, is assumed to be introduced directly into the imaginary zones according to the temperature levels of plumes, without mixing with such heat in the occupied-space stratum. Similarly, the outside air flowing inside through the openings is assumed to be introduced into the imaginary zones according to its temperature level, with no heat exchange taking place en route. Consequently, in the daytime in summer, the outside air is assumed to flow into the middle or upper stratum to cool the wall faces of the strata in the stagnant heat mass region, to then conceivably ease high-temperature radiation from these wall faces to the occupied space, without mixing with the air in the occupied space stratum (26 ℃ constant). This easing of high-temperature radiation is believed to contribute to a reduction in the cooling load (sensible heat) of the occupied space. Strictly speaking, there is a cooling load (latent heat) in human body heat and the outside air inflow. However, the effect of this latent heat is excluded from analysis in this paper.

3.2 Operation in spring or autumn

Based on the assumption of "non-air-conditioning of the occupied space", the operation of the openings in spring or autumn is set in the same manner as in summer. A case of "cooling of the occupied space alone", with all the openings kept closed, is also assumed. Thus, 4 cases in total are analyzed.

Table-1. Cases analyzed.

Summer				Spring			
Case No.	Occupied Space Cooling	Opening to Outside Air: 1 opening in top stratum	Opening to Outside Air: 2 openings in upper & lower strata	Case No.	Occupied Space Cooling	Opening to Outside Air: 1 opening in top stratum	Opening to Outside Air: 2 openings in upper & lower strata
1-1	○	-	-	2-1	-	-	-
1-2	○	○	-	2-2	-	○	-
1-3	○	-	○	2-3	-	-	○
1-4	-	-	○	2-4	○	-	-

Note : In the table, " ○ "represents "used" and "-""not used".

4. RESULTS

4.1 Air temperature and operative temperature

Air temperatures in the upper, middle and lower strata in summer and operative temperatures in the center portion of the occupied spaces of Space-I and Space-II are shown in Figure-3 and 4, respectively.

In Space-I, Case 1-2 in which only the top stratum opening is open, as compared to Case 1-1 in which all the openings are closed, shows reductions in both the day's maximum temperature and the day's average temperature, particularly in the upper and middle strata. Such reductions are even more markedly manifest in Case 1-3 where, in addition to the top stratum opening being open, those in the middle stratum are also opened. Moreover, Case 1-3 shows a slight reduction in operative temperatures also. This indicates that removal of the stagnant mass of heat in the upper and middle strata by the buoyant ventilation has the effect of raising the level of comfort in the occupied space. Also, in Case 1-4 of non-air-conditioning of the occupied space, while the upper- and middle-stratum temperatures are lowered by the buoyant ventilation more than those in Case 1-1, operative temperatures rise. This indicates that in summer when the outside-air temperature levels are high, cooling of the occupied space is essential.

In Space-II, in which solar radiation is very moderate compared to Space-I, temperature levels are on the low side by and large, but differences between the above cases clearly show a tendency quite similar to that in Space-I. However, for the reason that no heat exchange by convection between Space-I and Space-II is supposed to occur, effects of the outside air flowing in from the openings in the upper and lower strata in Cases 1-3 and 1-4 appear to be very marginal in Space-II, compared to Space-I.

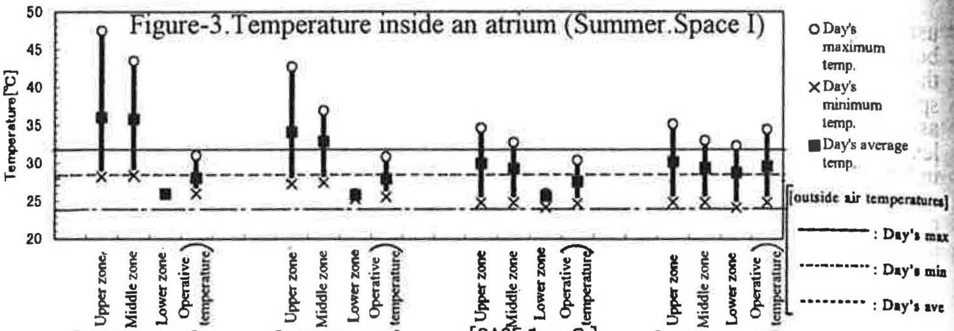


Figure-3.Temperature inside an atrium (Summer.Space I)

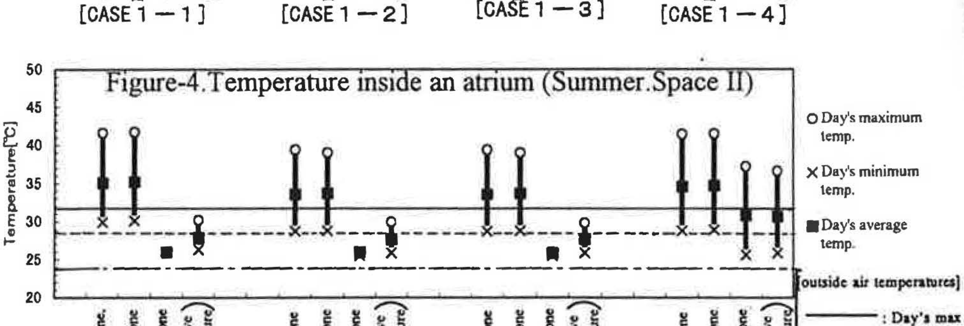


Figure-4.Temperature inside an atrium (Summer.Space II)

Next, the results for spring are shown in Figure-5 and Figure-6, in the same manner as the results for summer.

In both Space-I and Space-II, Cases 2-1, 2-2 and 2-3 show approximately the same tendency in the spring as in the summer. One notable difference is that the effects of opened cooling on the operative temperatures in the occupied space become more pronounced in the spring than in the summer. This can probably be attributed to the generally low levels of the outside air temperatures in the spring as compared to the summer, with the result that the wall faces in the stagnant heat mass region in the upper and middle strata are effectively cooled by the outside air, greatly affecting the radiation environment in the occupied space. Also, in Case 2-4, overall temperatures are on the high side, compared to Cases 2-1 and 2-2. These results indicate that it is better in terms of both cooling energy consumption and level of comfort to adjust the thermal environment inside by buoyant ventilation, rather than air-condition the occupied space with the openings kept shut.

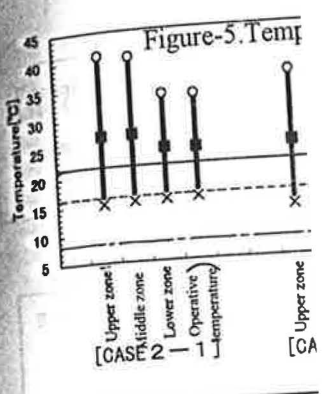
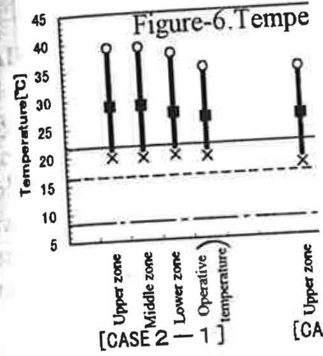


Figure-5.Temp



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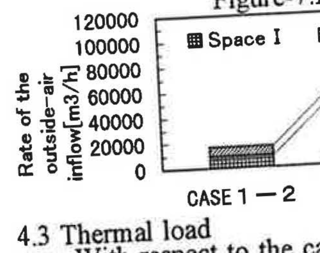

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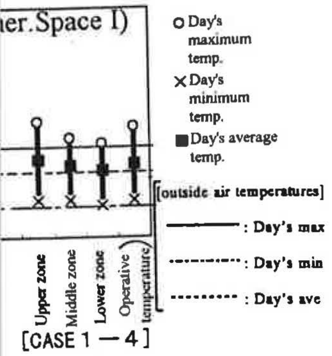

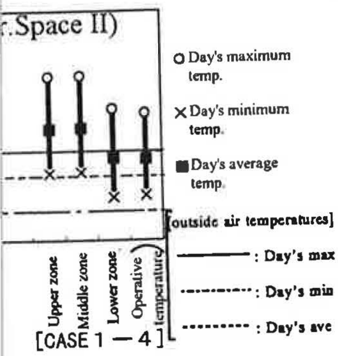

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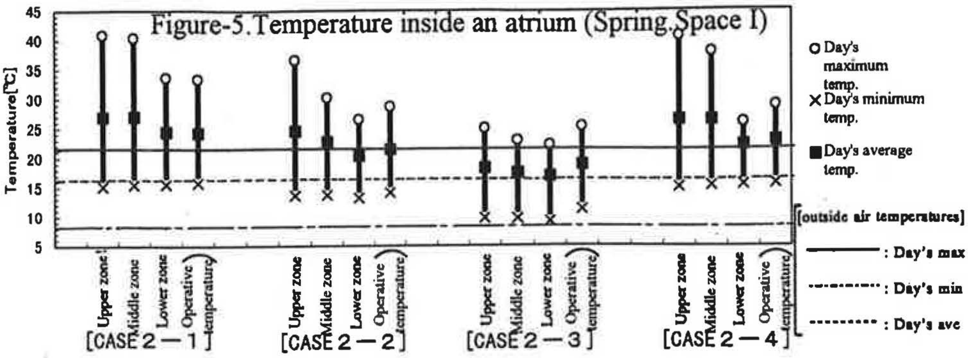


Figure-5.Temperature inside an atrium (Spring.Space I)

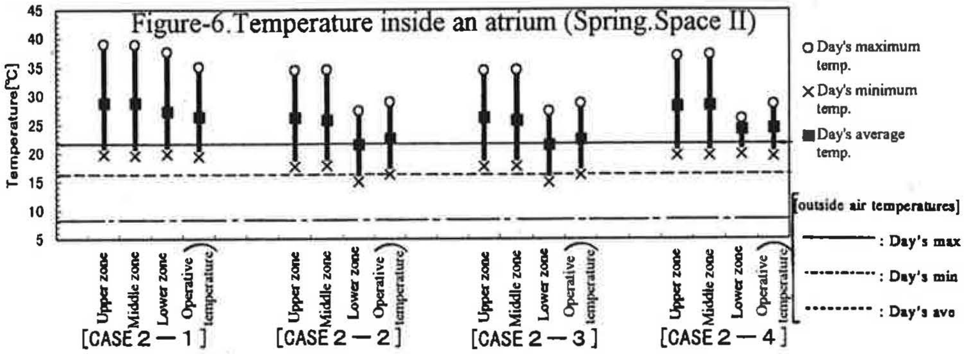
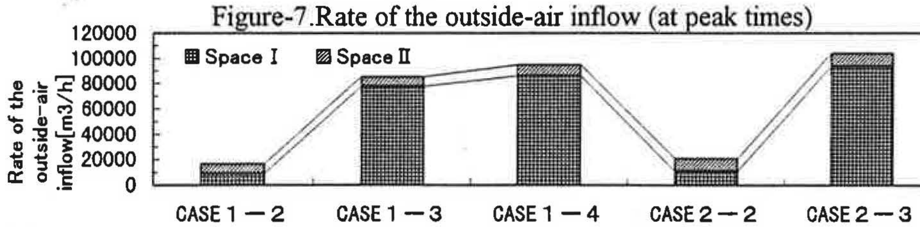


Figure-6.Temperature inside an atrium (Spring.Space II)

4.2 Outdoor air inflow through openings

For the cases in which openings are opened to the outside air, the flow rates of the outside air from the openings at peak times of cooling load are shown in Figure-7. From Figure-7, it can be seen that as compared to Cases 1-2 and 2-2 in which only the top-stratum openings are open, the rate of the outside-air inflow can be expected to increase by 4 to 6 times in Cases 1-3, 1-4 and 2-3 where the openings in the middle stratum in Space-I are additionally opened.

Figure-7.Rate of the outside-air inflow (at peak times)



4.3 Thermal load

With respect to the cases involving the air-conditioning of the occupied space, cooling loads (sensible heat) at peak times of cooling and for all-day cooling are shown in Figure-8 and Figure-9, respectively. From these figures, it can be seen that in summer, cooling loads (sensible heat) are reduced by opened cooling, both at peak times of cooling load and in all-day cooling, indicating a good possibility of obtaining reductions in air-conditioning equipment capacity and cooling energy (sensible heat). Particularly in Case 1-3
in which, besides the top-stratum openings in Space-I and Space-II, the middle-stratum openings in Space-I are additionally kept open, the cooling load (sensible heat) can be decreased by about 20% more both at peak times of cooling and in a all-day cooling than in Case 1-1 in which all the openings are shut.

Figure-8.Cooling load--Sensible heat-- (at peak times)

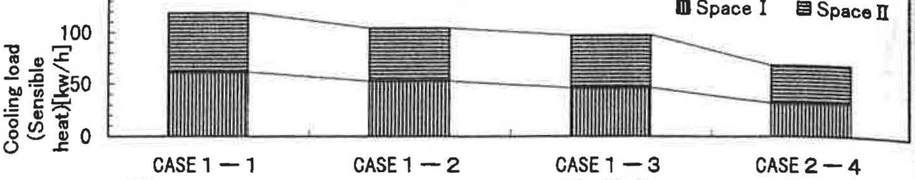
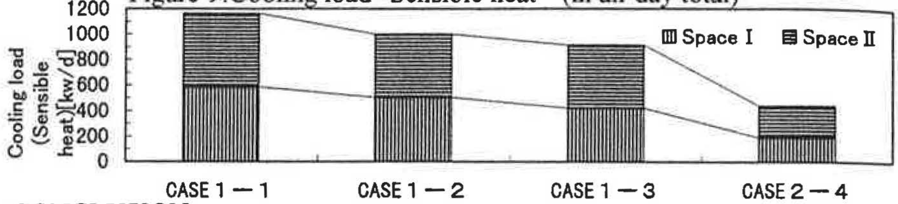


Figure-9.Cooling load--Sensible heat-- (in all-day total)



5. CONCLUSION

It has been found that by opening the top- and upper-stratum openings in the cooling space, the mass of stagnant heat in the top and upper strata is removed, to reduce the effects of high-temperature radiation on the occupied space and thus improve the thermal environment in the occupied space. It has also been found that in the summer, the cooling load (sensible heat) of the occupied space can be reduced by about 20% both at peak times of cooling load and in all-day cooling, permitting reductions in air-conditioning equipment capacity and cooling energy (sensible heat) consumption. In the spring also, opened cooling alone can adequately maintain the thermal environment in the occupied space in appropriate conditions.

6. ACKNOWLEDGMENTS

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A SIMPLIFIED CO(
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1. INTRODUCTION

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