A MEASUREMENT OF THE THERMAL PERFORMANCE AND AIR DISTRIBUTION OF INDOOR SPORTS GROUND USING SWIRLING FLOW TYPE NATURAL VENTILATION SYSTEM

K. SAKAI[1], O. ISHIHARA[2], S. NAGANO[3]

1:Graduate School of Science and Technology, Kumamoto University, Japan
2:Department of Architecture, Faculty of Engineering, Kumamoto University, Japan
3:Technical Research Institute, Fujita corporation, Japan

ABSTRACT

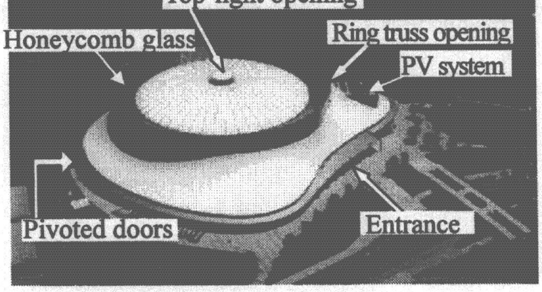
This report describe the thermal performance and air distribution of a Kumamoto prefectural indoor sports ground in Japan. The swirling flow type natural air ventilation system was adopted in combination with environmental symbiotic technique, and attempts was made to positively harmonize the system with the environment. In the measurements, emphasis was put on the identification of thermal environment and on the verification of the swirling flow type natural air ventilation system. From the measurements, it was confirmed that, by adjusting the opening of the doors on the lower portion of the outer wall in the indoor sports ground, air flow characteristics within the sports ground can be controlled, and it is possible to generate swirling flow without relying on mechanical force, and that confortableness is improved on the audience seats in the swirling flow air ventilation, while comfortableness on the sports ground is increased in the intra-ground air ventilation.

INTRODUCTION

In a large scale facility typically represented by an indoor stadium, environmental conditions are often adjusted by dividing the air-conditioning system to the system for audience seats and that of the sports ground. As the air ventilating system for audience seats, a system has been proposed, in which swirling flow is generated by circulating air flow fans and it is tried to improve comfortableness of the audience by the increase of airflow velocity[1].

In contrast, the present authors have proposed a natural air ventilation system, in which swirling flow is generated in a large space without relying on mechanical force but by a combination of air ventilation force, based on wind force and temperature difference in vertical direction, and pivoted doors.

In the indoor sports ground(completed in 1997) built within the compound of the Kumamoto Prefectural General Sports Park, the swirling flow type natural air ventilation system was



Photograph 1. Outside view

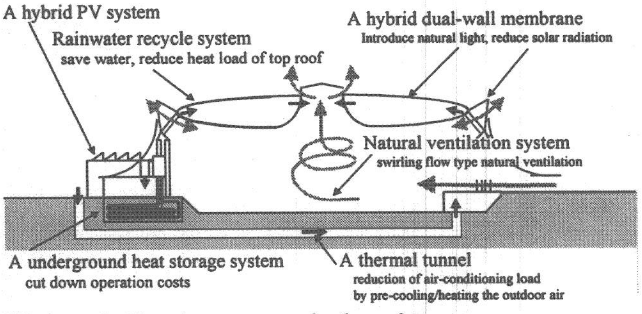


Figure 1. Environmental planning

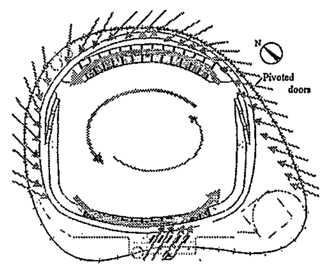
adopted in combination with environmental symbiotic technique, and attempts was made to positively harmonize the system with the environment. In the present report, the results of our study on the effectiveness of the swirling flow type natural ventilation system are presented.

General features of the indoor sports ground

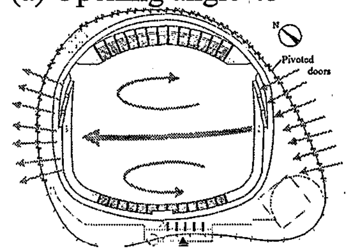
This sports ground (Photo. 1) is a roofed multi-purpose ground where the inhabitants of the prefecture can enjoy various types of sports regardless of the weather conditions. The sports ground has a dome of 32 m in height up to membrane surface, ground area of 11,000 m^2 ,and 2,000 seats for visitors or audience, and it is used for sports game such as football, tennis, softball, and so on. The roof to cover the sports ground is designed as a hybrid dual-wall air-inflated membrane structure, and by pressurizing the air within the membrane to a pressure slightly higher than the atmospheric pressure, the shape of the roof is maintained.
Unlike the conventional single-wall membrane structure, there is no need to apply pressure in the indoor sports ground, and it is possible to freely provide openings. Because this sports ground is generally open to the inhabitants of the prefecture, it is managed under the control of prefecture, and due consideration is given on the reduction of the operating cost by introducing environmental symbiotic technique as shown in Fig. 1.[2]

Swirling flow type natural ventilation system

In this sports ground, air-conditioning system is provided for the attached facilities such as administration office, conference room, lounge, indoor swimming pool, etc., while the audience seats area is designed in such manner that thermal environmental condition can be maintained by natural ventilation.
Openings are arranged at the top-light area at the center of the dual-wall membrane structure, at ring truss on upper portion of outer wall of the structure, and at the pivoted doors on the lower portion of the outer wall. The pivoted doors on the lower portion of the outer wall can be manually opened (opening angle 45° and 90°). It is attempted to control air ventilation performance within the sports ground by adjusting the opening of the doors.
Fig.2 is a conceptual drawing of the natural air ventilation system. In an air ventilation system, in which the doors can be opened at an angle of 45° with respect to wall surface, the ventilation force caused by stack effect from the top-light area is used as driving force, and it is intended to generate swirling flow within the sports ground without relying to mechanical force. In a system to open the doors at an angle of 90°, external air is introduced into the ground area, and it is expected to improve comfortableness for the sports players.



(a) Opening angle 45°



(b) Opening angle 90°

Figure 2. Conceptual drawing of the natural air ventilation system

OUTLINE OF MEASUREMENTS

The measurements were made during the time when artificial lawn was laid on the ground surface in August 1997. The ground surface was provided with artificial lawn on the northern half and with backing materials (rubber chips in black color) on the southern half.
In the measurements, emphasis was put on the identification of thermal environment and on the verification of the swirling flow type natural air ventilation system.

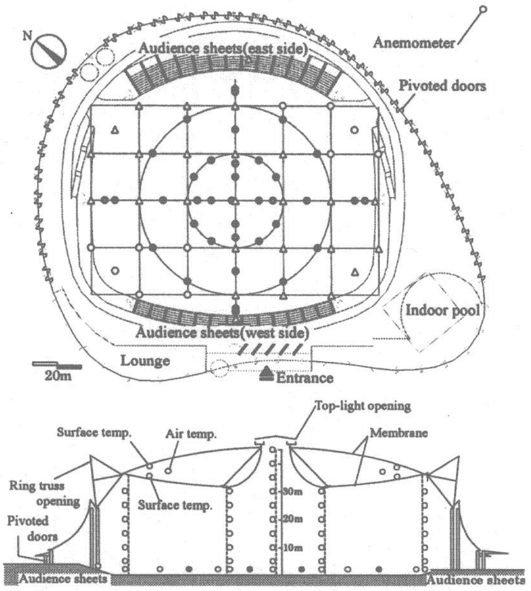


Table 1. Measurement patterns

Pattern	Opening angle*	Top-light opening	Ring-truss opening
0-C-C	Close	Close	Close
45-O-C	45°	Open	Close
45-O-O	45°	Open	Open
90-O-C	90°	Open	Close
90-O-O	90°	Open	Open

*:pivoted doors on the lower portion of outside wall

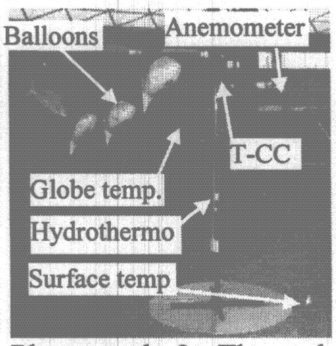
Table 2. Measurement schedule (August, 1997)

	10:00	12:00	14:00	16:00	18:00
13	0-C-C				
15	45-O-C	90-O-C	45-O-C	45-O-O	
16	45-O-C				
17*	90-O-C	90-O-O	45-O-O	45-O-C	

*:with fuming experiment

Figure 3. Measuring points(○ :Surface temp.+Air temp. ●:Wind direction △ :○ + ● + Globe temp.+Humidity)

Fig. 3 summarizes general outline of the measuring points. At each points, surface temperature, air temperature, wind velocity, wind direction and relative humidity were measured. The measurements were carried out at measuring interval of 5 minutes. For the identification of wind direction, four commercially available balloons (filled with helium gas; fish type) were connected together, and this was fixed on a pole using string. Wind direction was determined in 16 azimuth by visual inspection, and the results were recorded at 5-minute interval. The installing condition of the pole is shown in Photo. 2. Fuming experiment was also carried out to identify the air flow characteristics. Measurement patterns are shown in Table 1, and measurement schedule is summarized in Table 2.

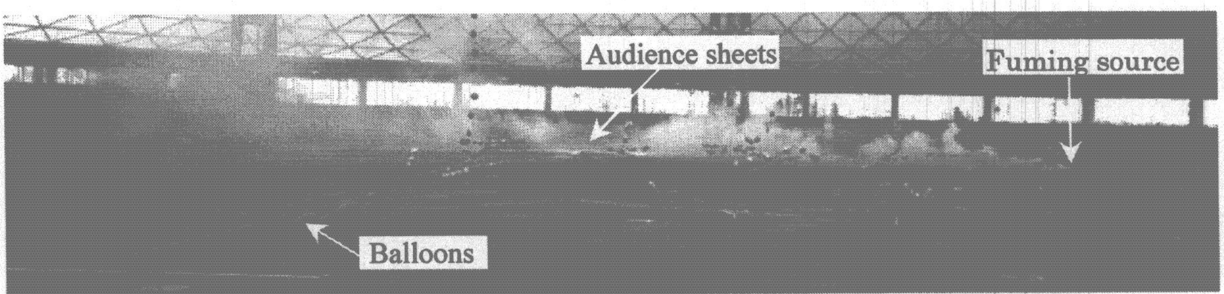


Photograph 2. The pole at the measuring point

RESULTS AND DISCUSSION

Fuming experiment

The results of the fuming experiment of 45-O-C when the doors on the lower portion of the outer wall were opened at 45 ° are shown in photo. 3. It is clearly confirmed how the fume was swirling from the fuming source counterclockwise along the outer wall. The balloon (fish type) placed at GL+1.5 m was moving from left to right with its head facing leftward on this side in the photograph. In the pattern of 90-O-C(not shown), it is seen how the fume was advancing toward the center of the sports ground.



Photograph 3. Fuming experiment(45-O-C) Outdoor wind velocity=5.46m/s, direction=E, August 17. 1997.

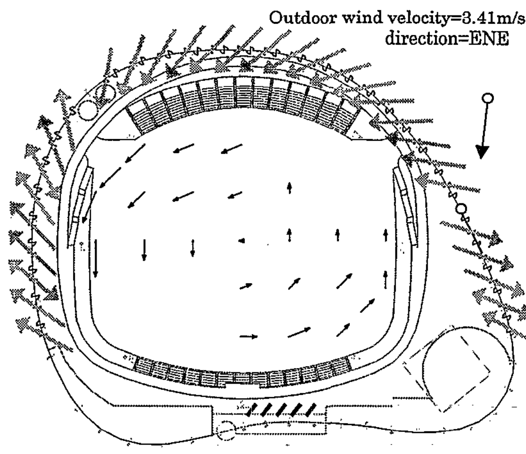


Figure 4. Wind velocity vectors(45-O-C)
13:00 August 16, 1997 Outdoor temp.=30.4°C
→ :2m/s Indoor temp.=30.9°C(Ave.)

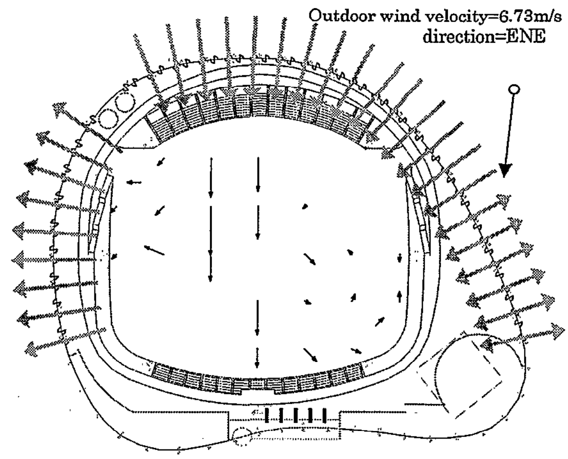


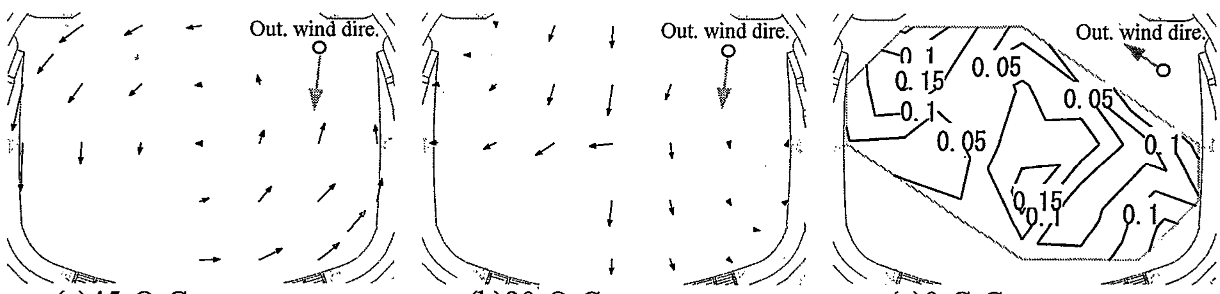
Figure 5. Wind velocity vectors(90-O-C)
11:00 August 17, 1997 Outdoor temp.=28.3°C
→ :2m/s Indoor temp.=29.3°C(Ave.)

Air flow characteristics

Fig. 4 shows wind velocity vectors at the opening of 45° when the doors on the lower portion of outer wall were at the opening angle 45° (45-O-C), and Fig. 5 shows the vectors when the doors at the opening angle of 90° (90-O-C). The arrows shown on the doors of the lower portion of the outer wall represent the wind direction only, and these do not agree with the vectors with respect to the time.
In 45° pattern shown in Fig. 4, wind velocity was high on the outer periphery of the sports ground, while it was lower at the center, and swirling flow moving counterclockwise was seen. Wind velocity was somewhat higher on upper left portion in the figure than on right lower portion, and this may be attributed to the fact that the upper portion of the figure was on upwind side. Similar swirling flow was seen in the other 45° patterns (not shown). In the planning stage, it was assumed that wind flows into the internal space over total circumference of the doors on the lower portion of the outer wall in 45° pattern and it flows out through the opening at the top-light area by stack effect. In fact, however, it was confirmed that there was a site on wind outflow side.
In Fig.5, the wind flowed almost in the same direction as external wind direction, and no swirling flow was formed. Also, the wind velocity at the center of the sports ground was predominantly high, and this agreed well with the condition, which was assumed at the planning stage.

Average wind velocity and temperature

Wind velocity vectors in the patterns of 45-O-C, 90-O-C and 0-C-C are shown in Fig. 6.
In the pattern of 45-O-C, the swirling flow similar to the one shown in Fig. 4 was generated. In this pattern, external wind velocity was within the range of 3-6 m/s, but there was less external influence on the swirling flow (Wind velocity at the outer periphery was 0.8 m/s, and it was 0.5m/s or less at the center.).
In the pattern of 90-O-C, it was flowing almost in the same direction as the external wind, and circulating flows were generated on left upper portion and right lower portion in the figure. Wind velocity in the circulating area was approximately 0.5 m/s or lower, and it was 1 to 2 m/s at the main stream.
In the pattern of 0-C-C, i.e. when the doors were totally closed, the air flow was almost even at the wind velocity of 0.15 m/s or less.



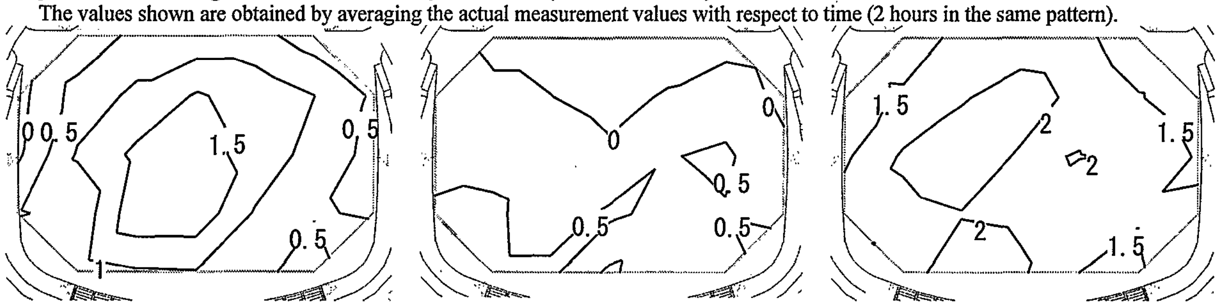
(a)45-O-C 12-14:00 Aug. 16
Outdoor wind velo.=5.2m/s, direction=ENE

(b)90-O-C 12-14:00 Aug. 15
Outdoor wind velo.=3.3m/s, direction=ENE

(c)0-C-C 15-17:00 Aug. 13
Outdoor wind velo.=2.2m/s, direction=S

Figure 6. Averaged Wind velocity vectors(⟶ :2m/s)

The values shown are obtained by averaging the actual measurement values with respect to time (2 hours in the same pattern).



(a)45-O-C 12-14:00 Aug. 16
Outdoor temp.=30.3°C(Ave.)

(b)90-O-C 12-14:00 Aug. 15
Outdoor temp.=32.2°C(Ave.)

(c)0-C-C 15-17:00 Aug. 13
Outdoor temp.=30.0°C(Ave.)

Figure 7. Averaged Air temperature

These values were obtained by standardizing the measured values in accordance with external air temperature standard and were averaged with respect to the time (in the same manner as wind velocity).

Fig. 7 shows the air temperature distribution within the sports ground in the patterns of 45-O-C, 90-O-C, and 0-C-C. In the pattern of 45-O-C, air temperature around the ground was almost at the same value as external air temperature. Temperature at the center of the ground was 1.5°C higher than the external air temperature, and this may reveal that wind velocity at the center was low and there was heat pool at this site.

In the pattern of 90-O-C, temperature within the sports ground was maintained almost on the same level as the external air temperature. Temperature was higher on downwind side, and this may be because the air flowing through the doors on the lower portion of the outer wall was warmed up by the ground surface while it was moving.

In the pattern of 0-C-C, temperature was about 2°C higher than the external air temperature, and temperature distribution was even.

From these results, it was confirmed that, by adjusting the opening of the doors on the lower portion of the outer wall, air flow characteristics within the sports ground can be controlled, and it is possible to generate swirling flow without relying on mechanical force.

Thermal environmental performance

Fig. 8 shows distribution of SET* in the pattern of 45-O-C at GL+1.5 m, and Fig. 9 shows the distribution in the pattern of 90-O-C. Calculation was base on the assumption that the visitors are sitting on chairs at rest (metabolic rate 1 Met; clothing rate 0.6 clo).[3]

During the swirling flow air ventilation, swirling flow is turned to concentric as in the case of temperature distribution on horizontal surface, and temperature was more than 32°C at the center of the sports ground, while it was about 28°C at the peripheral area.

The value of SET* at the peripheral area was substantially less difference in warm and cold feeling among the audience. During the intra-ground air ventilation, the value of SET* at the center of the sports ground was lower than 28°C, and it was 30 to 31°C on the left side and the right side of the figure. This may be because wind enters from the upper portion of the

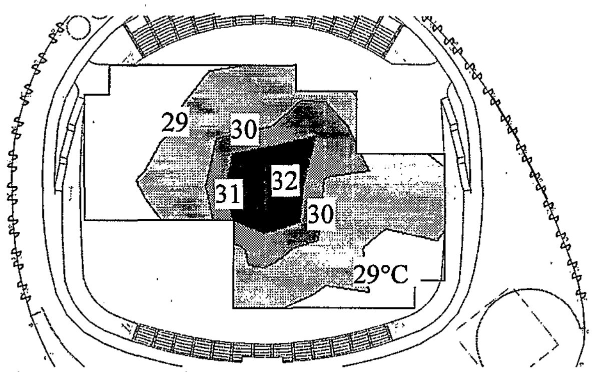


Figure 8. SET* (45-O-C)(13:00 August 16)
Outdoor wind velo.=3.4m/s, direction=ENE Outdoor temp=30.4°C
Membrane surface temp.=37.6°C, Ground surface temp.=31.2°C

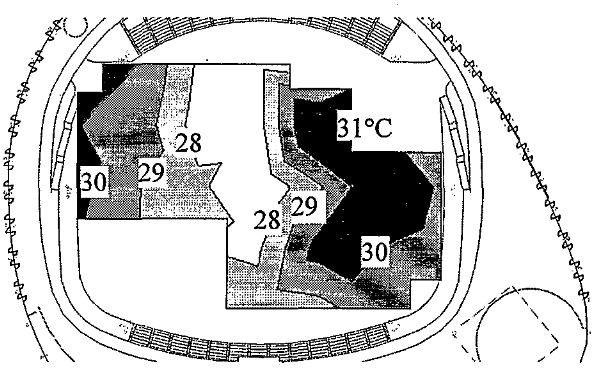


Figure 9. SET* (90-O-C)(11:00 August 17)
Outdoor wind velo.=6.7m/s,direction=ENE Out door temp.=28.3°C
Membrane surface temp.=34.5°C, Ground surface temp.=30.5°C

figure and flows toward the lower portion, and there are circulating areas on the left side and the right side. These results suggest that confortableness is improved on the audience seats in the swirling flow air ventilation, while comfortableness on the sports ground is increased in the intra-ground air ventilation.

CONCLUSIONS

In the present study, we evaluated effectiveness of the swirling flow type natural air ventilation system based on the results of measurement. The findings obtained were as follows:
(a) It was demonstrated that thermal and airflow characteristics within the space can be controlled by adjusting the opening. In particular, it was confirmed that swirling flow can be generated without relying on mechanical force but by setting the opening of the doors on the lower portion of the outer wall to 45°.
(b) In the swirling flow air ventilation, it is possible to introduce external air while suppressing the changes of external wind, and characteristics of swirling flow such as the increase of wind velocity over the audience seats can be identified.
(C) It was found that confortableness on the audience seat is improved by the swirling flow air ventilation, while comfortableness on the ground can be increased by the intra-ground air ventilation.

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REFERENCES

1. Murakami, S and Akabayashi, S. 1985. Wind Tunnel Test on Air Velocity Distribution of Gymnasium with Natural Ventilation and Fan for Circulation, Monthly Journal of Institute of Industrial Science, University of Tokyo, Vol.37, No.6, pp.27-30(in Japanese).
2. Sakai, K, Ishihara, O, et al. 1997. Development of an underground heat storage system using midnight electric power, Part.3, Proceedings of the 7th International Conference on Thermal Energy Storage, pp.653-658.
3. ASHRAE. 1993. Physiological Principles, Comfort and Health, ASHRAE Handbook 1993 Fundamentals, Chapter 8.