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Planning outline and analysis of actual energy operational performance from completion to present in Japanese and foreign large domes and stadiums‐Tokyo Dome, Fukuoka Dome, Odate Dome, Sapporo Dome, Kaohsiung Stadium –

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Abstract Summaryt: *The authors have been planning, designing, supervising, and verifying domes and stadiums for over 20 years. These buildings were designed as local sports facilities or multi-purpose facilities for large audiences.*

These facilities have individual characteristics reglecting their regions. Design intentions and methods of environmental planning have changed with the times, and actual energy consumptions levels vary with the type of events and number of event days.

We compare these domes and stadiums from environmental perspective, and analyze the operational improvement and energy management performance. We believe that such case studies have not previously been conducted.

We analyze the methods of these domes and stadiums, with respect to load reduction, natural energy utilization, energy systems, and renewable energy. We compare and analyze the reduction rates of actual energy data from completion to the present, and discuss the mention the issues concerning environmental planning of large-scale domes and stadiums in the future.

Keywords: ***domes and stadiums, Japanese and foreign countries, environmental planning, annual actual energy consumption and visitors***

1. History of Japanese large domes and stadiums

After the 1980s in Japan, city stadiums and sports facilities were ready for replacement, and several plans for all-weather and multi-purpose stadiums were proposed. Becouse they would allow sporting events and exhibitions to be held on rainy days, large domes projects were also proposed. In addition, inner domes were constructed in the U.S.A., membranes with high degrees of weather resistance, transparency, strength, fire resistance were developed, and the national building standard law was developed, special certification by the minister of construction was introduced. Tokyo Dome was completed in 1988 as the first air-supported dome in Japan. In the early 1990s, dome projects retractable roofs as the new attraction were

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proposed. Fukuoka Dome was completed in 1993 as a large retractable roofs dome. In the 1990s midium-size domes for local governments were actively proposed. Regionally specicific development, such as the use of local wood and natural energy was also proposed, with Ohdate Jukai Dome as one example. The determination of the World Cup would be held in Japan in 2002 led to planning in Japanese various cities of football stadiums meeting the FIFA standard of natural grass. Football stadiums with full roof were planned in Sapporo and Ohita. Now that the Tokyo Olumpics of 2020 determined, plans for a new National Stadium and other arenas are in progress.

2. Features of domes and stadiums designed by authors

2-1. "Large space as an artificial environment" / Tokyo Dome

This was the first air-supported dome in Japan. Air pressure supports the membrane roof with steel wire reinforcement. The dome controls air pressure, increasing the pressure during high winds, snowfall, exit of the audience, and evacuation. Evacuation is carried out for maintenance of the membrane roof, and in case of emergency such as fire. The pressuring capacity has been maintained for a long period of time. Environmental planning features includes the cooling and heating of the seats each level; the maintenance of natural lighting from the membrane roof; and the minimization of air leakage. Minimization of air leakage is intended to minimize the operating costs.

Fig-1 Tokyo Dome / Interior photo

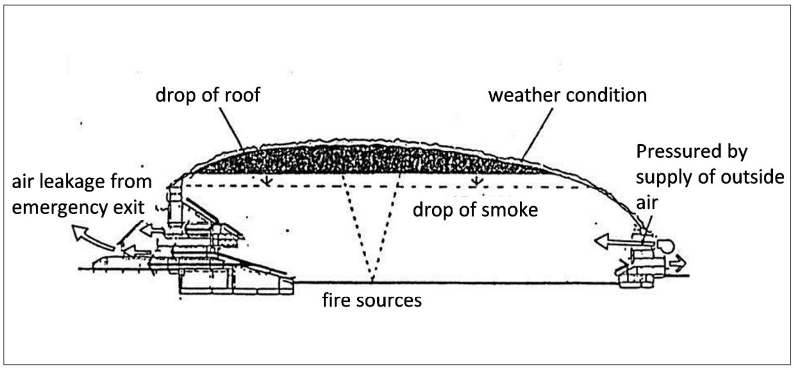

Fig-2 Roof keeping and accumulation of smoke in case of emergency

2-2. "Large space convertible between indoor and outdoor" / Fukuoka Dome

This dome was planned in Fukuoka for multi-purpose use, such as baseball, concerts, and exhibitions. It was the first dome to incorporate large retractable roofs. Roof opening and closing still continues today. Environmental planning features include the placement of the field to maximize the sunshine; the selection of weather conditions to determin whether the roof should be open or closed; verification of airflow and temperature during roof opening; the determination of air flow through the stands by the circulating flow fans; and the consideration of rainwater reuse.

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Fig-3 Fukuoka Dome / Interior photo

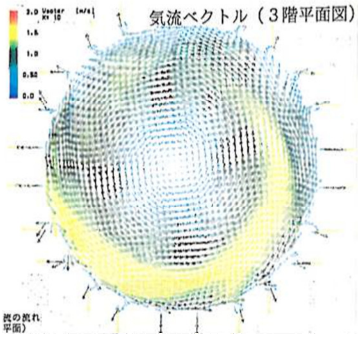

Fig-4 Air flow in stands by circurating flow fans

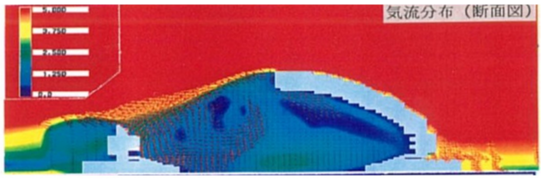

Fig-5 Air flow CFD at roof opening

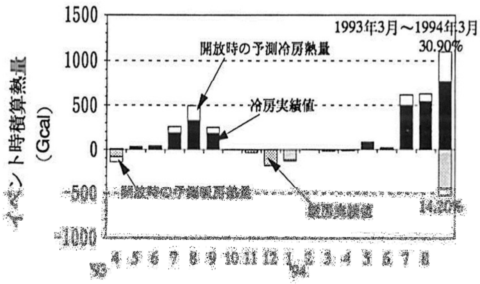

Fig-6 Monthly arena cool load & heat load and effect of retractable roof ('93.4-'94.8)

2-3 "Local sports dome using natural energy and local materials" / Odate Jukai Dome

This dome is located at Odate in Akita prefecture, and has a hybrid structure of wood and steel. It was planned as a core facility for sports promotion in the region, as well as for use of local citizens. Environmental planning features include conservation of the site's forest; the use of local wood; maximum use of natural ventilation and daylight; outside air introduced from the pond side; heating of the bench seats, and reduced life cycle environmental impacts.

Fig-7 Odate Jukai Dome / Interior photo

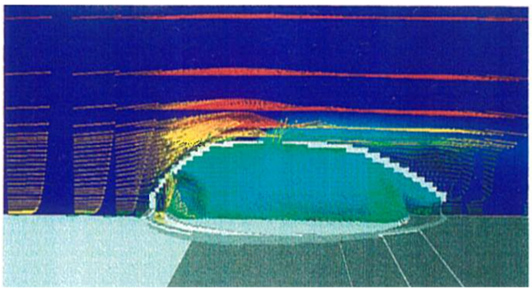

Fig-8 Airflow CFD / Natural ventilation

2-4 "Large space with summer and winter modes in cold/snow region" / Sapporo Dome

This is a large dome in a cold and snowy region. It is the city's facility for baseball, soccer, concerts, and exhibitions. Many events can be held even during the cold and snowy season. The natural grass stage moved to the field for soccer games. The large openings utilize natural ventilation and daylighting, and work together with exhaust openings and top light in the roof top. Environmental planning features include insulation and air tight; thermal storage; seat air conditioning using slit openings; the design of air flow through trench, stand slab, air chamber, large space, and finally the roof exhaust opening; geothermal heat in the trench; well water use and rainwater reuse. An energy management strategy was necessary to increase the operation of natural ventilation and reduce use of the heat source.

Fig-9 Sapporo Dome / Interior photo

Fig-10 Interior photo at moving wall open

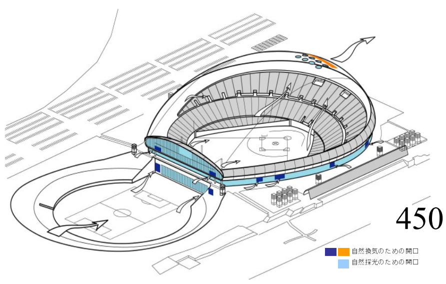

Fig-11 Diagram of air flow at natural vent.

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2-5. "Open Stadium that generates energy"/ Kaohsiung Stadium

This is an outdoor stadium in the southern region of Taiwan. It is planned as an international athletics stadium. The form is open on the main station side. The lower level of the stands is also open to the inner field and outer facade, and the canti-lever roof covers the stands. This shades the stands, improves air flow, and provides light illumination at night. See-through photovoltaics panels form a roof that covers the stands.

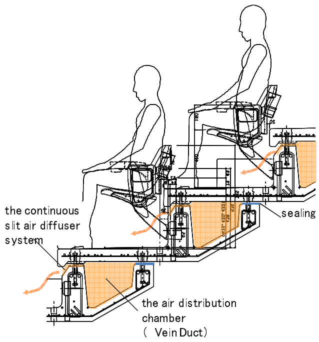

Fig-12 Sapporo / air diffuser system

Fig-13 Kaohsiung Stadium / Exterior photo

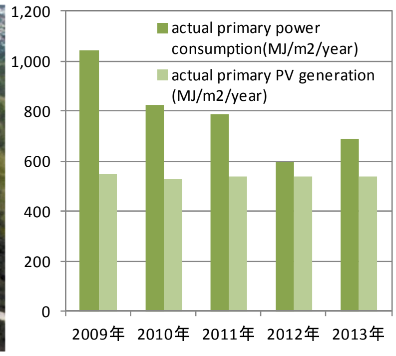

Fig-14 Power consumption & PV generation

2-6. Design intent and method

It is important in the planning of domes and stadiums that the collaboration between building design, environmental design, and MEP design occurs in the early stage. It is also important to study the planning the placement of the stadium, section, external shape, and the placement of the openings, considering the district temperature, humidity and wind direction. Maintenance of the thermal environment, air flow around the stands and seats, and ensuring an adequate supply of daylight are also important.

2-7. Methods of reducing the environmental load

Several methods exist to reduce the environmental loads of domes and stadiums. These include the lighting load by daylight; occupied zone air conditioning to primarily target the stands and field; cooling load reduction by natural ventilation; use of the heat storage of the stands and floor for maintenance of the thermal environment; reduction of potable water consumption by rainwater and wastewater reuse; and reduction of the lighting and air conditioning loads due to the outside of the arena. Air conditioning accounts for a large proportion of an indoor stadium's load. It is necessary for cooling and heating to be in accordance with cold weather to provide heating and ventilation for the audience.

2-8. Local climate and large space

Tokyo and Fukuoka are located in warming areas, whreas Sapporo and Odate are located in cold areas. Kaohsiung is hot and humid all year round. In each case, the insulation, air-tightness, use of natural ventilation are different. And wind direction in the district is also different. In Fukuoka Dome the orientation of the roof opening and the axis of the back net/screen are defined by the effects of shade and the external wind. In Odate Dome, the placement of the pond was determined by the outside air introduced from the main wind direction. In Sapporo Dome, the openings of the movable wall are determined by the main wind direction, and insulated or airtight lines are carefully chosen. In Kaohsiung Stadium, it

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was planned that the prevailing wind will flow through the audience, and the roof of the canopy was installed accordingly.

3. Study on actual management performance and energy consumption of domes

3-1. Ensuring the attraction, repeaters, and various events

Tokyo Dome, Fukuoka Dome, and Sapporo Dome are located in large cities. Events are divided mainly between the baseball season and the off-season. Dependings on the dome and particular year, the number of days when events were held (except for construction, removal, and practice) has reached 130 to 220 days per year. During baseball season, franchise baseball teams hold professional games 30 to 75 days a year. Baseball games of other teams and intercity baseball games etc. are also held. In Sapporo Dome, franchise soccer team had done approximately 10 games per year. American football games and the like are also occasionally held in each dome. In the off-season, exhibitions have become annual events. A few concerts have also been held. For artists and event promotion companies, these are very important event. Odate Dome is an all-weather facility aimed at regional development, with a focus on sports. The major events are tournaments for Akita prefecture and Odate city. The number of annual users is approximately 20 million, and the number of days used is stable at over 300.

Students and sports fans in the region have become regular attendees of the dome.

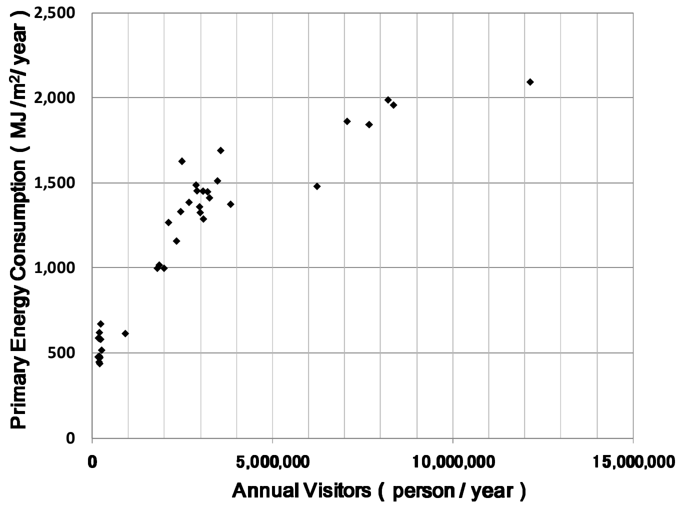

Fig-15 Annual visitors and primary energy consumption

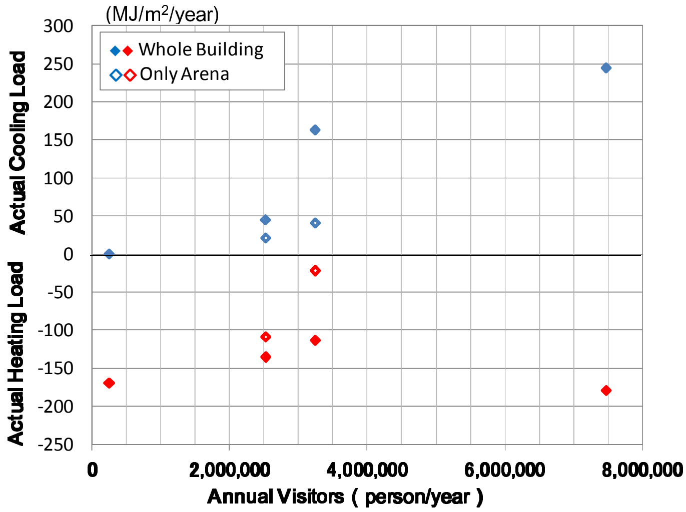

Fig-16 Annual visitors and cooling load / heating load

3-2. Actual primary energy consumption

Figure-15 shows the results of the survey for primary energy consumption of the entire building, and the annual number of visitors. If the number of visitors increases, the primary energy consumption also tends to increases. However, if the number of visitors is very large (on the scale of several million people), energy consumption per unit area tends to level off.

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For a local dome, the annual number of visitors is only a few hundred housand. The primary energy consumption is small, approximately 500MJ/m2/year.

3-3. Actual cooling and heating load

Figure-16 shows the results of the survey for the cooling and heating loads and the annual number of visitors. If the number of visitors increases, there is a tendency that the cooling load also increases. The rate of air conditioning to the overall consumption is as high as 50%; the effect on energy consumption is large. In the two domes, the arena air-conditioning line is measured individually. For the reason that operating hours for arena is short, the ratio of arena cooling and heating load to all loads is not particularly high. In Odate Dome, the cooling load is zero because there is no cooling system; meanwhile, the heating load per unit area is at the same level as the other large domes.

3-4. Effects and actual results of natural utilization

Natural energy utilization, (such as the use of daylight, natural ventilation, etc.) is very effective in domes and stadiums.

With regard to daylight, the stadiums use different methods, such as daylight from a membrane roof (Tokyo, Odate); daylight from retractable roofs (Fukuoka); daylight from top light and movable wall openings(Sapporo); and an outdoor environment(Kaohsiung). It is very important for sports domes and stadiums to provide natural light to athletes and the audience.

Natural ventilation is impossible in Tokyo Dome, because it is an air supported dome. Meanwhile, the powers of exhaust fans are very few for same reason. Air leakage volume for the closed state is approximately 150,000 m3 /hour and has not changed since completion. The percentage of annual energy consumption by air pressured fan power is only 2.2%. In Fukuoka Dome, the arena is exposed to outside air when the roof are open. In Odate Dome, we installed openings in the exterior wall and roof, and actively planned natural ventilation. Kaohsiung Stadium is an outdoor stadium, and it is planned to utilize natural ventilation between the front and rear of the stands.

With regard to renewable energy, photovoltaic(PV) panels were recentry installed in Sapporo Dome. The 1 MW solar installation in Kaohsiung stadium is remarkable. See-through PV panels were installed over the entire stand area considering access to natural light and views of the sky. The generated power is consumed at the stadium, and the extra power is sold to the power company. The annual generated power is slightly less than the current power consumption, but nearly balanced. Consumption of this stadium is rather low, nearly achiving a zero energy stadium.

With regard to the actual effects, in Fukuoka Dome, lighting consumption was reduced by 20% and the cooling load was reduced by 31% one year after completion. In Odate Dome lighting consumption was reduced by 69% with membrane daylighting, and the cooling load was reduced by 92%. In Sapporo Dome Naturalventilation was in operation 75 to 82% of the time, and cooling load was reduced 83% by the use of natural ventilation, night purge, and

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geothermal cool trench. Kaohsiung Stadium is an outdoor stadium, and the air conditioning load and daytime lighting power consumption are zero.

3-5. Maintenance and replacement

Maintenance is commissioned to a company or department professional. The averall consumption and subdivided energy consumption are monitored continually. Each dome analyzes the effects of annual visitors, additional events, the impact of a mild/cold winter and hot / cool summer, and the power saving and generator operation after 3.11 Japan Earthquake. Each dome has improved a plan for the next year. In Tokyo Dome the heat sources, the air pressure control system and the building automation and control system etc. have already been replaced. Each dome is now studying arena lighting system replacements utilizing advanced LEDs.

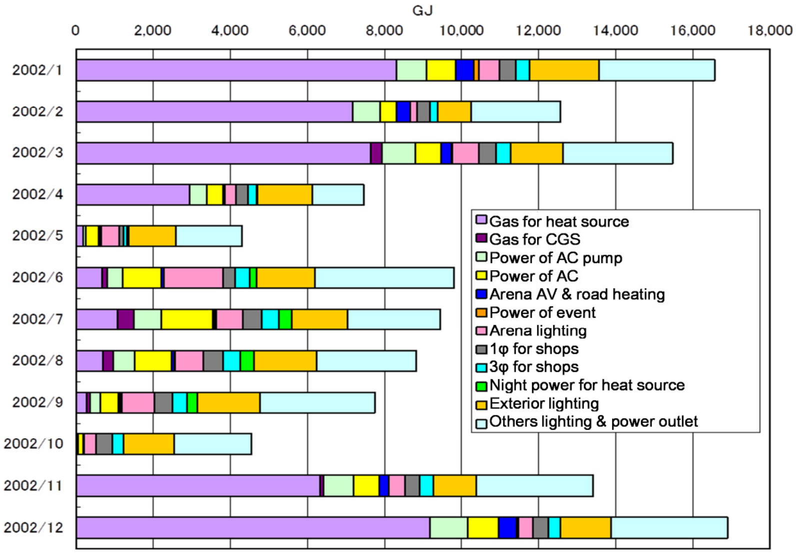

Fig-17 Sapporo Dome / Monthly energy consumption (divided items)

4. Future issues and environmental planning in large audience and scale domes/stadiums

With regard to issues in large audience and scale domes/stadiums in the future, we believe the followings. Planning 20 to 50 years ahead, we emphasize design that is intimate to the district landscape, in harmony with the natural characteristics of the local area, and conductive to diversity of more events and more local people. It is necessary to create facilities that transmit local culture.

With regard to environmental planning, the introduction of advanced technology is expected because of various development, such as greater opening to the outdoors, and increased utilization of natural energy, and generative energy. Because the site and the building area are large, they provide an easy way to generate energy. It is expected that district carbon neutrality initiatives or zero energy stadiums will advance this trend. If there are such opportunities, we would like to participate in the future.

【References】 1)System planning and installation of Tokyo Dome(parts1,2,and 3),1990.Jan, Apr, May, SHASE 2)Air conditioning and plumbing systems of Fukuoka Dome, 1995.Dec.,SHASE 3)Environmental planning and installation of Odate Jukai Dome, 1999, Nov.,SHASE 4) Planning and implementation of environmental system and airconditioning in Sapporo Dome, 2004, Oct.,SHASE

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