621: Passive Environmental Control Methods for District and Building Scales on Taketomi Island

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Abstract

The purpose of this study is to clarify the effect of the passive environmental control methods in the traditional vernacular of Taketomi Island, a small village in Japan. The indoor thermal environment for building scale and the effects of thermal environmental relaxation and windbreaking for district scale are analyzed based on field measurement. The following results were obtained: 1) Windbreak, that is, shelter belts around the village decrease the wind velocity in the village. In particular, the effect of windbreak improves in the case of south wind. On Taketomi Island, numerous typhoons pass through every year, so this windbreak defends the houses from the strong south wind. 2) Alleys covered with the white sand are superior in the thermal environment compared to the alleys of asphalt and concrete pavement, and also stone walls made of coral are superior to the walls made from reinforced concrete in this thermal environment. 3) In summer, the thermal environment in traditional vernacular houses is by no means comfortable, due to the change of architectural forms and resident's life styles. Indoor air temperature of the houses is higher than that outside during the day.

Keywords: Indoor and outdoor thermal environment, windbreaks, Taketomi Island, hot and humid region

1. Introduction

Many kinds of passive environmental control methods can be found in Japanese traditional vernacular houses and villages. In Japan, it is often said that a house should be built especially in consideration of summer season, so accordingly there are many devices for creating a comfortable environment in summer. Taketomi village is famous as an example of the traditional style of architecture retained in a hot humid region. Therefore, Taketomi village has been designated to include "Preservation Districts for Groups of Historic Buildings" since 1987. As architectural characteristics of this village, stone walls surrounding the houses, alleys covered with white sand and windbreaks around the village and other features are prominent. Several studies have been made analyzing these features from the viewpoint of historical and landscape aspects [1] [2]. However, the effect of the passive environmental control methods in this village has not yet been studied. These methods in a traditional vernacular village are the result of wisdom and rationality that has been cultivated for years, so these methods also present great possibilities to modern Architecture. The purpose of this study is to clarify the effect of the passive environmental control methods in the traditional vernacular of Taketomi Island, a small village in Japan, as a typical example of hot and humid regions.

2. Investigated area

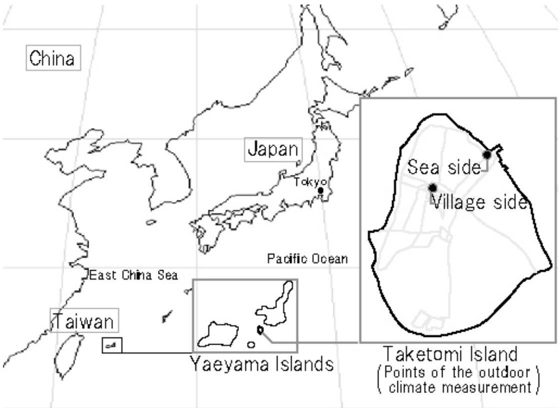


Figure 1: Location of the survey area

2.1 The climatic and local characteristics

Taketomi Island belongs to the Yaeyama Islands, and it is located in the south-western end of Japan (latitude, 24° north; longitude, 124° east, Fig.1). The entire island is surrounded by a coral reef, and it has been designated the "Iriomote-Ishigaki National Park". This island is small and flat. The circumference of the island is about 9km and the area is 5.41 km^2. This area is warm all the year round and the mean outdoor air temperature is 23.3 degrees, the mean outdoor humidity is 82%, and the mean annual rainfall is 2,406mm, so it has both subtropical and oceanic climates. Moreover, the peculiar culture and customs of Ryukyu have survived in this area, and the concept of "feng shui" characterizes the village formation.

2.2 The village characteristics

The village, which is located at the center of island, is divided into three villages: Nishiyashiki village, Higashiyasiki village and Nakasuji village. The total area of the villages is 38.3ha (900m in the north/south direction, 600m in the east/west

Photo 1: The landscape of Taketomi village (The village characteristics)

direction, Fig. 2). All of Taketomi village has been designated as including “Preservation Districts for Groups of Historic Buildings" since 1987. The village is surrounded by forest, and this forest acts as a windbreak. The traditional houses are surrounded by coral stone walls with a height of about 1.5m. Most of the alleys in this village are covered with white sand, and roads of asphalt and concrete pavement are few (Photo 1). The “Taketomi Island Landscaping Manual” [3] was developed to provide rules for new construction and reconstruction in 1994 in order to maintain the landscape. This manual was the result of investigation and the analysis of this village for two years, beginning in 1992. Therefore, the details of houses, for example, housing form, size of dwelling, exterior, and construction materials are decided based on these rules for new construction and reconstruction in this village.

2.3 The architectural characteristics

The traditional vernacular houses on Taketomi Island are made of wood and they are divided into two buildings (Fig.3). The houses consist of a main building called the “Fuhya” and an annex used as kitchen, which is called the ”Tohra”. Both parts face the south. Most of the houses have a traditional red-tiled roof, and long eaves. They are also surrounded by a coral stone wall and a wall called a “Hinpun” which stands in front of the entrance to the *Fuhya*. There are many kinds of *Hinpun* in this village. For example, the coral wall type, the planted type, the movable type and so on. The *Hinpun* is a characteristic constituent of “Ryukyu” architecture and it has various roles, such as protection against evil spirits, strong winds and observation by others from outside. On the sites of the houses, several trees called “Fukugi” are planted which protect the house from strong winds and solar radiation. The original traditional houses did not have the glass sashes and sliding doors called “Fusuma” and “Shouji”, so the house remained open in the daytime. On the other hand, rain shutter doors were closed in the nighttime or inclement weather. However, since the residents’ lifestyles have changed in recent years, glass doors have been installed in many houses and the indoor space has been divided using “Shouji” and other methods. In addition, the *Tohra* has tended to lose its original function as a kitchen and is instead used as a storehouse or has disappeared with the changes in residents’ lifestyles.

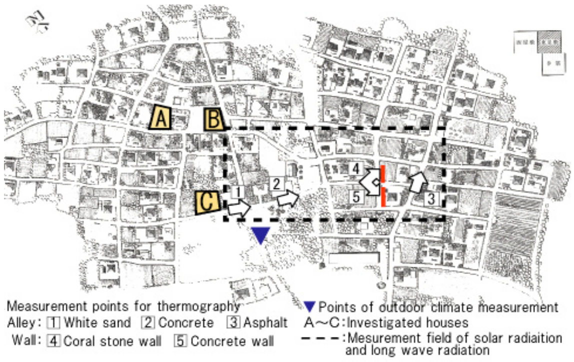
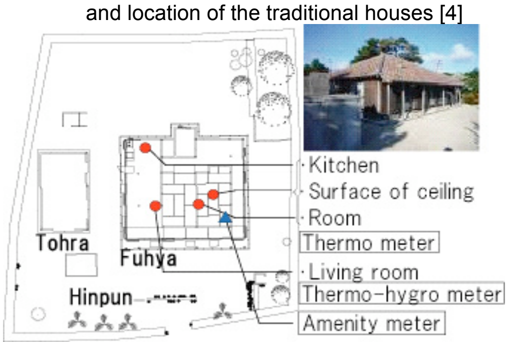
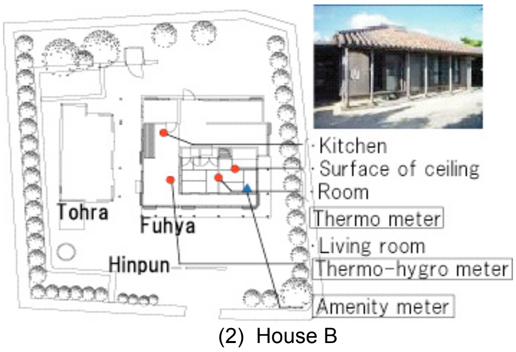


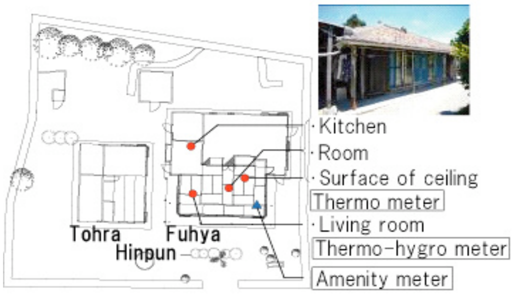
Figure 2: Outdoor measurement points and location of the traditional houses [4]



(1) House A



(2) House B



(3) House C

Figure 3: Measurement points of indoor environment

3. Overview of measurements taken

3.1 The schedule for measurement

Measuring procedures were conducted during the summer from August 26 to September 4, 2006. It was fine from August 26 to 31, and it was fine and sometimes cloudy weather after September 1. There were squalls on August 26 and 27. The lower part of Figure 5 shows the schedule of measurements taken.

3.2 Measurement objectives

Measurements were focused on the thermal and wind environment of the outdoor space in the village, and the indoor thermal environment in traditional houses. Measurement categories are given in Table 1. For outdoor measurements, thermographies were taken at five points in the village (Fig.2) and the radiant environment was measured at six points, such as white sand alleys, asphalt and concrete alleys, and lawns and so on (Fig.4). Moreover, the outdoor climate was measured at two points, in the village and at the sea side (Fig.1). For indoor measurements, three traditional houses shown in Fig.3 were selected based on the following conditions: (1) The traditional styles of architecture had been retained. (2) The houses all faced south. (3) The houses were still inhabited. Since there are almost no inhabited houses which retain completely the traditional style of architecture, houses which had been partly renovated were selected, despite condition (1).

Table 1: Measurement categories and instruments

	Measurement categories	Instruments
Outdoor	Meteorological observation Air temperature, relative humidity, wind velocity and direction, solar radiation, rainfall and atmospheric pressure	Weather station "Vantage PRO"
	Thermography	Infrared radiometer
	Solar radiation and long-wave radiation	4 components radiometer (2 directions)
Indoor	Air temperature, surface temperture relative humidity	Thermo meter Thermo-hygro meter (Portable sensor)
	Air temperature, relative humidity, wind velocity, globe temperature	Amenity mater

3.3 Measurement methods

3.3.1 Outdoor climate

Fig.1 shows the measurement points, by the sea and beside the village, of the outdoor climate, and the measurement instruments were set 2.0m above ground level, where there were no surrounding obstacles. The interval of measurement was set at 30 minutes. The measurement period was the same as the total measurement period, and was set to last from August 26 to September 4. As outdoor climate elements, air temperature, relative humidity, wind velocity and direction, solar radiation, rainfall and atmospheric pressure were all measured.

3.3.2 Thermography

Fig.2 shows the measurement points for thermography. The measurements were conducted at five points over intervals of three hours. The measurement period was from 6:00 AM August 26 to 6:00 AM August 29.

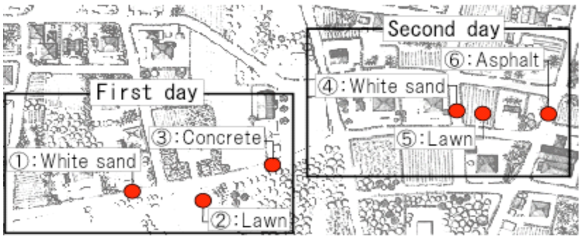


Figure 4: Measurement points of solar radiation and long wave radiation

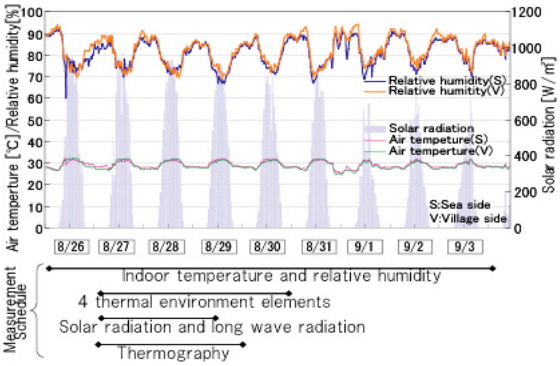


Figure 5: Result of outdoor climate measurement and schedule for measurement

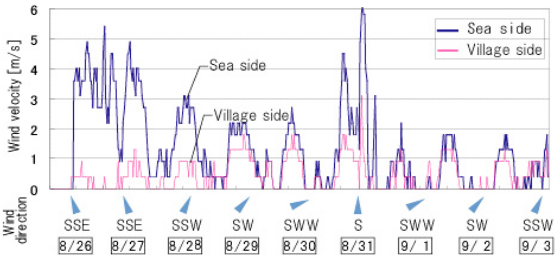
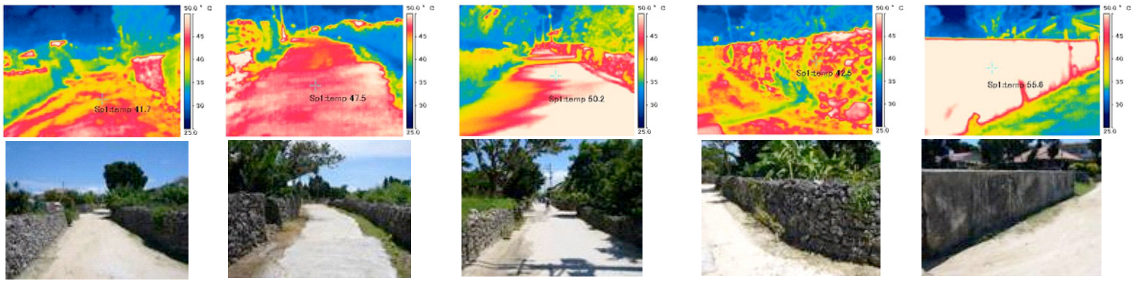


Figure 6: Wind velocity and wind direction

3.3.3 Solar radiation and long wave radiation

The measurement of the radiant environment was conducted for four kinds of alleys (white sand, lawn, concrete and asphalt) at the six points shown in Fig. 4. The measurement interval was 3 hours. The three kinds of arrays (white sand, lawn and concrete) were measured on the first day (8/28). The arrays of white sand, lawn and asphalt were again measured on the second day (8/29). Although the simultaneous measurement for the four kinds of alleys in a day was the best measuring method, it was difficult because the available measurement instruments were limited in number and each measurement point was separated from the others. For these reasons, the measurements were carried out separately on two days. The radiant environment was evaluated by measuring solar radiation and long wave radiation separately for six directions (up, down, front, back, left, and right) at 1.1m above ground level. The measurement period was from August 27 to 29. In order to evaluate



(1) White sand alley (2) Concrete alley (3) Asphalt alley (4) Coral stone wall (5) Concrete wall

Figure 7 Thermograpies (3:00 PM on 8/28)

the outdoor thermal environment in the alley spaces, mean radiant temperature (MRT) was calculated using the measurement data for solar and long wave radiations. For the calculation of MRT, the method which has been proposed by B. W. Olesen [5] and Y. Nakamura [6] was used.

3.3.4 Indoor air temperature and relative humidity

Fig. 3 shows the measurement points, and the sensors were set 1.8m above floor level. The interval of measurement was set for 30 minutes, and the measurement period was from August 26 to September 3.

3.3.5 Indoor thermal environment (SET*)

In order to calculate SET*, amenity meters which measure air temperature, humidity, wind velocity and globe temperature simultaneously were set 0.6m above floor level in the houses [Fig.3]. The measurement period for house B was from August 28 to 29, and for house C was from August 26 to 27. In house A, the measurement was not carried out because of trouble with the instrument. For the calculation of SET＊, clothing insulation and metabolism were set at 0.5clo and 1.0met respectively.

4. RESULTS

4.1 Outdoor climate measurement

Fig. 5 shows the results of outdoor climate measurements for both the sea side and the village side. There was almost no difference in air temperature between the sea side and the village side, since Taketomi Island is very small. Fig. 6 shows the results for wind velocity and wind direction at both points. The wind velocity on the village side was lower than that on the sea side. This difference in wind velocity is due to the effect of the windbreaks around the village. In particular, this tendency was remarkable when the wind direction was the south, on August 26, 27, 28 and 31. The main reason is that the village is located in north part of the Island and windbreaks on the south side are wider than those on other sides. On Taketomi Island, many typhoons pass through every year, so these windbreaks defend the houses from the strong south wind. It can be inferred from these results that the traditional houses have survived on Taketomi Island under such wind conditions despite the fact that many houses on other islands have been rebuilt as reinforced concrete buildings due to damage by typhoons.

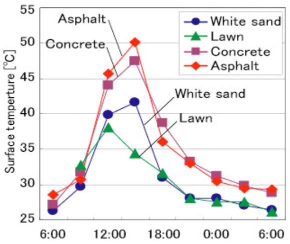


Figure 8: Alley surface temperature

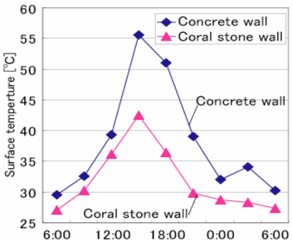


Figure 9: Wall surface temperature

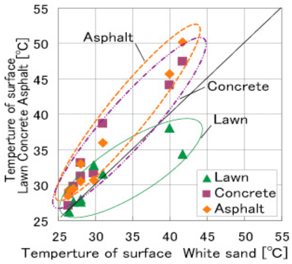


Figure 10: Relationship of surface temp. between white sand and lawn, concrete, asphalt

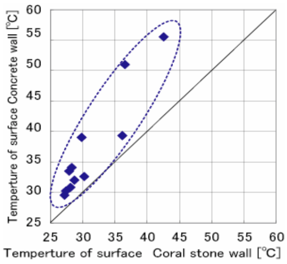


Figure 11: Relationship of surface temp. between coral stone wall and concrete wall

4.2 Thermography

Measurement results for thermographies of the alleys and walls are shown in Fig. 7. Although measurement was performed every three hours, only the results for 3:00PM on 8/28 when the temperature of alley and wall surfaces became highest have been shown here. As shown in Fig. 7, the surface temperature of a white sand alley was lower than that of both asphalt and concrete alleys, and the surface temperature of a coral stone wall was also lower than that of a concrete wall. The reason why the surface temperature of such a white sand alley remains so low is that its albedo is high and the alley readily retains water. The reason why the surface temperature of such a coral stone wall remains so low is that coral is a porous material and its heat capacity is very small.

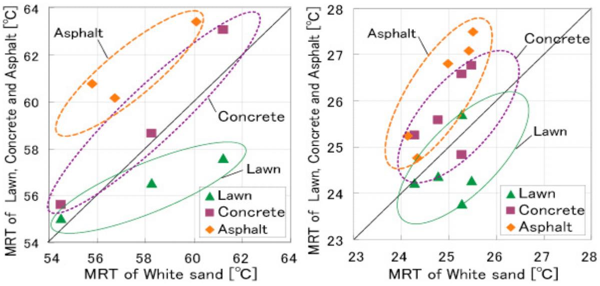
Figs. 8 and 9 show the time series for each surface temperature, including white sand, lawn, concrete and asphalt alleys, and concrete and coral stone walls. Figs. 10 and 11 show the relationship between the various surface temperatures of alleys and walls. As shown in Figs. 8 and 9, the surface temperature of the coral stone wall was lower than that of the concrete wall through a day, and the surface temperature of the white sand alley was also lower than that of the concrete and asphalt alleys through a day. In particular, the difference between the various surface temperatures of alleys grew larger from noon to 6:00PM. On the other hand, the difference between the coral stone wall and the concrete wall became small in the morning (6:00am-noon), while the difference grew to 13 degrees or more in the late afternoon (15:00pm-21:00pm). The reason for this result is that normally such walls face west.

4.3 MRT

From the results of thermographies, it was clarified that the surface temperature of white sand alley was lower than that of concrete and asphalt alleys. However, it is difficult to conclude that an alley of white sand is superior to alleys of concrete and asphalt in thermal sensation. Since the low surface temperature means that the degree of solar reflection is high, the radiant environment may get worse because of reflected solar radiation. Therefore, here, it was determined whether white sand alleys are superior in this radiant environment by evaluating MRT based on the measurement results of solar and long wave radiation. The relationships of MRT for each measurement point during daytime and night time are shown in Fig. 12 separately. This figure indicates that the MRT of the white sand alley is lower than that of asphalt and concrete alleys, and the radiant environment of the white sand alley is close to that of a lawn. It was determined from the results that the radiant environment of white sand traditional alleys in Taketomi village is superior to that found in modern alleys of asphalt and concrete. These results lead to the conclusion that white sand alleys and coral stone walls passed down by tradition in Taketomi village for many years not only harmonize with the landscape but also have a relaxation effect on the outdoor thermal environment.

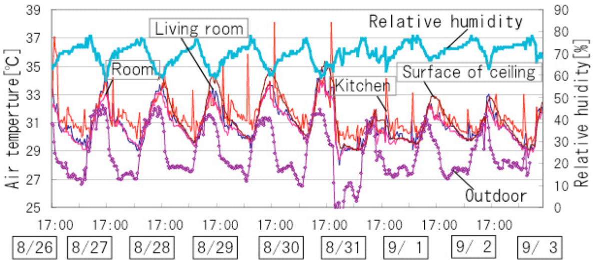
4.4 Indoor air temperature and relative humidity

Fig.13 shows the results of indoor measurement in three traditional houses. Indoor air temperature was always higher than the outdoor air temperature in all rooms and houses. In particular, the difference of air temperature between indoor and outdoor became large at night because of the dissipation of heat absorbed during daytime. The indoor air temperature was about 3-4 degrees higher than the outdoor air temperature and the indoor thermal environment was uncomfortable. The difference between indoor and outdoor temperature was small from September 1 to 3, because it was cloudy on these days and solar radiation was low; however, indoor air temperature was still higher than outdoor. These results may have occurred because the ventilation performance became poor owing to the installation of glass sashes in the house's openings. An additional possible explanation may be that since the function of the kitchen had moved to the *Fuhya* from *Tohra* and the use of home electric appliances had increased, internal heat load had also increased.

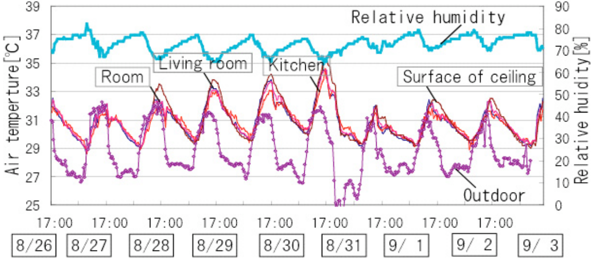


(1) Day time (2) Night time

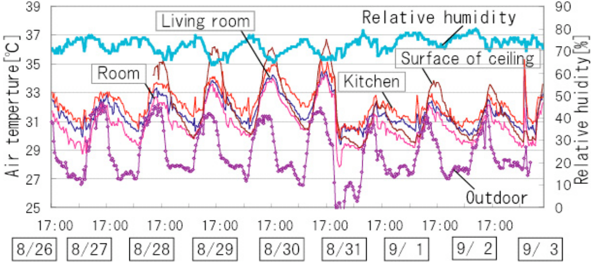
Figure 12: Relationships of MRT between white sand alley and lawn, concrete, asphalt alley



(1) House A



(2) House B



(3) House C

Figure 13: Indoor temperature and relative humidity

4.5 SET*

Fig. 14 shows indoor measurement results for air temperature, MRT, wind velocity and SET* calculated from measurement data. Although the outdoor environmental conditions were not necessarily in accord for the three houses, indoor SET* results proved higher than indoor air temperature by about 3 degrees. The comfortable range for SET* is from 22.2 to 25.6 degrees according to the ASHRAE HAND BOOK [7], so the measurement result exceeds the comfortable range. In house B, the wind velocity data were close to 0m/s at all times, since the glass sashes were kept closed during the measurement. On the other hand, in house C, the wind velocity sometimes became high, since the glass sashes had been opened temporarily on August 29. Corresponding to the wind velocity, SET＊ became lower by about 4 ℃ at the maximum in house C. This result clearly shows that natural ventilation or draft is important in providing indoor thermal comfort for residents. The traditional vernacular houses in Taketomi village have an open structure, so the residents should live with the glass sashes opened in order to utilize the available indoor ventilation. However, since tourism has prospered on Taketomi Island in recent years, many houses keep the sashes closed temporarily to avoid the tourists' noise and inquisitive gaze. It follows from what has been said that the indoor thermal environment in traditional vernacular houses has grown worse because of the modernization of resident's lifestyles and their houses, and because of the development of the tourist business.

5. Conclusion

In this study, the indoor thermal environment for building scale and the effects of thermal environmental relaxation and windbreaking for district scale on Taketomi Island are analyzed based on field measurement. The following results were obtained:

1) Windbreaks, that is, shelter belts around the village decrease the wind velocity in the village. In particular, the effect of windbreak improves in the case of south wind. On Taketomi Island, numerous typhoons pass through every year, so these windbreaks defends the house from the strong south wind.
2) Alleys covered with the white sand are superior in the thermal environment compared to the alleys of asphalt and concrete pavement, and also coral stone walls are superior to the concrete walls in the thermal environment.
3) In summer, the thermal environment in traditional vernacular houses is by no means comfortable, due to the modernization of resident's lifestyles and their houses, and because of the development of the tourist business.

6. Acknowledgements

We would like to thank the investigated house holds and associate professor M. Gouta and graduate student T. Fujihira, Tokyo Denki University, for their cooperation.

7. References

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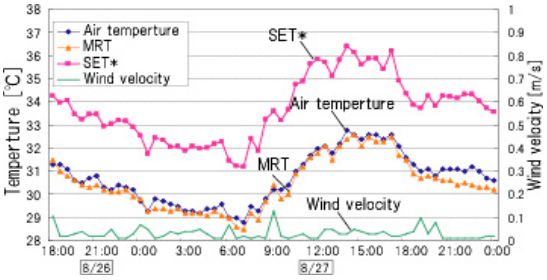
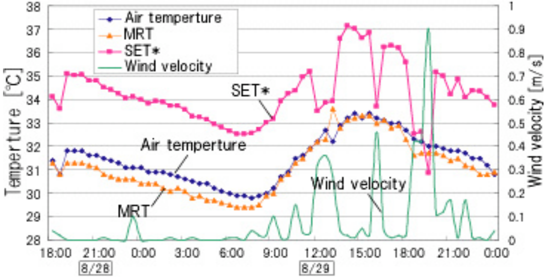


(1) House B



(2) House C

Figure 15: Result of SET＊, air temp., MRT and wind velocity

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