Passive cooling effect of building features in traditional Japanese buildings

H. Yoshino
Tohoku University, Japan

K. Hasegawa and S. Matsumoto
Akita Prefectural University, Japan

ABSTRACT

Japanese traditional buildings have many features, which are effective for cooling interior. For examples, "farm house" has thatched roof, large window and earthen floor, and "storehouse" has a roof with air gap and thick mortar wall. It is important to apply these traditional technologies to modern buildings from the points of view of energy saving and environment symbiosis based on the understanding of physical principle.

In this study, the indoor temperature and relative humidity of these two types of houses were measured during a summer period to look into the cooling effect of these features. In addition, computer simulation was conducted to investigate to what extent of these kinds of technologies can provide on the cooling effect. As a result, it was clarified that the solar shading by thatched roof is effective and so on.

1. INTRODUCTION

In traditional buildings, there are various vernacular technologies devised uniquely to the region where people lived without resorting to fossil fuels. From the viewpoint of solution of global environmental problems, we can learn a lot from these vernacular technologies inherited from the past. In Japan, there are several kinds of traditional buildings, e.g. farm house and storehouse, and they have the locality of various features, which are effective for cooling interior. The farm house has thatched roof, large window, and earthen floor, while the storehouse has a roof with air gap and this type of house is made with thick mortar wall. It is important to apply these traditional technologies to modern buildings from the points of view of energy saving and environment symbiosis based on the understanding of physical principle.

This paper firstly describes the characteristics of indoor thermal environment and the cooling effect of four traditional buildings, which are located in Miyagi prefecture of the northern area in Japan. The investigated buildings are included traditional farm buildings and repaired buildings for the improvement of indoor thermal environment mainly during the winter season. Secondly, the cooling effect of traditional technologies was studied by means of computer simulation using a model, which takes the multi-zone effects of heat transfer and air flow distribution into consideration.

2. MEASUREMENT OF INDOOR THERMAL ENVIRONMENT IN FOUR TRADITIONAL BUILDIGNS

2.1 Description of Investigated Buildings

Table 1 describes the four investigated traditional buildings locating in the Miyagi prefecture of Japan. This area is situated in the northern portion along the Pacific Ocean and its latitude is 38°16'. The mean outdoor temperature and relative humidity of Sendai central city in Miyagi Prefecture is 24.1°C and 81%, respectively. All investigated buildings were constructed by the wood-frame construction method and built in approximately 100 to 250 years ago. House A, built in 1870s, is a typical farm house and still remains in its origination. This house has eaves for solar shadings, a thatched roof and large openings to enhance cross ventilation as

Table 1: Description of investigated buildings

House A	Completion*	1875
	Construction	wooden, one story
	Roof	thatched roof
	Wall	wood board
House B	Completion*	1750(originaly), repaired in 1987
	Construction	wooden, one story
	Roof	steel roof
	Wall	wood board, stucco finishing partially
House C	Completion*	1895
	Construction	wooden, two story
	Roof	thatched roof
	Wall	stucco finishing
House D	Completion*	1870
	Construction	wooden and clay wall strorage structure
	Roof	roof tile
	Wall	wood board and clay wall

* approximately age

shown in Photo 1. House B (c.f. Photo 2), which was originally a traditional farm house built in 1750s, had been repaired in 1987 in order to improve the indoor thermal environment during the winter.

Through the repair, this house had changed from a thatched roof to a steel finishing roof and was thermally insulated in the walls, floors and ceilings. House C (c.f. Table 1) is also a traditional farm house built in 1890s and its walls are finished by stucco. House D, built in 1870s, has a dwelling unit that is constructed with wooden structure and ‘mise’, which is a traditional merchant house defined in Japanese architectural history. ‘Mise’ consists of a northern house (clay wall storage structure) and a southern house (wooden structure). No air-conditioning system for cooling was adopted in all the investigated houses, instead electrical fans were used in each house.

2.2 Measuring Method

Temperatures at five to seven points and relative humidity at three other points in each house were measured continuously for a week by resistance thermopile and data logger. The measuring points were set in the living room (1.1 m and 5 cm above the floor level), other rooms included a main bedroom (1.1 m above the floor level) and attic space. The measurements were taken in August of 1995.

Photo 1: Outside View of House A.

Photo 2: Outside View of House B.

2.3 Results

2.3.1 Thermal Environment of Living Room

Figure 1 shows the temperature profiles of all the investigated houses for a period of four days. Occupants of all the houses opened win-

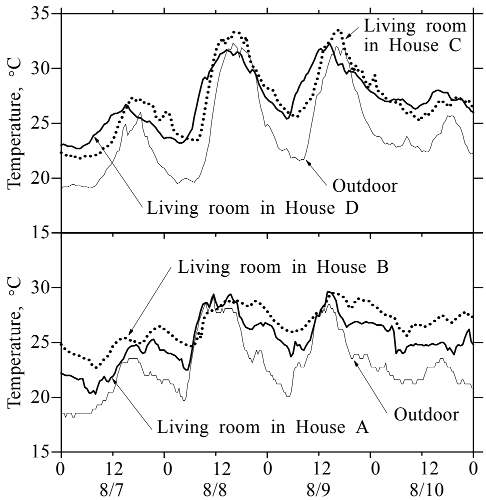

Figure 1: Temperature profiles of living room.

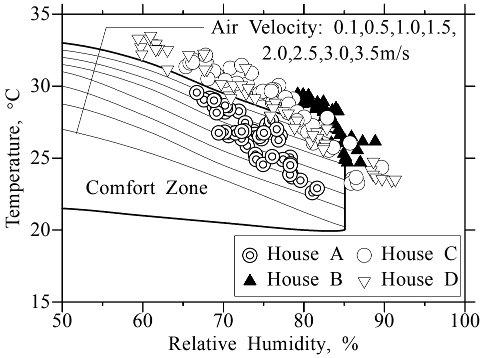

Figure 2: Measured data plotted on the Olgyay's bioclimatic chart.

dows for getting cross ventilation during day time and closed them during night time. There are the relationship between these occupants' behavior and indoor temperatures. The indoor temperatures during day time were maintained around the outdoor temperature and during night time the indoor temperatures were 5 to 7°C higher than the outdoor temperature. Especially, the temperature profiles of House B during night time were stable in comparison with that of other houses, because of the thermal insulation of envelopes.

In order to evaluate the indoor thermal comfort of investigated houses, the hourly measured data were plotted on the Olgyay's bioclimatic chart (Olgyay, 1963) as shown in Figure 2. The thermal environment of House A, which preserves a traditional form since it was built, is within a comfort zone, but those of the others are not. As for Houses B, C and D, if more cross ventilation was able to introduce, the time within a comfort zone should be increased. But, the relative humidity of House B, which was a repaired farm house, was higher than that of other houses and the ratio within a comfort zone is the lowest among the other investigated houses.

2.3.2 Thermal Environment of Clay Wall Storage Structure

Figure 3 shows the indoor temperature profiles of the northern house and southern house of 'mise' in House D. The difference in the thermal environment of these houses should indicate the effect of thermal mass by the clay wall storage structure. The maximum temperature of the wooden southern room varied about 1 to 2°C

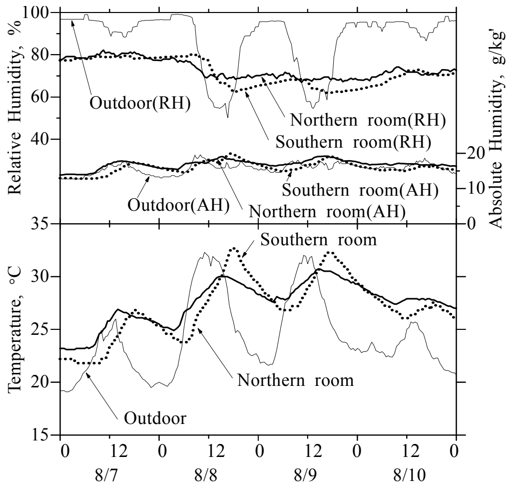

Figure 3: Room temperature and humidity profiles in House D room.

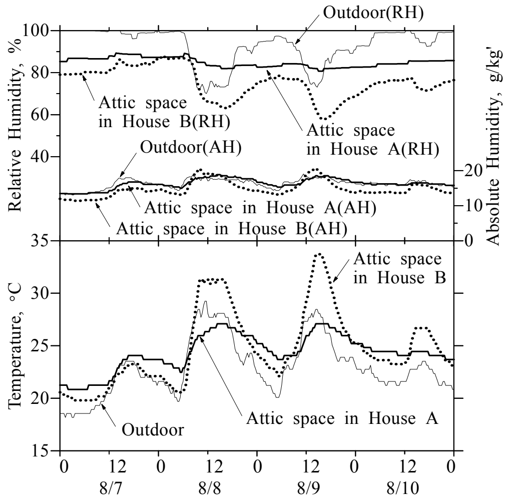

Figure 4: Temperature and humidity profiles in an attic space.

higher than the outside temperature during daytime. On the other hand, the room temperature of the northern room was stable all day long, and varied 2 to 4°C lower than the outside temperature during day time. During night time, the room temperature did not drop. This is due to the thermal capacity of thick walls, which is a clay storage structure.

2.3.3 Temperature and Humidity in Attic Space

Figure 4 shows the temperature and humidity profiles of an attic space in House A and House B. The temperature in House A was found in the range between 22 and 27°C as compared with that of outdoor temperature, and its maximum temperature was 2°C lower than that of outdoor. That is considered as the effect of thermal capacity of the thatched roof. On the other hand, the temperature in House B, of which the roof was finished with the steel, varied widely and the maximum temperature reached to 34°C during day time. The relative humidity of the attic space in House A was steady around 80%, as compared with that of outdoor. This is due to the thermal capacity and the moisture adsorbed and desorbed performance of thatched roof. On the other hand, the relative humidity in House B varied widely, especially in a clear day. It is clear that the difference of temperature and humidity depends on the roof materials.

3. COOLING EFFECT OF TRADITIONAL FEATURES BY CALCULATION

3.1 Calculation Method

In order to study the effect of vernacular technologies on cooling interior, the calculation was adopted the response factor method for heat transfer (Hasegawa et al., 1983). Figure 5 and Figure 6 show a model building for calculation which is simplified from the typically traditional buildings in Miyagi Prefecture of Japan. The external wall component of this building is only wood board with no insulation, and that is chosen to represent the envelope of a traditional building. In the fundamental condition, the effect of evaporative cooling on the wet surface of thatched roof was not taken into consideration. The model building has three rooms; two rooms on the first floor and an attic space. The thermal mass of furniture in an attic space derives from timbers, beams and lattices. It is assumed that there are four occupants living in this building. Table 2 shows the fundamental condition for calculation. Table 3 shows the condition for 11 test cases including a fundamental condition. In Case 7, the evaporative cooling effect on the wet surface of thatched roof was taken into consideration as the sol air temperature which included the evaporative effect of the wet surface (Hokoi and Matsumoto, 1983).

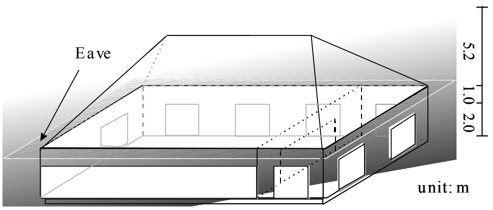

Figure 5: Perspective of a model building.

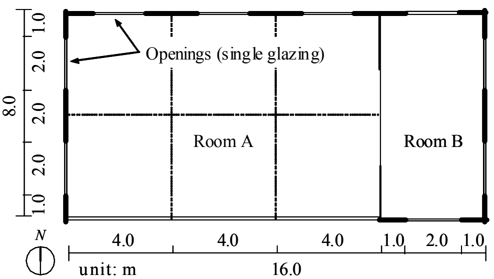

Figure 6: Plan of a model building.

3.2 Comparison between Measurement and Calculation

Figure 7 compares the measured and calculated

Table 2: Fundamental condition for calculation

Structure, Story	Wooden, one story
Materials of roof	Thatch
Floor Area	128 m^2
Number of rooms	2 rooms and attic space
Surface of floors	Room A: *tatami* mat Room B: wooden board
Thermal mass of furnitures	Rooms: 4.5 kcal/m^3°C Attic space: 1.15 kcal/m^2°C
Effective area of windows	43.2 m^2
Windows	Single grazing (5 mm)
Air change rate	1.0 ach
Ventilation among each room	Not taking into consideration
Depth of Eaves	210 cm (south and west) 140 cm (east), 60cm (north)
Family numbers	Parents and two children
Weather data	Standard weather data in Sendai

Table 3: Calculation cases

Cases	Conditions for calculation	Cooling effect
Case 1	Fundamental condition	
Case 2	30 ach during all time	Natural ventolatioı
Case 3	20 ach from 6:00 to 18:00 1 ach form 18:00 to 6:00	
Case 4	Without shadings	Solar shadings (Depth of eaves)
Case 5	60 cm (all directions)	
Case 6	Thatched roof: including in the effect of evaporative cooling	Roof materials
Case 7	Steel	
Case 8	Steel with thermal insulation (GW24K 65mm)	
Case 9	Soil floor	Floor materials in Room B
Case 10	Soil foor with the day time ventilation of 20 ach	
Case 11	Soil floor with night time ventilation (20 ach)	

temperatures of House A and Case 1 respectively. Since the standard weather data of Sendai was used for calculation, the outdoor temperature was different from measured data. So it is difficult to evaluate the agreement between the calculation and the measurement. But the characteristics of the temperature profiles of Room A and the attic space are similar.

3.3 Calculation Results

3.3.1 Effect of natural ventilation

Figure 8 shows the calculation results of the cooling effect of natural ventilation through opened windows on indoor temperature in Room A. In the case where air change rate is thirty times per hour (Case 2), the indoor temperature is closer to the outdoor temperature than that of the fundamental case (Case 1) during day time. In the case where air change rate is one time per hour (Case 1), the indoor temperature is 1 to 2^{o}C lower than the outdoor until 2 p.m. during day time, but the decrease of indoor temperature in night time is smaller than that of the other cases. In Case 3, the temperature profiles during day time are similar to that of Case 2 and during night time to that of Case 1.

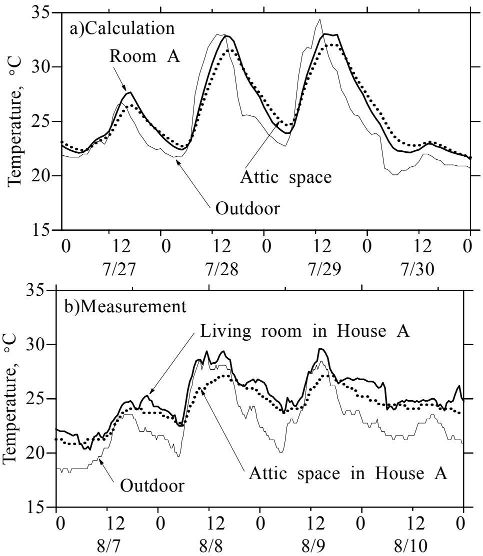

Figure 7: Comparison between measurement and calculaiton.

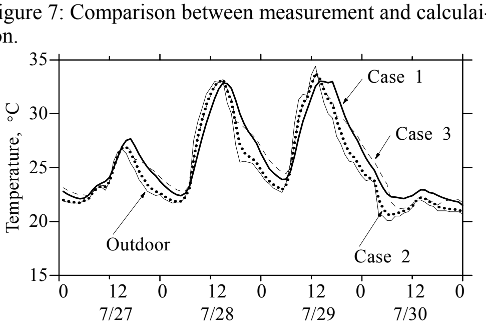

Figure 8: Effect of natural ventilation.

3.3.2 Effect of Solar Shading

Figure 9 shows the calculation results of temperature profiles and the transmitted solar radiation through window openings in a sunny day of summer. In the case without solar shadings on the southern window openings (Case 4), the transmitted solar radiation of Room A is larger than that of the cases with solar shadings (Case 1 and Case 5). In the case where the depth of eaves is 210cm (Case 1), the temperature of Room A is around 2^{o}C lower than that of the other cases during day time. In Room B which has southern and eastern openings, the transmitted solar radiations from 8 a.m. to 1 p.m. are different among other cases, and the temperature of Room A in Case1 is around 1^{o}C lower than that of the other cases. In the early morning, the transmitted solar radiations are similar among each case.

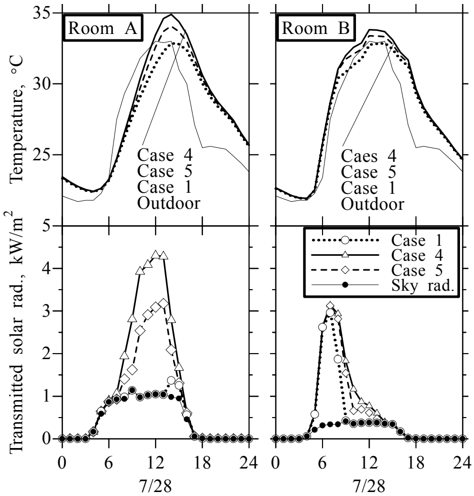

Figure 9: Effect of solar shadings.

3.3.3 Effect of Evaporative Cooling on the Wet Thatched Roof Surface

Figure 10 shows the calculation results of the temperature profiles of Room A and the attic space. In the case where the roof surface materials is steel (Case 7), the temperature of attic space varies steeply and the maximum temperature reaches at 45°C in day time. In the case of the thatched roof, the temperature of an attic space is lower than outdoor temperature, and its maximum temperature is 2°C lower than outdoor. In the case where the effect of evaporative cooling on wet surface (Case 6) is considered, the temperature of the attic room is slightly lower than that in Case 1 where the cooling effect is not included. The temperature of Room A in Case 1 is lower than that of Case 7 during day time. The effect of evaporative cooling on wet thatched surface for reducing the room temperature is not large. In this calculation, the ratio of wet condition on roof surface was defined as 0.2. Since the effect of evaporative cooling is influenced by this ratio, further consideration of adequate values is required.

3.3.4 Effect of Thermal Mass on Soil Floor

Figure 11 shows the calculation results of the room temperature at 2 a.m. and 2 p.m. in a sunny day. In the case of the soil floor (Case 9), the temperature of Room B at 2 p.m. is 5°C lower than that of Case 1, where thermal mass is not included in the floor. The effect of the thermal mass in Room B caused the decrease of 1°C in Room A. The cooling effect of thermal mass on the floor with night time ventilation (Case 12) is similar as Case 9, and the effect of cooling storage by night time ventilation does not appear remarkably.

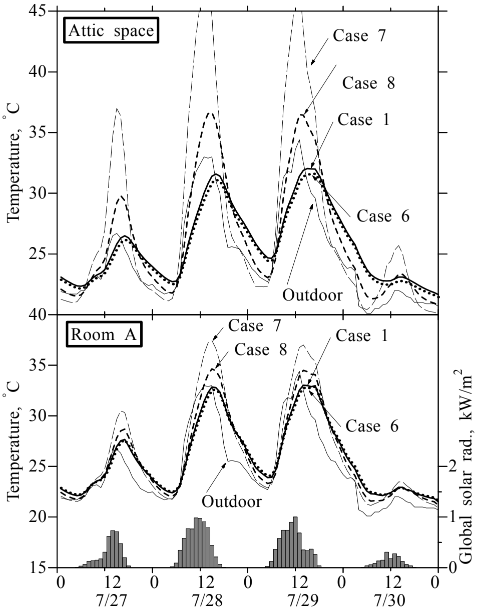

Figure 10: Effect of evaporative cooling on the wet thatched roof surface.

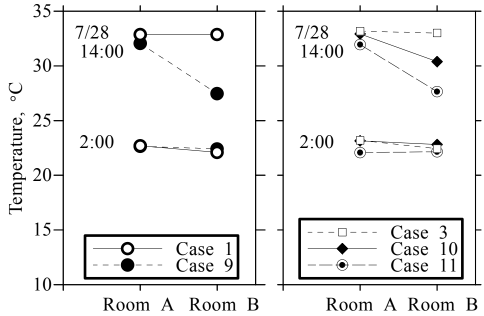

Figure 11: Effect of thermal mass on soil floor.

4. CONCLUSIONS

There are several kinds of Japanese traditional buildings and they have the locality of various features, which are effective for cooling interior. This paper describes the evaluation of these technologies for passive cooling by means of field measurement in those traditional buildings and computer simulation. The indoor temperature and humidity of these houses have been measured during the summer to investigate the cooling effect of these features. It is indicated that the cooling technologies of traditional buildings such as solar shading by thatched roof decreases indoor temperature. The computer simulation revealed that natural ventilation, solar shading by thatched roof and thermal mass by soil floor are effective for cooling interior.

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