THERMAL COMFORT IN THE TRADITIONAL JAPANESE HOUSE

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ABSTRACT

The purpose of studying vernacular Japanese architecture is to understand to what extent a house with large opening surfaces, no thermal insulation and very low environmental impact can become a valuable shelter during cold winters and hot humid summers. The reason of this result is to be found in the strict relationship between the socio-cultural context and the environmental characteristics of the building. The occupant's behavior, the way of dressing, relaxing, living inside the house is a complement of the thermal, daylight and solar performances of the envelope. The comfort conditions are actively sought by the inhabitants and are guaranteed in winter by the use of thick cloths and small objects to heat locally the body. In summer the operation of large surface of paper panels and the connection with the outside nature trough the veranda, are an effective way to cope with the hot and humid climate. As a result the study of the traditional Japanese house demonstrates that one cannot analyze the environmental performances of a building without considering the socio-cultural context in which it is built.

KEYWORDS

Social behavior, adaptive comfort

INTRODUCTION

There are only minor differences between a typical traditional house in Hokkaido, the extreme north, and Kyushu, the extreme south (Rapoport 1969). The purpose of this research is to explore the links between fabric, form and performances of a building and the socio-cultural context in which it is built. The traditional Japanese house has in fact large surfaces of paper wall and it is not thermally insulated. These characteristics allow the heat inside to be easily dispersed during the winter and large amounts of solar gain to enter during the summer. As a consequence, heating the space during the winter would be extremely inefficient. Since the traditional Japanese house does not have any central heating, instead of heating the inside air, the inhabitants heat themselves using small objects and thick cloths (Sdei 2005).

In the summer however a high degree of flexibility of the external envelope helps the inhabitants to cope with the extremely hot and humid climate in Japan. The paper panels in fact can be completely opened allowing for cross ventilation. The role of the veranda during this season is crucial since it becomes a space of recreation (Engel 1964), shaded for most part of the day and where it is possible to enjoy the effects of ventilation.

Although the environmental performances of the house and as a consequence the behavior of the inhabitants are very different in winter and summer, the veranda is a key element of the Japanese house all year round. The space of the veranda plays technically the role of a window in western architecture, providing light, air and view of the exterior. However since the veranda is a flexible space, it offers other opportunities. In winter it is mainly used as a working place because of the sunlight and daylight availability while in the other seasons it is a recreational space where one can enjoy daylight, breeze and the view of the garden (Sdei 2005).

The solutions expressed in the traditional Japanese house are particularly important today because

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they show that a more responsible human behavior and a more adaptable design can cut dramatically the amount of energy needed throughout the year. Perhaps there is here a possible input for a more environmentally responsible and energy efficient approach to domestic life in the West. An emphasis on studying the occupants' needs and their interactions with the space they live in might be fruitful (Sdei 2005). The analyses and results presented and combined in this paper were conducted in two stages: The theoretical model involved winter and summer measurements while the monitoring of three traditional Japanese houses conducted in September 2006 gave real results for the summer conditions.

METHOD OF ANALYSIS

Technical characteristics of the non insulated envelope – Thermal Modeling

The traditional materials of the Japanese house have been timber, rice paper and bamboo. Because of their high thermal transmittance, they offer very poor insulation compared to, for example, modern glass fiber insulation material (Sdei 2005). Walls, floor and roof are not insulated. A very simplified model composed by a south facing room was evaluated using ESP-r, a thermal simulation program. The room has an east-west axis and measures 6.2 by 3.5 meters as converted from the Japanese typical tatami dimensions. Structurally the room is composed by a suspended floor, paper walls on four sides and the roof is modeled as an independent zone. The suspended floor is formed by a web of wooden beams covered by the typical tatami mat thick 20 cm in total (U value of 0.26 KWh/m²K). To simplify matter, the beams were modeled as a continuous layer 5cm thick, surmounted by a 15 cm tatami mat. The translucent paper panels structurally composed by a double order of wooden strips were modeled as a continuous system of paper rice[i] 1mm thick. The roof complex structure was modeled as a continuous wooden layer 15 cm thick.

The long side of the room faces south and has a veranda. The performances of the room were evaluated for the two critical seasons, winter and summer, with and without veranda in order to have an exact picture of its distinctive thermal features. There is no heat exchange between the three sides of the room made of rice paper and the exterior space. The only heat exchange happen trough the south façade and the only solar gain comes into the house trough the south facing paper panel.

The internal heat gains were differentiated in winter and summer because of the different occupancy pattern (Table 1). In order to have realistic results the ventilation rate was considered constant during the winter (equal to 2 ac/h) and variable during the summer depending on the pressure coefficient on the paper wall.

	summer		winter	
	Sensible heat	Latent heat	Sensible heat	Latent heat
men	100 W	15 W	100 W	15 W
women	85 W	13 W	85 W	13 W
Light	100 W		100 W	
appliances			100 W	

Table 1: heat emission from inhabitants

The comfort analysis was conducted using two main parameters: clothing level and activity level. In accord with the descriptions of the typical multilayer kimono traditionally worn inside the house (Taut 1958) the clothing level used during the calculation is equal to 1.7clo in winter and 0.3clo in summer. The people considered at rest inside the room have a metabolic rate of 1.546met[ii]. Because of these approximations, the modeling process was less successful than the monitoring.

Summer Monitoring

The first house analyzed is in Okayama prefecture, near Himeji. It is a large traditional countryside house with a core composed by four rooms, divided by the fusuma. There are two verandas and traditional shoji on the external skin. The living room faces south, the major orientation. No air conditioning is used inside the space. Few parts were added to the original scheme by the occupants on a second stage: the east veranda, the kitchen and toilets on the west side, the toilets on the south side. Glass panels were added to the more external southern and eastern thresholds to protect from the high wind speed (1.2m/s east; 5m/s south). Traditional and modern elements, like fusuma and glass panels, are present in the same space and melted inside the house. The fusuma and shoji are the flexible elements of the house. When the fusuma is open the eating and living room become one permeable space. The equipments for thermal measurement, placed on each room and veranda the 5th September started recording the 6th at 9am. Temperature and relative humidity are measured every two minutes for twelve days. All the equipment stopped recording the 17th at 1pm and were collected the 18th.

The second house analyzed is in the same countryside context and neighbor to the first one. It is a bigger and more recently refurbished house. It has traditional and modern materials such as glass panels on the external skin. The equipment for thermal measurement was placed in the veranda the 5th September and in the rest of the house the 10th.

The third case study is in Tokyo in the Nakano-ku area near Shin-Egota station. It is a small two storey town house with a barber shop owned by the occupants on the ground floor. There is an air conditioning system not in use during the measurements. The equipments were placed the 9th at 11.30am and collected the 15th at 7.30 pm.

RESULTS ANALYSIS

Winter temperature - modeling

The winter temperature of the Japanese archipelago can be extremely low and in Hokkaido, the northernmost island, snow can reach depths of more then 3 meters (Engel 1964). The average annual temperature of Tokyo (latitude 35.41°) used as a base for the calculation is similar to that of Rome, the home city of the author of this paper.

Most literature argues that the indoor temperature of the traditional Japanese house differs only few degrees from the outdoor (Taut 1958, Engel 1964, Heschong 1979). However the results of the analysis (Figure 1) show that the internal and the external temperature can differ in winter up to 8.7 degrees C during the day and up to 5.46 degrees during the night. Therefore thermal comfort can be assured using thick cloths and small objects to heat locally the body of the inhabitants. In fact, for the effect of the heat emitted by the occupants, the kotatsu and some solar gain, the night time internal temperature rises 5°C above the external and the average daytime temperature becomes 14.33 degrees C. The veranda is not enclosed and does not have any effect on the inside temperature since its roof does not shade from the solar radiation during the winter months.

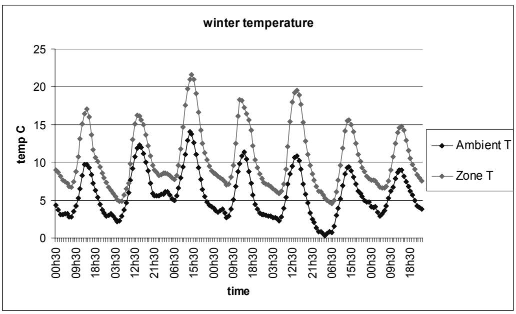

Figure 1

Comfort analysis - modeling PMV, PPD

Thermal comfort, a condition of satisfaction with the thermal environment, is expressed by two main parameters: the predicted mean vote (PMV) and the predicted percentage of dissatisfied (PPD). The first parameter represents a measure of the thermal sensation of a large population of people exposed to a certain environment and the second is the percentage of dissatisfied people at each PMV (ESRU 2005).

Despite the absence of any insulation or central heating, the predicted mean vote (Figure 2) shows a sensation only slightly cool during the night and neutral during the day. This is only due to the use of thick cloths inside the house, the same used outside. At night, a thick blanket will help to keep warm the inhabitants.

The PPD indicates the percentage of dissatisfaction distributed throughout the time. In the examined model the percentage of dissatisfaction (Figure 3) is inferior or equal to 20%, the condition deemed acceptable, for 32% of the time. The lowest PPD value, equal to 5%, corresponds to a PMV equal to 0 and is generally achieved during the day, because of the presence of some solar gain. The highest values are generally touched in the morning between 2 o'clock and 6.30 when the highest discomfort verifies.

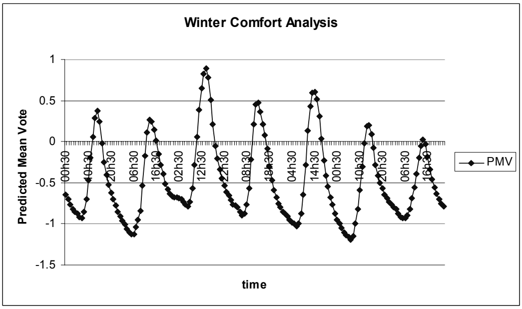

Figure 2

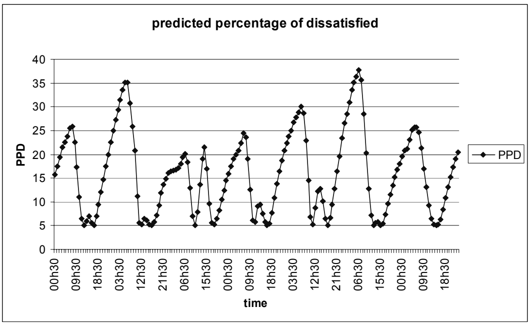

Figure 3

Winter and summer relative humidity - modeling

The relative humidity is a critical factor in the definition of thermal comfort. The interior winter microclimate is dry during the day and humid at night. The indoor values are in a range between 20% during the day and 70% at night.

During the day, systems to humidify the air like containers of water will have a beneficial effect on the microclimate. In this season however the inhabitants of the traditional Japanese house use no systems to control the relative humidity since the most unpleasant parameter is the temperature.
During the summer, ventilation strategies take place to provide comfort. The results of the model show that the inside air temperature and relative humidity are the same as the outside. This is due to the high ventilation rate allowed by the movable paper panels.
The veranda becomes a key element where to enjoy the effects of ventilation during the summer. During the winter days, the relative humidity in the veranda is 30%, the same than outside. For this reason opening the *shoji* during the winter days may be a good system to humidify the inside air.

Summer temperature – modeling and monitoring

In summer the roof of the veranda shades the inhabitants from the hot summer sun, in this way it is possible to fully enjoy the effects of ventilation in strict relationship with the nature outside. The house, open on both sides, becomes a suspended place where protected from rain and sun the inhabitants can spend most of the day. The following sections analyze the technical aspects of the house related to the veranda.
The results of the modeling process show that there is no difference between the ambient and the internal air temperature in the summer months. Theoretically, the internal air temperature is in fact lowered down by the high ventilation rate of the free flowing ambient air throughout the house. The modeled room has a light wooden structure, no insulation and behaves as a lightweight envelope. The veranda, able to block the solar beam radiation on the paper wall, does not lower the inside temperature any further. The large surfaces of movable paper panels provide the most effective strategy to ventilate the room and control the inside air temperature.
The thermal monitoring of three traditional Japanese houses conducted in September 2006 describes however different scenarios. The results of the house in Tokyo (Figure 4, 5) in line with the expectations and with the results of the modeling process show that the indoor temperature can be 2 or 3 degrees higher than the outdoor. Perhaps, especially in the afternoon, the inside air temperature can drop below the ambient and the house becomes cooler. The veranda becomes generally the coolest place of the house and in some cases the temperature under the eaves is even lower than the ambient because of the reduction of the solar radiation.

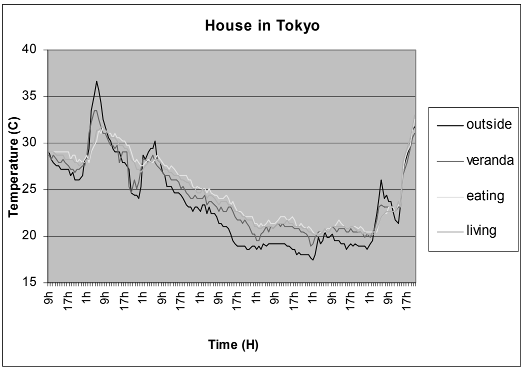

Figure 4, 5

The two houses monitored in the countryside (Figure 6, 7 and Figure 8, 9) show similar results, different from those of the previous case. The indoor temperature is here from 2 to 5 degrees higher than the outdoor and the temperature in the south verandas can be by 5 degrees higher than in the rest of the house. These two houses are considerably bigger in size than the house in Tokyo. The glazing, added to the south and east façades at the edge of the verandas in order to enclose the space, repair against the wind and increase the inside usable surface reduces the ventilation rate and overheats the veranda.

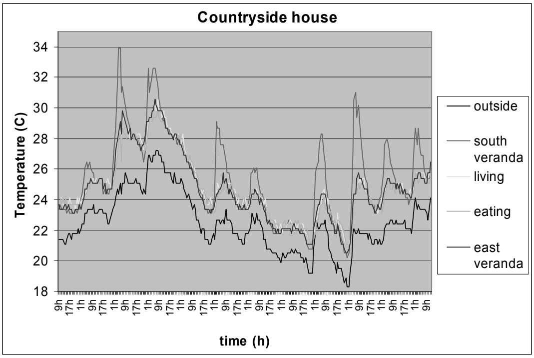

Figure 6, 7

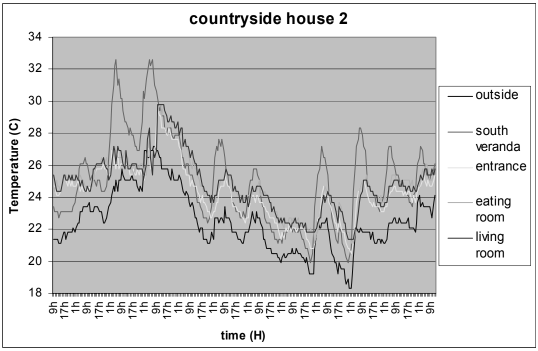

Figure 8, 9

Solar beam radiation on the paper wall - modeling

The roof of the veranda shades the paper wall from the solar radiation. The depth of the roof is generally variable, depending on the house type and the site location. The traditional house located in the town of Tokyo for instance, have a very small veranda, 1.2 meters wide, which is a dimension justified by the general lack of space in the Japanese towns. The verandas of the two houses in the countryside are generously wider and become as autonomous spaces enclosed between two layers of paper wall mixed with glass.

The climate data for the horizontal solar radiation modeled for a week between the 1st and the 7th of August show that the diffuse radiation has a constant trend while the direct radiation is variable. The model shows that the veranda reduces considerably the peaks of energy coming from the hot sun inside the house at the Tokyo's latitude. However the eaves of the veranda are not able to eliminate the diffuse component that is still present on the *shoji*. The veranda provides comfort by shading the direct rays coming from the sun. In particular 70 W/sqm (Szokolay 1980) of reduction on solar radiation can contribute to improve the sensation of comfort by a degree.

DISCUSSION

The environmental and social role of the veranda

In Japanese architecture the flexibility of the space between the interior and exterior, *engawa*, makes the dialogue with nature like a constant exchange (*en* means passage, from the house to the nature) (Fuccello 1996) and plays an important role in social behavior. Because of its characteristics it was used all year round in different ways depending on the season.

The veranda during the winter was traditionally the ideal space in which to dry, sew and iron the *kimono* because of the strong solar radiation and the protection from the rain. This space was also originally used to receive guests, tea and cakes were offered to them and *hibachi* and *Tabako-bon* (tobacco box) were placed on the floor as a welcome (Engel 1964).

During the summer the timber floor of the veranda, cooler than the *tatami* inside, was a place of recreation for adults and children (Engel 1964). As the shoji are open during the day there is no separation between the veranda and the rest of the house. Cross ventilation and the shade of the roof provides the comfort as demonstrated by the house in Tokyo.

These traditional behaviors, as well as the traditional materials are today however not in use anymore, the life of the Japanese has changed as well as the materials that compose the house. These adaptive behaviors not only modified the Japanese way of life but also the role of the veranda that overheats in summer and performs in fact as a conservatory as demonstrated by the two houses in the countryside.

CONCLUSION

In this paper the author explained how a very bad insulated envelope with a very simple structure can become comfortable in Japan. The inhabitants in fact in winter do not heat the space enacting a non rational use of energy but rather they heat themselves. In fact, when the outside temperature is low and the inhabitants spend most of their time inside they use small objects and thick clothes to heat the body (Sdei 2005). In the summer, on the other hand, the house type allows high ventilation rate and becomes comfortable when the movable paper panels are completely opened. The very uncomfortable high ambient temperature and relative humidity are in this way avoided. However the use of modern materials and a change in the occupant's behavior and life style modified the traditional house that can perform today differently, overheats in summer and require artificial means to cool down the air.

Perhaps there are two lessons here for a more sustainable and energy efficient approach to modern domestic life in the East and the West. A responsible occupant's behavior that considers the weaknesses of a house type and acts as a consequence can transform a bad insulated envelop in a comfortable place. The adaptation of the house to a more modern life style and the use of modern materials can completely reverse the simple and beautiful way a traditional dwelling performs.

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[i] Experimental measurements of the traditional rice paper used for the typical Japanese screens show that this material is a very good diffuser, able to absorb a large quantity of light. The first experiment was conducted projecting direct light on a large vertical surface of shoji paper. when the angle of the incident direct light changed. The values of transmission and absorption were assumed constant at different angles of incident light since very few variations of the brightness were measured on and behind the paper. The diffuse reflection was found using the grey card method and the following formula: Rrp= Rgc/Lgc * Lrp, where Rrp is the reflectance of the rice paper, Rgc=0.18 is the reflectance of the grey card, Lgc=148cd/sqm is the luminance of the gray card and Lrp=440cd/sqm is the luminance of the rice paper. The diffuse transmission was calculated with an experiment as the ratio of the luminance of a white box and the luminance of the same box covered with a sample of rice paper Diffuse reflection r = 53%; diffuse transmission t = 17% ; diffuse absorption α = 30%. These last two experiments were conducted under an artificial sky

[ii] 1met=58W/m² is the unit of the heat output from the human body