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# Measurements of the Thermal Environment of Traditional Houses and An Application Study of Insulated Buildings Using Thermal Concepts of Traditional Houses

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## Abstract

In this report, we will try to validate some of the wisdoms of our ancestors, who lived in the humid and hot summer climate south of Hokkaido.

We measured the thermal environment of traditional houses on Honshu island, and from the measured results confirmed the wise constructional concepts of our ancestors for comfortable living in the summer. In addition we propose that some of the traditional and intellectual technics are useful to improve the thermal environment of insulated and air-tightened buildings during the summer in Hokkaido. Thus, we presented an application study on such dwellings and a feasibility study on the open cooling of an office building and clear canopy space in Hokkaido.

## 1. Introduction

Kenko, a poet and an essayist in the early 14th century, said "When we plan housing, we should do it with consideration to all summer conditions." When we describe the sultry climate of summer in Japan, we often quote from his writing, which emphasized the high humidity and hot summer. At his time, the most beautiful scenes were expressed by using poetic words such as, snow, moon, and cherry blossom. Furthermore, the imagery of snowfall was probably admired in Japanese poetry because the coldness of winter did not disturb daily living so much, when a little hearth was used in a room, even if the room air temperature was almost equal to the outdoor temperature.

Hokkaido, at a latitude from 42° to 45°N, is the northernmost island of Japan. The outdoor temperature drops to between  $-10^{\circ}$  and  $-30^{\circ}\text{C}$  in winter and the snow often reaches 1.5 m in places. The development of Hokkaido began about one hundred years ago. One of the reasons for the late start was the extreme cold and heavy snowfall in the winter. Although the summer in Hokkaido is short, the outdoor temperature can reach  $30^{\circ}\text{C}$  and the solar radiation is rather strong. Therefore,

in Hokkaido, it is necessary to consider the summer conditions, as well as the winter conditions, when designing the thermal environment of a planned building.

In this report, we infer the thermal environment of traditional houses south of Hokkaido and introduce some application studies for insulated buildings in Hokkaido using their thermal concepts in high humidity and hot summer.

## 2. Measurement of the Thermal Environment of Traditional Houses

### 2-1 Country Dwellings and City Dwellings :

In Japanese we call traditional country dwellings, "Minka", and traditional city dwellings "Machiya". \*1

The thick roof of a Minka is made of Japanese pampas (reed) grass which keeps out the heat of strong solar radiation in summer. A Minka is an "Open Style" dwelling, which has some large openings and air leakage in its walls. It is easy for them to displace heat and moisture because of the amount of air ventilation through the room spaces or wall cavities. On the other hand during the rainy season, landslides caused by torrential rains always severely damage some dwellings alongside the hills south of Hokkaido. The question arise, "Why do we build on such sites ?" Whereas flat lands in the country, we can use flat and wide ground more efficiently for farming. When we build houses at the foot of the south slope, which is covered with copse, this location is warm in winter because of sufficient sunshine and little seasonal wind, as well as cool in summer because of cold downward airflow through the copse of the slope. Fig.1 shows an ideal sketch of a Minka and a Machiya, respectively. A Minka utilizes the temperature difference between day and night. It has a displacement ventilation system in summer season. In this case, the ventilated air moves horizontally. These conditions provide inhabitant with comfortable living in the sultry summer.

Machiya were built shoulder to shoulder in commercial districts. In old times, feudal lords usually placed a tax on the frontage of the dwellings. Therefore a Machiya had a narrow frontage and a greater depth from the face of the street or passage. The dwelling density of Machiya (2 storied wood town house) was 70-80 houses/ha. The density is almost as had as that of recent city planning with apartment houses (5 stories of a flat type). Negative aspects center on shortcomings of the neighborhood and environmental conditions. The most serious danger in the case of such a high density is the chance of a conflagration.

Machiya were usually composed of thick fireproof walls between neighbors, the tile roofs, some storehouses with thick clay walls, a passage way to the streets which also served as routes of escape in the event of a fire, and many thickets in the courtyards to live on a friendly proximity basis with nature and at the sametime provides privacy.

Consequently, though Machiya had a "Closed Style" against the heat from outside, the inner spaces were connected relatively open with each other (See Fig.3.). The warm and highly humid air was exhausted quickly through the high-roofed passage way "Toori Niwa",

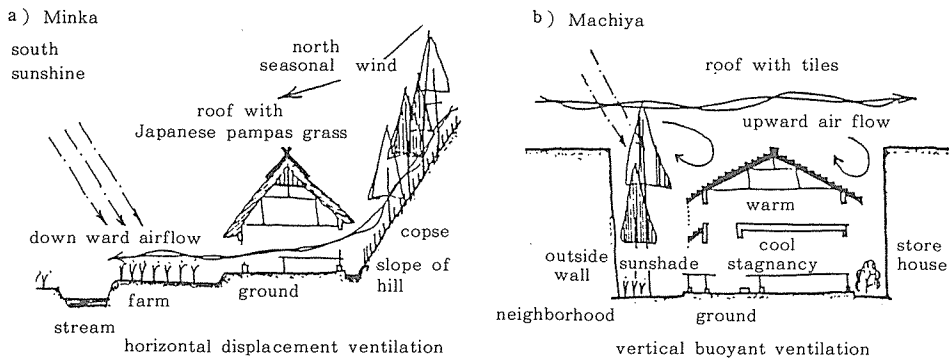


Fig. 1 Ideal sketch of a Minka and Machiya

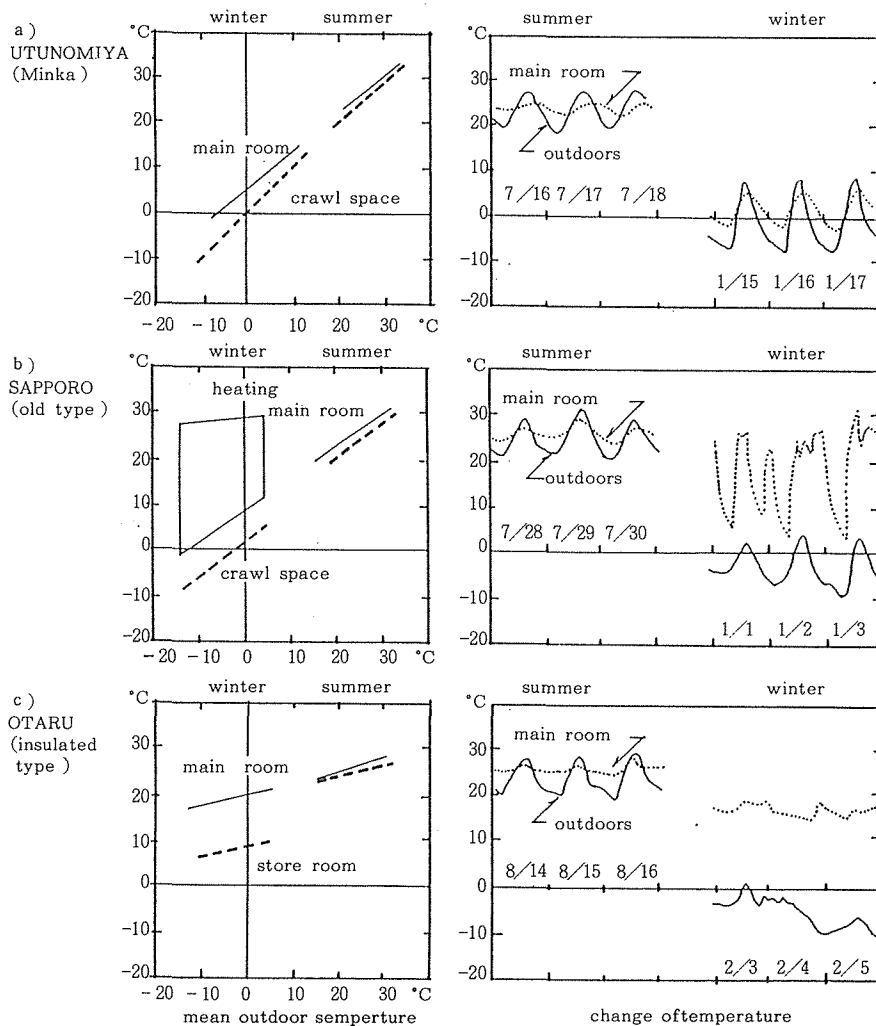


Fig. 2 The thermal environment of typical dwellings

and also air which was cooled by the thermal storage of the ground, stagnated in crawl spaces for long periods of time. Machiyas were cooled and shaded by the many thickets and utilized the 2nd floor (storeroom) for a buffer space from solar radiation. Furthermore, Machiya utilized the temperature difference between summer and winter, as well as between day and night. It had a buoyant ventilation system. In this case, the ventilated air moved vertically. These are wisdoms of Machiya which provided comfortable living in a town of high dwelling density in the sultry summer season.

### 2-2 From a System to Remove Moisture to a System to Conserve Heat :

Fig.2a shows the thermal environment of a Minka. Though a Minka is cool in summer, the room air temperature in winter is almost equal to the outdoor temperature.

When the older houses in Hokkaido are heated, raising the room air temperature except for the main room to 20°C is difficult. However, the air temperature becomes immediately equal to the outdoor temperature, like a Minka, if they are not heated (See Fig.2b.). This is because *older houses in Hokkaido are not insulated satisfactorily*. They were built with a system to remove moisture in highly humid climate. We have made a lot of effort to change building construction from, a system which removes moisture, to a system which conserves heat. Fig.2c shows the thermal environment of a recent insulated house in Hokkaido. In winter, the daily change of room air temperature is small and the temperature difference in the house becomes even, as a whole. At the same time, however, we have a hot indoor climate, in such a house, in the summer season. Thus, ten years ago, we thought we should revise our building concepts to improve a hot indoor climate. To do this we looked back to the wisdoms of the cool "Machiya" in summer.

### 2-3 Thermal Environment of "Machiya" in Summer :

We measured the thermal environment of several Machiyas in Kyoto for six weeks during the hot summer. Fig.3 shows one of them and the temperature distribution. The air temperature at the ceiling level is high and the air temperature at the floor level is low and cool.

Fig.4 shows the section of another machiya in this the change of air temperature and the distribution of temperature difference based on the outdoor temperature is shown. The air temperatures of the crawl space and of the first floor level are lower than the mean temperature of the outdoors throughout the day. Fig.5 shows the relation between the air temperature and the outdoor temperature from one hour to the next. The air temperature of the back yard "Ura Niwa" is always lower than that of the outdoors. In addition the transition of the ground surface temperature moves along the horizontal axis throughout the day. These tendencies do not change in the summer season. Fig.6a shows the vertical distribution of temperature, based on the outdoor temperature from one hour to the next. At night, the cool outdoor air flows into the lower part of the occupant space and the warm air flows out from the higher part like the highroofed passage way "Toori Niwa". During the day, moreover, the cool air stagnates at the first floor level. This upward opening system for buoyant air circulation is the second wisdom of the cool "Machiya". Fig.6b shows

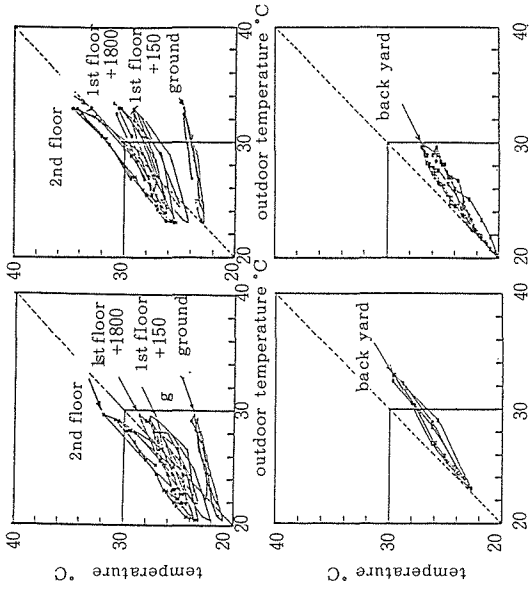


Fig. 5 Relation of air temperature and outdoor temperature

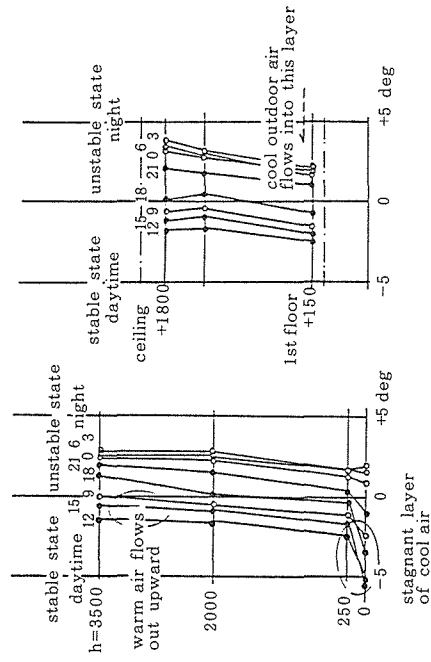


Fig. 6a Vertical distribution of temperature from one hour to the next

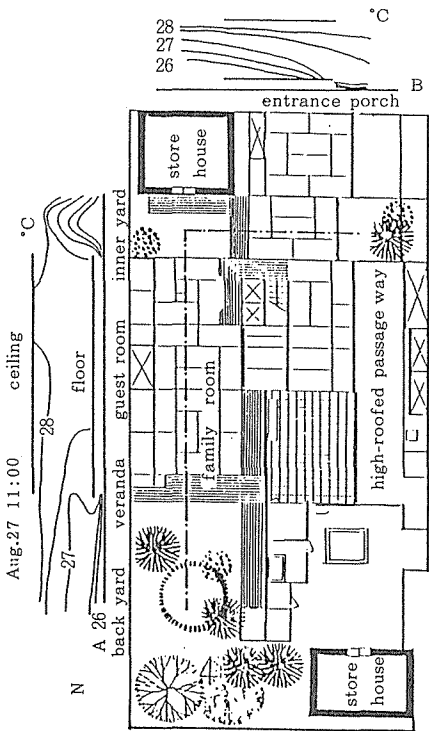


Fig. 3 Temperature distribution of a Machiya in summer

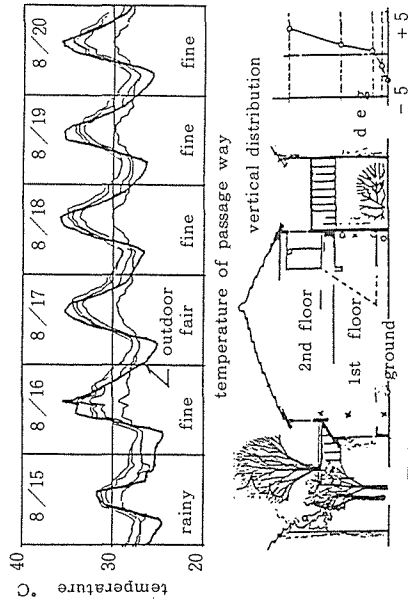


Fig. 4 Vertical distribution of mean temperature difference

the relation between the time of sunshine and the temperature difference of room air and outdoor air. The temperature difference, in the case of the ground, becomes larger when it is fine and hot. The ground crawl spaces or yards become the cooling source to cool the occupant space of the first floor during the hot summer. This is the third wisdom of the cool “Machiya”.

If there is a warm wind over the Machiya, the cavity space, like the occupant space and the yards, has two air circulations when the ground temperature is lower than that of the other parts. One is the main circulated currents and other is the sub circulated current as shown in Fig.7b. There is the sub circulated current in the cool lower part of stagnant layer and the main circulated current of the upper part does not directly come into the stagnant layer. Because of this mechanism, there is a cool and soft breath of air in the occupant space of a Machiya. Fig.8 shows the radiant temperature. The thermal storage of the cool ground of a “Ura Niwa”, “Toori Niwa” and “Tsubo Niwa (i.e. inner yard)”, as well as the crawl space, makes a comfortable and cool zone, just as the stagnant layer in the occupant spaces.

What is the first wisdom of the cool Machiya ? Of course, it is the closed style against heat from the outside. The thick walls, the heavy clay storehouses, the storerooms of the 2nd floor, and the deep thickets in the yards, they have a function as thermal insulation or a sunshade to cool in a sultry climate.

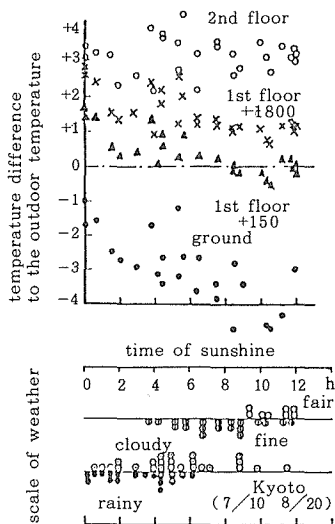


Fig. 6b Relation between outdoor temperature and sunshine

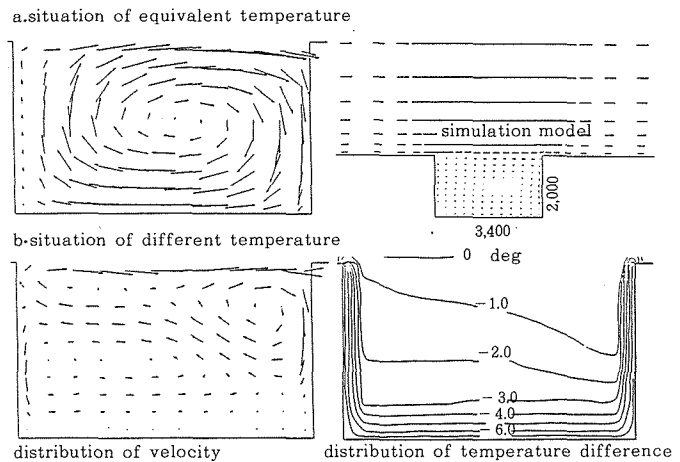


Fig. 7 Numerical analysis of air circulation

### **3. Application Studies of Thermal Insulated Buildings by Using the Thermal Concepts of a “Machiya”**

#### **3-1 Improvement of the Thermal Environment of Thermal Insulated Houses :**

Fig.9a) shows one of the thermal insulated and air-tightened houses in Hokkaido and their thermal environments. In summer, the air temperature of the majority of occupant spaces is higher than that of the outdoors, and the changes of room air temperature are large. In this case, they have thermal insulation and thermal storage of their own in their own way manner.

However, the pattern of all summer conditions was not considered adequately to be comfortable in the short and hot summer of Hokkaido. One of them is the upward opening system for buoyant air circulation such as seen in a Machiya. Fig.9b) shows an adequately insulated case which would be considered to be comfortable under such summer conditions. The warm air is exhausted through the high side openings and the monitoring for buoyant ventilation. Furthermore, the room air temperature on the first floor is low and cool. Its change becomes a flat transition, which is influenced by the thermal storage of the ground. Fig.10 shows the relation between the mean air temperature of the main room and the mean outdoor temperature throughout the day. In the case of the house as shown in Fig.9b) its transition of room air temperature moves horizontally throughout the year. In this case, its indoor climate is not cold in winter, and is never hot in summer.

#### **3-2 Improvement of the Thermal Environment of Office Rooms by Using Open Cooling :**

Most cooling equipment has been designed assuming that the building is a closed system. Even if it is cooled, the distribution of air temperature will be affected by the remnant heat of people, lighting, etc. and the warm zone will always appear at ceiling level. When warm air at ceiling level is exhausted smoothly through high side opening not only the thermal environment will be improved, but also the cooling load will be reduced. In the numerical analysis, by using the Successive Integration Method\*2, we attempted to divide a room into three parts (upper,middle and lower), and discuss the feasibility of open cooling. Fig.11 shows the simulation model, which is cooled by using the floor cooling\*3. Fig.12 shows the variations of room air temperature, the amount of excluded heat at the cooling tower, the amount of excluded heat by ventilation when the high side opening is opened, as well as those conditions when the system is closed. Case A is not cooled and opens the high side opening. The room air temperature reaches 30°C in the daytime so that it is difficult for the opening to improve the thermal environment by itself. Case B is cooled and closes the opening. The room air temperature does not reach 30°C, but ventilation will be required by an other means. Case C is cooled and opens the high side opening. The thermal load becomes smaller than that of Case B and the ventilation is expected to be about 300 m<sup>3</sup>/h in the daytime. The variation of room air temperature is almost equal to that of Case B. Case D is cooled during the night. Though the amount of ventilation becomes smaller than that of Case C in the daytime, this open cooling is the most economical.



### 3-3 Improvement of the Thermal Environment of a Clear Canopy Space by Using Buoyant Ventilation through High Side Openings :

When an arrangement of apartment houses is being planned, most arrangements are designed to utilize the advantages of southern exposure, due to the consideration of solar radiation in winter season. We will propose a planning arrangement, that the facades of two apartment houses are confronted in pairs and the space between these two buildings is covered with the clear glazing roof\*4. By the tentative proposal, we will be able to obtain a snow-free and unfrozen courtyard space and a larger and more sunny garden than exists in the present arrangement, if the proposed case has an equal density condition to the present case.

In the numerical analysis, we tried to divide the clear canopy space into three parts (See Fig.13.), and to discuss the thermal environment in it. Fig.13 shows the simulation model of flat type apartment houses and a clear canopy space.

Fig.14 shows the variation of air temperature and the thermal load during the coldest season in Sapporo. The room air temperatures of both residences are controlled at 20°C by the central heating. The air temperature in the clear canopy space is higher than 0°C during the night, because of the heat from the residences and the heat from the ground floor which was heated by the solar radiation during the daytime. The temperature rises to almost 20°C during the day. Therefore, the courtyard under the clear canopy does not freeze during the night and can be used to take in the sun, to enjoy leisure, or to go for a walk during the daytime. The capacity of heating equipment for the individual dwellings becomes 6.7kW. The mean value for the heating load (i.e. 3.8kW) is smaller than that of the present arrangement .

Fig.15 shows the variation of air temperature during the hottest season in Sapporo. Case A is the calculated results without a sunshade. If the high side openings were opened, the air temperature of the clear canopy space becomes higher than 40°C when the height of its openings is small. Case B shows the adequate effect of buoyant ventilation through the larger height of the high side openings and of the awning covered on the canopy roof. In this case, the air temperature of the canopy space, as well as the residences, will become lower

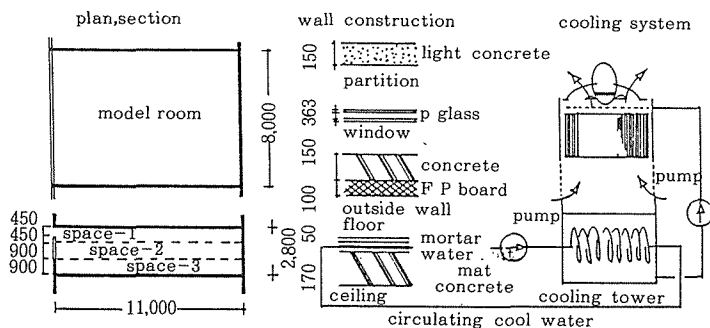


Fig. 11 Plan, section, wall construction and cooling system

than 30°C during the hottest season.

### 4. Conclusion

1. Though "Machiya" has a closed style against the heat from outside, the inner spaces are connected with a relatively open flow between each other. Fundamental concepts to live comfortably in the sultry summer are the upward opening with buoyant ventilation, the thermal storage of the ground to cool the main occupant space, and a sunshade to keep out the solar radiation.
2. The building concepts and wisdoms to cool "Machiya", are also useful for improving the

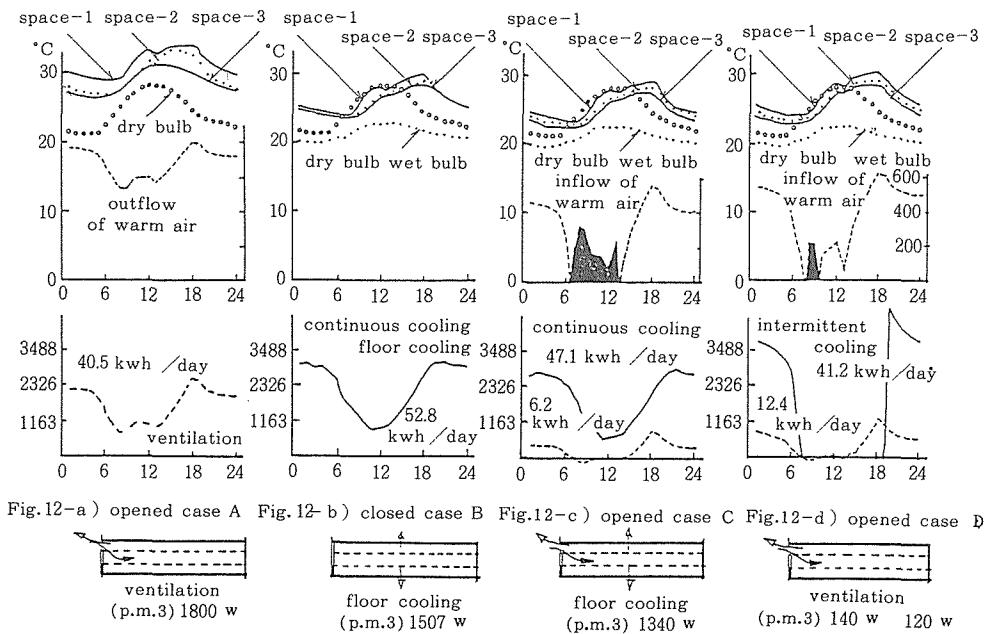


Fig. 12 Temperature and thermal load

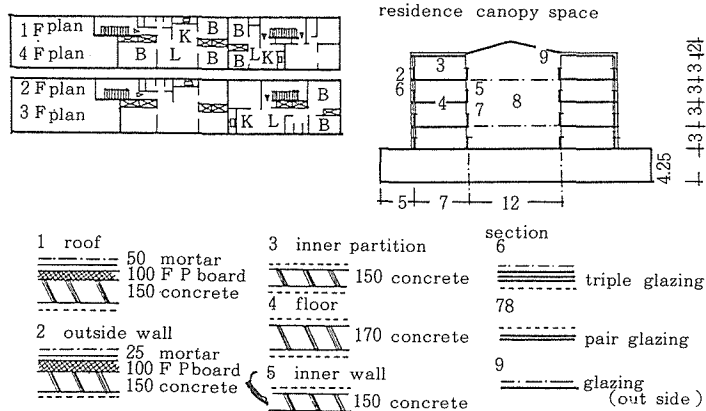


Fig. 13 Plan : section and wall construction

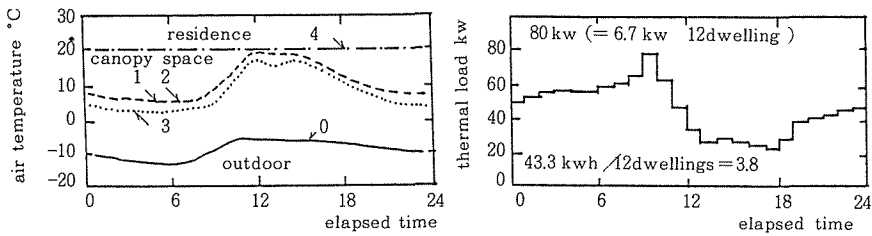


Fig. 14 Variation of temperature and thermal load during the coldest season

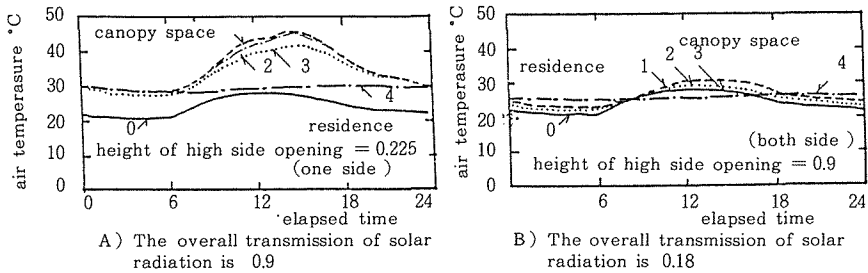


Fig. 15 Variation of temperature during the hottest season

thermal environment of the adequately insulated dwellings during the hot summer in Hokkaido.

3. The indoor thermal environment can be improved more gently and comfortably by a combination of the high side openings and floor cooling. It is useful to open the high side openings to lower the air temperature at ceiling level in the daytime, as well as at night when the outdoor temperature drops.
4. If the courtyard between the apartment houses is covered with a clear canopy, it becomes snow-free and freeze-free space during the night even in the coldest season. If the air conditioning is not adopted in summer, the larger height of high side opening and the awning on the clear canopy are required. In such a case, the air temperature of residences and canopy space will be lower than 30°C during the hottest season in Hokkaido.

### 5. Acknowledgments

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