ENVIRONMENTALLY FRIENDLY CITIES, Proceedings of PLEA'98, Lisbon, Portugal, June 1998
Pages 291-294 © 1998 James & James Science Publishers Ltd

Thermal performance of a passive-designed dwelling unit and the influence of residents' dwelling condition

NOBUYUKI SUNAGA

Tokyo Metropolitan University
Graduate School of Engineering, Dept. of Architecture
1-1 Minami-osawa, Hachioji, Tokyo 192-03, JAPAN
nobsun@arch.metro-u.ac.jp

Abstract

Passive and low energy houses are not yet widespread throughout the world. One of the reasons is that their actual performance has not been clarified. In recent years, the number of houses has been increasing in Japan, however, there are very few examples of multiple dwelling building whose performance has been clarified. The annual thermal performance of two dwelling units in a multiple dwelling building in Japan is measured and their high performance is verified. The two dwellings have the same floor plan and same passive systems, but their thermal performance are clearly different, owing to the difference in the residents' dwelling conditions. This indicates that it is necessary to specify the mechanism and the performance of houses to house users.

INTRODUCTION

Recently, the global environment problem has become aggravated, and it should be required, in the architectural field, that all buildings utilize natural energy and minimise fuel energy consumption. However, Passive and Low Energy Architecture has not yet been popularized worldwide. One of the reasons is that the actual thermal performance of such buildings, especially dwellings which are familiar to the general public, has not been clarified.

In recent years, the number of houses using passive and low energy methods has been increasing gradually in Japan. However there are few houses whose thermal performance has actually been measured. Therefore, a subcommittee of the Architectural Institute of Japan, of which the author is a member, has been carrying out field measurements about passive and low energy houses and developing a database for them [1]. However there are very few examples of multiple dwelling building.

The author has measured and analysed the annual thermal performance of two dwelling units in a multiple dwelling building in Japan. The dwelling unit, which is a maisonette type and has a sunspace, is designed to incorporate passive methods, such as the direct gain system and natural cross-ventilation. The two dwellings have the same floor plan and same passive systems, but the dwelling conditions of residents are different, and therefore, the thermal performances are different.

In this paper the annual thermal performance of the dwelling units and the influence of the dwelling conditions or the lifestyle of residents on the thermal performance are discussed.

OUTLINE OF BUILDING AND DWELLING CONDITION

Two dwelling units, "dwelling A" and "dwelling B", in a multiple dwelling building built in March, 1996 in the south Kanto region of Japan are examined in this study. The building is made of reinforced concrete, and these dwelling units are maisonette types and have two-story sunspace. Both dwellings have same floor plan, but dwelling A is on the west side of the grand and 1st floors of the building and dwelling B is the middle unit on the same floors. Therefore, the heat loss coefficient of dwelling A is 2.2kW/°Cm^2, which is slightly larger than that of dwelling B, 1.9kW/°C m^2. The total floor area of these dwellings is each about 130 m^2. Figure 1 illustrates the floor plan and the cross section of these dwellings.

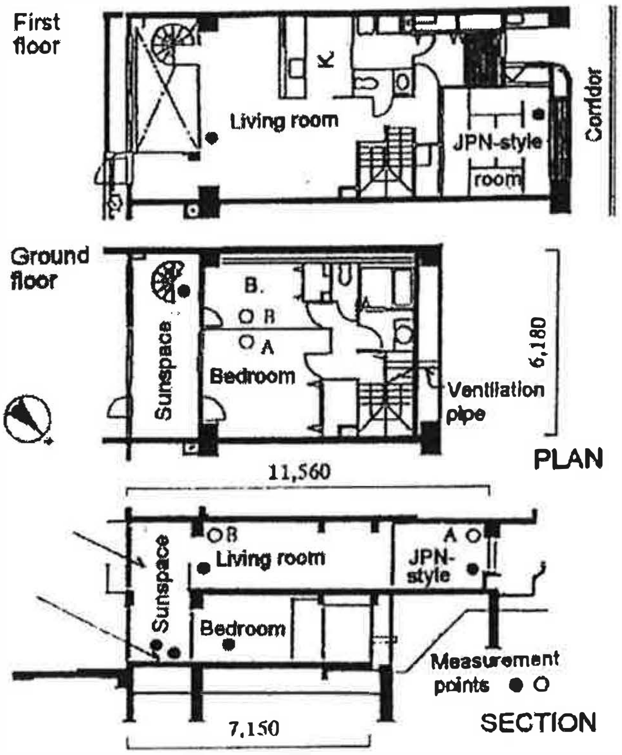

Figure 1. Plan and section of the dwelling units.

The sunspace faces south-east, and solar energy gained through the large double glazing window in winter heats the inside of the dwelling and is stored in the concrete floor of the sunspace and other concrete parts of the dwelling owing to the outside insulation. Direct sunlight in sununer is shaded by the eaves and the white blind. To promote natural cross-ventilation, the transom windows above the doors of all rooms can be fully opened, and a ventilation duct connected with the space under the floor, which is open to outside air, is also installed at the stairway.

The number of residents is two adults in dwelling A, and two adults and one child in dwelling B. The residents of dwelling A are interested in the passive systems of this dwelling unit and actively try to improve cross-ventilation in the summer, while the residents of dwelling B initially did not understand the system well.

The cooler was used for several hours from evening to night on hot days in dwelling B in the summer, though usually not in dwelling A. As auxiliary heating, in dwelling A, a portable fan convector, which is connected the gas water heating facilities installed in each dwelling unit, was used in the morning and evening, and an electric carpet was used for 3 - 4 hours per a day in the winter. At dwelling B, a kerosene fan heater was used only on cold days until the end of February. The total consumption of kerosene in the winter of '96-'97 was about 180 litres.

ENERGY CONSUMPTION

The measurement survey was carried out from the end of June, 1996 to the beginning of July, 1997. The annual energy consumption of these dwellings is shown in Table 1. The average for dwelling units of multiple dwelling building in this region is also given [2].

Energy consumption is high for dwelling B, compared with dwelling A. However, on deducting the electric power consumption of 1.12 Gigacalorie which is estimated to have been used for the tropical fish, it becomes the same level as dwelling units in the city area with a floor area of about half that of these dwellings. Furthermore, the estimated energy consumption for space heating is as much as that for dwellings in this region. Considering the scale of the dwellings, it is possible to say that the energy consumption of these dwellings is quite low.

THERMAL ENVIRONMENT IN SUMMER

Figure 2 shows the frequency distribution of room temperature in summer, from July 1st to August 31st, 1996.

In both dwellings, the room temperature in the living room, which is on the upper floor, is the highest in the dwelling and varies in the range of 24 - 34°C. Because the cooler was not used very often, the room temperature often exceeded 30°C.

The room temperature in dwelling B, where the windows were often closed in the daytime because of the absence of the residents, is higher than in dwelling A. In dwelling A, because the residents actively improved cross-ventilation, the room temperature in the sunspace, the bedroom and the Japanese-style room remained below 26°C for about one-quarter of all periods.

Figure 3 shows an example of the room temperature change in each room in the summer. In dwelling B, where the windows were often closed, the temperature difference among the rooms is small, while in dwelling A, in which cross-ventilation was promoted, the room temperature in the sunspace and the Japanese-style room decreased during the nighttime with the decrease of outdoor air temperature and became 24 - 26°C . This is 2 - 3°C lower than that in the living room in dwelling A and about 2°C lower than that in the same rooms in dwelling B.

As mentioned above, the thermal environment in a dwelling is improved during the summer by opening windows and promoting cross-ventilation.

THERMAL ENVIRONMENT IN WINTER

The frequency distribution of room temperature in winter, from December 1st, 1996 to February 25th, 1997, is shown in Figure 4. On the whole, the temperature in dwelling B is higher than that in dwelling A, and there are some hours when it exceeds 25°C. The temperature in the Japanese-style room, on the north side of the dwelling, is lower than that in the other rooms, most of which were 13 - 15°C. One of the reasons is that the psychrometer was set near the window, and there were some times during which the temperature was below 10°C due to the opening of windows while the room was being cleaned.

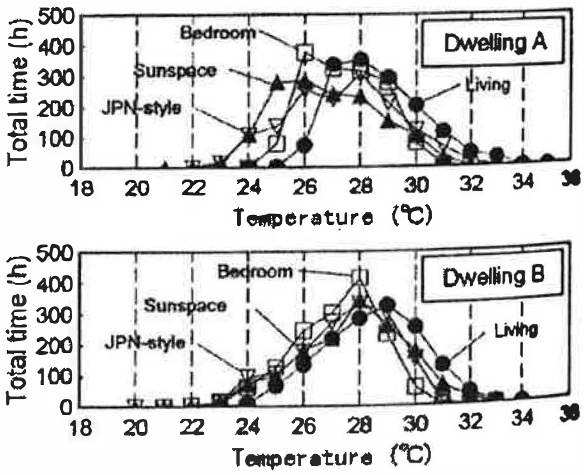

Figure 2. Frequency distribution of room temperature (July 1st - August 31st).

Table 1. Annual energy consumption. [Secondary energy, unit: Gigacalorie]

	Measurement value		Average value of dwelling units in this section [2]	
	Dwelling A (Floor area: 129m²)	Dwelling B (Floor area: 131m²)	Suburb area (Floor area: 75 m²)	City area (Floor area: 62 m²)
Electric power	2.83 (3286 kWh)	5.23 *1 (6076 kWh)	2.30	3.45
Gas	5.03 (513 m³)	7.97 (813 m³)	6.37	8.73
Kerosene	-	1.60 (180 litre)	-	-
Total	7.85	13.19 *1	8.66	12.2
Heating energy	1.00 *2	1.60	1.15	1.25

*1 It includes the consumption for keeping tropical fishes of about 1.2 gigacalorie. *2 Estimated value from the gas consumption.

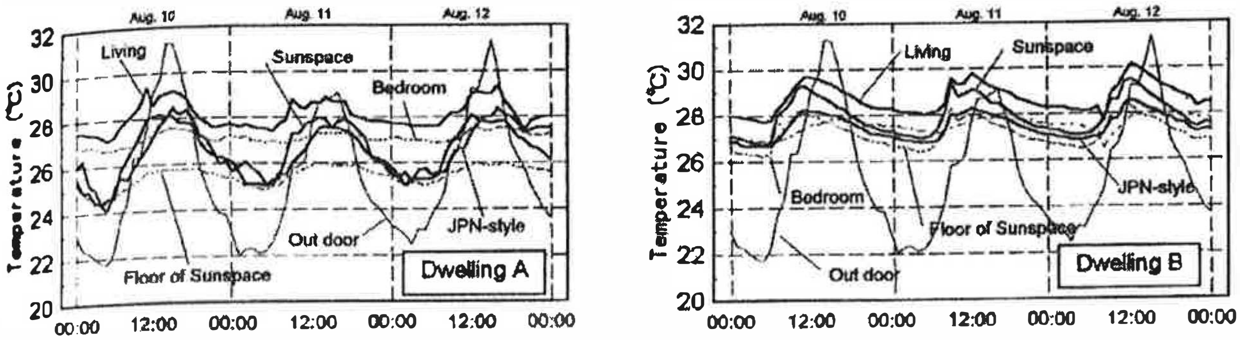

Figure 3. An example of the room temperature change in the summer (August 10th - 12th).

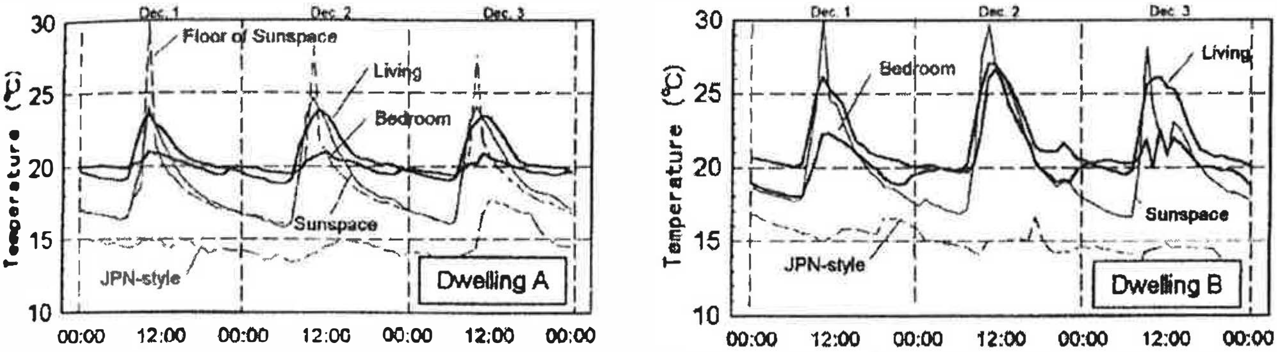

Figure 5. An example of the room temperature change in the winter (December 1st - 3rd).

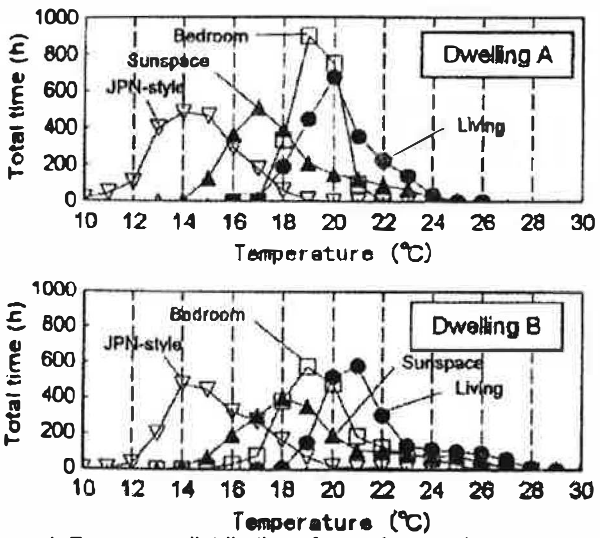

Figure 4. Frequency distribution of room temperature (December 1st - February 25th).

Figure 5 shows an example of the room temperature change in the winter. Generally, the room temperature in dwelling B is higher than that in dwelling A and the fluctuation of them is greater. The room temperature in the living room varied between 19 - 24°C at dwelling A and 20 - 26°C in dwelling B. The sunspace temperature was 16 - 25°C in dwelling A and 17 - 30°C in dwelling B.

The minimum room temperature in the early morning was 19 - 20°C in the living room, 16 - 17°C in the sunspace and 13 - 15°C in the Japanese-style room. Except for the Japanese-style room, the temperature is keeping equal to or above 15°C which is the standard for good dwelling.

Incidentally, the room temperature in the bedroom in dwelling B rose in the daytime on December 2nd following the room temperature in the sunspace, and became higher than 25°C. This was considered to be a result of opening the door between the bedroom and the sunspace.

It also rose again after 10 PM again, as a result of closing the doors when going to bed. A similar room temperature rise is seen in dwelling A.

ANNUAL TEMPERATURE FLUCTUATION AND INFLUENCE OF SHADING THERMAL STORAGE FLOOR IN WINTER

Room temperature fluctuation in the living room

The annual fluctuation of the room temperature in the living room in both dwellings is shown in Figure 6, along with that of the outdoor air temperature and the insolation. Figure 6 is plotted using only 4 data per day, taken at 6 AM, 12 AM, 6 PM and 12 PM. Therefore, the maximum value and the diurnal range are not always precise, but it is sufficient to clarify the trend of the change.

The temperature of dwelling B is generally higher than that of dwelling A. This is considered that this is due to the difference in the location in the building and of the dwelling conditions of the residents.

The diurnal range for dwelling B becomes larger from the middle of October. This phenomenon is explained below.

Room temperature fluctuation in sunspace and influence of shading thermal storage floor

The room temperature fluctuation in the sun pace is shown in Figure 7, which was plotted on the same manner as Figure 6. The fluctuation range of the sunspace temperature is slightly wider than that of the living room temperature.

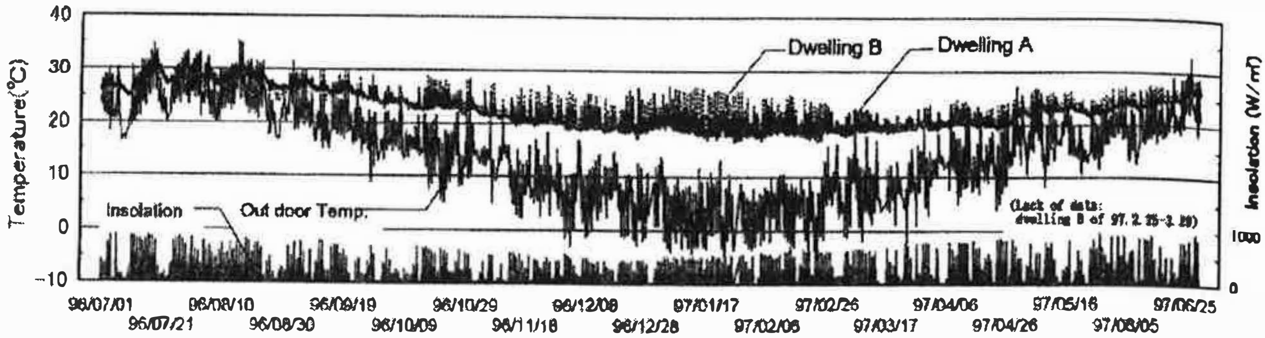

Figure 6. The annual fluctuation of room temperature of the living room.

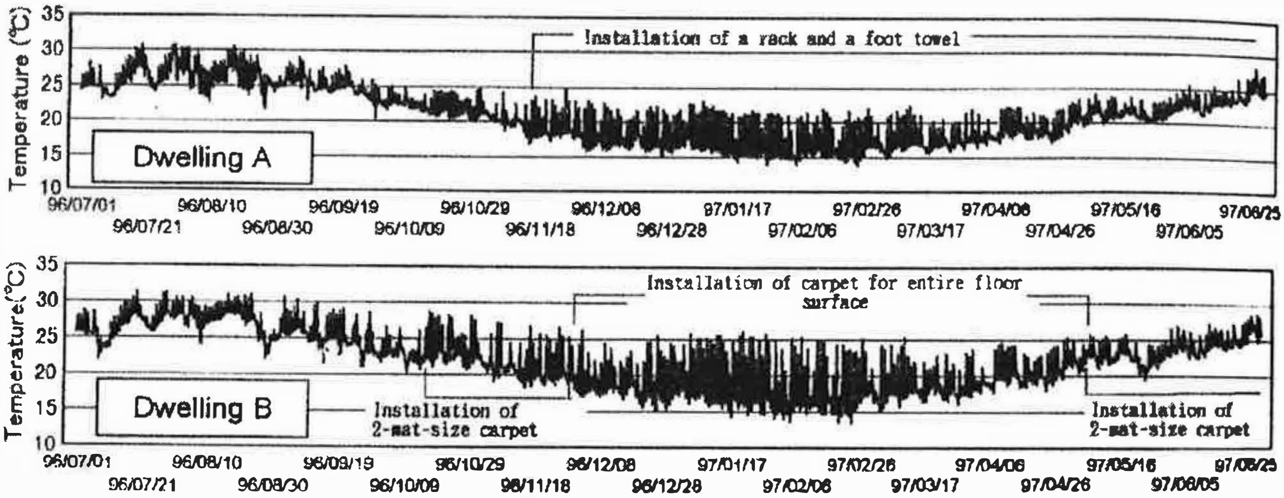

Figure 7. The annual fluctuation of room temperature of the sunspace.

The diurnal range for dwelling B is wider than that for dwelling A, except during the summertime. The residents of dwelling B spread a carpet of 2-mat-size (about 3.5 m^2) over the centre of the thermal storage floor of the sunspace in the middle of October for the following reasons. (1) It is painful to lay on the floor when sunbathing due to the hard surface finish of floor. (2) Nylon stockings tear when walking on the floor. Moreover, they installed tilelike carpets over the entire floor surface on November 23rd.

Therefore, the room temperature fluctuation in the sunspace of dwelling B becomes wide in 2 steps. The change of the diurnal range of the living room temperature mentioned above is mainly a result of installing these carpets.

On the other hand, in dwelling A, the fluctuation range widens slightly from the middle of November. The reason is considered that a rack for potted plants (about 30cm ~70cm ~100cm height, 2 shelves) was set near the window of the sunspace and a foot towel (about 0.7 m^2) was spread over the floor.

In this way, it is understood that the detrimental influence of covering the floor, which is the main heat storage part, by placing sun shade bodies, such as a rack and potted plants, and by installing a carpet is significant in the direct gain system.

After this measurement result was shown to the residents, they changed the tilelike carpet to a smaller 2-mats-size carpet at the beginning of May.

Considering the above-mentioned details, it is clear that the clarifying the influence of the residents' dwelling conditions on the performance of the dwelling and informing residents of such an influence are very important to attain to the original performance of the building.

CONCLUSION

The energy consumption of these dwelling units is low and their thermal environment maintained at a good level, though there are some hot hours in summer. It considered, therefore, that this dwelling unit has high thermal performance.

Furthermore, the thermal performances of the two dwelling units are clearly different from each other owing to the difference in the residents' dwelling conditions, such as the utilization of cross-ventilation and the placement of shading bodies on the thermal storage floor. Therefore, it is necessary to enlighten building users by specifying the mechanisms and the performances of buildings, especially in the case of Passive and Low Energy Architecture.

REFERENCE

1. N. Sunaga et al., 'Database of Passive and Low Energy Houses and analysis of their trends', the proceedings of the 14th PLEA conference, Vol.2 (1997), 333-338
2. T. Sawachi et al, 'Energy consumption for different uses in dwelling and its estimation formulas – Study of energy consumption in residential buildings from the viewpoint of life style on the basis of national scale surveys Part 1 –", Transactions of Architectural Institute of Japan, No.462 (Aug.,1994), 41-48