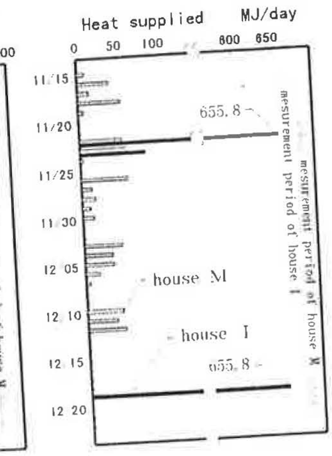

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Fig. 8 Amount of heat supplied by heater per day

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House with a Solar System
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THERMAL EFFECT OF SUNSPACE ON INDOOR ENVIRONMENT OF PASSIVE SOLAR HOUSE: MEASUREMENT AND COMPUTER SIMULATION

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ABSTRACT A passive solar house with sunspace made of reinforced concrete was constructed in Sendai, Japan in 1984. One year measurement of room temperatures were recorded. Also, detail measurements have been made during the summer and winter seasons.

Further, calculation of indoor temperature was conducted using response factor methods for studying the thermal effects of the sunspace on the indoor environment. This paper describes the measurement and calculation results.

1. INTRODUCTION

Sunspaces are becoming popular in Japanese houses to obtain an additional room for amenity and horticulture. From the point of view of thermal comfort, the sunspace can get so much solar radiation that in the daytime during the winter, that space is warm and comfortable. However, the sunspace is easily over-heated in the daytime during the summer and becomes too cold in the night during the winter. If thermal mass is installed in the sunspace, the large fluctuation of room temperature can be reduced by absorbing the heat into the mass during the day and releasing heat during the night.

A reinforced concrete passive solar house with a sunspace was constructed in Sendai, Japan in 1984. One year measurements of room temperatures have recorded and detail measurements have also been made for a week during the summer and winter seasons. Additional indoor temperatures were predicted from the data using the response factor method to study the thermal effects of the sunspace and other strategies on the indoor environment. This paper describes the measurement results of the passive solar house and the calculation results on how to improve the indoor environment by the sunspace and the other strategies.

2. DESCRIPTION OF THE PASSIVE SOLAR HOUSE

The two-storied passive solar house, which has a large sunspace attached to the southern wall, is made of reinforced concrete furnished with 30 mm glass wool insulation. The first floor plan and the section are shown in Figures 1 and 2, respectively. The total floor area of the house except for the sunspace is around 250 m^2 and the inside air volume is 700 m^3. The sunspace has a floor area of 32 m^2 and an inside air volume of 200 m^3. All windows have double glazing (K=2.51 kcal/m^{2}h°C) and low-E glass is used for the glass wall of the sunspace. The K-value of double glazing with low-E glass is 1.88 kcal/m^{2}h°C.

From measurements, the air change rate for an indoor-outdoor pressure difference of

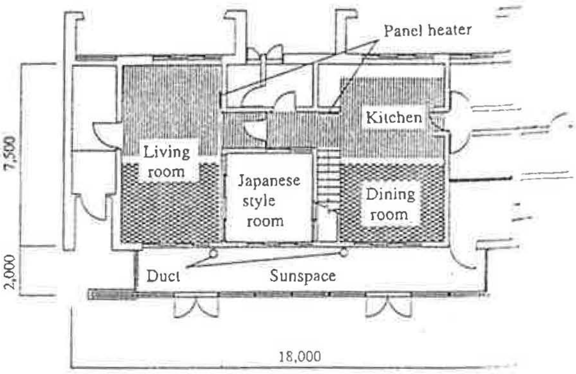

Figure 1. First floor plan of the investigated house

50 Pa, is 2.3 times per hour. It can be said that this house is airtight. The equivelant leakage area of glass walls is 139 cm^2.

In the living room, dining room, study room (2nd floor) and bedroom (2nd floor), air-conditioners (Capacity is 2240 kcal/h for cooling and 3500 kcal/h for heating) are installed. In the living room and hall way, hot water panel radiators are installed (Capacity is 1980 kcal/h and 1134 kcal/h, respectively). Electric heat is used in the dining room.

Two occupants, a couple, are living in this house. The wife is in the house during the day. Table 1 shows the occupant's behavior related to heating and cooling.

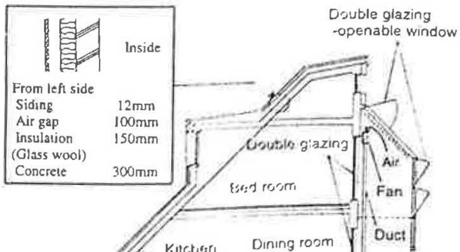

Figure 2. Section of the investigated house

Table 1. Occupant's behaviour

Term	Living Style
Summer	1 Opening windows between sunspace and other rooms early in the morning. 2 Operating air-conditioners in rooms except for the Japanese style room from morning to night. 3 Shading the sun at the windows between rooms on 2nd-floor and the sunspace. 4 No shading in the sunspace. 5 Opening windows of sunspace from 6 to 21 o'clock.
Winter	1 Operating panel heaters with hot water during daytime, and an electric heater only in the kitchen in the morning and evening. 2 When it is hot in the sunspace, occupants open windows between the sunspace and other rooms to intake hot air.

3. MEASUREMENT RESULTS

3.1 Measurement Method and Period

Measurement of temperature and humidity started on Aug. 23, 1994 using small data loggers connected to sensors. Additional detail temperature measurements were made from July 31 to Aug. 8, 1994 in the summer and from Feb. 1 to 8, 1995 in the winter using the thermocouples and data logger.

3.2 One-Year Measurement

Figure 3 shows the profiles of daily mean temperature and humidity during one year. The sunspace temperature decreases with the outdoor temperature but the temperature difference between them is more than 10°C during the winter. Room temperatures are stable during the whole year between 20 and 26°C. Humidity of the outdoor and the sunspace changes day by day but that of the inside rooms is fairly stable around 30% in the winter.

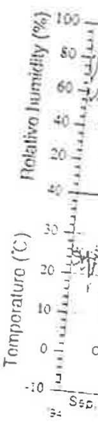

Figure 3.

3.3 Temperature in Su

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3.4 Temperature in Winte

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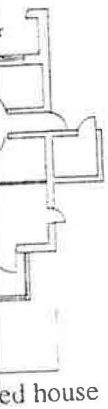

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Section of the investigated house

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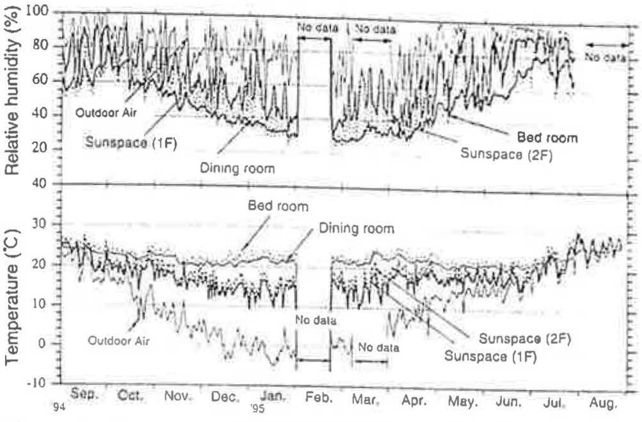


Figure 3. Temperature and humidity profiles for one year

3.3 Temperature in Summer

Figure 4 shows the temperature at each room and solar radiation for three days from Aug. 4 to 6, 1994. The temperature of the sunspace was always about 5°C higher than that of the outdoor air and increased to a maximum of 39°C at the maximum during the daytime because of no sunshade even with the windows of the sunspace open during the daytime. The temperature of the bedroom and the dining room were stable at around 25°C from the occupant's operation of air-conditioners as indicated by the questionnaire. The temperature of the bedroom decreases in the night time.

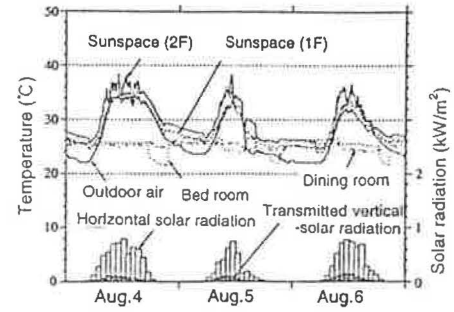


Figure 4. Temperature profiles in summer

3.4 Temperature in Winter

Figure 5 shows the temperature and the solar radiation for three days from Feb. 3 to 5, 1995. The temperature of the sunspace changes greatly with that of the outdoor air and is 10 to 25°C higher than the outdoor temperature. The temperatures of the bedroom and the dining room were stable at around 22°C except for the daytime on Feb. 3. On that day the record of the occupant's behavior indicates the panel heater was not operated and the windows between inside rooms and the sunspace were open during the daytime. The panel heaters were operated and the windows were closed on Feb. 4. The difference of occupant's behavior between two days influences the room temperature change. Namely, the temperatures of the bedroom and the dining room become about 6°C and 4°C higher in the daytime than the temperatures of those rooms in the early morning. However, the temperatures of those rooms did not change on Feb. 4.

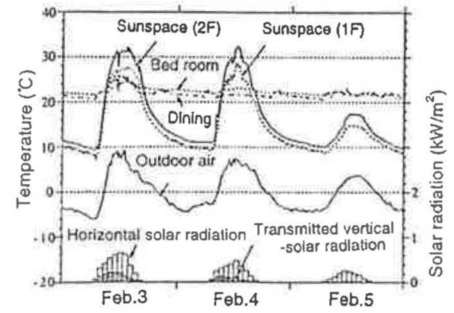


Figure 5. Temperature profiles in winter

4. EFFECT OF SUNSPACE AND OTHER STRATEGIES BY CALCULATION

4.1 Calculation Method

In order to study the effect of the sunspace and the strategies for improving the thermal condition, the calculation has been done using the response factor method for heat transfer with the multi-room ventilation calculation model. Figure 6 shows a model building for calculation which is simplified from the actual passive solar house. The model building has three rooms, that is the first floor room, the second floor room and the sunspace. Table 2 shows the fundamental condition for calculation. Table 3 shows the conditions for 11 cases.

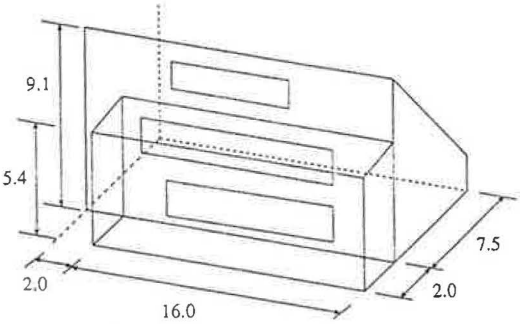


Figure 6. Model for calculation

Table 2. Conditions for calculation

Structure	Reinforced concrete
Sunspace direction	The south
Total floor area	Building: 250m^2 / Sunspace: 32m^2
Room volume	Building: 763m^3/ Sunspace: 205m^3
Number of rooms	3
Number of walls	37
Thermal mass of furniture	4.5kcal/m^3°C
Effective area of window	Building: 48m^2 / Sunspace: 113m^2
Details of window	Building: Double grazing / Sunspace: Low-E, Double glazing
Ventilation among each rooms	Taking into consideration
Occupancy, Heat generation	According to living schedule
Weather Data	Standard weather data in Sendai

4.2 Comparison between Measurement and Calculation

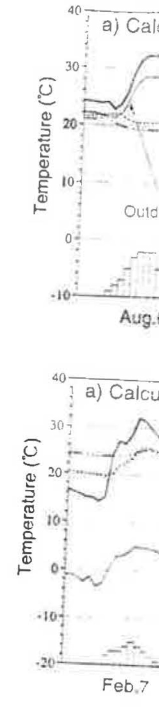
Figure 7 shows the comparison of temperature between measurement and calculation in two cases of the summer and the winter. As the standard weather data of Sendai is used for calculation, the outdoor temperature and the amount of solar radiation are different from those shown in the measurement. So it is difficult to evaluate the agreement between calculation and measurement. But the characteristics of the profiles of the sunspace and the room temperature are similar between them.

Table 3. Cases for calculation

Cases		Conditions for calculation
Case1		No sunspace (Summer)
Case2		No sunspace (Winter)
Case3		Sunspace attached (summer)
Case4		Sunspace attached (Winter)
Winter	Case5	Insulating the glass wall of sunspace during the night
	Case6	Opening windows between sunspace and rooms at daytime
	Case12	Case5 + Case6
Summer	Case7	Shading the solar radiation into sunspace
	Case8	Opening windows of sunspace from 6 to 21 O'clock
	Case9	Opening windows of sunspace all day
	Case10	Case9 + Opening windows between sunspace and rooms from 18 to 5 O'clock
	Case11	Case7 + Case10

4.2 Calculation Results

(1)Effect of sunspace Figure 8 shows the calculation results of the effect of the sunspace on indoor temperature in the winter and summer. In the summer, where the sunspace is attached to the house without sunshade and ventilation, the temperature of the sunspace greatly increases to more than 60°C at the maximum during the daytime and the room temperatures are kept 10°C higher than that of the room temperature without the sunspace. In the winter, the room temperatures in the case of the house with the sunspace are also kept 13°C higher than that in the case of no sunspace. The sunspace is effective for warming the room in the winter but it causes



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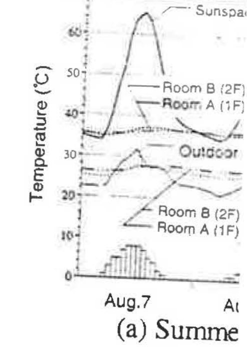

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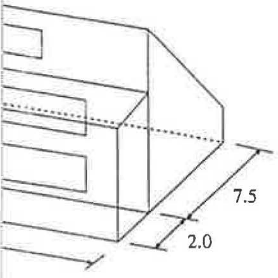

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	Building: 48m² / Sunspace: 113m²
	Building: Double grazing / Sunspace: Low-E, Double glazing
	Taking into consideration
	According to living schedule
	Standard weather data in Sendai

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- Case10

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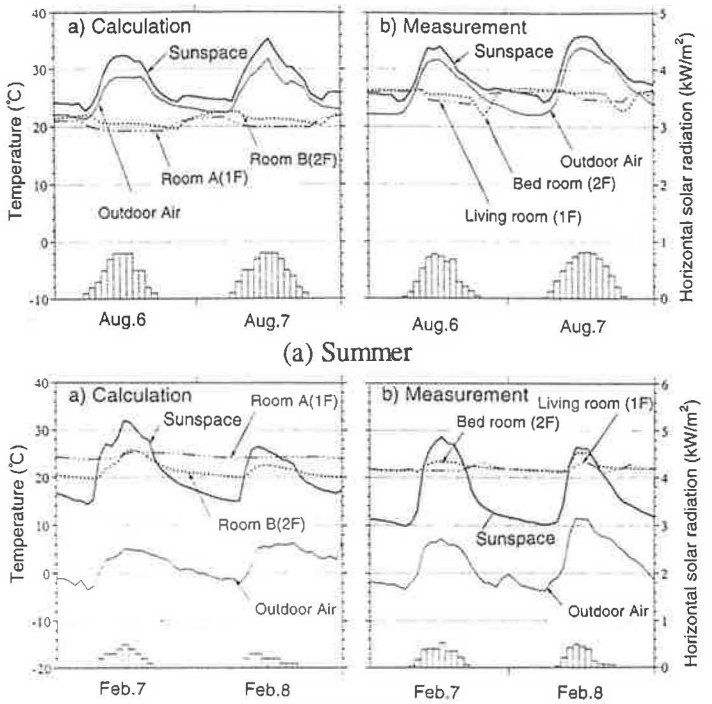
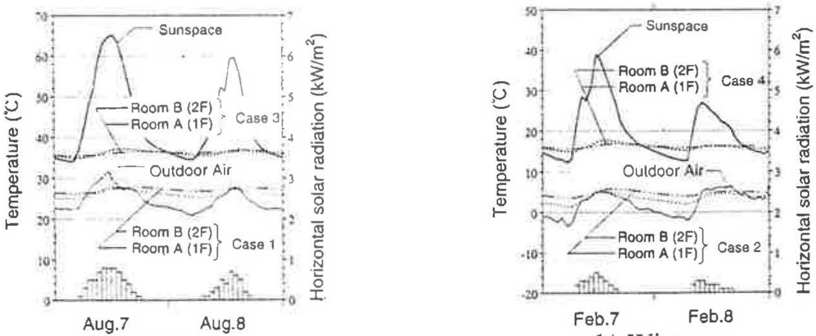


(a) Summer

(b) Winter

Figure 7. Comparison between calculation and measurement



(a) Summer　　(b) Winter

Figure 8. Calculation with and without sunspace

over-heating in the room.

(2)Effect of night time insulation and internal ventilation in the winter Figure 9 shows the calculation results of the effect of the night time insulation and the internal ventilation between the sunspace and the rooms. In the case where the night time insulation is installed on the glass walls of the sunspace (Case 5), the sunspace temperature increases to 5°C higher than that in Case 4 with no insulation. The room temperature also increases to 2°C higher than that in Case 4.

In the case where the internal air is naturally ventilated between the sunspace and the room, the rise of the sunspace temperature is controlled and the room temperature increases

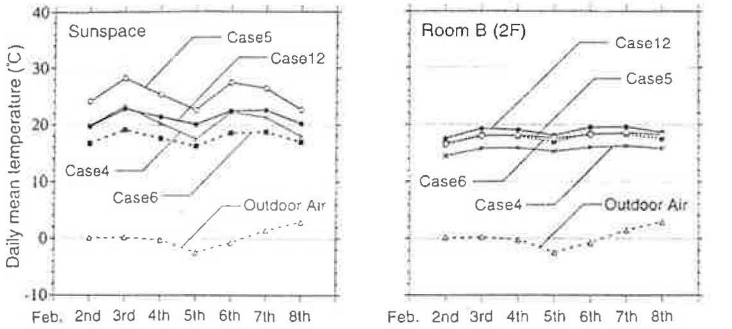


Figure 9. Effect of night insulation and open windows(Winter)

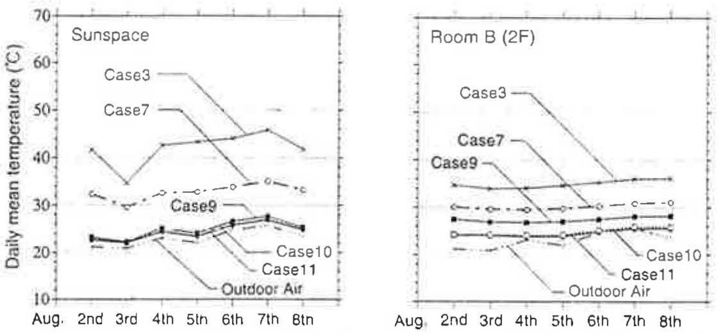


Figure 10. Effect of shading and open windows(Summer)

a little.

In the combination(Case 12) of Case 5 and Case 6, the room temperature increases to 4°C higher than that in Case 4.

(3)Effect of sunshade and night time ventilation in the summer Figure 10 shows the calculation results of the effect of the sunshade and night time ventilation. In the case where the sunspace is installed with the sunshade (Case 7), the sunspace temperature decrease remarkably and the room temperature also decreases. When the sunspace is naturally ventilated through open windows on all days, the sunspace temperature is close to the outdoor temperature and the room temperature decreases by 3°C. In addition, when the room is naturally ventilated through the open windows, both the sunspace temperature and the room temperature are close to the outdoor temperature.

5. CONCLUSIONS

Room temperatures of a passive solar house with sunspace, which is made of concrete with thich insulation, were measured for one year. The room temperature was stable due to the heavy mass during the whole year and the sunspace temperature was influenced greatly by the solar radiation and the natural ventilation.

Calculation results on the effect of the sunspace and the several strategies on the room temperature and the sunspace temperature show that the sunspace is very effective for the room temperature rise in the winter and the night time insulation is especially effective. It is important to install the sunshade and to open windows for ventilation. These effects on indoor temperatures could be estimated by the calculation.

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1. INTRODUCTION

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2. THE TEST BUILDI

The house being simulated in
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