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EFFECTS OF THERMAL INSULATION LOCATED IN THE EARTH AROUND A SEMI-UNDERGROUND ROOM: A TWO-YEAR MEASUREMENT IN A TWIN-TYPE TEST HOUSE WITHOUT AUXILIARY HEATING

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ABSTRACT

In order to obtain fundamental data on the thermal performance of a semi-underground house, a twin-type test house was constructed on a university campus in September 1984. The test house has two rooms with south-facing windows above the ground surface and a corridor between the two rooms. The floor level is 1.3 m below the ground surface. Insulation of 0.1 m depth and 1.35 m width was installed horizontally around the room on the east at a level of 0.3 m below the ground surface. This insulation is called "horizontal insulation." The room on the west has no such insulation. The total heat transmission rate of the construction above the ground surface per unit floor area is about 1.2 W/K·m^2. Both rooms were very airtight, compared to other recently constructed detached houses in Japan. Long-term field measurements were made in two situations: one in which the rooms had weather shutters (from soon after construction until October 8, 1985) and the other in which there were no shutters (from November 1, 1985, to March 31, 1987). There was no auxiliary heating or cooling system during the experiment. Our study clarified that horizontal insulation was effective in reducing the annual temperature fluctuation of indoor air.

INTRODUCTION

In Japan in recent years, underground rooms have been receiving greater attention as a result of the need to increase floor area in detached houses located on narrow sites. Utilizing the underground soil's potential for heat storage is desirable for both energy conservation and thermal comfort.

However, there are many issues that should be analyzed in designing underground constructions. For example, for a semi-underground room that has windows, there are no data on the thermal environment of a room receiving incident solar radiation or of long-term thermal behavior. Research on the thermal environment of the underground room has been done in many countries, but almost all researchers used computer analysis for calculating heating and cooling loads. There are a few papers of detailed measurements in actual underground rooms, which were reported by Grondzik et al. (1981), Bligh and Knoth (1983), Goldberg et al. (1984), Yoshioka et al. (1986), and others.

The purpose of this study was to obtain fundamental information for designing a semi-underground room, especially the effect of thermal insulation located in the earth around the room. For this purpose, a twin-type underground test house was constructed and long-term measurements were made of its thermal performance. This paper reports the results of measurements of temperatures of the test rooms, wall surfaces, earth, outdoor air, and heat flux, which were made for two years and four months with no use of auxiliary heating.

DESCRIPTION OF THE TEST HOUSE

A twin-type test house for the experiment was constructed on a university campus in September 1984. Figure 1 shows the test house viewed from the southeast. The test house has two rooms with a south-facing window above the ground surface and a corridor between the two rooms. The floor plan is shown in Figure 2. The depth of the test rooms is 5.4 m and the width is 2.7 m. The room on the west side is designated Room C, and the room on the east side, Room D. Details of the construction are shown in Figure 3. The floor level is 1.3 m below the ground surface. The side walls of the house above the ground surface

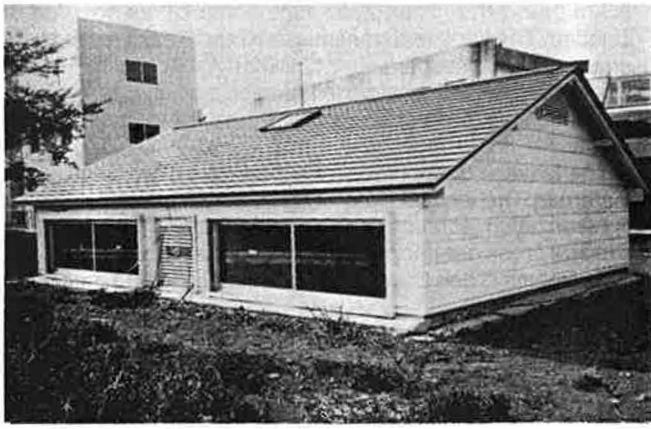

***Figure 1** Exterior of the test house*

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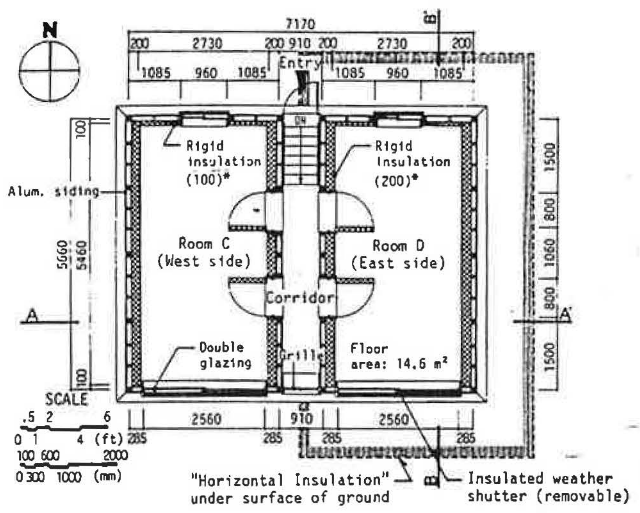


* All insulation are foam polystyrene boards.

Figure 2 Floor plan of the test house

have 0.2 m of foam polystyrene insulation and metal sidings for finishing over the air layer that connects the outdoor air so as to shield the indoor thermal environment from the effect of solar radiation. The wall facing the corridor and the ceiling of each room are insulated with 0.2 m of foam polystyrene to minimize heat flow through the walls and ceiling. This is because the rooms were assumed to be under the room of the first floor and the wall facing the corridor was assumed to be the internal wall. The entrance doors have 0.1 m insulation. During the measurements, the 0.1 m foam polystyrene board was attached to these doors. The height of the south-facing window, which has double glazing, is 0.8 m and the width is 2.56 m. The small windows on the north wall are 0.8 m high and 0.96 m wide. When necessary, these windows can have weather shutters that have 50 mm foam polystyrene.

A portion of the concrete walls, around the ground surface, has 0.1 m insulation. Only Room D is surrounded by insulation 0.1 m deep and 1.35 m wide ("horizontal insulation") at a level 0.3 m below the ground surface. Room C has no such insulation. The total heat transmission rate of each room above ground per unit floor area is 1.17 $W/K \cdot m^2$ (1.01 $kcal/m^2 \cdot h \cdot °C$). Under the floor of the corridor, T-shaped insulation is furnished for minimizing the heat flow through the earth between the two rooms.

The leaks in the building envelope were filled with sealing materials. The results of the airtightness measurement by the pressurization technique are shown in Table 1. The equivalent leakage areas per floor area for the pressure difference of 9.8 Pa in Rooms C and D were 186 and 145 mm^2/m^2, respectively. After 10 months, those values in Rooms C and D were 165 and 174 mm^2/m^2, respectively. Both of the test rooms were very airtight compared to other recently constructed detached houses in Japan (Yoshino 1986).

TABLE 1
Airtightness of Two Test Rooms

Experiment no.		Q_r	n	A_r	A_r*	A_r**
Experiment #1 (with weather shutters)	Room C	38.0	1.87	2710	186	40
	Room D	29.7	1.60	2120	145	31
Experiment #2 (without shutters)	Room C	33.7	1.91	2410	165	35
	Room D	35.6	1.61	2510	174	37

Q_r = air flow rate at reference condition for Δp of 9.8 Pa, where Δp is pressure difference between indoor and outdoor (m^3/h)
n = exponent of the pressure difference (-)
A_r = effective leakage area at the reference condition (mm^2)
A_r* = specific effective leakage area per floor area at the reference condition (mm^2/m^2)
A_r** = specific effective leakage area per exterior wall area at the reference condition (mm^2/m^2)

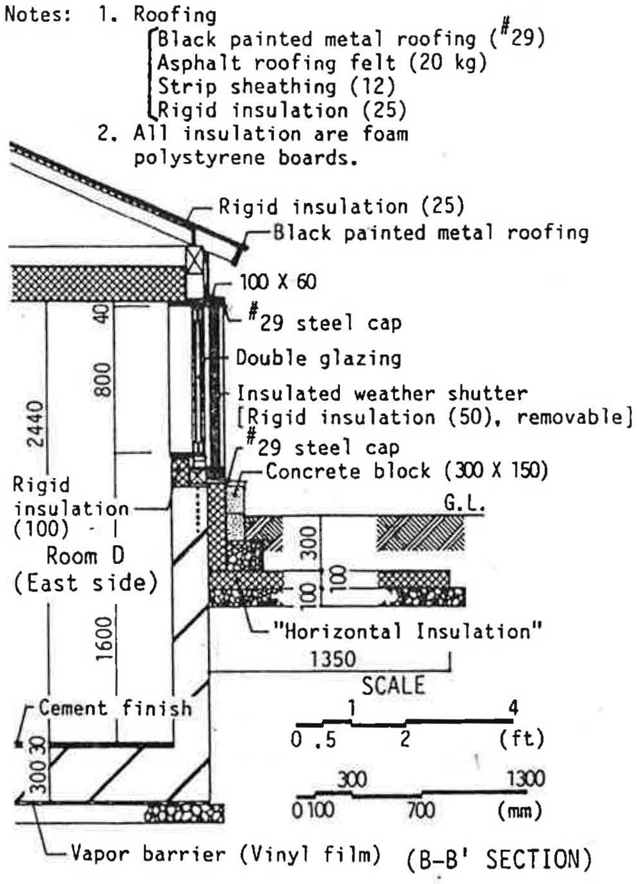

Notes: 1. Roofing
Black painted metal roofing (#29)
Asphalt roofing felt (20 kg)
Strip sheathing (12)
Rigid insulation (25)
2. All insulation are foam polystyrene boards.

Figure 3 Detail of section of the test room (Room D)

DESCRIPTION OF MEASUREMENTS

Measurement Techniques

The temperatures of soil, outdoor air, indoor air, and wall surfaces were measured by copper-constantan thermocouples 0.3 mm in diameter, and the data were stored on computer disks every 20 minutes. The thermocouples used for these measurements were accurate to within ±0.1°C. The thermocouples for measuring air temperatures were covered with aluminum tubes to avoid the influence of radiant heat transfer from their surroundings. The outdoor air temperature was measured in a screen installed on an observation field beside the test house. The indoor air temperature, a key temperature, was measured 1.2 m above the floor level, at the center of the room, and at one-fourth of the room's depth from the northern wall surface (see Appendix A). The positions of the thermocouples are shown in Figure 4. Each pair of thermocouples, arranged in symmetrical positions from the center of the corridor, had the same length and were made from the same lot of wire. There were 135 temperature-measuring points. The outdoor and indoor air humidities were measured by high-polymer humidity sensors with an error range of ±3% and were recorded in the same way as the measurements of temperature. Heat flux through the walls, solar radiation, nocturnal radiation, and incident solar radiation through glazings were also measured. These values, measured every 2 minutes, were integrated and recorded every 20 minutes. Figure 4 includes the positions of the heat flux meters that had an error range of ±5%.

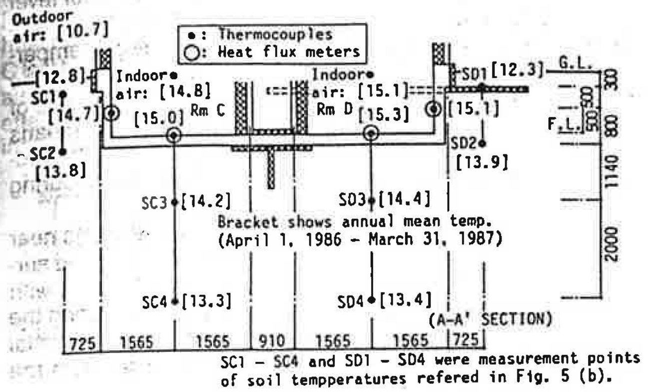


Figure 4 Positions of main measurement points

Experimental Conditions

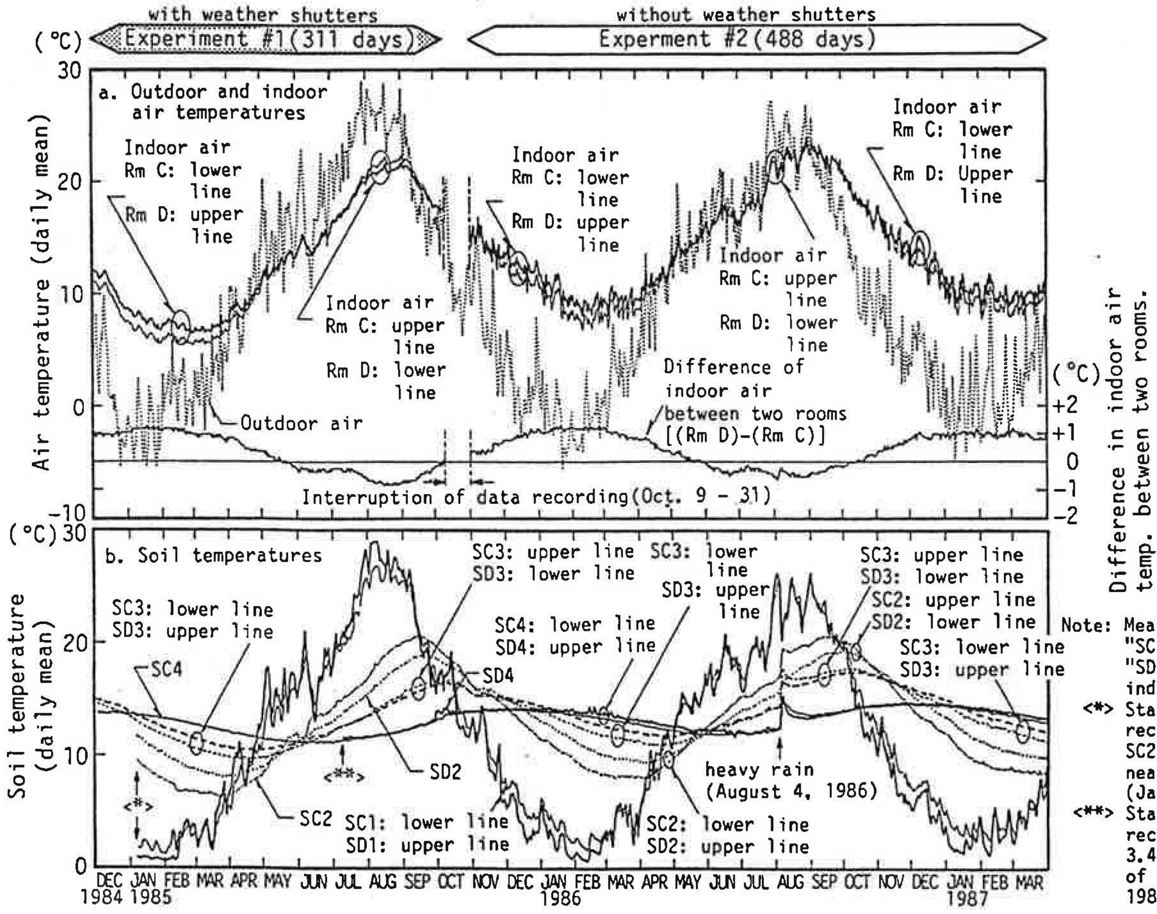
Both rooms had insulated weather shutters during the first year, from December 2, 1984, to October 8, 1985, in order to avoid disturbing the heat gain due to incident solar radiation. During the second year, from November 1, 1985, to March 31, 1987, measurements were made without the shutters. There were no auxiliary heating and cooling systems throughout the experiments. In this paper, measurements for the first year and second year are designated "Experiment #1" and "Experiment #2," respectively. After March 1988, both rooms were heated and maintained at 20°C. The results of that experiment will be reported in the future.

RESULTS OF THE EXPERIMENTS

Long-Term Fluctuation of Temperatures and Heat Fluxes

Indoor Air and Outdoor Air Temperatures Figure 5a shows the temperature profiles of outdoor air and indoor air in both rooms from December 2, 1984, to March 31, 1987. The temperature in each room changed along the curve like a sine wave, and the annual temperature fluctuation was much smaller than that of the outdoor air. In the case of Experiment #1, the differences between the maximum and minimum monthly mean indoor temperatures of Room C and Room D were 0.56 times and 0.50 times, respectively, as large as the difference in outdoor air temperature. In Experiment #2, the differences of Room C and Room D were 0.58 times and 0.52 times, respectively. The daily fluctuations in Experiment #2 without the weather shutters were larger than those in Experiment #1 and were affected by the change in outdoor temperature.

The difference between the daily mean indoor air temperatures of the two rooms is also shown in Figure 5a. The air temperature of Room D with horizontal insulation was slightly higher during the winter and, inversely, slightly lower during the summer than that in Room C. The period when the air temperature of Room D was higher was one-and-a-half months longer than the period when the air temperature of Room D was lower. The maximum temperature difference between the two rooms was 1.2°C during the winter in both experiments. During the summer, those values were 0.8°C and 0.6°C in Experiments #1 and #2, respectively. Although the temperature differences between the two rooms during the winter and summer are small, the temperatures of the inner surface of the envelope and the soil around the rooms were different between the two rooms;



Note: Measurement points "SC1" - "SC4" and "SD1" - "SD4" were indicated in Fig. 4.
<*> Start of data recording of SC1, SC2, SD1, and SD2 near R.C. wall (Jan. 6, 1985)
<**> Start of data recording of SD4 3.44 m below F.L. of Rm D (July 14, 1985)

Figure 5 Temperature profiles of outdoor air, indoor air, and soil

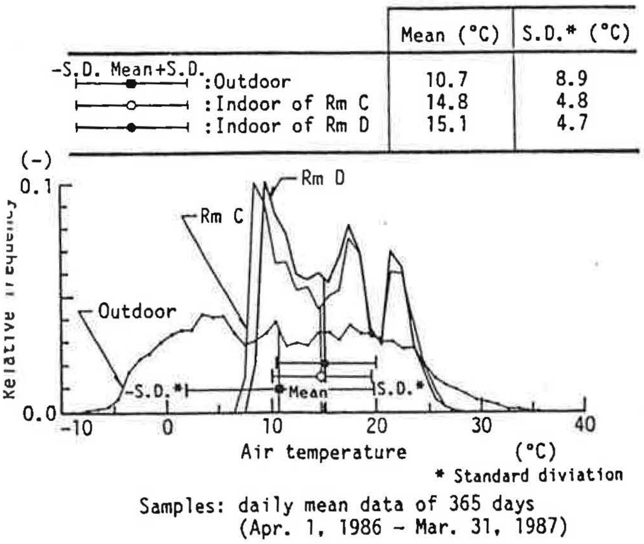


Figure 6 *Frequency distributions of temperatures of outdoor air and indoor air of the two rooms*

also, those temperatures of Room D were higher during the winter and lower during the summer than those of Room C (see Figure 5b and Figure 8). Therefore, it can be said that the small temperature difference has a meaningful significance. These results show that horizontal insulation is effective in reducing the annual temperature fluctuation of indoor air.

Figure 6 shows the frequency distributions of the daily mean temperatures of the outdoor and indoor air of the two rooms in Experiment #2. The distribution of outdoor air temperature shows a trapezoid. The distributions of the two room temperatures have three peaks that show the most frequent temperatures during the winter, middle season, and the summer. The temperature that shows a peak during the winter in Room D with horizontal insulation is 1°C higher than that in Room C, but the temperatures that show peaks during the summer and the middle season are the same in both rooms. The standard deviations of Rooms C and D were calculated to be 4.8°C and 4.7°C, respectively.

Soil Temperatures Figure 5b shows the long-term soil temperatures of the eight points indicated by black circles in Figure 4. The soil temperatures at points 3.44 m below the floor level (SC4 and SD4) were stable. The amplitude of the annual temperature swing was about 2°C. Compared with the soil temperatures at points 1.44 m below the floor level (SC3 and SD3), the heat flow was downward from the end of May to the end of December and upward during the other season. This means that the soil under the floor contributed to decreasing the fluctuation of indoor temperature, serving as a heat source during the winter and as a cool source during the summer.

Comparing the soil temperatures between the points near Room C and Room D, which are 1.6 m below the ground surface (SC2 and SD2), the soil temperature near Room D with horizontal insulation (SD2) was 1°C to 3°C higher during the winter and 1°C to 2°C lower during the summer. The horizontal insulation is effective for protecting the soil itself from the influence of the outdoor temperature.

Yearly Mean Temperatures Figure 4 shows the mean temperatures of soil, indoor air, outdoor air, and so forth, averaged from April 1, 1986, to March 31, 1987. The mean outdoor air temperature was 10.7°C. The mean indoor air temperatures of Rooms C and D were 14.8°C and 15.1°C, respectively. The mean temperatures of various points in the earth were between the outdoor air and indoor air temperatures. The temperatures at the lowest points in the earth under Rooms C and D (SC4 and SD4) were 13.3°C and 13.4°C, respectively. These values are about 3°C higher than the outdoor mean temperature. The earth temperatures on the side of Room D (SD2 to SD4) were a little higher than the earth temperatures on the side of Room C (SC2 to SC4) due to the horizontal insulation. Although the temperature differences of the indoor air, inner surface, and soil between the two rooms are small, the temperatures in and around Room D are 0.1°C to 0.4°C higher than those of Room C, as shown in Figure 4. Therefore, it can be said that those small temperature differences between the two rooms are meaningful.

Heat Flux through the Walls and Floors Table 2 shows the monthly amount of heat flux measured at the points marked in Figure 4. The heat flux during December 1984 through May 1985 was estimated by the method described in Appendix B. The heat flowed through the floors from soil to indoor air during the winter and, inversely, from indoor air to soil during the summer. There was no difference in the monthly amount of heat flux through the floor between the two rooms. The heat flux through the wall of Room D with the horizontal insulation was significantly different from that of Room C without such insu-

TABLE 2
Monthly Total of Heat Flux (December 1987 - March 1987) (MJ/m² · month)

Dec. 2, 1984 - Oct. 8, 1985
Experiment #1: with weather shutters (no solar gain)

Measurement Point		DEC 1984	JAN 1985	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	JAN 1986
Room C	Floor	1.56	2.18	1.41	0.93	-0.60	-2.10	-1.81	-9.84	-10.45	-3.18	---*	2.14	5.30	8.33
	Wall	0.31	0.02	-0.57	-0.94	-1.81	-2.18	-1.21	-0.21	2.35	3.85	---*	-0.70	-4.03	-2.79
Room D	Floor	1.87	2.15	1.68	1.24	-0.30	-2.18	-1.81	-9.66	-10.10	-3.50	---*	2.56	5.06	8.67
	Wall	1.24	1.56	0.56	0.30	-1.21	-2.50	-1.51	-4.00	-2.63	1.83	---*	0.35	0.56	2.52

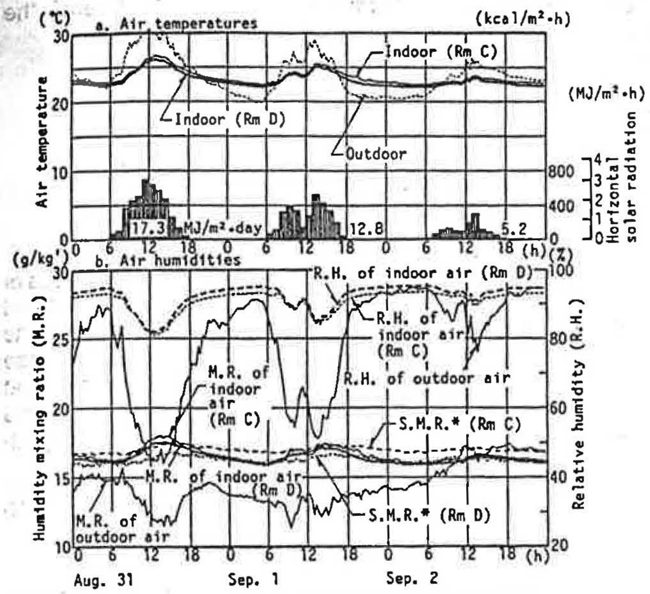
Estimated values** <-+-> Measured values

Nov. 1, 1985 - Mar. 31, 1987
Experiment #2: without weather shutters

(continue)		FEB 1986	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	JAN 1987	FEB	MAR
Room C	Floor	---*	5.87	0.54	-6.56	-6.75	-6.84	-10.32	-7.64	3.69	5.63	7.45	8.40	6.86	10.28
	Wall	---*	-7.09	-5.87	-5.69	-2.69	-2.75	-3.02	-1.63	-2.50	0.35	-0.84	-2.06	-4.90	-3.96
Room D	Floor	---*	5.57	-0.90	-6.84	-6.77	-7.41	-9.79	-9.05	3.32	4.87	6.95	8.22	6.53	9.17
	Wall	---*	-1.06	-3.89	-6.49	-4.54	-4.50	-6.40	-3.58	0.82	3.07	2.24	1.62	0.05	-3.41

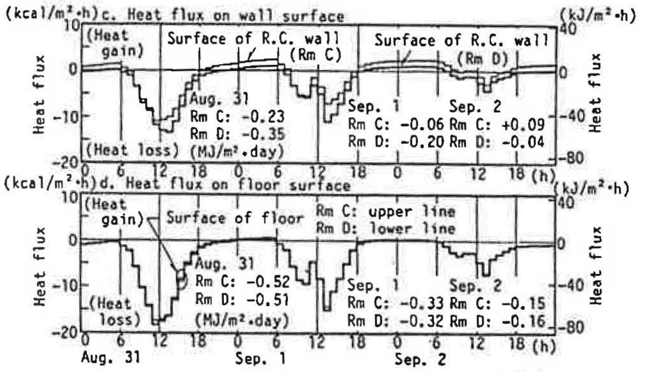
Note: Positive value shows the heat flux from the concrete surface to indoor air.
* No data
** Heat flux meters were installed on June 9, 1985, before which heat flux data were estimated by a correlation analysis using actual data of heat flux and temperature difference between concrete surface and indoor air (see Appendix B).

lation. The values of the flux through the walls measured in February 1985 and in February 1987 show that Room D gained heat from the soil beneath the horizontal insulation and Room C lost heat through the soil near the wall to the outdoor air. It was also found that Room D was cooled during the summer more effectively than Room C. These results show that horizontal insulation is effective in utilizing heat stored in the soil.



*S.M.R. means saturated humidity mixing ratio for temperature of a measurement point located on the center of north-half of floor surface

Figures 7a and 7b *Typical hourly fluctuations of temperatures and humidities during the summer in Experiment #2 (Aug. 31-Sept. 2, 1986)*

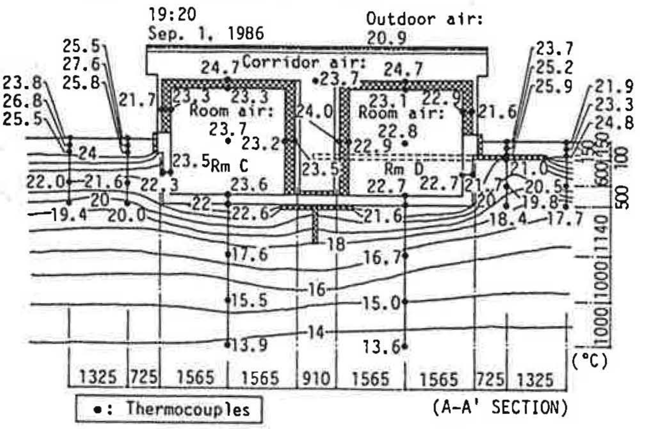


Figures 7c and 7d *Typical hourly fluctuations of heat fluxes during the summer in Experiment #2 (Aug. 31-Sept. 2, 1986)*

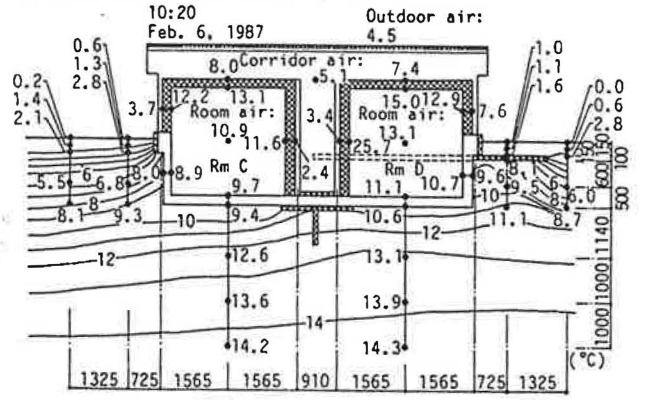
Indoor Thermal Environment during the Summer in Experiment #2

Figure 8a shows the isotherms in the earth at 19:20 on September 1, 1986, when the temperature difference between the two rooms was maximal during the summer. Figure 7 shows the profiles of temperature, humidity, and heat flux for three days including September 1.

Indoor Air Temperature and Humidity As shown in Figures 7a and 7b, the temperature of Room C was always higher than that of Room D for these three days. The mean temperatures of Rooms C and D were 23.6°C and 23.3°C, respectively, and the widths of temperature swing were 1.3°C to 3.9°C and 1.3°C to 3.7°C, respectively. A slight difference in the width between the two rooms occurred on a day with a lot of sunshine. The widths of the temperature swing of both rooms during the same period in Experiment #1 were about 1°C (Hasegawa et al. 1987, 1988).



a. Isotherms at 19:20 on Sep. 1, 1986



b. Isotherms at 10:20 on Feb. 6, 1987

Figure 8 *Typical soil isotherms during the summer and the winter in Experiment #2*

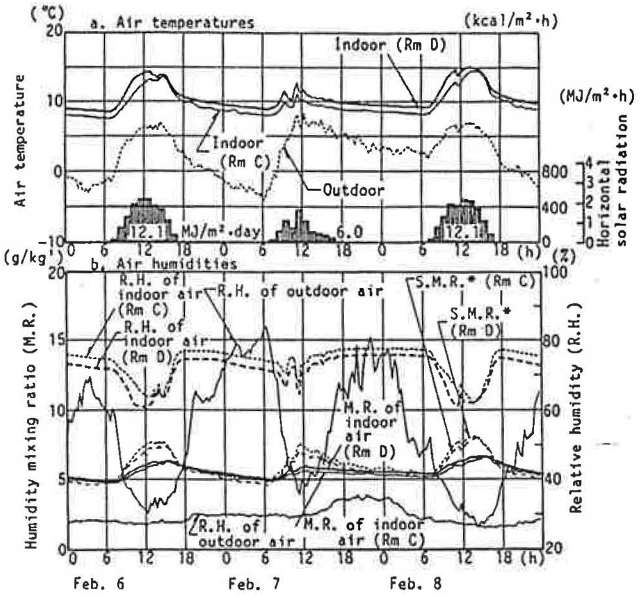
The humidity of both rooms was around 90%. Among the measuring points of the internal surface temperature in each room, the lowest temperature appeared at the floor surface on the north side. The saturated humidity mixing ratio corresponding to this floor surface temperature in each room was near that of the room air. Therefore, there possibly was vapor condensation, but it couldn't be found by observation from the outside through the windows. Compared with the humidity mixing ratio measured during the summer in Experiment #1, the humidity mixing ratio in Experiment #2 was about 4 g/kg' less, because the indoor humidity was extracted due to the windows being opened before the beginning of Experiment #2.

Heat Flux through Walls under the Ground Surface and Floor Figures 7c and 7 d show the profiles of heat flux over three days. The heat flux through the wall under the ground of Room D with the horizontal insulation was below the heat flux of Room C, which means the soil around Room D acted more effectively as a cool source than the soil around Room C. There is no difference between the profiles of heat flux through the floors of the two rooms. The heat through the floor flows from the room to the soil consistently during this period.

Soil Isotherms Figure 8a shows that the temperature in the soil under the horizontal insulation of Room D was less than that of the corresponding points in the soil of Room C and that the isotherms below the horizontal insulation rose like a hill. It is estimated that the heat flows down to the right from the underground wall to the soil.

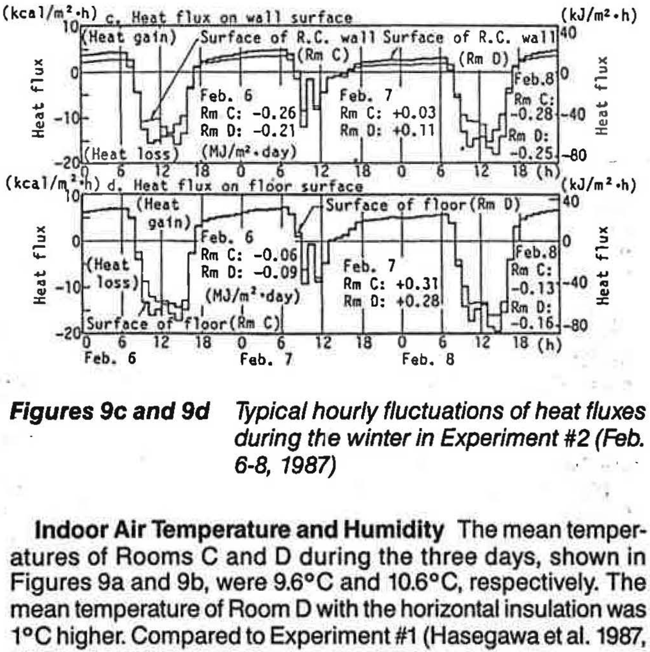
Indoor Thermal Environment during the Winter in Experiment #2

Figure 8b shows the isotherms in the earth at 10:20 on February 6, 1987, when the temperature difference between the two rooms was maximal during the winter. Figure 9 shows the profiles of temperature, humidity, and heat flux for three days including February 6, 1987.



* S.M.R. means saturated humidity mixing ratio for temperature of a measurement point located on the indoor glazing surface of north window.

Figures 9a and 9b *Typical hourly fluctuations of temperatures and humidities during the winter in Experiment #2 (Feb. 6-8, 1987)*



Figures 9c and 9d *Typical hourly fluctuations of heat fluxes during the winter in Experiment #2 (Feb. 6-8, 1987)*

Indoor Air Temperature and Humidity The mean temperatures of Rooms C and D during the three days, shown in Figures 9a and 9b, were 9.6°C and 10.6°C, respectively. The mean temperature of Room D with the horizontal insulation was 1°C higher. Compared to Experiment #1 (Hasegawa et al. 1987, 1988), the mean room temperature in Experiment #2 was 3°C to 4°C higher due to the incident solar radiation, but the temperature difference between the two rooms was the same. The width of the temperature swing in a day was larger in Room D in a day with a lot of sunshine and smaller in Room D in a day with little sunshine. The relative humidity was about 70%. From the middle of November to the beginning of April, vapor condensation occurred occasionally on the windows in the north walls of both rooms.

Heat Flux through Walls under the Ground Surface and Floor As shown in Figures 9c and 9d, there was heat flow from the room to the envelope during the day. Conversely, during the night, it flowed from the envelope to the room. The daily amount of heat storage at two points in each room was about 30 kJ/m^2 larger in Room D on February 6 and 8. The amount of heat released from the floor during the night was the same between the two rooms, but the amount of heat released from the walls of Room D was larger, which shows the effect of the horizontal insulation.

Soil Isotherms Figure 8b shows that the temperature in the soil around Room D under the horizontal insulation was higher than that around Room C. The heat flowed from the walls to the earth in both rooms. The direction of heat flow was diagonally upward in the case of Room C and diagonally downward in the case of Room D.

ANALYSIS OF THE EFFECT OF SOLAR HEAT GAIN AND HORIZONTAL INSULATION ON ROOM TEMPERATURE

Solar Heat Gain and Monthly Mean Room Temperature

The heat gain per month from the soil to the room was estimated and compared between the two rooms on the basis of the monthly amount of solar heat gain through the glazings and monthly mean indoor-outdoor temperature difference. It was assumed that the heat loss per month from the room envelope above the ground surface was balanced with the monthly heat gain due to the incident solar radiation through the glazings and from the room envelope below the ground surface, disregarding air infiltration. The heat balance equation is:

$$\Sigma UA \cdot \Delta T_m = HG_s + HG_b \tag{1}$$

where

ΣUA = total transmission rate of the room envelope above the ground surface, MJ/month·K

ΔT_m = monthly mean indoor-outdoor temperature difference, K

HG_s = monthly amount of the heat gain due to incident solar radiation, MJ/month

HG_b = monthly amount of the heat gain from the room envelope below the ground surface, MJ/month

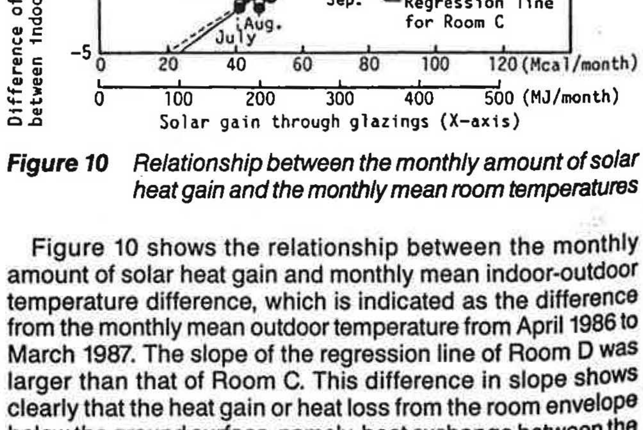


Figure 10 *Relationship between the monthly amount of solar heat gain and the monthly mean room temperatures*

Figure 10 shows the relationship between the monthly amount of solar heat gain and monthly mean indoor-outdoor temperature difference, which is indicated as the difference from the monthly mean outdoor temperature from April 1986 to March 1987. The slope of the regression line of Room D was larger than that of Room C. This difference in slope shows clearly that the heat gain or heat loss from the room envelope below the ground surface, namely, heat exchange between the room air and the soil around the room, cannot be disregarded and that the horizontal insulation around the room influences its amount.

For example, in January, the indoor-outdoor temperature difference in Rooms C and D was 9.4°C and 10.4°C, respectively. The heat loss through the envelope above the ground surface was calculated as 456 MJ and 507 MJ, respectively. The solar heat gain in January was measured at 435 MJ. Therefore, the heat gain through the envelope under the ground surface in Rooms C and D was estimated at 21 MJ and 72 MJ, respectively, using Equation 1. The amount of heat gain in Room D with the horizontal insulation is 51 MJ greater than that of Room C. It can be said that this value is the necessary heating load for Room C in order to keep the indoor temperature of Room C equal to that of Room D. In the same manner, in order to equalize the indoor temperature between Room C and Room D, the annual heating and cooling loads required are estimated at 251 MJ and 59 MJ, respectively.

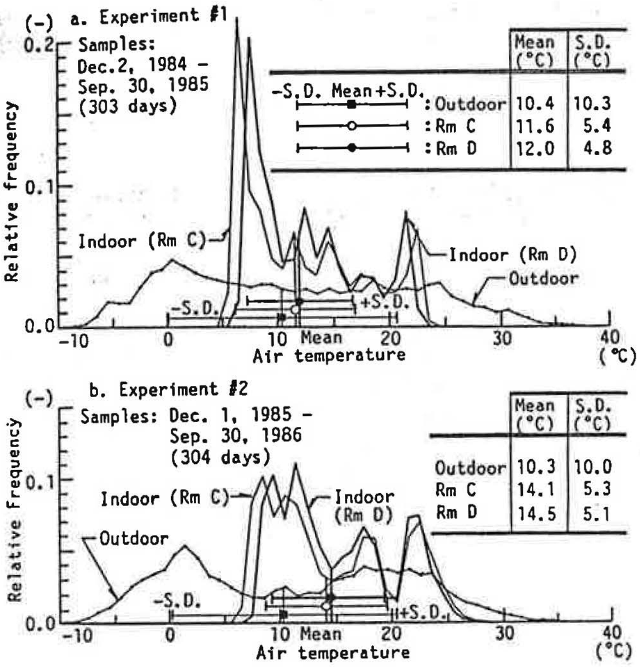


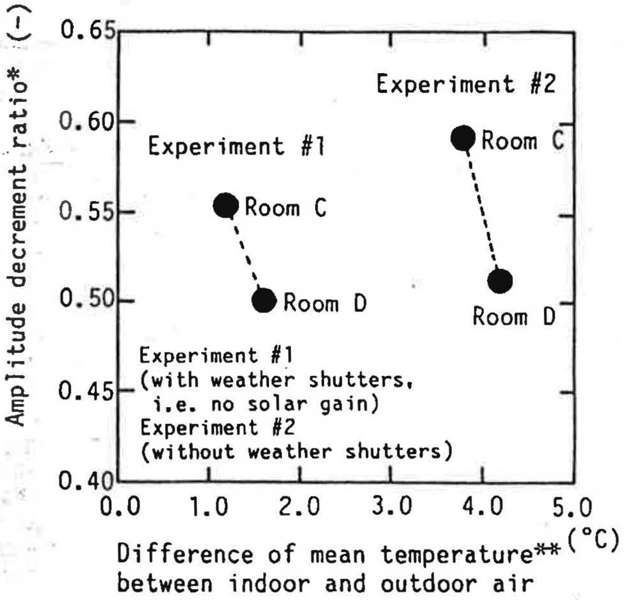
Figure 11 *Frequency distributions of temperatures of outdoor air and indoor air in Experiments 1 and 2*

Comparison of Frequency Distributions of Room Temperatures

Figure 11 shows the frequency distributions of the indoor temperatures of Rooms C and D and outdoor air temperature in both Experiments #1 and #2. The data came from the period between December and September of the following year. In Experiment #2, the room temperatures are distributed in a higher range and the peaks during the winter are smaller than those in Experiment #1.

Yearly Mean Room Temperature and the Maximum Difference in Monthly Mean Room Temperature

Figure 12 shows the effects of solar heat gain and the horizontal insulation by comparing the four measured values of indoor temperature of the two rooms in Experiments #1 and #2. The x-axis indicates the difference in mean temperature between indoor and outdoor air for 10 months. The y-axis indicates the ratio of the maximum difference in monthly mean temperature of indoor air to that of outdoor air. The solar heat gain caused the rise of the mean room temperature to 2.5°C. The maximum difference in monthly mean room temperature decreased about 10% due to the installation of the horizontal insulation in both Experiments #1 and #2.



Note:

* (amplitude decrement ratio)

$$= \frac{\text{(maximum - minimum difference in monthly mean temperature of indoor air)}}{\text{(maximum - minimum difference in monthly mean temperature of outdoor air)}}$$

** Mean air temperatures were calculated on basis of the data recorded from Dec. 1984 to Sept. 1985 for Experiment #1 and from Dec. 1985 to Sept. 1986 for Experiment #2.

Figure 12 *Comparison of air temperatures in both rooms between Experiment #1 and Experiment #2*

SUMMARY OF OBSERVATIONS

1. The amplitude of the yearly fluctuation in room temperature was 0.5 to 0.6 times as large as that of outdoor temperature. The amplitude of the room with horizontal insulation in the earth was about 10% smaller than that of the other room without such insulation in both Experiments #1 and #2, and this result implies that the reduction of the effect of horizontal insulation was not influenced very much by incident solar radiation. The difference in daily mean temperatures between Rooms C and D in February was 1.2°C at its maximum in both experiments.
2. The isotherms in the soil covered with horizontal insulation 0.3 m below the ground surface were very different from those in the soil without such insulation. The temperature of the soil covered with insulation was 1°C to 3°C higher during the winter and 1°C to 2°C lower during the summer than the soil temperature without insulation. The horizontal insulation was effective in shielding the soil itself from the influence of the outdoor temperature.
3. The yearly mean indoor temperature of Room D and the soil temperatures around Room D were 0.3°C higher at the maximum than those of Room C due to the effect of the horizontal insulation.
4. The mean room temperatures during Experiment #2 were about 3°C higher than those during Experiment #1 due to the heat gained by solar radiation.

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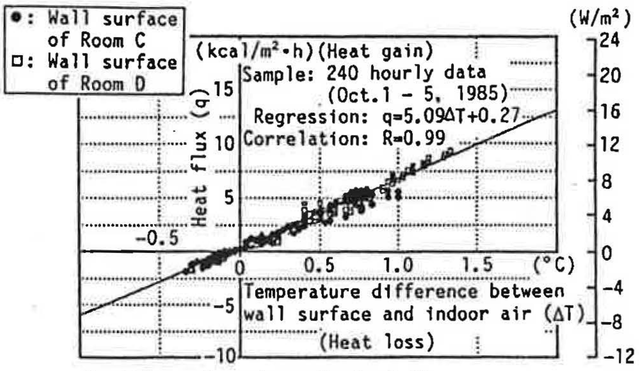
APPENDIX A

The room temperature distribution was examined by measuring vertically at the five points of 50, 500, 1200, 1900, and 2350 mm above the floor level at the same position as that of the key temperature and also horizontally at the three points of one-fourth, one-half, and three-fourths of the room depth from the northern wall surface, which were 1.2 m above the floor level.

During the night and a day with a little solar radiation, the temperature difference between the different points was less than 0.2°C. During a day with a lot of solar radiation, the vertical temperature difference was 2.5°C and 2.1°C at the maximum for Room D and Room C, respectively, and the horizontal temperature distribution was 0.8°C at the maximum.

APPENDIX B

It was clarified using the data from October 1 to 5, 1985, that heat flux has a positive correlation with the difference between room air and the concrete surface of the envelope situated near the heat flux meter. For example, the relationship for the wall surface is shown in Figure A1. The heat fluxes for the wall and the floor were estimated on the bases of the regression lines between those two factors.



Positive value shows the heat flux from the R.C. wall surface to indoor air

Figure A1 *Relationship between the wall surface-indoor air temperature difference and the heat flux on wall surface*

DISCUSSION

Jeff Christian, Oak Ridge National Laboratory, Oak Ridge, TN: Why did you not use auxiliary heating? How can you determine the cost-effectiveness of foundation insulation without saving auxiliary heating and mechanical cooling energy?

H. Yoshino: This is the first-stage experiment. In the second stage, since January 1988, auxiliary heating has been used. The study of cost-effectiveness of insulation will follow in the future.