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INDOOR CLIMATE AND ENERGY CONSUMPTION OF SUPER INSULATED HOUSES IN A MILD CLIMATE REGION OF JAPAN

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INTRODUCTION

Two super insulated houses were built according to the Canadian R-2000 construction manual, in Sendai, Japan. The purpose of the construction is to clarify how much space heating energy is saved in a mild climate, and whether there are any problems related to indoor air quality and humidity in the winter and the thermal indoor environment during the summer, compared with an ordinary frame-construction house.This paper describes the measurment results of indoor temperature, humidity snd indoor air guality for the winter and summer seasons, and annual energy consumption.

CLIMATIC CONDITIONS OF SENDAI, JAPAN

Honshu main island of Japan is located at a northern latitude of between 30 and 40 degrees. Although the area of Japan is small, it has various climatic conditions. With heating degree days, based on a room temperature of 18°C and a daily mean outdoor temperature of 16°C at which space heating is used, two areas are characterized by more than 3000 heating degree days: the northern Tohoku District and Hokkaido, and the mountain areas in the Chubu district in the centre of Honshu Island. One-tenth of the population in Japan lives in these areas.

The city of Sendai with 2500 heating degree days based on 18°C,where the two R-2000 houses are situated, has a mean outdoor temperature of 1°C and 24°C in January and August, respectively. The mean relative humidity is 68% and 82% in January and August, respectively.

TWO HOUSES FOR MEASUREMENT

Two houses will be discussed, an ordinary wood-frame-construction house (House K) and a R-2000 house (House S). Figure 1 shows the floor plans of a R-2000 house. The floor area of House K and House S is 120m^2 and 165m^2,respectively. The windows of a R-2000 house has double panes. Those of House K have single panes. In a R-2000 house, the walls are composed of both 5 cm polystyrene foam insulation and 14 cm fiberglass insulation, while House K has 10 cm mineral wool insulation. House K has a hot water heating system with a fan convector in each room. But actually, only the fan convector in the living room was used. House S has a water heating system with panel radiators. House S has a central duct system for ventilation with an air-to-air heat exchanger. House K has a sensible heat exchange type with a bypass for taking in outdoor air.

Heat loss coefficient per floor area is 1.72 kcal/m^{2}h°C(2.0W/m^{2}K) and 0.80 kcal/m^{2}h°C (0.93 W/m^{2}K) for House K and House S, respectively, as measured by Matsuo's method (Matsuo 1981) on the basis of indoor-outdoor temperature difference and intermittent space heating

energy consumption. Airtightness of the house envelope was measured by the fan pressurization method and was expressed as an equivalent leakage area (ELA) per floor area for the indoor-outdoor pressure difference of 9.8 Pa. The ELA for House K and House S was 2.85 cm^2/m^2 and 0.37 cm^2/m^2, respectively. The airtightness standard for Canadian R-2000 homes can be converted into an ELA of 0.9 cm^2/m^2. It can be said that the R-2000 house are extremely airtight and House K is slightly airtight.

TEMPERATURE AND HUMIDITY IN THE WINTER AND THE SUMMER

Daily Profiles in the Winter

Figure 2 shows temperature and humidity profiles of two houses averaged for a week during the winter. The livings were occupied during the mentioned period. Occupant behaviour was not normalized.

1) House K The dining-living room temperature measured at a point 1.1m above the floor level was 18°C - 24°C from 8 am to 12 pm. But, after the heater was turned off, the room temperature fell rapidly and became 12°C by daybreak. The temperatures of the master bedroom and the Japanese-style room were lower and remained between 9°C and 13°C all day long. The relative humidities of the living- dining room and the Japanese-style room were between 40% and 45%.

2) House S The temperatures of three rooms varied between 13°C and 20°C. The difference between the temperatures of these three rooms was small. An electric heater "Kotatu" was used in the living room for local heating. A "Kotatu" is a Japanese style electric heater which is mounted under a low table covered with a quilt. People sitting on the floor heat their legs under the low table. The relative humidity of the dining-living room is 39% -43%.

Daily Profiles in the Summer (No Air-Conditioning)

Figure 3 shows temperature and humidity profiles of two houses averaged for a week during the summer.

1) House K Windows were open during the day and closed during the night. The temperatures of the dining-living room and the master bedroom were higher than the outdoor temperature all day long. The relative humidities varied between 55% and 70%.

2) House S During the day, windows were open and during the night, windows were closed. The mechanical ventilation system was always in operation. The temperatures of the three rooms were stable all day long From 9 am to 3 pm, the indoor temperature was a little lower than the outdoor temperature. During the night, the indoor temperature did not drop even though the air-to-air exchanger was not used. The relative humidity of the dining-living room varied between 70% and 85%.

COMPARISON OF THERMAL ENVIROMENT IN VARIOUS HOUSES IN THE WINTER

The room temperatures of various houses in the Tohoku District were measured by the authors (Hasegawa and Yoshino 1987). The number of houses was 139. The thermal environment of the three houses reported in this paper is compared to that of the other houses. The mean room temperatures during the evening family time after supper were used for comparative analysis of thermal environment. The 141 houses including the two R-2000 houses were categorized into seven groups except for House K as follows:

A. "PHC Houses" sold by the public housing corporation in the main eight cities of the Tohoku District (78 houses, constructed in 1968-1979).

B. "Rural Houses" in the rural area of Yamagata Prefecture(30 houses, constructed before 1978).

C. "Village Houses" in a rural village of Iwate prefecture(9 houses, constructed in 1970-1981 except for one old house).

D. "Insulated Houses" with a kerosene or gas space heater in the city of Sendai (7 houses, constructed in 1981-1984).

E. "Floor Heated Insulated Houses" with floor heating in the city of Sendai (6 houses, constructed in 1982-1984). These houses have concrete floors, including hot water pipes for heating and thermal insulation between the floor and the ground.

F. "R-2000 Houses" reported in this paper.

G. "Multi-Family Houses" constructed of reinforced concrete in the city of Sendai (9 houses, constructed in 1964-1971).

Vertical Temperature Difference in the Living Room

Figure 3 shows the relationship between the vertical temperature difference and the indoor-outdoor temperature difference. The vertical temperature difference is the temperature difference between 5 cm and 1.1 m above the floor level. These temperatures were averaged during the evening family time. The vertical temperature differences are slight in the Floor Heated Insulated Houses and the R-2000 houses. There are three data for House S measured in the winters of three years, 1989, 1990 and 1991. But, except for these houses, the vertical temperature difference is distributed between 3°C and 14°C and the ratio of the temperature difference between 5 cm and 1.1 m above the floor to the temperature difference (non-dimensional vertical temperature) ranges from 0.18 to 0.55. The vertical temperature difference in some of the PHC Houses and Rural Houses is significantly large and that in Insulated Houses rather small. The vertical temperature difference of House K is relatively large.

Temperatures of Lavatory and Corridors

Figure 4 shows the temperature difference between the living room and the lavatory or the temperature difference between the living room and the corridor averaged during the evening family time for the measurement period. Each temperature is indicated as the difference from the outdoor temperature. Temperatures of the lavatory and corridor in the Rural Houses and the Village Houses, including House K, are between 2°C and 5°C while the living room temperature is 20°C. Corresponding temperatures in the Insulated Houses, the Floor Heated Insulated Houses and the R-2000 Houses are between 8°C and 18°C for the lavatory and corridor, while that of the living room is 20°C. The distribution of the temperature is due to the differences in the levels of thermal insulation and airtightness, and the types of space heating systems employed.

AIR TIGHTNESS AND AIR QUALITY

Figure 5 shows the relationship between the effective leakage area per floor area, Ar^* and the daily mean concentration of CO_2, including the other houses in Sendai measured by Yoshino et al (1986 and 1990). This also includes the data obtained by spot measurements(Kamata 1989) in houses in Sapporo, the main city of the Hokkaido District. The concentration of CO_2 was very high for two houses with unvented portable kerosene heaters. With the exception of these two houses, the CO_2 concentration in may houses with Ar^* less than a rank of 3 was more than 1000 ppm. The CO_2 concentration in R-2000 houses was relatively lower due to continuous mechanical ventilation.

ANNUAL AMOUNT OF ENERGY CONSUMPTION

Figure 6 shows the distributions of the annual amount of energy consumed for space heating, water heating and others by the three houses; these distributions are compared with the mean values for houses in all of Japan, in the Tohoku District and in the Hokkaido District in 1988 (Nakagami 1989). The total energy consumption for House K and House S is between the average for all of Japan and of the Tohoku District. The share of energy consumed for space heating is 30% for all of Japan, 50% for the Tohoku District and 70% for the Hokkaido District. The reason why the amount of energy consumption for space heating in the Tohoku District is

less than that in the Hokkaido District is not only differences of climatic conditions but also differences of heated space ratio, that is, only the living room is heated in almost all houses in the Tohoku District. But the share of space heating energy consumption for House S with heavy insulation is 28% and also the amount of space energy consumption is less than that of House K, in which only the living-dining room was heated. It can be said that a thermally comfortable environment can be obtained in a super insulated house without an increase of space heating energy consumption.

CONCLUSIONS

1) The result of the airtightness test showed that a super insulated house constructed according to the Canadian R-2000 manual was very airtight compared with the other houses.

2) Indoor environment during the heating season of the super insulated house was more thermally comfortable, compared with that of houses in general in Japan. During the summer, the indoor temperature in this house was stable with respect to the outdoor temperature in the day and did not decrease at night time even if the outdoor air temperature dropped. In order to keep indoor temperature from rising during the summer, it is important to install adequate shading devices to prevent solar radiation from entering the rooms.

3) The CO_2 concentration in the super insulated houses was lower than that of the other airtight houses due to continuous mechanical ventilation.

4) The amount of space heating energy consumption for a super insulated house was less than that of ordinary houses in Tohoku District in which only the living dining room was heated.

5) It was concluded that super insulated houses constructed in a mild climate region of Japan realized thermally comfortable indoor environment with no problems related to indoor air quality and in increasing energy consumption.

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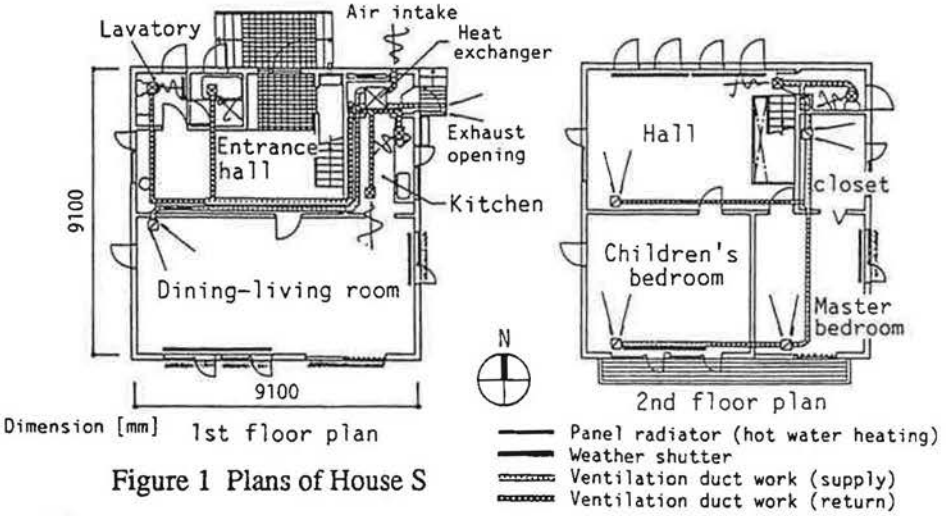


Figure 1 Plans of House S

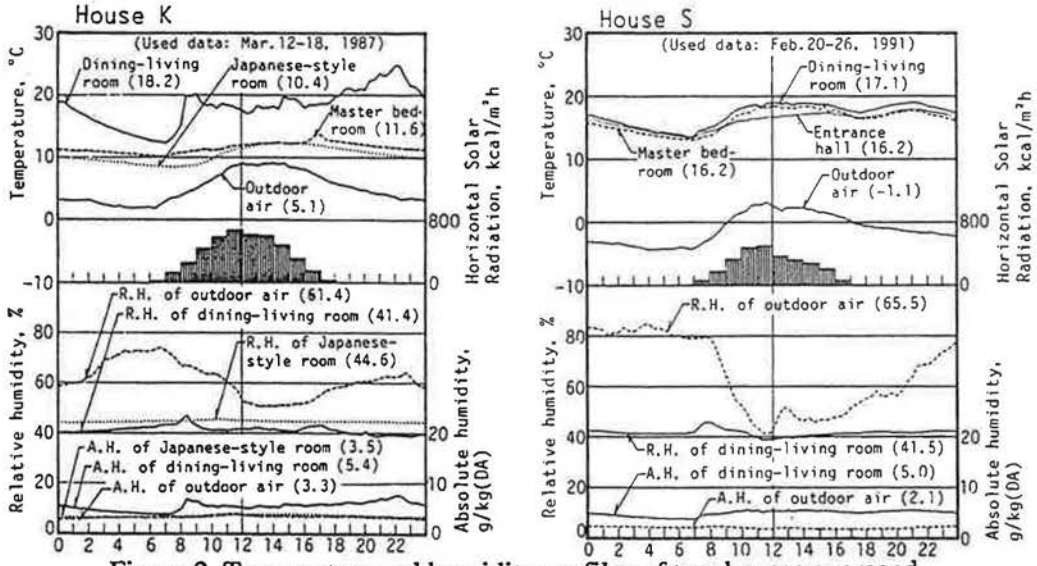


Figure 2 Temperature and humidity profiles of two houses averaged for a week during the winter

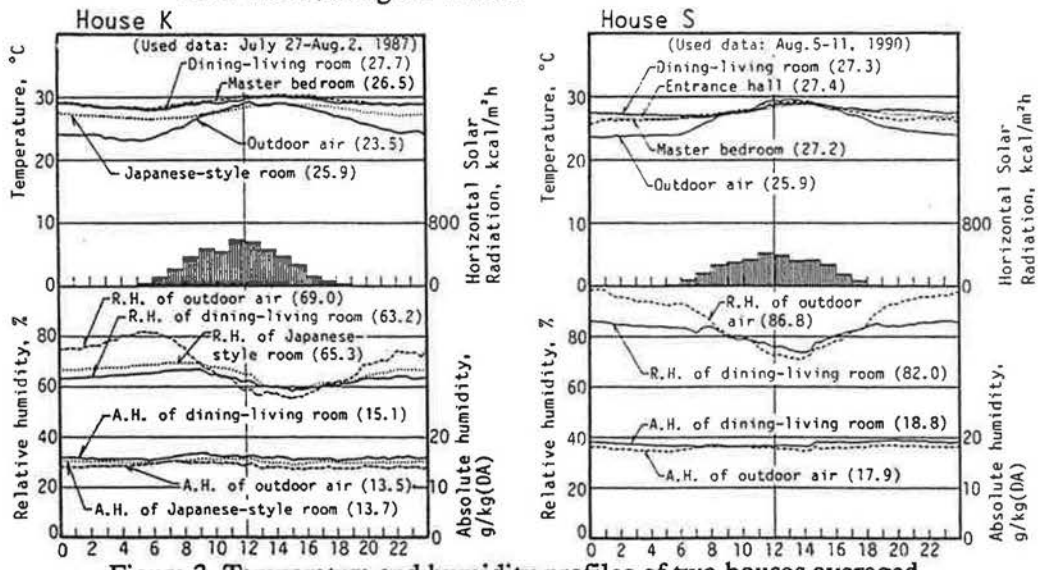


Figure 3 Temperature and humidity profiles of two houses averaged for a week during the summer

The figure in parentheses shows a mean value.

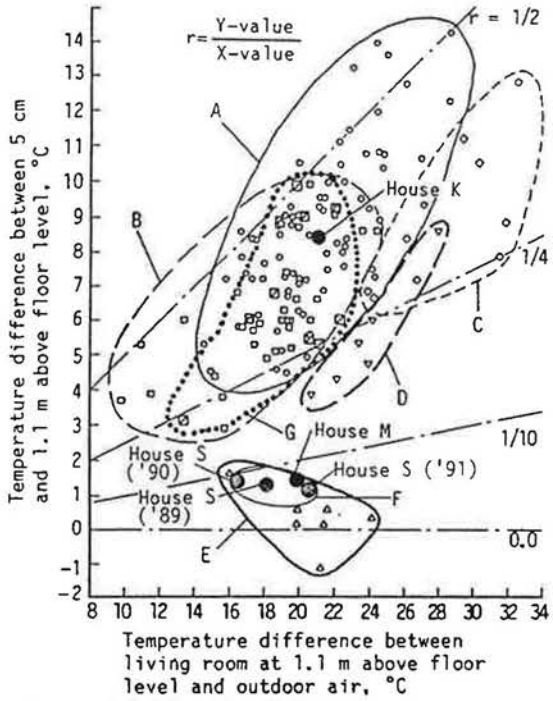


Figure 4 Living (or dining-living) room temperature and vertical temperature difference during the evening family time

A : "PHC Houses" sold by the public housing corporations in the main 8 cities of the Tohoku District (78 houses, constructed in 1968-1979).
B : "Rural Houses" in rural areas of Yamagata Prefecture (30 houses, constructed before 1978).

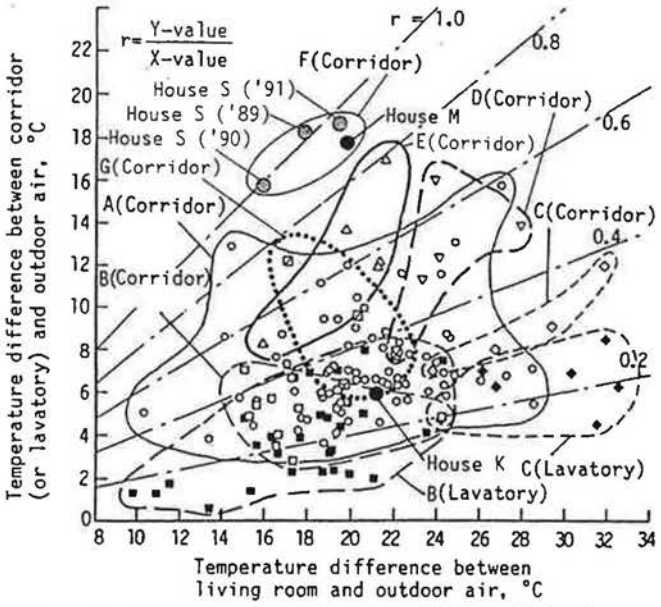
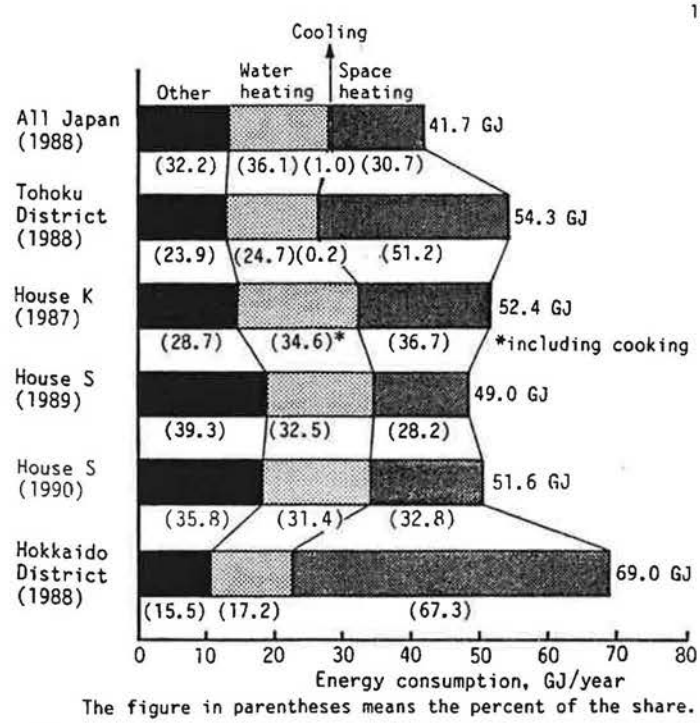


Figure 5 Temperature of living (of dining-living) room and corridor (or lavatory) during the evening family time

C : "Village Houses" in a rural village of Iwate Prefecture (9 houses, constructed in 1970-1981 except for one old house).
D : "Insulated Houses" with a space heater in the city of Sendai (7 houses, constructed in 1981-1984).
E : "Floor Heated Insulated House" with floor heating in the city of Sendai (6 houses, constructed in 1982-1984).
F : "R-2000 Houses" built in accordance with the Canadian R-2000 Manual in the city of Sendai (2 houses, constructed in 1988)
G : "Multi-Family Houses" constructed of reinforced concrete in the city of Sendai (9 houses, constructed in 1964 and 1971).



The figure in parentheses means the percent of the share.

Figure 6 Mean CO_2 concentration during a week and eguivalent leakage area per floor area

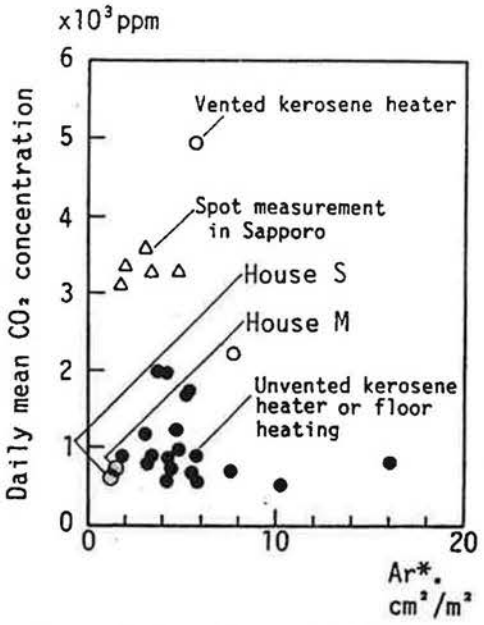


Figure 7 Annual amount of energy consumption for a dwelling