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EFFICIENCY OF SOLAR RADIATION ON HEATING ENERGY CONSERVATION OF RESIDENTIAL BUILDINGS

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ABSTRACT

In this paper, energy saving potential utilizing the heating effect of solar radiation is analyzed by simulation. The dynamic simulation software "THERB[1)]" is used, and the effect of solar radiation on energy saving is explained for several simulation conditions. In addition, the heating load of energy-efficient housing is compared with that of standard housing.

INTRODUCTION

In recent years, concern for the environment has increased markedly, and consequently the demand for sustainable housing has risen. On this basis, the evaluation model, from the Institute for Building Environment and Energy Conservation: CASBEE – home (detached house) assessment manual[2)], was proposed as a system to evaluate the environmental performance of buildings. Under the heading "Using energy and water conservatively" we investigated the amount of the heating and cooling energy reduction possible by using renewable energy sources such as solar and wind power. It is necessary to examine the effect of reducing heating loads in particular, and this research aims to clarify by simulation the amount of heating load reduction possible via the heating effect of solar radiation for a typical detached house.

OUTLINE OF SIMULATION

The evaluation method

The evaluation method of the "CASBEE – home (detached houses)" is shown in Table 1. The heating energy reduction is calculated by the combination of the construction area (Table 2), the obstacles to solar irradiance (Table 3), the building direction (Table 4) and the utilization of renewable energy sources (Table 5). The actual energy used is primarily influenced by the performance of individual air-conditioning units, therefore our research calculates the heating loads only.

Load data of model

We used the dynamic simulation software "THERB", which estimates the hygrothermal environment and space conditioning load of buildings under typical living conditions, the standard house model from the "Architectural Institute of Japan" and the "Expanded AMeDAS Weather DATA[3)]" for climate conditions. The air-conditioning schedule was set by SCHEDULE Ver.2.0,

Table 1
Heating load reduction

Area	Heating energy reduction	Location 3		Location 2		Location 1
		Direction1	Direction2	Direction1	Direction2	
Area 1 Area 2	Approximately 10%	Method 1 Methods 1+2 Methods 1+3	Method 1 Methods 1+2 Methods 1+3 Methods 1+2+3			
	Approximately 20%	Methods 1+2+3				
Area 3	Approximately 10%	Method 1	Method 1	Methods 1+2+3	Methods 1+2+3	
	Greater than 20%	Methods 1+2 Methods 1+3 Methods 1+2+3	Methods 1+2 Methods 1+3 Methods 1+2+3			
Area 4 Area 5	Approximately 10%	Method 1	Method 1	Methods 1+2	Methods 1+2+3	
	Greater than 20%	Methods 1+2 Methods 1+3 Methods 1+2+3	Methods 1+2 Methods 1+3 Methods 1+2+3	Methods 1+2+3		

Table 2

Construction areas

Area name	Feature
Area 1	Cold areas where amount of solar radiation is very low.
Area 2	Cold areas where amount of solar radiation is low.
Area 3	Cold areas where amount of solar radiation is high.
Area 4	Areas where amount of solar radiation is high.
Area 5	Hot areas where amount of solar radiation is high.

Table 4

Details of directions

Direction name	Direction of heat collection aspect
Direction 1	±15° from due south
Direction 2	±30° from due south

Table 3

Location details

Location	Level of obstacles to solar irradience	Standard duration of sunshine
Location 1	Obstacles block about 50% of available solar radiation.	Solar radiation is obtained for more than 3 hours. e.g between 10:30 and 13:30
Location 2	Obstacles block about 25% of available solar radiation.	Solar radiation is obtained for more than 5 hours. e.g between 9:30 and 14:30
Location 3	Obstacles block about 0% of available solar radiation.	Solar radiation is obtained all day.

Table 5

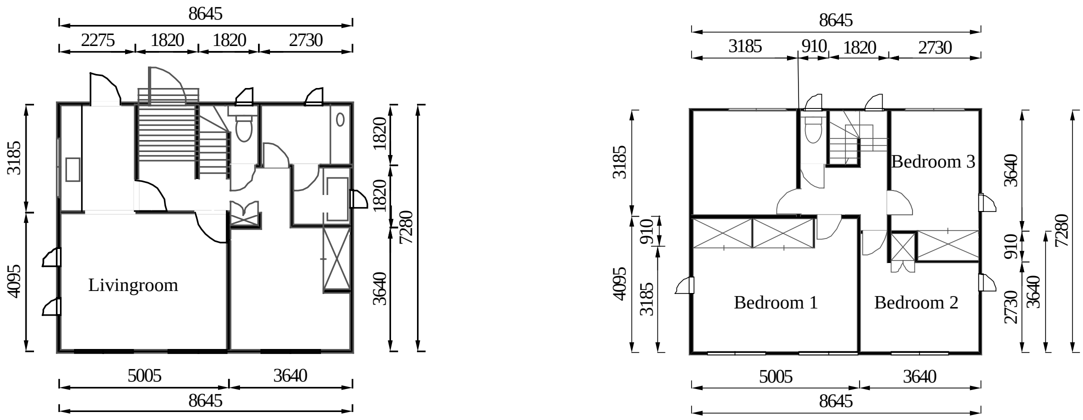
Energy saving methods

Method title	Method	Assumption
Method 1	Heat insulation method in windows	Heat transmission of all openings is fewer than 2.91W/m^{2}K.
Method 2	Heat collection method	Window area for heat collection fills 20% of the architectural area.
Method 3	Thermal storage method	Thermal capacity of every thermal storage part increased by 120kJ/m^{2}K.

and the air-conditioned rooms were set to be the living room, bedroom 1, bedroom 2, and bedroom 3. The air-conditioning was switched on in December, January, February and March, and the preset heating temperature was assumed to be 20°C.

Setup conditions

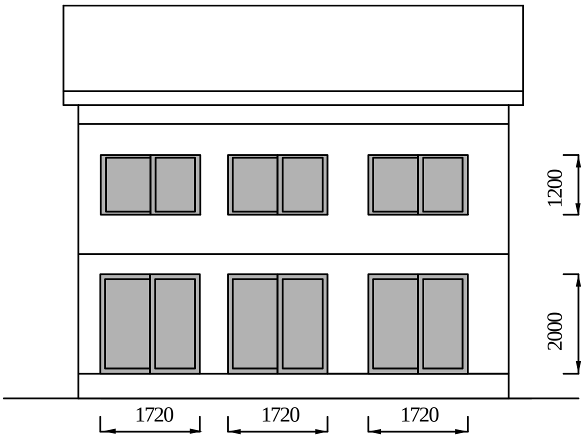
Under the classification of "obstacles to solar irradiance (Table 3)", in "Location 1" direct solar radiation is obtained during the hours between 10:30 and 13:30, and in "Location 2" the direct solar radiation is obtained between 9:30 and 14:30.



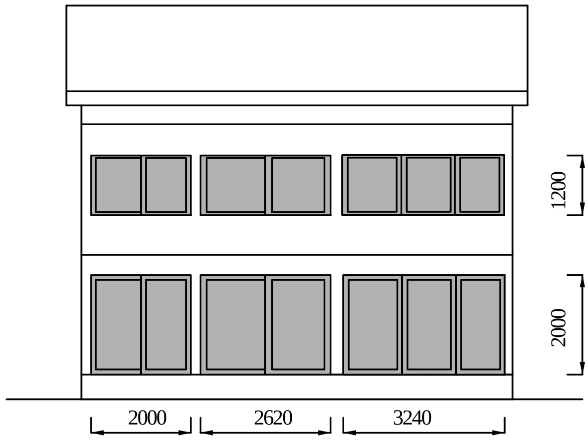
(a) Ground floor plan *(b) Upper floor plan*

Figure 1

Standard house model [mm]



(a) Method 2 not applied



(b) Method 2 applied

Figure 2
Method 2 details [mm]

Table 5
Method 3 details

(a) Method 3 not applied

Storage part	Composition [mm]
Exterior wall	Plasterboard [12], Dead-air space, Plyboard [9] Foam insulation [40], Dead-air space, Siding board [15]
Floor	Plyboard [10], Plyboard [12], Foam insulation [70]
Interior wall	Plasterboard [12], Dead-air space, Plasterboard [12]

(b) Method 3 applied

Storage part	Composition [mm]
Exterior wall	Plasterboard [56], Dead-air space, Plyboard [9] Foam insulation [40], Dead-air space, Siding board [15]
Floor	Tile [12], Mortar [40], Foam insulation [70]
Interior wall	Plasterboard [30], Dead-air space, Plasterboard [30]

Under the classification of "building direction" (Table 4), in "Direction 1" the heat collection aspect is set to 0° i.e. due south. In "Direction 2" the heat collection aspect is set to 30° toward both the east and west, referenced from due south (0°).

Under the classification of the "methods of renewable energy" (Table 5):

In "Method 1" all the glass in the openings was double insulated, and heat transmission of all the openings was reduced from 6.51W/m^{2}K to 2.91W/m^{2}K.

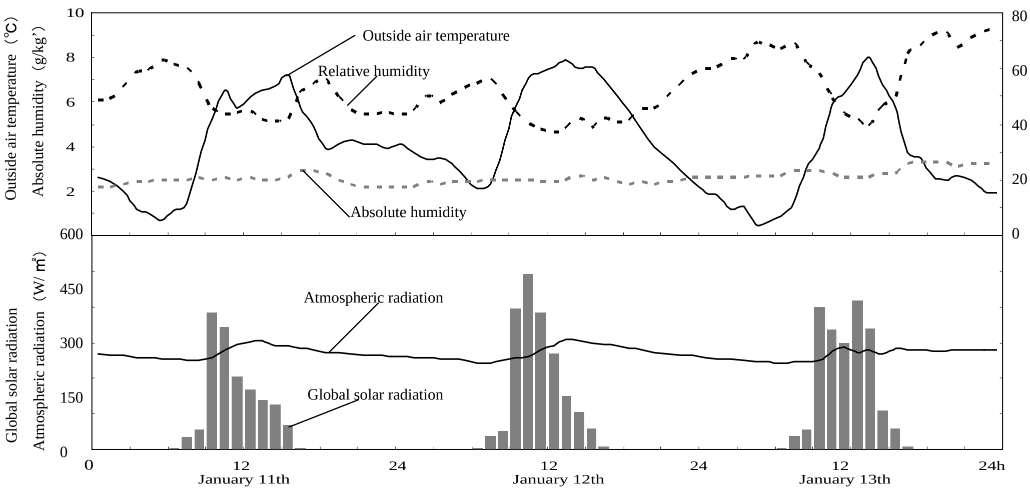
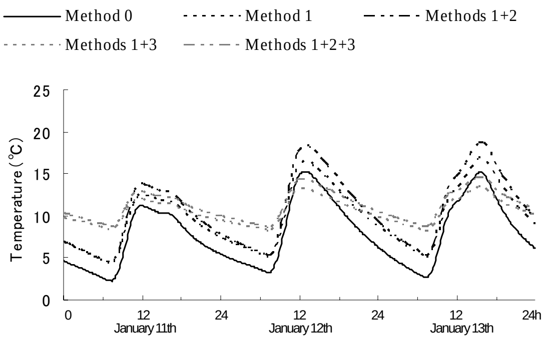
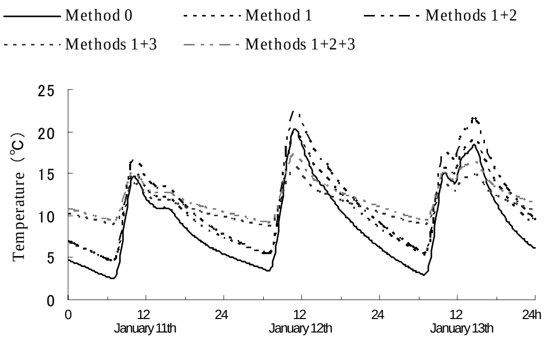


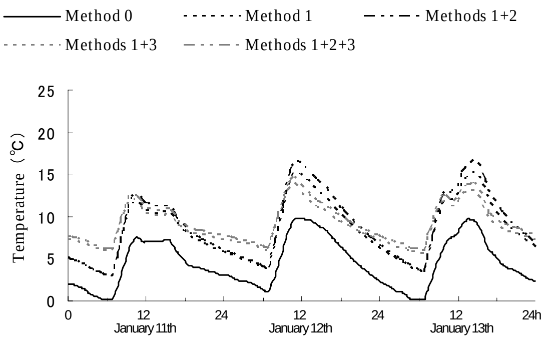
Figure 3
Climate data in Kyoto



(a) Interior air temperature



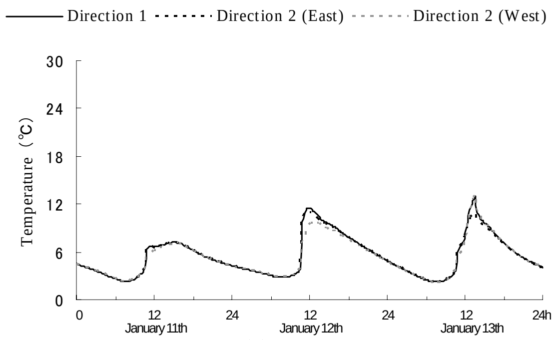
(b) Floor surface temperature



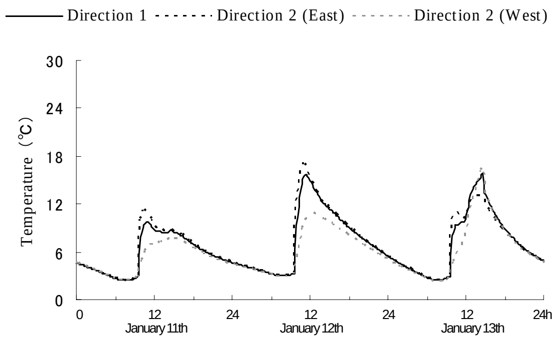
(c) Window surface temperature

Figure 4

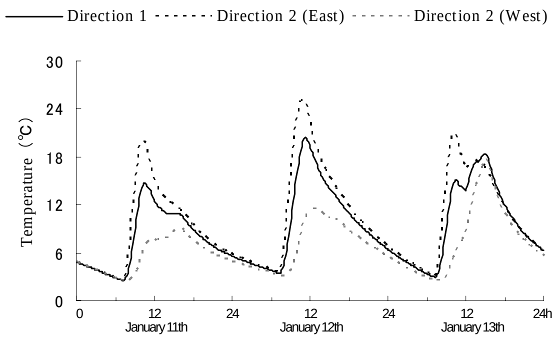
Influence of each method



(a) Location 1



(b) Location 2



(c) Location 3

Figure 6

Influence of each direction

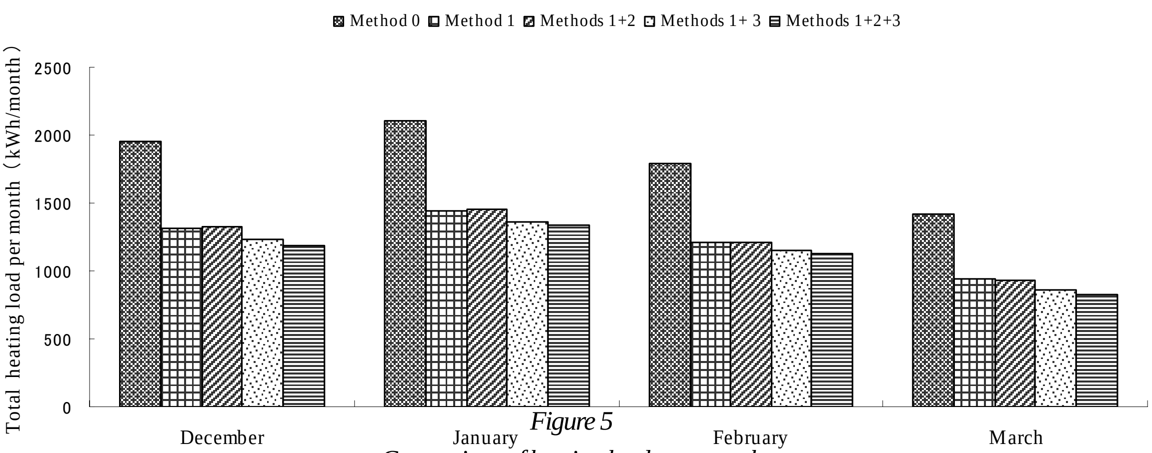


Figure 5

Comparison of heating loads per month

In "Method 2" the area of the window was changed from Figure 2 (a) to Figure 2 (b). As a result, the window area for heat collection fills 20% of the architectural area.

In "Method 3" the composition of thermal storage was changed from Table 6 (a) to Table 6 (b), and the thermal capacity of every thermal storage part increased by 120kJ/m^{2}K.

"Method 0" is where no energy saving methods were applied.

RESULTS AND DISCUSSION

Effect of each technique

Figure 3 shows typical climate data for three days in Kyoto (Area 3) in January. In "Area 3", "Location 3", "Direction 1", the change of temperature for each technique in the living room (non-air conditioned) is shown in Figure 4 (a). Figure 4 (b) shows the surface temperature change of the floor in the living room under the same condition as for Figure 4 (a). Figure 4 (c) shows the surface temperature change of the window in the living room under the same conditions as for Figure 4 (a).

"Method 0" shows a temperature value close to the outside temperature. In contrast, in Figures [4(a), (b), (c)] "Method 1" gives a value that is higher than the outside temperature, thus "Method 1" may be an effective method to inhibit indoor cooling in winter.

In Figure 4 (b), the floor surface temperature of "Methods 1 and 2" is higher than that of "Method 1" alone, when the amount of solar radiation is high. However, in Figure 4 (a) the indoor temperature of "Method 1" is almost the same as that of "Methods 1 and 2", when there is no solar radiation. An increase of heat flowing from the inside may have caused this result. On the other hand, the indoor temperatures of "Methods 1, 2 and 3" are higher than that of "Methods 1 and 3", when there is no solar radiation. Accordingly "Method 2" combined with "Method 3" may be an effective method for inhibiting the reduction of indoor temperature in winter.

In Figure 4 (a), the interior air temperatures of "Methods 1 and 3" and "Methods 1, 2, and 3" are lower than "Method 0", "Method 1", and "Methods 1 and 2", when the amount of solar radiation is high. However, the indoor temperature of "Methods 1 and 3" and "Methods 1, 2, and 3" remain stable, whereas the others show fluctuating results, when there is no solar radiation. Accordingly, "Method 3" may be an effective method for regulating the interior air temperature in winter.

In "Area 3", "Location 3", "Direction 1", the change in the integrated value of heating loads per month is shown in Figure 5. "Methods 1, 2, and 3" is the most effective combination for reducing the heating load, with a 38.3% reduction compared with "Method 0".

Influence of each direction

In Kyoto (Area 3), "Location 1", "Method 0", the living room (non-air conditioned) floor surface temperature change for each direction is shown in Figure 6 (a). Figure 6 (b) shows the results for "Location 2", and Figure 6 (c) for "Location 3".

Figure 6 (a) shows that the maximum temperature variation is about 3K, when the amount of solar radiation is at its highest. However, the effect on interior air temperature is very small.

Figure 6 (b) shows that the maximum temperature

Table 6

Heating load reduction in Kyoto

Area	Heating load reduction	Location 3		Location 2		Location 1
		Direction 1	Direction2	Direction 1	Direction2	
Kyoto	Approximetly 30%	Method 1 Methods 1+2	Method 1 Methods 1+2	Method 1 Methods 1+2	Method 1 Methods 1+2 Methods 1+3 Methods 1+2+3	Method 1 Methods 1+2 Methods 1+3 Methods 1+2+3
	Approximetly 35%	Methods 1+3	Methods 1+3 Methods 1+2+3	Methods 1+3 Methods 1+2+3		
	Approximetly 40%	Methods 1+2+3				

difference is about 8K, and there is a small effect on the interior air temperature.

Figure 6 (c) shows that the maximum temperature difference is about 16K, and there is a noticeable effect on the interior air temperature.

Calculated result

Table 6 shows the percentage change in heating load reduction for a year in Kyoto (Area 3). A combination of "Location 3", "Direction 1", and "Methods 1, 2, and 3" appears to be the most effective in reducing the heating load. The percentage change in heating load reduction is different in other construction areas, but for maximum effectiveness the combination of direction, location, and methods remain the same.

COMPARISON OF ENERGY-EFFICIENT HOUSING WITH STANDARD HOUSING

Input Data

The heating load of energy-efficient housing was compared with that of standard housing. Input data for standard house was Kochi (Area 3), "Location 3", "Direction 1", "Methods 1, 2, and 3".

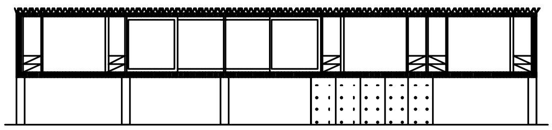
The energy-efficient house (Motoyama town house) is shown in Figure 7[4]. The windows are double glazed, the window area for heat collection via solar radiation is about 40% of the architectural area, and it is south-facing. Concrete is used for the inner walls and floor giving this house superior heat storage performance. The airconditioning schedule of this house is the same as that of the standard house.

In analyzing this house, "Case 1" is the house in its normal configuration, "Case 2" is where the supporting stilts are eliminated, and "Case 3" is where the insulating material of the floor is doubled in thickness.

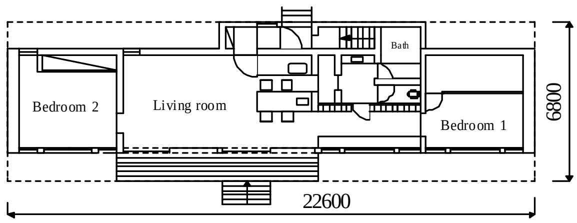
Case study

Figure 8 (a) shows the change in interior air temperature in the living room for a typical three day period (1/12, 1/13, 1/14) in January. Figure 8 (b) shows the surface

(a) South side appearance

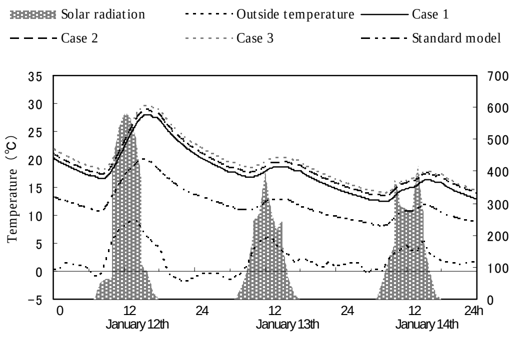


(b) South side elevation plan

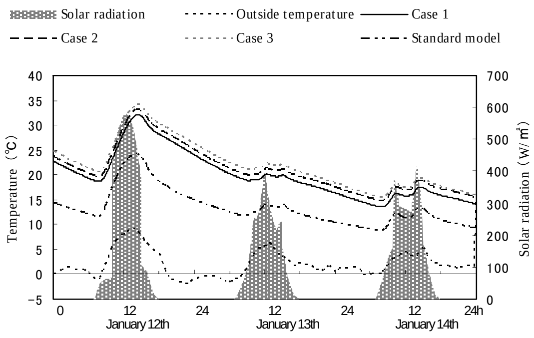


(c) Floor plan

Figure 7
Motoyama town house [mm] 4)

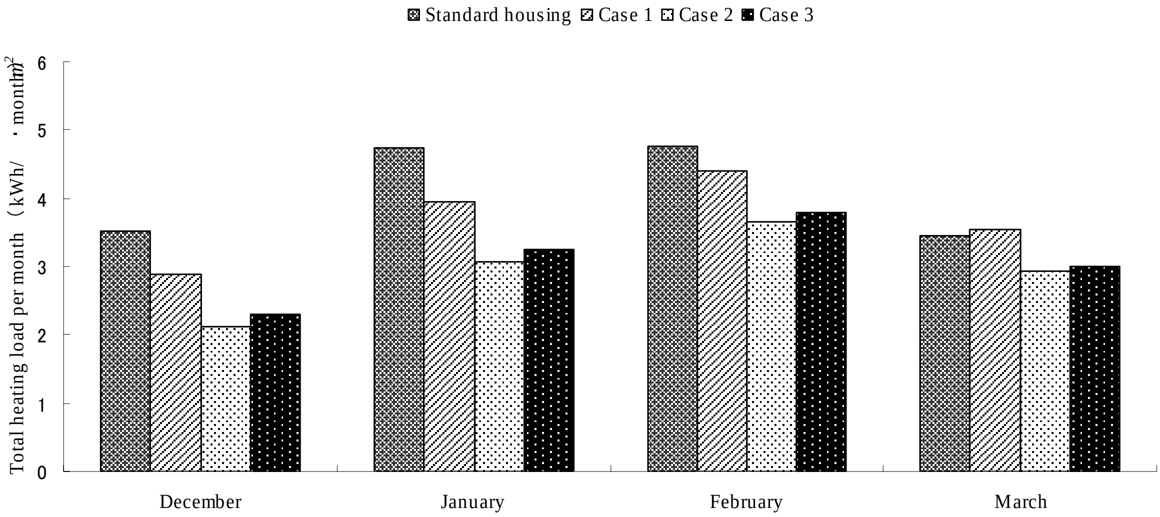


(a) Indoor air temperature



(b) Floor surface temperature

Figure 8
Energy-efficient house case study results



temperature change of the floor in the living room over the same time period. The interior air temperature of the energy-efficient house is consistently higher than that of the standard house, which may be caused by the differences in window area for heat collection between the two houses. The floor surface temperature of the energy-efficient house is also consistently higher than that of the standard house, even when the amount of solar radiation is low, which may be caused by differences in the heat capacity between the houses.

Calculated result

Heating loads per m^2 for a month are shown in Figure 9, and the load for the energy-efficient house is 10% less than that of the standard house. It appears that "Case 2" is the most effective in reducing the heating load, possibly because of the increased insulation in the floor compared with the standard house.

CONCLUSION

This paper has set out to determine by simulation the amount of heating load reduction possible using solar radiation. A maximum of about 40% reduction was found using a combination of energy saving methods. In addition, the heating load of an energy efficient house was found to be 10% less than that of the standard house, therefore, the floor and elevation plans may have an effect on reducing the heating load.

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