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Effect of Thermal Performance and Lifestyle on the Thermal Environment and Energy Consumption for a Well-insulated and Airtight Detached House in a Warm Climatic Area

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ABSTRACT

This paper describes the effects of thermal performance and lifestyle on the thermal environment and energy consumption for well-insulated and airtight detached houses in warm climatic areas by the measurement and numerical simulation of the thermal environment and energy consumption of a detached house in the Tokai region of Japan. The results of the measurements were 1) the comfort of temperature was evaluated to be high because the vertical temperature difference of the living room was small and 2) the energy consumption was equal to 1.3 times as much as other research in Aichi Prefecture. On the other hand, the results of the numerical simulation were that 1) it was found to be more effective to reduce the usage of the domestic hot water supply and lighting fixtures than it is to improve shelter performance in order to reduce total annual energy consumption, 2) it was effective to consider lifestyle in cases of detached houses with fully high thermal performances in warm climatic areas such as the examined house, and 3) the total annual energy saving effects of changing the number of family members were found to be 2% for 3 people and 8% for 2 people.

KEYWORDS

Thermal performance, Lifestyle, Thermal environment, Energy consumption, Detached house

INTRODUCTION

According to an estimation (Ikaga *et al.* 2007), the ratio of houses which conform to the Japanese standard of residential energy conservation notified in 1999 (Institute for Building Energy Conservation 1999) (i.e., the 1999 standard) was reported to be only 7%. Therefore, there is a need to improve shelter performance in order to reduce residential energy consumption. However, it is difficult to reduce residential energy consumption which is caused by occupants' life styles as well as by thermal

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performance. In order to make clear the effects of thermal performance and lifestyle on thermal environment and energy consumption for well-insulated and airtight detached houses in warm climatic areas, measurement (Adachi and Genjo 2012) and numerical simulation of the thermal environment and energy consumption for a detached house in the Tokai region of Japan were carried out.

There are many previous studies that confirmed the effects of buildings' thermal performance and occupants' behavior on building energy consumption in Japan such as a simulation study using a standard housing model (Hasegawa *et al*. 2006) and questionnaire surveys (Mizutani *et al*. 2006, Mori *et al*. 2003). The simulation study revealed that it would be possible to decrease the annual energy consumption by not only improving thermal insulation levels of building envelopes but also by a shift to low impact life styles according to the results of a calculation on nine cities in Japan under twenty-nine conditions, including shelter performance and occupants' behavior. A national scale questionnaire on residential energy consumption and energy usage (Mizutani *et al*. 2006) revealed that there is a clear correlation between energy consumption and energy usage. A questionnaire survey for the residents of detached houses in the Kinki area (Mori *et al*. 2003) was carried out and revealed that the annual energy consumption and energy saving behavior have a high correlation with each other. The family member number has not been examined so far in this research field, although the structure of the family in Japan has changed with the decreasing birthrate and aging population. In the simulation study of this paper, family member number was considered as one of the parameters concerning occupants' life style which have an effect on the annual energy consumption.

RESEARCH METHOD

Description of the house investigated

A detached house (house K) located in Toyokawa City, Aichi Prefecture, Japan was selected for the measurements. Figure 1 shows the floor plan of the investigated house. Table 1 summarizes a description of the investigated house. The house conforms to the thermal performance equivalent to Zone III that belongs to cold climates for the 1999 standard even though the house is located within Zone IV which belongs to warm climates. Electricity and LPG were used as heat sources. Family member number was four.

Description of measurement

Temperatures and relative humidities were measured every 10 or 15 min by a small data logger set 1.1m above the floor level in the living room, the bedrooms, the hall and outdoors as measurement items of the thermal environment. The measuring point for the vertical temperature difference was set only in the living room at 0.1 m

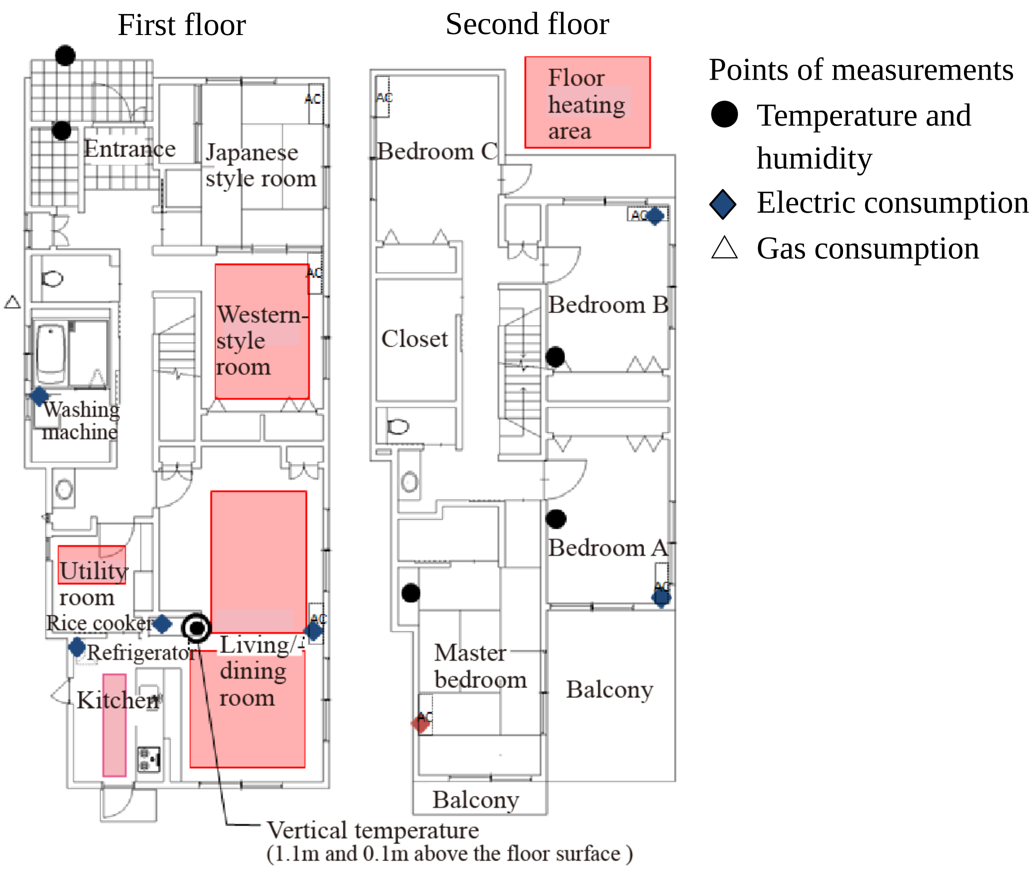

Figure 1. *Floor plan of House K*

Table 1. *Description of the house investigated*

Completion	2010
Structure	Wooden framework
Total floor area (m^2)	193
Heat loss coefficient per unit floor area (W/m^2K)	2.26
Heat gain coefficient (-)	0.06
Equivalent leakage area (cm^2/m^2)	0.6
Heating system	Air conditioner with electricity Floor heating with gas
Cooling system	Air conditioner with electricity
Ventilation system	Duct balanced ventilation (Mechanical air supply per room and centralized mechanical exhaust)
Domestic hot water system	High-efficiency gas water heater
Other system	Photovoltaic power system (4.5 kW of solar cell capacity) Bathroom dryer with gas

above the floor surface. Electric consumption and LPG were measured as heat sources. Electric consumptions for purchase power, sell power, the refrigerator, and the three air conditioners (in living room, bedroom A and bedroom B) which were the most often used of all seven air conditioners settled in house K, were measured every 15 min, 30 min, 1 h, 1 month by the energy consumption recording system. LPG consumption was measured every minute by a pulse-type flow meter and a data logger set on the gas meter. LPG consumption was classified into four types of use (domestic hot water, floor heating, cooking and bathroom dryer) using records on LPG usage by the occupant. Calorie conversion was performed for each energy source, that is, 3.6 MJ/kWh for electricity (secondary conversion value), 100.4652 MJ/Nm^3 for LPG. The measurement had been undertaken over one year from the beginning of May, 2011.

Outline of numerical simulation

The numerical simulation was performed using the coupling model of the transient systems simulation program TRNSYS Ver. 16 (University of Wisconsin 2000) with a calculation model for indoor heat generation pattern called SCHEDULE Ver. 2.0 (SHASE 1996). Parametric study with the same housing model as house K by numerical simulation techniques was conducted. Effects of shelter performance, occupants' life styles such as set point temperature for heating/cooling, usage pattern of domestic hot water supply and lighting fixtures, and the family member number on the energy consumption were analyzed. The simulation results were compared with the baseline which was reflected by the usage pattern for house K (Shelter performance: Zone III of the Japanese standard of residential energy consumption, Set point temperature for heating/cooling: 20 ^{o}C/27 ^{o}C, family member number: 4 people). Concerning the use of the domestic hot water supply, the pattern for using hot water every day for filling the bathtub, hand washing, and face washing was set as the baseline, on the other hand, the pattern for filling the bathtub every one day and using water for hand washing and face washing in summer and midseason were set as the energy-saving type. The lighting time of energy-saving type was shortened one hour compared to that of the baseline and the lights in the hall, toilets were turned off. A decrease in family member numbers to three people or two people with the changing of life stages was supposed.

RESULTS

Results of measurement

The temperature fluctuations on the hottest day (August 18, 2011; daily average outdoor temperature was 30.6 ^{o}C) and the coldest day (February 3, 2012; daily average outdoor temperature was －0.9 ^{o}C) of the measurement period are shown in

Figure 2(a) and Figure 2(b), respectively. In summer, the temperature in the living room was seen to drop to around 27 °C because of the operation of the air conditioner, although it went up to 31 °C as shown in Figure 2(a). On the other hand, in winter, the temperature in the living room was seen to be kept at over 13 °C. In addition, the comfort of the thermal environment was evaluated to be high because the vertical temperature differences of the living room in both summer and winter were within only 3 °C of each other as shown in Figure 2.

The comparison of annual energy consumption classified by heat source between house K and the average of the results from other research (Jyukankyo Research Institute 2009) is shown in Figure 3(a), and the per unit floor area classified by end use is shown in Figure 3(b). In the estimation of energy consumption per unit floor

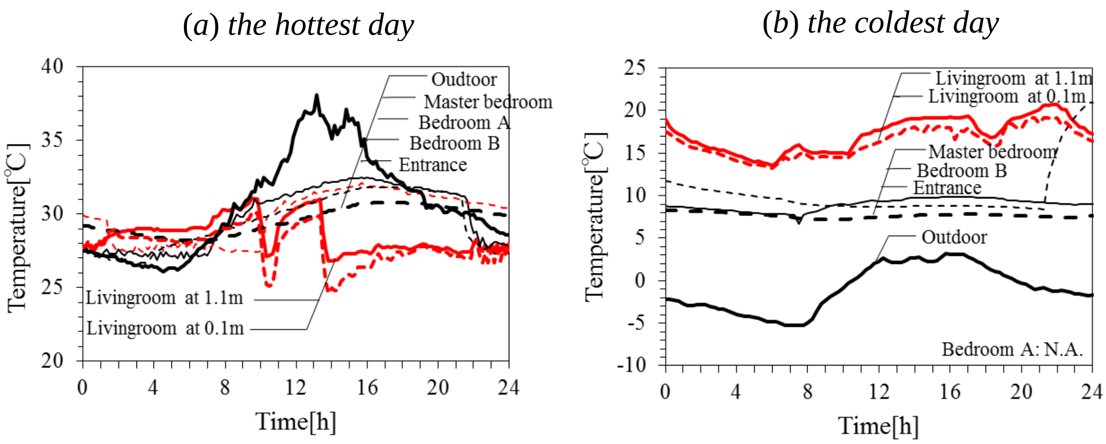

Figure 2. *Temperature fluctuations on the hottest day(a) and the coldest day(b)of the measurement period*

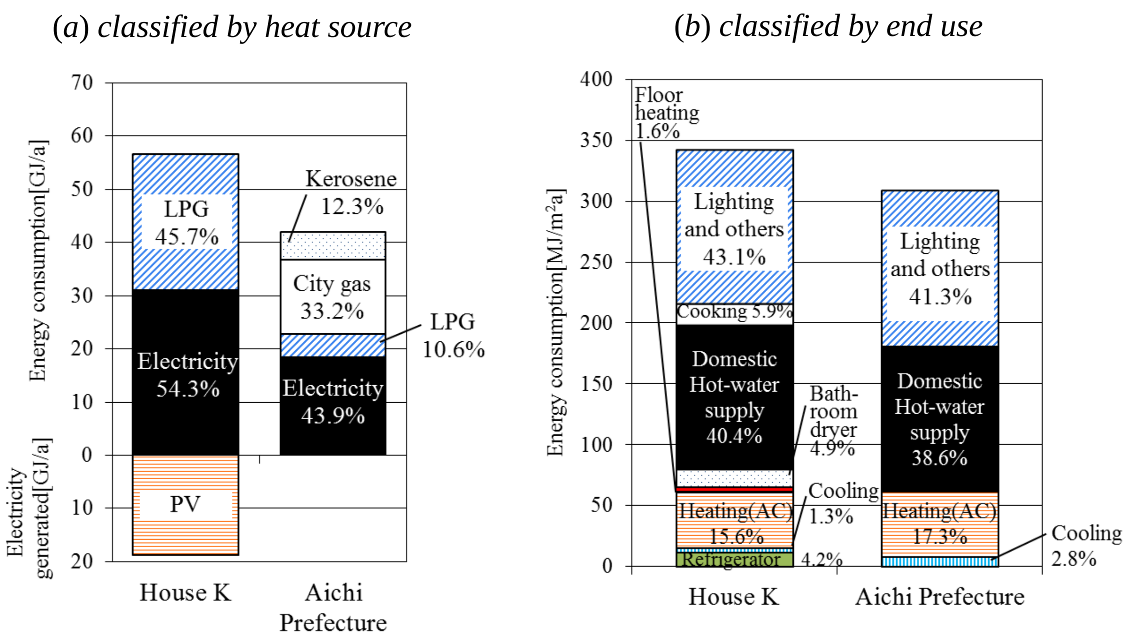

Figure 3. *Comparison of annual energy consumption*

area in Figure 3(b), the floor area of house K is defined as 165 m^2 excluding the Japanese style room and Bedroom C, and the average floor area in Aichi Prefecture (Ministry of Internal Affairs and Communications 2008) is defined to 135.37 m^2. The total annual energy consumption was 57 GJ/year and was equal to 1.3 times as much as other research in Aichi Prefecture as shown in Figure 3(a). In addition, the solar power generation amount was found to be 19 GJ/year and it was equal to about one third of the total annual energy consumption. Therefore, it can be said that the natural energy application is efficient in the area where house K located. The annual energy consumption per unit floor area was found to be 350 MJ/m^2year and was equal to 1.1 times as much as that for other research in Aichi Prefecture as shown in Figure 3(b). The total annual energy consumption was 37% for 'lighting and others', 35% for domestic hot water supply, 13% for heating, 4% for bathroom dryer, 4% for refrigerator, 1% for floor heating, and 1% for cooling, in order of energy consumption. The energy consumptions for 'lighting and others' and domestic hot water supply account for nearly 70% of the annual total energy consumption. The energy consumption for heating and domestic hot water supply was found to be slightly less than that of the other research in Aichi Prefecture. It was noted that the consumption of the air conditioner in the Japanese style room that was not measured was classified into the energy consumption for 'lighting and others' in Figure 3(b), because of an irregular life style change of an occupant in winter.

Results of numerical simulation

Table 2 shows the simulation results. In the case where the shelter performance equals Zone I of the 1999 standard, energy consumption for space cooling increased by 6% for lighting and others in Figure 3(b). Energy consumption for space heating decreased by 31% compared to the baseline, therefore the total annual energy saving effect was found to be 2-4%. Energy consumption for space heating and space cooling are found to fluctuate by 20-30% compared to that for space heating and space cooling of the baseline. In the case where energy consumption in air conditioner usage in the Japanese style room which was caused by the life style change of an occupant is included in the energy measurement, the set point temperature for heating and cooling changes by 2 ^oC or 1 ^oC. On the other hand, the energy saving effect of the total annual energy consumption was found to be 8% in the case of energy-saving in the use of domestic hot water supply or lighting fixtures. The total annual energy saving effect of the changing of the number of family members was found to be 2% for 3 people and 8% for 2 people.

Table 2. *Simulation results*

Item		Annual energy consumtion[MJ/a]					
		Cooling	Heating	Appliances	Lighting	Domestic hot water	Total
Baseline		2453	7291	11463	15023	18795	55025
Parameter		Ratio for baseline [%]					
Shelter performance	Zone I	106.4	68.9	100.0	100.0	100.0	96.2
	Zone II	94.3	90.8	100.0	100.0	100.0	98.5
Hot-water supply	Energy-saving	100.0	100.0	100.0	100.0	75.9	91.8
Set point temperature for heating/cooling	22/26℃	123.2	133.8	100.0	100.0	100.0	105.5
	18/28℃	76.1	77.5	100.0	100.0	100.0	96.0
Lighting fixture	Energy-saving	96.4	119.5	100.0	62.4	100.0	92.1
Family numbers	3 people	89.7	106.2	99.6	99.8	94.1	98.2
	2 people	74.4	96.5	97.8	94.4	88.3	92.4

DISCUSSION

As shown in Table 2, the energy saving effect of total annual energy consumption was found to be a few percent in the case of an improvement of shelter performance. Therefore, it indicates that it is more effective to save on the use of the domestic hot water supply and lighting fixtures as the shelter performance is the present Zone III than to improve shelter performance in order to save total annual energy consumption. The effect of the number of family members on annual energy consumption was shown to be generally equal to those of the occupants' behaviors such as the use of domestic hot water supply and lighting fixture.

CONCLUSION

From the results of the measurement of the well-insulated and airtight detached house which conforms to the 1999 standard, it is seen that the comfort of thermal performance is evaluated to be high. Additionally, the energy consumption per unit floor area is found to be nearly equal to that for other research in Aichi Prefecture, although it is indicated that the annual total energy consumption is 1.3 times as much as that of other results in Aichi Prefecture. On the other hand, as for the results of the numerical simulation, it was effective to consider lifestyle in the case of the detached houses with fully high thermal performances in warm climatic areas such as the examined house. The effect of the number of family members which is one of the parameters on the occupants' life style was found to be 8% in the case of two people and equal to those by energy-saving use for hot water supply and lighting fixture. Detached houses with low shelter performance are still common in Japan, therefore it is important to promote both the improvement of thermal performance and a consideration of lifestyle in order to save energy consumption.

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