117: SOME TRIALS FOR HEATING & COOLING-FREE HOUSING IN SAPPORO, HOKKAIDO

Masamichi ENAI*[1], Sadeghian M. TAGHI *[2]

*[1] *Graduate School of Engineering, Hokkaido University*
N13W8 Kta-ku, Sapporo, 060-8628 JAPAN, Fax: +81-11-706-7828, E-mail address: enai@eng. hokudai.ac.jp
*[2] *Consultant Taghi for Building Environment*

ABSTRACT Recently most detached houses in Hokkaido have become more highly insulated and airtight. Some of them use a passive ventilation system, but they still have to use a mechanical exhaust system due to Building Code regulations in Japan. Thermal insulation thick enough to accomplish a heating and cooling free house is not in place yet; particularly the thermal resistance of windows in Hokkaido has proven to be inadequate. It is true that in Sapporo, there are some difficulties in achieving a heating-free house, but relatively good solar radiation can be expected during the cold season. For example, during the daytime when regular pair glass windows are used, there is more solar radiation than Low-e glass windows. On the other hand, during the night time, heat loss through regular pair glass window s are larger than that from Low-e glass windows, so it is better to use an insulation shutter over pair glass windows. In this report, critical conditions for heating-free housing in Sapporo are discussed based on the analysis results of numerical simulations throughout the year, and appropriate thickness of the thermal insulation is suggested.

1. INTRODUCTION

Most recently built houses in Hokkaido meet the thermal standard of the Next Generation Housing (heat loss coefficient per floor area $Q \leq 1.6$ W/m^{2}K), and some are even designed to meet Q1 Housing Guideline ($Q \leq 1.0$ W/m^{2}K) of NPO. However, they do not reach the thermal level demonstrated widely in Germany and Sweden. Certainly, on calculation, the more highly insulated and airtight the house becomes, the higher the room temperature rises without limits, and it is possible to build a heating-free house utilizing waste heat[1)]. But Hokkaido is at lower latitude than Central Europe. If efforts to realize a heating-free house would result in the need to install a full cooling system, such an approach is like putting the cart before the horse.

In this trial, a wooden model house with a standard floor plan was used to explore energy conservation performance of the Next Generation Housing. Heat gains in the house were estimated from a 2005 survey conducted by NHK (Nippon Hoso Kyokai/the Japan Broadcasting Corporation). Solar radiation through windows was calculated from HASP data. Changes in room temperature throughout the year were numerically analyzed by using the Successive Integration Method[2)]. Three levels of thermal performance were set up by changing conditions such as thickness of the thermal insulation. Then numerical analysis was made in the case where measures for winter were implemented, and also in the case where measures for winter and summer were implemented. Finally, based on the analysis of the results, a plan to achieve heating & cooling-free housing in Hokkaido was suggested by using a critical index ($18\ ^{\circ}C \leq$ tolerable room temperature $\leq 30\ ^{\circ}C$).

2. THE SUBJECT HOUSE AND ITS THERMAL PERFORMANCES

For the numerical analysis of room temperature and thermal loads, the Architectural Institute of Japan sets a benchmark test house with a standard floor plan. However, when heating-free housing is considered, solar radiation through windows is one of the key factors that more or less determines the success or failure of the house. So, in this experiment, instead of the AIJ's suggested floor plan, the standard floor plan of the Next Generation Housing, in which all rooms have south windows, was adopted. The size of south windows was similar to that of the Next Generation House used by IBEC[3)]. The floor plan of the subject house is shown in Figure 1, and a south elevation and a cross section are shown in Figure 2. The Japanese Building Code regulations require the ratio of window areas to floor areas to be more than 0.2, and this subject house met this requirement. For the experiment, three levels of thermal performance were set up by changing the thickness of thermal insulation on ceilings, the thermal resistance of windows, the thickness of the exterior wall insulation and the ventilation rate. Details are shown on Table 1 and Table 2.

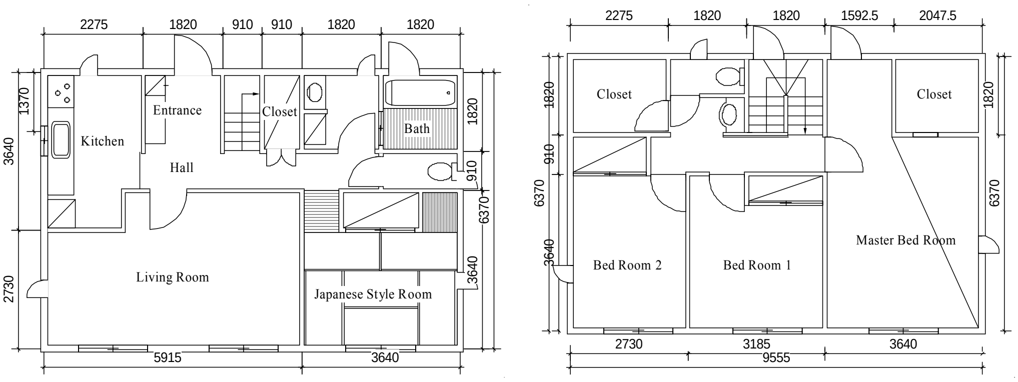


Figure 1 Floor Plan of the Subject House (Left: 1st Floor Plan, Right: 2nd Floor Plan)

Figure 2 South Elevation View (Left) and Cross Section (Right)

Table 1 Heat Loss Coefficient Estimation by Floor Area [W/m²K] in the Case of Level (3) Thermal Performance

Gross Floor Area S=			121.7 m^2	Air Volume B=			316 m^3
Spec.	A	U	AU	Heat Loss from Earth Floor	L_{f1} or A_{f1}	U_{f1} or U_{f2}	
Ceiling	60.8	0.075	4.56	Perimeter L_{f1}	31.9	0.42	13.38
				Interior Area A_f	33.0	0.12	3.96
External Wall	131.1	0.128	16.78	Sum. (2)			17.34
				Air Change rates		n =	0.1
Window	27.4	1.3	35.56	Heat Loss by Ventilation (3)			9.49
Door	2.1	2.2	4.55	Sum. of Heat Loss (4)			88.28
Sum.	219.26		61.45	**Heat Loss Coefficient Q**			**0.73**
Heat Loss Thermal Transmission (1) ∑AU =			**61.45**	**Recommended Value of Heat Loss Coefficient [kW/m²K] for District 1in Japan**			**1.60**

Table 2 Calculation Table

District Ⅰ)	Sapporo	1st Floor Area= 60.9 (m^2)	Gross Floor Area	Height of 1F 2.6	Sum. of Air Volume
		2nd Floor Area= 60.9 (m^2)	121.7	Height of 2F 2.6	316.5 (m^3)

Site	Area of Roof, Ceiling, Floor, Earth Floor					Window (orientation), Door (D)				External Wall			
Room	Dimention (m) Horizontal by Vertical		Ceiling Area (m^2)	Floor Area (m^2)	Air Volume (m^3)	Dimention (m) Wide by Height		Area (m^2)	Orient.	Dimention (m) Wide by Height		Opening	Area (m^2)
1F													
Japanese Style Room	3.64	3.64	-	13.25	34.4	0.7	1.2	0.84	E	3.64	2.60	W	8.62
			-	-	-	1.6	2	3.20	S	3.64	2.60	W	6.26
Living Room	5.40	3.64	-	19.66	51.1	1.6	2	3.20	S				
						1.6	2	3.20	S	5.92	2.60	W	9.0
						1.2	0.4	0.48	W	2.73	2.60	W	6.6
Kichen	2.28	3.64	-	8.28	21.5	0.7	0.5	0.35	W	3.64	2.60	W	9.5
						0.4	1.2	0.48	N	2.28	2.60	W	5.4
Entrance Hall	7.2	2.73	-	19.66	51.1	0.9	2.3	2.07	D				
						0.4	1.2	0.48	N				
						0.7	1.2	0.84	N	7.28	2.60	W	15.5
						0.4	1.2	0.48	E	2.73	2.60	W	7.1
2F													
Master Bed Room	3.64	6.37	23.19	23.19	60.3	0.7	1.2	0.84	E	6.37	2.60	W	15.7
						1.6	2	3.20	S	3.64	2.60	W	6.3
						0.7	1.2	0.84	N	3.64	2.60	W	8.6
Bed Room 1	3.19 -	3.64	11.59	11.59	30.1	1.6	2	3.20	S	3.19	2.60	W	5.1
Bed Room 2	2.7 -	4.5	12.15	12.15	31.6	1.6	2	3.20	S	2.73	2.60	W	3.9
						0.7	1.2	0.84	E	4.55	2.60	W	11.0
2F Hall	2.2 -	6.3	13.86	13.86	36.0				E	2.73	2.60	W	7.1
						0.7	1.2	0.84	N				
						0.7	1.2	0.84	N	2.73	2.60	W	5.4
Sum.			**60.8**	**121.63**	**316**			**29.4**	Window Area/Floor Area=0.22				**131.1**

Transient response per perimeter of the basement was calculated under below conditions: outside: 1.25 [m] /inside:1.0 [m] from the center of the basement; Slab surface of the crawl basement space is 0.5 [m] lower than GL and 1.0 [m] deep; and outside ground depth is1.5 [m]. Transient response of the remaining area, that is 2.0 [m] subtracted from the aspect length of the crawl space, was calculated presuming it is insulated perfectly from outside by a 1.0 [m]-thick wall.

Conditions for the three levels of thermal performance:

Level (1) = wall insulation: 150 [mm], ceiling insulation: 200 [mm], overall heat transfer coefficient of the door/windows: 3.0/3.0 [W/m^{2}K], ventilation rate: 0.5 [ac/h].

Level (2) = wall insulation: 200 [mm], ceiling insulation: 300 [mm], overall heat transfer coefficient of the door/windows: 2.5/2.0 [W/m^{2}K], ventilation rate: 0.2 [ac/h] (heat recovery efficiency: 60%).

Level (3) = wall insulation: 300 [mm], ceiling insulation: 600 [mm], overall heat transfer coefficient of the door/windows: 2.0/1.3 [W/m^{2}K], ventilation rate: 0.1 [ac/h] (heat recovery efficiency: 80%).

3. DAILY ACTIVITIES AND HEAT GAINS

How occupants spend the time in the house varies between weekdays and weekends, and heat release values were determined according to family members' daily routines. These activities on a weekday and on a weekend are shown in Figure3, and the use of electrical appliances in each room is shown in Figure 4. In one day total, heat release from electrical appliances reached q_1: 800 [Wh/day]. Average solar radiation through windows (Low-e & triple) reached q_2: 900 [Wh/day] in the coldest season.

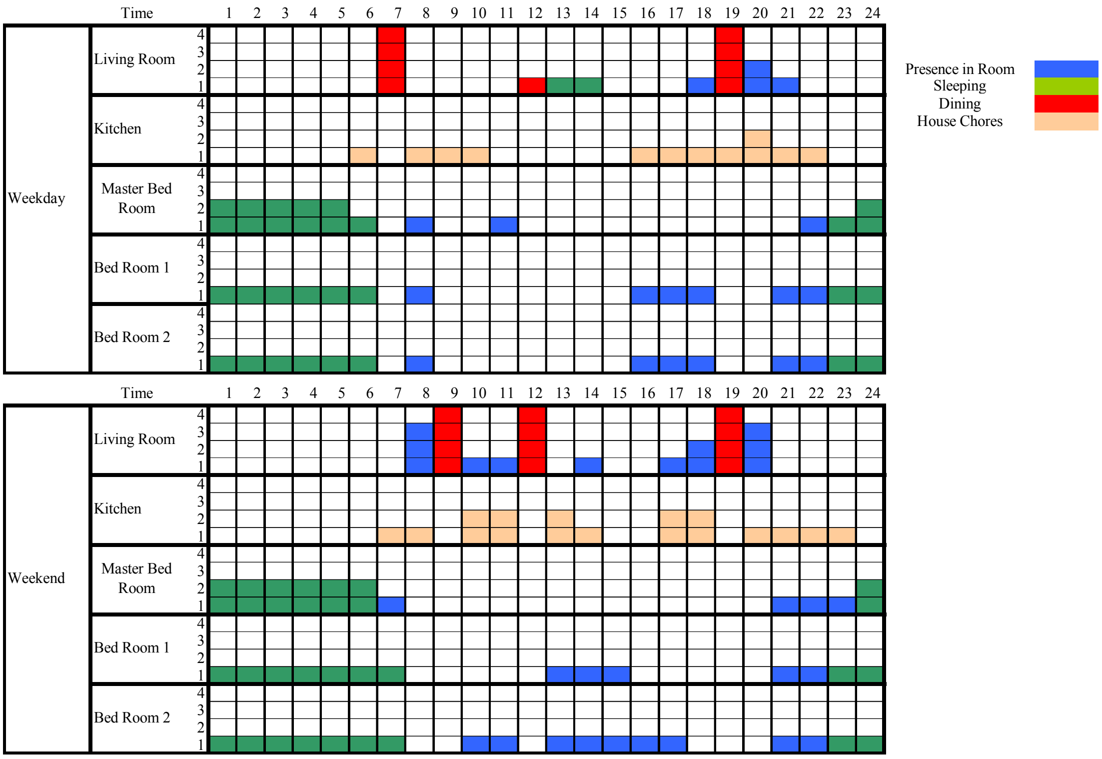
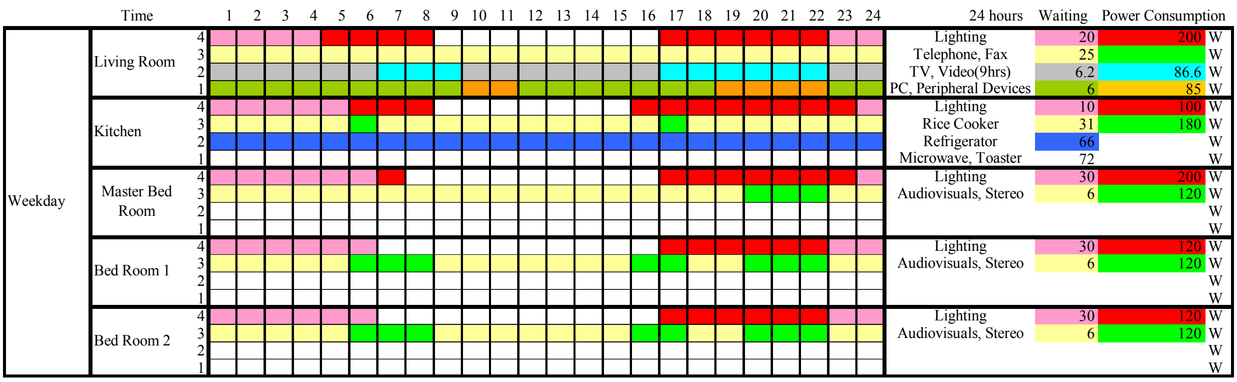


Figure 3 Activities Conditions by Family Members (Above: Weekday, Below: Weekend)



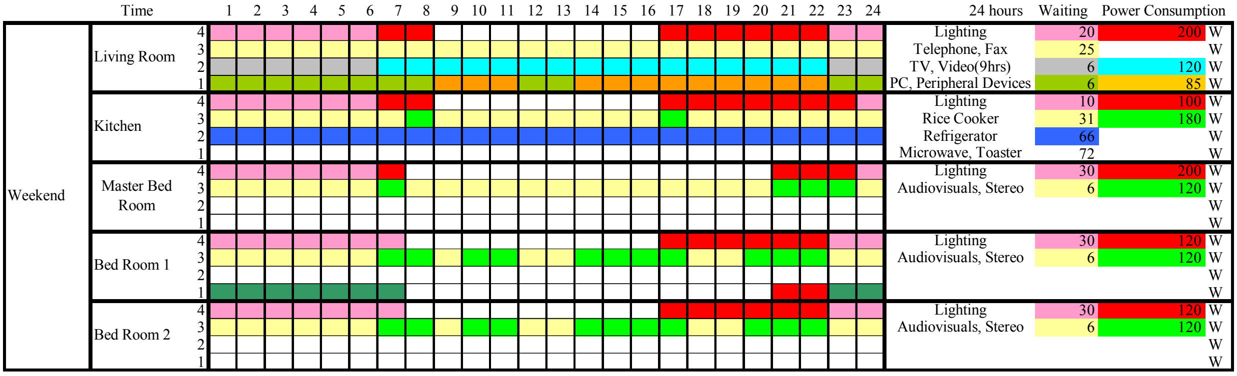


Figure 4 Power Consumption in Each Room (Previous page: Weekday, This page: Weekend)

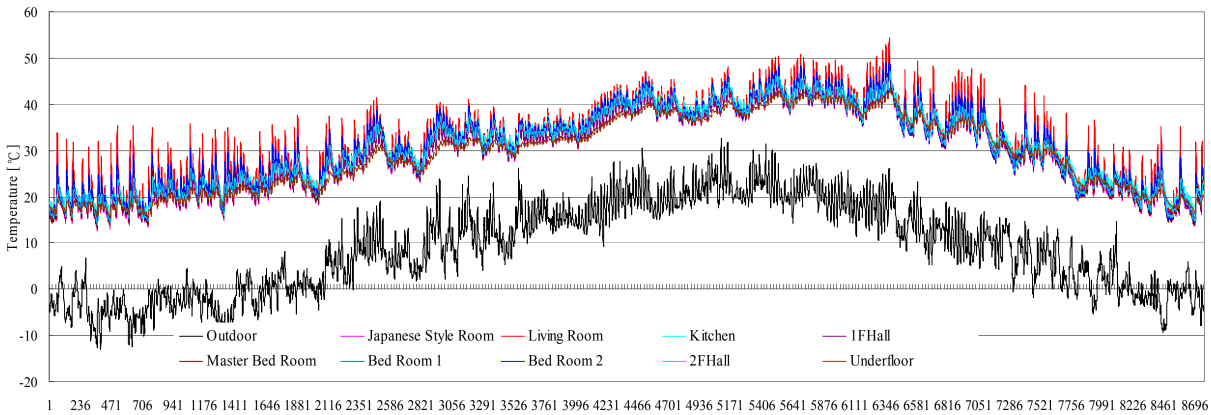
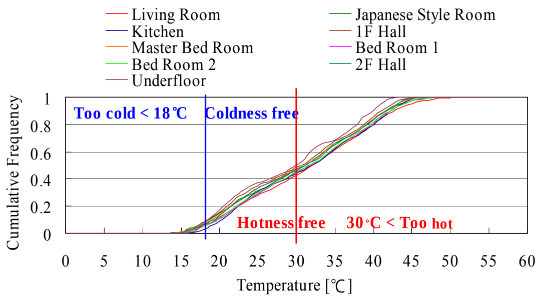


Figure 5 Changes in Temperatures throughout the Year in the Case of Level (3) Thermal Performance



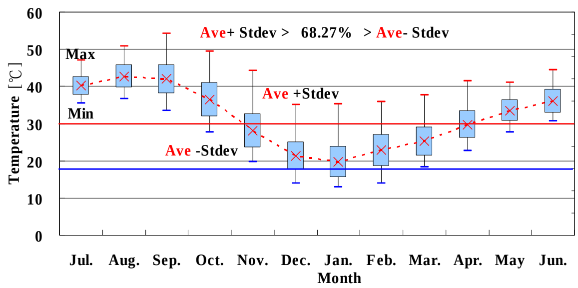


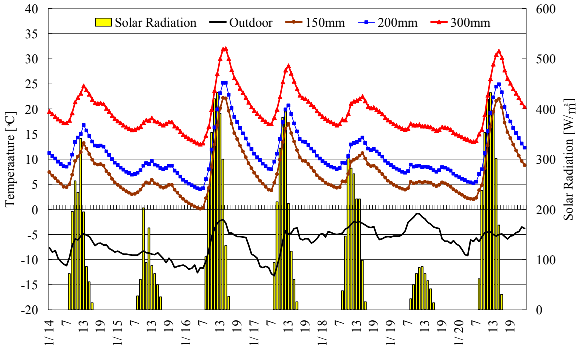
Figure 6 Cumulative Frequency Distribution throughout the Year

Figure 7 Box Plot form July to June (Living Room)

4. CHANGES IN ROOM TEMPERATURE AND NUMERICAL ANALYSIS

In any house, the first and the second season are the time for warm up operation to gain thermal benefit from the ground under floor. In this paper, calculation results from the third season are used. When the conditions for winter were used in summer without any modification, analysis of the room temperature throughout the year showed that on some days the temperature went over 40 °C and sometimes reached even 50 °C as shown in Figure 5 to Figure 7. Generally speaking, even in summer the thermal environment of a highly insulated and airtight house can be cool, if appropriate measures are taken; such as installation of sunshade, cool fresh incoming air during night-time which cools the structure, and daytime cross ventilation. All these efforts to cool the house can be done by occupants. Such measures to create a comfortable temperature during summer should be taken before installing an air conditioning system.

During the coldest season, the room temperature in Thermal Level (1)/ (2) houses fell below 5 °C as shown in Figure 8 and Figure 9, while in the Thermal Level (3) house, it did not fall below 15 °C. Temperature differences between rooms were very small. Therefore, the Thermal Level (3) is a requirement for a heating-free house in Hokkaido. However, even if the house is a Thermal Level (3) house, in winter, particularly on cloudy days, room temperature dropped to 15 °C. In order to prevent this, it is necessary to increase the thermal storage in the wooden house. Increasing insulation further is certainly not a realistic approach.



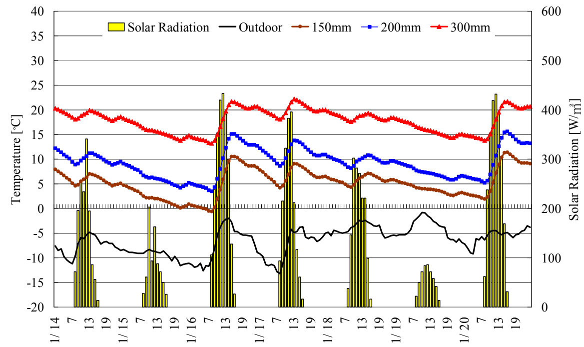


Figure 8 Results in the Coldest Season (1F: Living Room) Figure 9 Results in the Coldest Season (2F: Master Bed Room)

As a strategy to cope with temperature drop in winter, specifications of south windows were changed from the ones shown in Table 2 (triple Low-e glass) to pair glass specifications (U = 2.9 [W/m^{2}K]), and insulation shutters (U = 0.77 [W/m^{2}K]) were installed over south windows. After sunset they were closed and with sunrise they were opened to increase solar radiation through windows (Case-1). As a measure to prevent overheating on sunny days as seen in Figure 5, hollow spaces between partition walls were filled with diatom earth and ventilation at the rate of 1 [ac/h] was maintained between the underground crawl basement space and the first floor (Case-2). These measures were expected to reduce large fluctuations of room temperature.

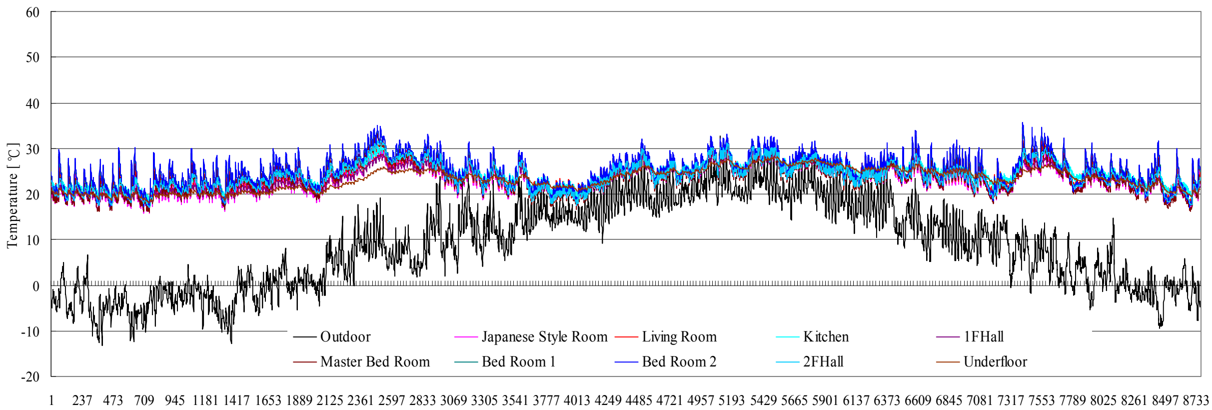
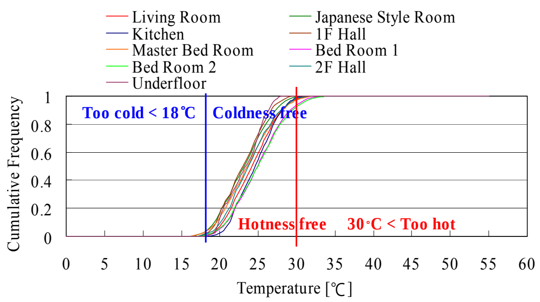


Figure 10 Temperature Changes in a Final Trial Case with Winter & Summer Strategies



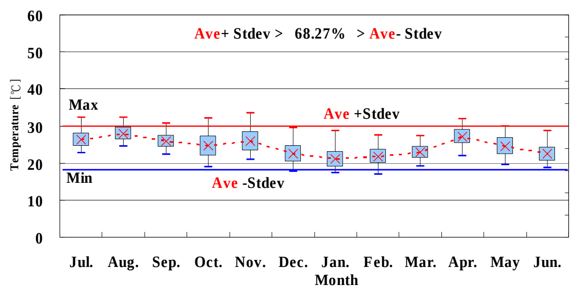


Figure 11 Cumulative Frequency Distribution throughout the Year Figure 12 Box Plot from July to June (Living Room)

As a strategy to cope with overheating in summer, sunshades (1F: 1 [m], 2F: 0.6 [m]) were installed over the top of south windows throughout the year (Case-3) and cross ventilation was conducted. The final trial as shown in Figure 14 was made up of 4 periods: heating-free period: November 10th to April 30th (heat exchanging ventilation: 0.1 [ac/h]), marginal period: May 1st to May 31st and September 24th to November 9th (no heat exchanging ventilation: 0.5 [ac/h]), first half of the cooling-free period (daytime cross ventilation: 1 [ac/h] + nighttime no heat exchanging ventilation: 0.5 [ac/h]), second half of the cooling-free period (daytime cross ventilation: 5 [ac/h] + nighttime convection between indoors and outdoors through highside windows).

When the above mentioned measures were taken, room temperature changed as shown in Figure 10. The cumulative frequency distribution shows that these temperature changes mostly fell within the range of critical index ($18\,^{\circ}C \leq$ tolerable room temperature $\leq 30\,^{\circ}C$), and hours when the temperature was out of this range was less than 10 % of the total time, which means it was an environment where people would not normally feel too cold or too hot. Therefore, it is fair to say that heating and cooling-free housing can be brought to realization if occupants are financially able and willing to take appropriate action.

Table 3 Conditions for Each Trial Case

Strategy	Basic performance	Pair glass + Insulation shutter	Diatomite grains + Ventilation between crawl space and 1st floor	Sunshade (1F: 1.0 m, 2F: 0.6 m)	
Level (3)	Yes	No	No	No	
Case-1	Yes	Yes	No	No	
Case-2	Yes	Yes	Yes	No	
Case-3	Yes	Yes	Yes	Yes	
Ventilation		Heating free	Marginal season	Cooling free	
				First stage	Late stage
Case-4	Case-3	1st Nov. to 31st Mar.: 0.1 ac/h in whole day	1st Apr. to 31st May.: 0.1 ac/h in whole day, 1st Oct. to 30th Oct.: 0.1 ac/h in whole day	1st Jun. to 30th Sep.: 1.0 ac/h in whole day	
Case-5	Case-3	1st Nov. to 31st Mar.: 0.1 ac/h in whole day	1st Apr. to 31st May: 0.5 ac/h in whole day, 1st Oct to 30th Oct. 0.5 ac/h in whole day	1st Jun. to 30th Sep.: 1.0 ac/h in whole day	
Case-6	Case-3	10th Nov. to 30th Apr.: 0.1 ac/h in whole day	1st May to 31st May: 0.5ac/h in whole day, 24th Sep. to 9th Nov.: 0.5 ac/h in whole day	1st Jun to 23rd Sep.: 1.0 ac/h in daytime and 0.5 ac/h in night	
Final Trial	Case-3	10th Nov. to 30th Apr.: 0.1 ac/h in whole day	1st May to 31st May: 0.5ac/h in whole day, 24th Sep. to 9th Nov.: 0.5 ac/h in whole day	1st Jun to 30th Jun.: 5.0 ac/h in daytime and 0.5 ac/h in night	1st Jul. to 23rd Sep.: 5.0 ac/h in daytime and convection in night

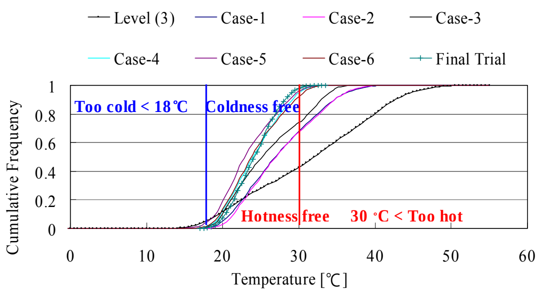


Figure 13 Ranges of Improvement

$18^{\circ}C \leq Tolerate\ room\ air\ temperature \leq 30^{\circ}C$

Living Room	Critical Index 18 °C	Critical Index 30 °C	Degrees of Improvement Diff. H	Degrees of Improvement Diff. C
Base	a from 0.0	b from 1.0	From Level (3)	From Level (3)
Level (3)	0.0572	0.5737	0.0000	0.0000
Case-1	0.0048	0.3195	-0.0524	-0.2542
Case-2	0.0001	0.3235	-0.0571	-0.2502
Case-3	0.0106	0.2610	-0.0466	-0.3128
Case-4	0.0147	0.0533	-0.0425	-0.5204
Case-5	0.0460	0.0413	-0.0112	-0.5324
Case-6	0.0177	0.0769	-0.0395	-0.4968
Final Trial	0.0057	0.0221	-0.0515	-0.5516

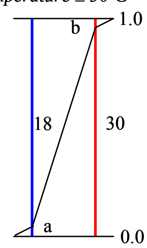


Figure 14 Degrees of Improvement

5. CONCLUSIONS

(1) In a wooden house which had 300 [mm] wall insulation, 600 [mm] ceiling insulation, 2.0/1.3 [W/m^{2}K] overall heat transfer coefficient of the door/windows, and 0.1 [ac/h] ventilation rate (heat recovery efficiency: 80%), changes in room temperature during the winter heating-free season fell within the critical index range, except for 6 % of the total time.

(2) In summer and marginal seasons, when sunshades were installed and appropriate measures for ventilation were taken, changes in room temperature during the cooling-free season fell within the critical index range, except for 3 % of the total time. But this paper's concept of heating & cooling-free housing does not deny the benefit of conventional heating or cooling equipment to reduce cold drafts or to enhance the comfort level for especially disabled people.

(3) Cost per floor area will increase by as much as 10 % to 12 % in order to realize Level 3 thermal performance. Although this would mean an extra cost of two million yen in a house with a total of 120 m^2 floor area, it is possible to amortize this in eleven years given the current kerosene price of 130 yen/***L***.

REFEENCES

1) Y. Sato, K. Kohri, H. Ishino: "A Study on Evaluation of the Thermal Performance of Detached Houses in Various Cities of Japan Using Natural Room Air Temperature", Journal of Environmental Engineering AIJ, No.573, 41-46, 2003.

2) N. Aratani, N. Sasaki, M. Enai: "A Successive Integration Method for the Analysis of the Thermal Environment of Building", Building Science Series 39 of NBS, 305-316, 1971.

3) Institute for Building Environment and Energy Conservation: "Standard and Guideline for Energy Conservation of the Next Generation Houses, 122, 1999 (In Japanese).