Efficiency of Energy Conservation Methods on Space Conditioning Load of Residential Buildings

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ABSTRACT

As a matter of national policy, we have to challenge to save energy in residential sector that contribute to CO_2 emission because the Kyoto protocol has taken effect in 2005. The amount of CO_2 emission in residential sector accounts for about 14% of whole CO_2 emission in Japan. The reduction of energy consumption is the most pressing issue to be settled in the immediate future. Then the energy consumption of residential buildings was monitored for two years around the country with the object of creating a national database. According to the results, it has been made clear that regional characteristics and every life style exert an extremely influence on the energy consumption, particularly concerning space conditioning.

In this paper, the efficiency of energy conservation methods, such as a change of living habits, on space conditioning load of residential buildings is clarified through the sensitive analysis with the numerical simulation which can predict the hygrothermal environment of the whole building. The control method of mechanical heating and cooling by thermal index PMV is one of the progressive features of the numerical simulation.

1. INTRODUCTION

The Kyoto protocol was adopted at the third conference of the parties to the UN framework convention on climate change (COP3) held in Kyoto in December 1997. The protocol was later ratified by 124 countries and the EU and went into force on February 16, 2005. The first five-year commitment period runs from 2008 to 2012. This protocol sets legally binding numerical targets for the reduction of carbon dioxide and other greenhouse gas emissions by the industrially advanced nations and calls on every country of the world to implement measures matched to its particular circumstances. The rates of greenhouse gas emissions reduction relative to 1990 to be achieved during the first commitment period were set at 6% for Japan. Nevertheless the energy consumption of civilian sector has kept increasing, thus it is predicted that, in the year 2010, greenhouse gas emissions will increase up to 10% more than those in 1990 in Japan.

To prevent the situation from getting worse, it is important to obtain necessary and accurate situation of the present residential energy consumption. Then the energy consumption of residential buildings was made a survey for long-term (from November 2002 to March 2005) on national scale. Fig.1 shows annual energy consumption from December 2002 to November 2003. The figures are arranged in order from highest to lowest energy consumption and are treated separately divided into detached houses and condominiums in each region. The amount of energy consumption is indicated as the secondary energy on the basis

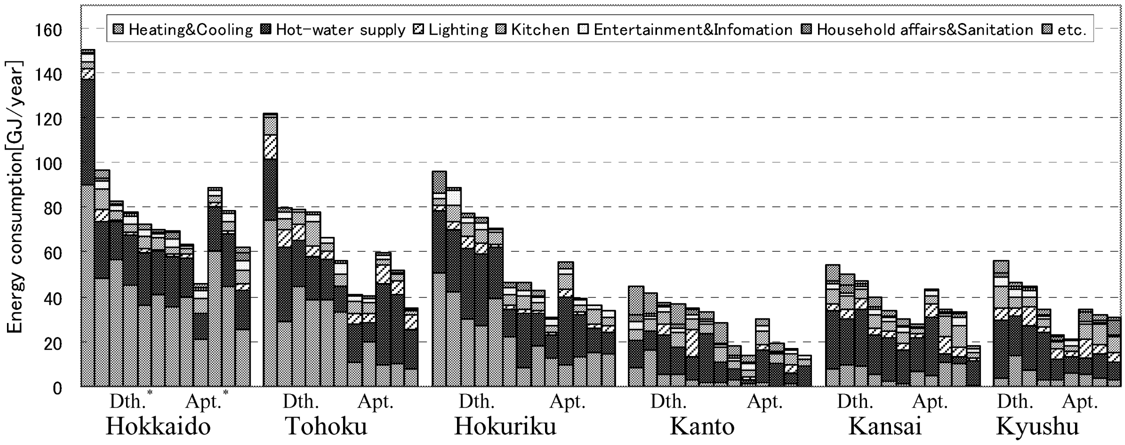


Fig.1 Annual energy consumption of residential buildings

*Dth.: detached house *Apt.: apartment

of the specific productivity as described in Table 1. The heating and cooling energy differs greatly between different regions of Japan. The energy consumption is exceeded above 40 GJ/year in many houses, particularly in Hokkaido and Tohoku. These results are used as the criterial amounts of energy consumed. Then the efficiency of energy conservation measures such as energy saving lifestyle on the heating and cooling energy is computationally simulated in a later section.

Table 1 Specific productivity to convert the secondary energy

Electricity	3.6MJ/kWh
City gas(4A-7C)	20.4MJ/Nm^3
City gas(13A,14A)	45.9MJ/Nm^3
Kerosene	36.7MJ/ℓ

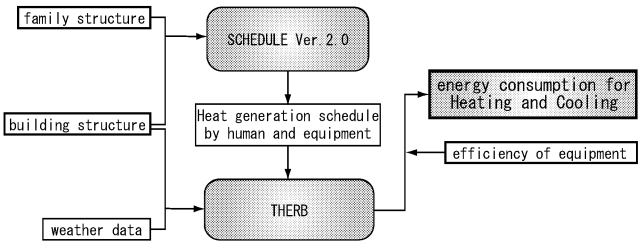


Fig.2 Calculation flow of energy consumption for heating and cooling

2. OUTLINE OF SIMULATION

2.1 Simulation software THERB

Simulation software called THERB (simulation software of the hygrothermal environment of the residential buildings) has been developed to analyze a heat, air and moisture phenomena in whole buildings in detail. THERB is the dynamic simulation software which can estimate temperature, humidity, sensible temperature, and heating/cooling load for multiple zone buildings and wall assemblies. The heat and moisture transfer models used in THERB such as conduction, convection, radiation and ventilation (or air leakage) are based upon the detailed phenomena describing actual building physics, and can be applied to all forms of building design, structure or occupant schedules, etc. All the phenomena are calculated without simplification of the heat and moisture transfer principles of any building component or element. Indoor air temperature and humidity can be calculated from heat and moisture balance of a space based on convection, ventilation, internal generation of heat and moisture. Control methods for space conditioning are classified into three types: heating, cooling, and simultaneous heating and cooling. Temperature and humidity set-point and ranges can be optionally set every hour.

Moreover the control of temperature and humidity is automatically performed in the case when the sensory index 'PMV (Predicted Mean Vote)' is set as the set-point of space conditioning. The Japanese general patterns for living of occupant and internal generation of heat and moisture are created by SCHEDULE Ver.2.0 and cross-linked with THERB which is based on national livelihood survey. Fig.2 shows calculation flow of energy consumption for heating and cooling.

Table 2 Characteristics such as thermal insulation performance and energy sources of object houses

	location	construction year	total floor area (㎡)	structure	thermal insulation performance: heat loss coefficient (W／㎡・K)	thermal insulation performance: equivalent gap area (c㎡／㎡)	energy sources: hot water (bath)	energy sources: hot water (kitchen)	energy sources: cooking	energy sources: heating	energy sources: cooling	number of family
Hokkaido	Sapporo	2000	128	wooden	1.7	0.6	kerosene	kerosene	electricity	kerosene	–	2
Tohoku	Morioka	2000	140	wooden	1.1	0.7	electricity	electricity	electricity	electricity	electricity	4
Hokuriku	Niigata	2002	131	wooden	2.2	0.4	kerosene	kerosene	electricity	kerosene	electricity	4
Kanto	Kashiwa	2002	108	wooden	3.1	5.6	gas	gas	gas	electricity	electricity	6
Kyushu	Kitakyushu	1998	133	wooden	3.7	4.5	gas	gas	gas	electricity	electricity	4

2.2 Building models

One of the monitored houses is selected to analyze its energy consumption in each region of Hokkaido, Tohoku, Hokuriku, Kanto and Kyushu. As a rule, the monitored annual energy consumption of selected houses is closer to the regional average than others. Table 2 lists characteristics such as thermal insulation performance and energy sources of all selected houses.

2.3 Heating and cooling schedule and performance of conditioning equipment

Table 3 and table 4 show the standardized schedule for heating and cooling of each house created on the basis of monitored results. Table 5 lists the coefficients of performance for heating and cooling systems. Northern areas in Japan such as Hokkaido and Tohoku, energy consumption are especially affected by heating although cooling is not required.

Table 3 Standardized schedule for heating of object houses

		hour of use																								term		preset
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	start	finish	(℃)
Hokkaido	living						■	■	■	■								■	■	■	■	■	■			10/13	5/26	21.2
	dining						■	■	■	■								■	■	■	■	■	■			10/13	5/26	21.2
	bedroom1						■	■	■	■								■	■	■	■	■	■			10/13	5/26	21.2
	bedroom2						■	■	■	■								■	■	■	■	■	■			10/13	5/26	21.2
	Japanese room						■	■	■	■								■	■	■	■	■	■			10/13	5/26	21.2
	Undressing room						■	■	■	■								■	■	■	■	■	■			10/13	5/26	21.2
Tohoku	living								■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■		11/1	5/10	21.4
	kitchen								■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■		11/1	5/10	21.4
	bedroom								■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■		11/1	5/10	21.4
	Japanese room								■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■		11/1	5/10	21.4
Hokuriku	living				■	■	■	■	■								■	■	■	■	■	■				10/15	5/8	21.3
	kitchen				■	■	■	■	■								■	■	■	■	■	■				10/15	5/8	21.3
	Japanese room				■	■	■	■	■								■	■	■	■	■	■				10/15	5/8	21.3
	Undressing room				■	■	■	■	■								■	■	■	■	■	■				10/15	5/8	21.3
	children's room				■	■	■	■	■								■	■	■	■	■	■				10/15	5/8	21.3
	bedroom				■	■	■	■	■								■	■	■	■	■	■				10/15	5/8	21.3
	family room				■	■	■	■	■								■	■	■	■	■	■				10/15	5/8	21.3
Kanto	living						■	■	■								■	■	■							12/3	5/2	20.7
	bedroom																				■	■				2/7	3/15	20.7
Kyushu	living								■												■	■	■			11/13	4/8	19.2
	bedroom																				■	■	■	■		12/3	2/13	19.2
	children's room									■																12/3	2/13	19.2
Standard	living							■											■	■	■	■	■			10/28	4/14	21.0
	bedroom1																		■							10/28	4/14	21.0
	bedroom2																			■	■					10/28	4/14	21.0

Table 4 Standardized schedule for cooling of object houses

		hour of use																								term		preset
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	start	finish	(℃)
Hokkaido		–																								–	–	–
Tohoku		–																								–	–	–
Hokuriku	living										■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	6/19	9/24	27.3
	bedroom	■	■																				■	■	■	6/20	9/22	27.3
Kanto	living																					■	■	■	■	6/20	9/22	25.0
Kyshu	living																			■	■	■	■	■		5/27	9/28	25.7
	bedroom																							■	■	5/28	9/29	25.7
	children's room																								■	5/28	9/29	25.7
Standard	living							■											■	■	■	■	■			6/2	9/21	27.0
	bedroom1																		■							6/2	9/21	27.0
	bedroom2																			■	■					6/2	9/21	27.0

Table 5 Coefficients of performance for heating and cooling systems

		Heating		Cooling	
		energy sources	efficiency	energy sources	efficiency
Hokkaido	living	kerosene	0.88	–	
	dining	kerosene	0.88		
	bedroom1	kerosene	0.88		
	bedroom2	kerosene	0.88		
	Japanese room	kerosene	0.88		
	Undressing room	kerosene	0.88		
Tohoku	living	electricity	0.9	–	
	kitchen	electricity	0.9		
	bedroom	electricity	0.9		
	Japanese room	electricity	0.9		
Hokuriku	living	kerosene	0.9	electricity	3.06
	kitchen	kerosene	0.9	electricity	5.71
	Japanese room	kerosene	0.9	–	
	Undressing room	kerosene	0.9		
	children's room	kerosene	0.9		
	bedroom	kerosene	0.9		
	family room	kerosene	0.9		
Kanto	living	kerosene	0.92	electricity	3.14
	bedroom	electricity	3.23	–	
Kyushu	living	electricity	3.1	electricity	2.53
	bedroom	electricity	3.13	electricity	3.73
	children's room	electricity	3.58	electricity	3.41

3. ENERGY CONSUMPTION REDUCTION BY ENERGY SAVING LIFESTYLE

3.1 Preset temperature change of space conditioning

3.1.1 Changing to publicly recommended temperature

Fig.3 shows the amount and rate of energy consumption reduction by changing the preset temperature for space conditioning to energy saving temperature (setting up the heating and cooling temperature at 20 and 28 degrees C which are publicity recommended). The reduction rate of energy consumption both heating and cooling is about 10% to 17% in all regions except Kyushu. The preset temperature for cooling in Kyushu tends to be set lower. Instead, the heating tends to be turn down because Kyushu is located in southern warm region in Japan. Thus the cooling energy consumption is decreased about 38% by keeping air conditioner at the publicity recommended temperature 28 degrees C; meanwhile the heating energy consumption is increased about 13% more than the existing conditions because the preset temperature for heating tends to be set lower than 20 degrees C even in current living environment.

3.1.2 Turning the heating and cooling down at one degrees C

In above mentioned results, the effect was not seen in one residential building. Then, Fig.4 show the amount and rate of energy consumption reduction, when the preset heating temperature is turned down at one degrees C in each region or when the preset cooling temperature is turned up at one degrees C in each region. The energy consumption is naturally decreased for both heating and cooling. In comparison with above mentioned results applying publicity recommended temperature to space conditioning in previous section, the heating energy consumption is more decreased in Kanto and Kyushu, however less decreased in Hokkaido, Tohoku, Hokuriku. Thus to save energy effectively, the publicity recommended heating temperature should be applied in northern cold regions such as Hokkaido and the heating should be turned down from current living environment in southern warm regions from Kanto. In contrast, the cooling energy consumption is more decreased in Hokuriku, however less decreased in Kanto and Kyushu. The publicity recommended cooling temperature has more effect to save energy than the measure of turning the cooling down at one degree C in southern warm regions.

3.2 Shortening of space conditioning time

Fig.5 shows the amount and rate of energy consumption reduction by cutting one hour for space conditioning from actual state in each region. The reduction rate for heating and cooling in each region are roughly less than 5% except the heating in Kanto. The reason why the tendency of heating energy consumption

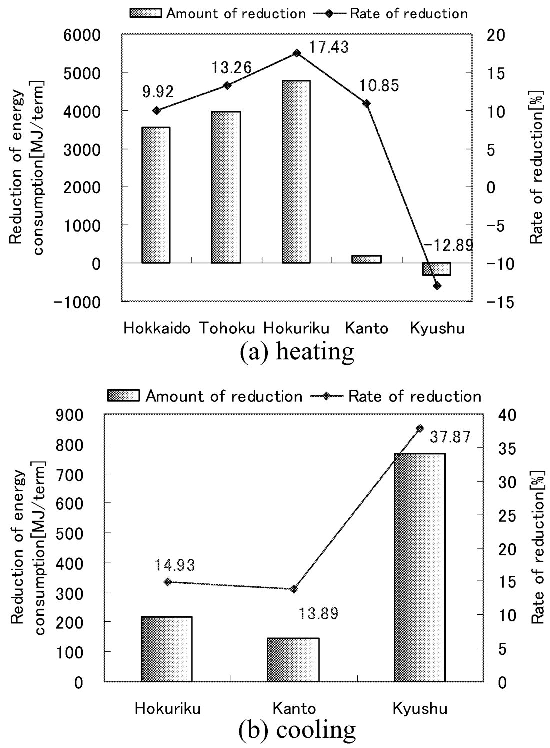


Fig.3 Amount and rate of energy consumption reduction by applying publicity recommended temperature for space conditioning (20 and 28 degree C at heating and cooling respectively)

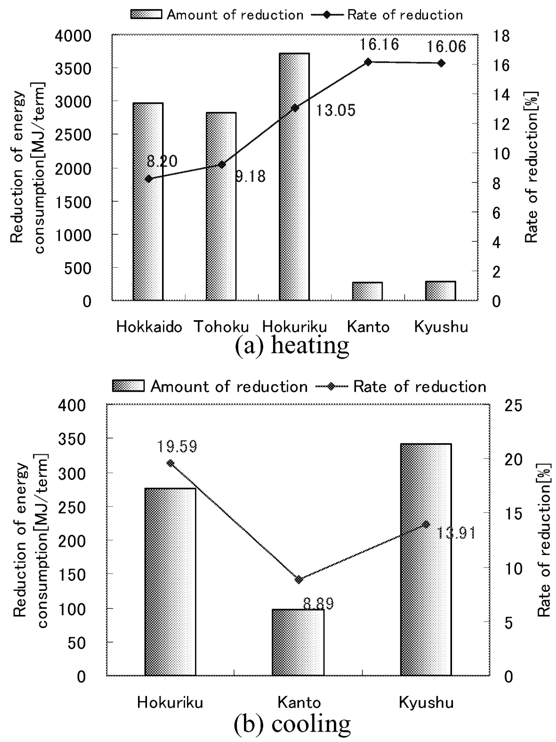


Fig.4 Amount and rate of energy consumption reduction by turning the space conditioning down at one degrees C from current living environment

reduction in Kanto differs from other regions is mainly attributed to the shortened time of day and its ratio to the total time of space conditioning. The time to be shortened is early morning kept cold and total heating time is only eight hours in whole buildings in Kanto. Since the amount of energy consumption reduction is also influenced by the shortened time and its hour, it is possible to be more decreased. However it is highly unlikely that space conditioning time will be shortened, particularly at the time of cold and hot. Namely, to cut the time for space conditioning is not found to be useful for energy conservation.

3.3 Having a little patience with chilly and sultry indoor environment

Fig.6 shows the amount and rate of energy consumption reduction by having a little patience with chilly and sultry indoor environment in each region. To quantify the effect of a little patience on energy conservation, the sensory index PMV is utilized, which is affected by following factors; temperature, radiant temperature, humidity, air current, metabolism and amount of clothing. The space conditions are only controlled, when the value of PMV becomes out of range, to adjust indoor environment at the values of standardized PMV minus or plus 0.3 respectively for heating and cooling by changing temperature and humidity with a certain amount of other factors. The standardized PMV is estimated from the actual measured value such as indoor temperature in each house. The reduction rate of heating energy consumption in Kanto and Kyushu are 25% and 22% respectively and become greater than the above mentioned three measures in previous sections. This measure also has a highly impact on heating energy conservation in Hokkaido, Tohoku and Hokuriku. Although a little patience with sultry indoor environment promises energy conservation, its effect seems to be less than the direct change of the preset temperature.

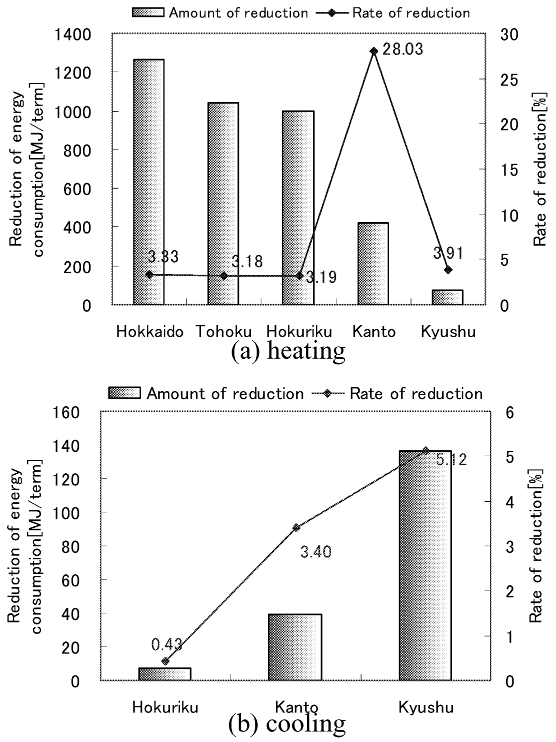


Fig.5 Amount and rate of energy consumption reduction by cutting one hour for space conditioning from actual state

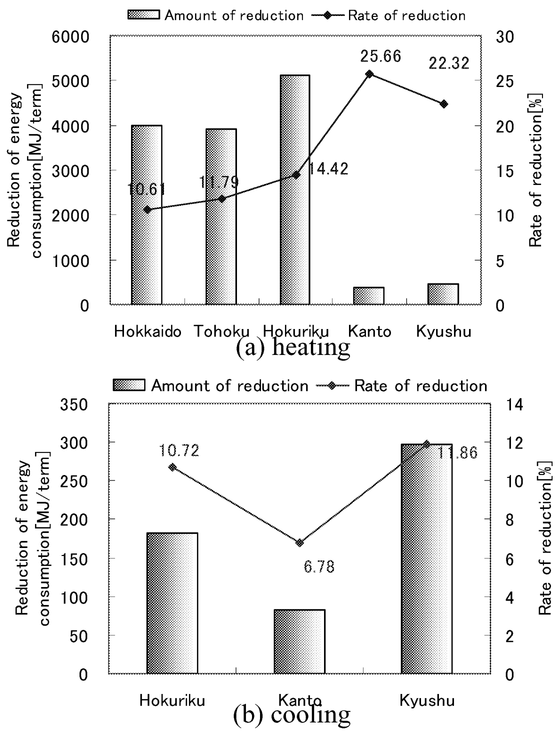


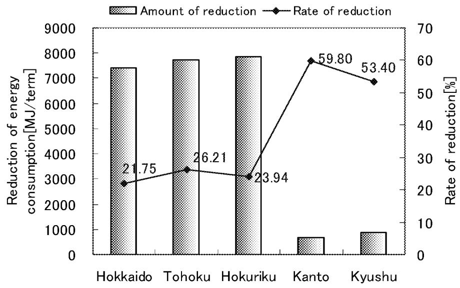
Fig.6 Amount and rate of energy consumption reduction by having a little patience with chilly and sultry indoor environment

3.4 Adjustment with clothing

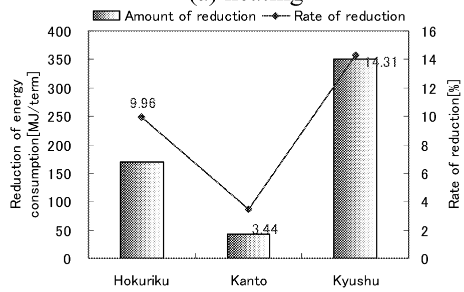
Fig.7 shows the amount and rate of energy consumption reduction by adjusting an amount of clothing for comfort temperature. The sensory index PMV is utilized as well as the previous section to quantify the effect of the appropriate clothing amount on energy conservation. The space conditions are controlled to the standardized PMV in each house under the assumption that the amount of clothing is changed from 1.1clo to 1.4clo in heating and from 0.5clo to 0.2clo in cooling. This measure has an extraordinary effect for heating energy conservation. The reduction rate exceeds more than 20%. Although the effect of the appropriate clothing amount for cooling on energy conservation is not as much as for heating, a certain level of the energy conservation is expected as the reduction rate becomes above 14% in Kyushu.

4. CONCLUSIONS

In this paper, the effect of energy saving lifestyle in the residential buildings on energy consumption for space conditioning is investigated through the computational simulation. The following measures are addressed; applying publicly recommended temperature for space conditioning, turning the heating and cooling down at one degrees C, shortening of space conditioning time, having a little patience with chilly and sultry indoor environment, adjusting the amount of clothing for comfort temperature. The major results obtained are as follows. The direct changing of preset temperature remarkably contributes to energy conservation although every measure to save energy has effect. In case that the publicly recommended temperature for space conditioning is applied, the reduction rate of energy consumption both heating and cooling is about 10% to 17% in almost all regions in Japan. The adjustment of the clothing amount for comfort temperature can extremely reduce energy consumption for space conditioning. Heating energy is decrease more than 20% in every region.



(a) heating



(b) cooling

Fig.7 Amount and rate of energy consumption reduction by adjusting an amount of clothing

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