New challenge for residential building energy efficiency standards in Japan: unify energy efficiency of envelope and housing appliances

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Abstract
Residential energy efficiency standards of many countries evaluate envelope performance. Japanese energy efficiency standards of residential building were revised in 1999, and include both a performance standard and a prescriptive standard for envelope energy efficiency. The target is for over 50 % of new houses to meet the standard in 2010. Efficiency of residential appliances are governed by the Top Runner standards. However, these standards consider each appliance individually, but do not evaluate the whole house comprehensively.

Because residential energy efficiency varies greatly depending on the performance of appliances, we developed a method to evaluate performance of both the envelope and the appliances, with the following characteristics. 1) Evaluate the energy efficiency of the envelope and appliance together. 2) Evaluate the energy efficiency of the whole house using total energy consumption specified for the space conditioning, water heating, lighting, and ventilation appliances at the time of construction. 3) Evaluate the efficiency for space conditioning and water heating appliances using efficiencies during actual operating time. 4) We have performed detailed measurements to understand the efficiency during actual operation. The evaluation method we developed will have a major impact on future Japanese standards for residential energy efficiency. In this paper, we discuss the composition of new standards for housing energy efficiency and explain our method for evaluating energy efficiency of household appliances.

Introduction
In March 2006, residential building energy efficiency standards in Japan were partly revised. Until then, the standards had addressed the energy efficiency of the building envelope, such as insulation, air-tightness and ventilation. In contrast, commercial building energy efficiency standards addressed energy efficiencies of both the building envelope and equipment and appliances in use (below, simply called appliances). However, because Japanese energy efficiency standards were not made mandatory, construction of housing meeting the standards has not progressed. The current revision makes reporting of the energy efficiency measures used mandatory at the time of construction, expansion, or major remodelling, for buildings of area 2 000 m^2. or more. It is expected that notification at the time of expansion or remodelling will promote energy efficiency retrofits of the housing stock. Also, the government decided to enact standards for energy efficiency of household appliances. Still, the only appliances for which standards have been set are those used in common areas of multifamily dwellings (for example, lighting in common hallways, elevators, and ventilation in underground parking areas). The standards do not target appliances used in individual housing units.

Residential energy efficiency varies greatly, not only depending on the envelope, but also on the appliances used. In order to set a standard that addresses both aspects, methods to evaluate performance of equipment are needed. We have developed such a method. With the development of this method, it has become possible to set a new energy efficiency standard that evaluates a house's envelope and appliances comprehensively.

In this paper, first we show the methods for evaluating space conditioning and water heating energy consumption, as evaluation methods for these end uses are particularly complicated and were developed from results of laboratory tests of equipment performance. Next, we show results for representative cases calculated using the evaluation methods. Finally, we discuss the application of the methods to energy efficiency standards.

Content and characteristics of current residential energy efficiency standards

Japan's residential energy efficiency standards were set in 1980, and after that were upgraded in 1992, 1999, and in 2006, when standards for equipment in common areas of multifamily housing were added. For the standard values, performance standards and prescriptive standards were set, varying by region. The current standard values are still those revised in 1999, but the 1992 and 1980 values are used in a ranking system to indicate housing performance.

The measures described below have been chosen as the performance standards. These standard values are set for each of six regions, divided from the north, according to heating degree-days.

- Annual heating/cooling load (Standard of annual heating and cooling load)
- Housing thermal loss (Standard of heat loss coefficient)
- Prevention of solar radiation (Standard of coefficient of solar heat gain)
- Housing air-tightness (Standard of equivalent leakage area per unit floor area)
- Proper ventilation
- Ventilation, elevators, and lighting energy consumption in common areas of buildings with floor area 2 000 m² or greater

For the prescriptive standards, the specified codes of design and construction shown below have been set.

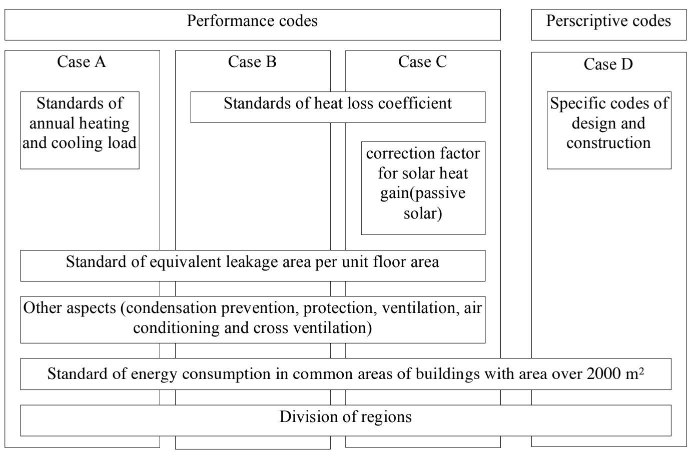


Figure 1. Examination process of the energy efficiency codes.

- Thermal transmittance of envelope & shading measure & airtight measure
- Specification of insulation elements

To determine that the standards are met, any one of the four case methods described below must be satisfied.

- Case A: Standard of annual heating and cooling load; Standard of equivalent leakage area per unit floor area; Other aspects; and Standard of energy consumption in common areas of buildings with floor area 2 000 m² or greater
- Case B: Standard of heat loss coefficient; Standard of equivalent leakage area per unit floor area; Standard of coefficient of solar heat gain; Other aspects; and Standard of energy consumption in common areas of buildings with floor area 2 000 m² or greater
- Case C: Standard of heat loss coefficient corrected in solar heat gain & Standard of equivalent leakage area per unit floor area & Standard of coefficient of solar heat gain; Other aspects; and Standard of energy consumption in common areas of buildings with floor area 2 000 m² or greater
- Case D: Specified codes of design and construction, and Standard of energy consumption in common areas of buildings with floor area 2 000 m² or greater

The goal of providing these four cases is to make the standards easier to use. For example, calculating the annual heating and cooling load requires the most effort, but it allows for great flexibility in the choice of windows and walls. On the other hand, if the design follows the specific codes of design and construction, there is no need to do any calculations at all. The builder and the owner can choose which compliance method to use, according to their own preferences.

The most important factor in building energy efficiency standards of Japan is the heat loss coefficient, but the standards are also consistent with other standard values. This is because the following procedures were used to set the standards.

1. Set prescriptive standards (for wall and roof, floor, and window structure), based on the structure of housing in each region, to implement the highest energy efficiency reasonably possible. Necessary conditions are that local builders can build it and there will not be an excessive cost increase. In other words, set a prescription for the highest efficiency practical.
2. Calculate the heat loss coefficient for construction to the above standards.
3. Compare the calculated result to the current standard of heat loss coefficient for the particular region, consider whether appropriate improvements can be made, and set new reference values for heat loss coefficients.
4. Conduct heat load simulations for models of houses implementing the new prescriptive heat loss coefficient standard value, and set the Standards of Annual Heating and Cooling Load.

Table 1. Standards of heat loss coefficient

	unit	divisions of regions					
		No.1	No.2	No.3	No.4	No.5	No.6
degree-day(HDD 18-18)	deg.day	over 3 500	3 000-3 500	2 500-3 000	1 500-2 500	500-1 500	under 500
reference value of the heat loss coefficient	W/ m²-°C	1.6	1.9	2.4	2.7	2.7	3.7

5. Set Specific Codes of Design and Construction for houses in each region meeting the new heat loss coefficient standard values.

Table 1 shows standards for the heat loss coefficient of each region.

Development of a new method to evaluate energy efficiency performance

Energy efficiency standards of Japan have not included standards for appliances used in individual housing units. The Top Runner Standards (TRS) govern appliances, but they do not help us know whether, for example, a heat pump air-conditioner or floor heating is more efficient. Also, many TRS evaluate energy consumption for a fixed efficiency and during maximum output, not evaluating the efficiencies of air-conditioners and boilers under actual conditions of use. Furthermore, to evaluate recently developed heat pump water heaters and residential co-generation systems, new evaluation methods are needed. At any rate, in order to evaluate the energy efficiency performance of the whole house, it was necessary to add the three elements below to the current standards.

- For space conditioning, water heating, lighting, and ventilation equipment that is built in at the time of construction, evaluate every end-use together, comprehensively.
- For space conditioning, evaluate energy efficiency of the envelope and appliances at the same time.
- In order to evaluate efficiency of each end-use, such as space conditioning, water heating, and lighting, at the same level, evaluate the efficiency during actual operation.

Because an evaluation method for envelope energy efficiency already exists, by developing evaluation methods for space conditioning and other appliances, it becomes possible to evaluate whole house energy efficiency. But, depending on the envelope energy efficiency, the load will vary. Efficiency of air-conditioners, in particular, varies greatly, depending on the load. Other appliances for which efficiency varies with load size include floor heaters, water heaters, and co-generation. For these appliances, changes in efficiency depend on the pattern of use. To develop a method of calculating energy consumption that accounts for these relationships, we do the following.

- Subdivide some regions, because some regions in the current standards are somewhat too large.
- Set standard usage patterns for heating, cooling, and water heating, and calculate annual heating load by region.
- Set the electricity consumption for lighting and plug loads, for co-generation.
- Perform measurements in the laboratory for air conditioners and floor heating, to analyse the relation between load and efficiency.
- Perform laboratory measurements of energy consumption for water heating boilers, heat pump water heaters, and co-generation, based on the water heating usage pattern. Analyse the efficiency of each appliance.
- From the set heat load and the results of analyses of equipment efficiency characteristics, we obtain a model for calculating whole house energy consumption.

FRAMEWORK FOR EVALUATION OF APPLIANCE ENERGY EFFICIENCY

The model for calculating energy consumption differs greatly depending on whether or not co-generation is used. For the case without co-generation, there are appliances corresponding to each end-use, such as heating, cooling, and water heating, so we calculate the energy consumption for each end-use and then obtain whole house energy consumption. For the case with co-generation, we calculate energy consumption of co-generation from the heat and electrical loads covered by the co-generation system. The electrical load includes electricity consumption by things such as lighting, ventilation, and air conditioners.

To evaluate energy efficiency performance we compare the results of calculated energy consumption for actual houses with the reference energy consumption value. If the former is less than the latter, the energy efficiency performance can be judged as meeting or exceeding the standard. That is, energy efficiency performance is judged as follows:

$E<=E_0$

E: calculated results of energy consumption for an actual house

E_0: calculated results of energy consumption for a standard house or appliance

$E=Eh+Ec+Ew+Ev+El-Es$

$E_0=Eh_0+Ec_0+Ew_0+Ev_0+El_0$

Eh: heating energy consumption; Ec: cooling energy consumption; Ew: water heating energy consumption; Ev: ventilation energy consumption; El: lighting energy consumption; Es: reduction in energy consumption from solar electric power generation and others

Once the standard performances of the house and its appliances are set, the standard values can be set. At what level the standards should be set is a matter of concern, because the results will directly impact the business of utilities and the construction industry. We hope for future discussion of opinions about new energy efficiency standards, in the process of setting of new standards.

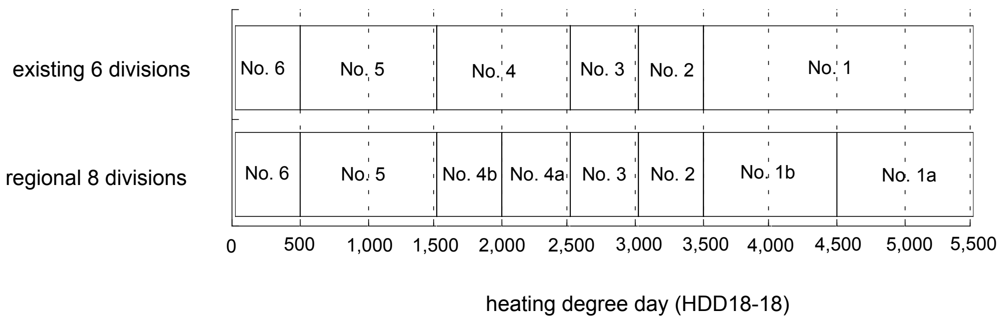


Figure 2. Revision of regional divisions.

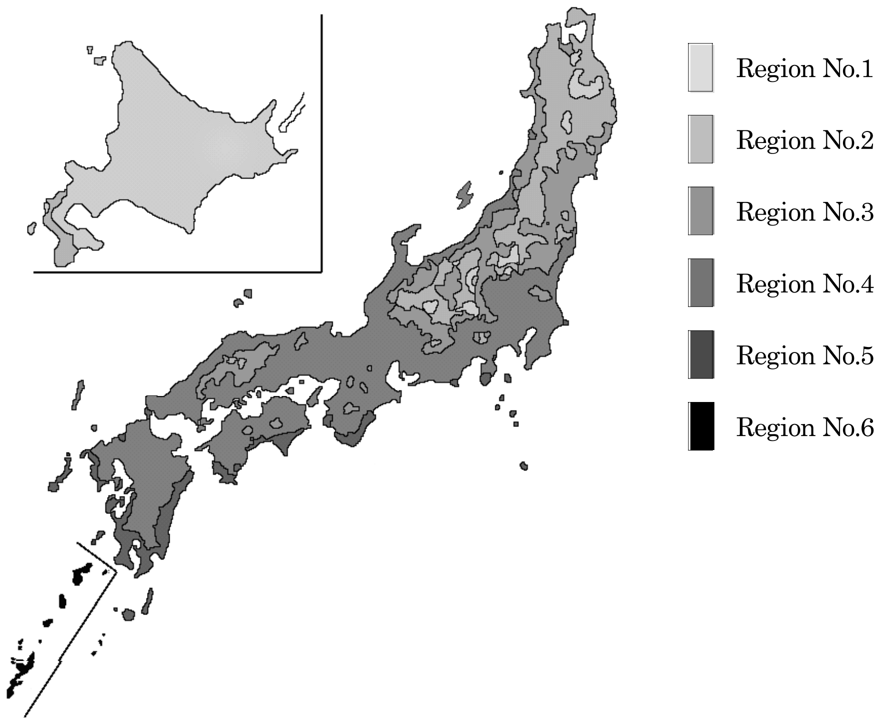


Figure 3. Regional divisions for the existing energy efficiency standard.

REVISION OF REGIONAL DIVISIONS

The current energy efficiency standards divide the country into six regions, by heating degree days (HDD). When considering energy efficiency of appliances, it is desirable to make the regions smaller, because the size and distribution of the space conditioning load influence appliance efficiencies. As a general rule, we decided to divide regions into increments of 500 HDD, with as little revision of existing standard regions as possible. Region No. 4 of the existing standard, from 1 500 to 2 500 HDD, covers a wide range of Japan, including such large cities as Tokyo, Yokohama, Nagoya, Osaka, and Fukuoka, with an extremely large residential population. Also, Region No. 1 has a relatively wide HDD range. Accordingly, we divided both Regions No. 1 and 4 into two parts, setting up eight new regional divisions.

EVALUATION METHODS FOR SPACE CONDITIONING ENERGY CONSUMPTION

Space conditioning energy consumption is determined by the following formulae.

$Eh=Lh*Ch$ $\qquad$ $Ec=Lc*Cc$

Lh: heating load
Lc: cooling load
Ch: efficiency of heating equipment
Cc: efficiency of cooling equipment

Setting space conditioning loads

We set the annual heating and cooling loads for various types of housing in each region by setting up models for detached and multifamily housing, and performing heat load simulations for standardized living conditions. Because in Japan, space conditioning is typically done room by room, we calculate heat loads for both the whole house and by rooms (here, living room and other rooms). Because few mainstream houses have energy efficiencies meeting the 1999 standards, we calculate envelope performance for two cases, the 1999 standards and the 1992 standards. We do not try to evaluate the performance of houses not meeting the 1992 standards. Even if such houses had very efficient appliances, they could not reach our reference energy efficiency level without supplementary measures, such as installing large solar cell.

For the cases below, we perform heating and cooling load simulations and set annual load levels per unit area.

- Regional divisions: 8 cases
- Housing types: detached and multifamily; 2 cases
- Space conditioning mode: whole house continuous operation, and room by room (called partial) intermittent operation; 2 cases; for partial, intermittent operation we calculate loads for the living room (LDK, or living, dining and kitchen), and for each other room
- envelope energy efficiency: meets 1999 standards and meets 1992 standards; 2 cases

In all, we calculated annual heating and cooling loads pre unit area for 64 cases (*Table 2*).

Efficiencies of space conditioning equipment, especially air-conditioners, vary greatly, depending on the load factor and the outdoor temperature. In Japan, it is very rare that the whole house is heated 24 hours per day, as is often the case in Europe and America. Many households only heat occupied rooms while people are present, and do not heat during sleeping hours. We call this the partial, intermittent heating mode. The reason energy consumed for heating is lower in Japan than in Europe and America is this difference in heating mode. The distribution of heating load for the whole house, continuous case is similar to the distribution of outdoor temperature, both being nearly normal distributions. In contrast, the distribution of heating load for the partial, intermittent case is wide, with a long tail. The percentage of time with partial load ratios for air-conditioners is very high, causing major decreases in efficiency during actual use. To investigate the load distributions further, we ran heat load simulations for various outdoor temperatures and various room uses.

To enable us to estimate distributions of air conditioner efficiencies during actual use, we divided our cases as follows.

- heating or cooling output power bins of 20 W/m^2 each
- four outdoor temperature bins: x < 2degC; 2degC < 7degC; 7degCx < 12degC; 12degC < x

Table 2. Annual heating and cooling load specified values (unit: MJ/m^2-year)

Envelope efficiency meets the 1999 standards				division of regions							
				1a	1b	2	3	4a	4b	5	6
heating	whole house continuous	detached & multifamily	whole house	308	255	267	293	269	199	127	--
	partial intermittent	detached	LDK*	--	--	436	445	385	302	187	--
			other room	--	--	206	224	203	129	77	--
		multifamily	LDK	--	--	287	329	278	202	115	--
			other room	--	--	206	224	203	129	77	--
cooling	whole house continuous	detached & multifamily	whole house	--	--	--	53	59	77	114	246
	partial intermittent	detached	LDK	--	--	--	87	96	132	189	412
			other room	--	--	--	5	8	17	29	105
		multifamily	LDK	--	--	--	60	68	101	147	357
			other room	--	--	--	5	8	17	29	105

*LDK is living, dining and kitchen area.

Envelope efficiency meets the 1992 standards				division of regions							
				1a	1b	2	3	4a	4b	5	6
heating	whole house continuous	detached & multifamily	whole house	364	304	421	463	481	356	261	--
	partial intermittent	detached	LDK*	--	--	627	636	619	484	343	--
			other room	--	--	315	351	351	232	162	--
		multifamily	LDK	--	--	451	438	382	285	204	--
			other room	--	--	315	351	351	232	162	--
cooling	whole house continuous	detached & multifamily	whole house	--	--	--	59	72	97	148	325
	partial intermittent	detached	LDK	--	--	--	91	108	150	220	484
			other room	--	--	--	5	8	17	28	110
		multifamily	LDK	--	--	--	70	78	114	167	399
			other room	--	--	--	5	8	17	28	110

We organize the results and offer an evaluation for typical housing. Our assumptions regarding this housing are thoroughly typical, but do not represent houses with large open spaces or complicated plans. For our typical houses, we conduct heat load simulations, sort the results into the bins described above, and then evaluate.

Figure 4 shows the frequency distribution for the heat load for detached houses in the Tokyo area, for the case of intermittent heating of the living room (LDK). The peak is at 40 to 60 W/m², and for less than 160 W/m² the distribution is close to normal. For the region less than 160 W/m², we can regard the room temperature as being essentially fixed, leading to a load under stable conditions. For the region greater than 160 W/m² the load distribution has a wide spread, and especially for outdoor temperatures less than 2°C, large output is required of heating appliances. We can regard this part of the distribution as the time when the heater starts up.

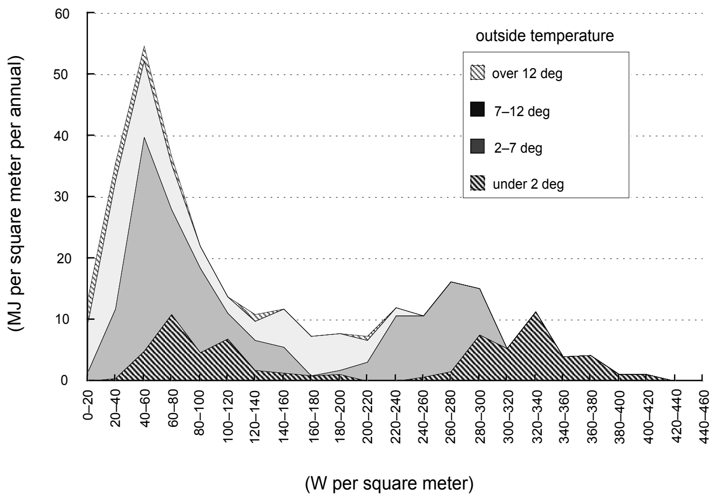


Figure 4. Frequency distributions for heat load for living room of a wooden, detached house in Region No. 4b. The envelope efficiency meets 1999 standards, and the heating mode is partial, intermittent.

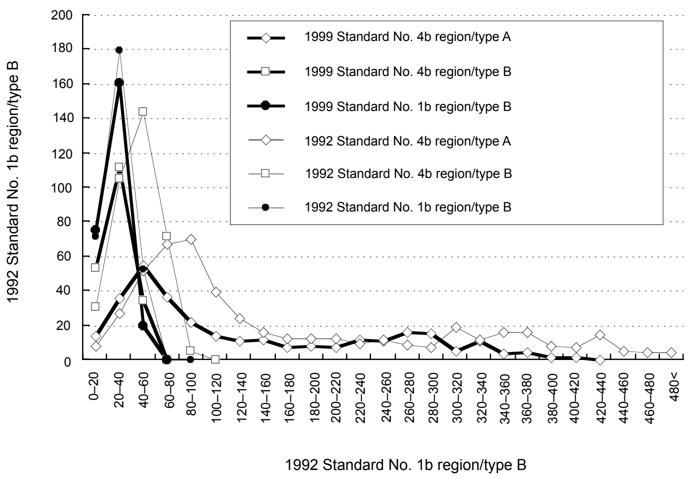


Figure 5. Comparison of frequency distributions for heat load for wooden, detached housing. Notes: 1999 Standard=envelope efficiency meets 1999 standards; 1992 Standard=envelope efficiency meets 1992 standards; type A=intermittent heating of the living area; type B=whole house, continuous heating

Figure 5 shows results for six different cases. Lower envelope efficiency shows a trend toward more spread in the heat load. Also, the cases of whole house, continuous heating show nearly normal distributions, with the maximum held to 80 W/m² and 120 W/m², for houses in Region No. 4b meeting the 1999 and 1992 standards, respectively. Region No. 1b is cold, so whole house, continuous heating is popular there. The envelope energy efficiency sought with the current standards is also quite high, so the heat load there has become even lower than in Region No. 4b.

Air-conditioner efficiency

In Japan, normally a single room is conditioned by a "separate type," split system, air-conditioner. Domestic shipments of this appliance have reached about 7 million units annually. In 2005 their diffusion reached 2.5 units per household, with an increasing trend each year. Improvements in air-conditioner efficiency have also been notable, with the current maximum efficiency exceeding an annual performance factor (APF) of 6. Efficiency standards for air-conditioners in Japan have changed from noting the coefficient of performance (COP) to the APF. The APF is an estimate of annual efficiency considering changes in outdoor temperature, based on measured data for specified COP and other conditions. The APF is among those indicators that consider efficiency during times of partial load ratio. However, the load that is assumed in the APF calculation is linked to the outdoor temperature, and is nearly normally distributed. The conditions for the APF calculation give the air-conditioners sufficient loads. As a result, the APF is quite similar as an index to the recently replaced COP.

Air-conditioner efficiencies increased dramatically from 1997 on. In 1999, the TRS were adopted and competition for efficiency increased, with investment in new technology. As a result, average efficiencies (COP) specified in 2004 were 5.2 for heating and 4.9 for cooling.

Improvement in air-conditioner efficiencies has been notable, but the values given are design efficiencies, from which it is difficult to evaluate efficiency during actual operation. Based on results of laboratory measurements of T. Sawachi and A. Hosoi and others (2006, 2003), and Y. Sakamoto and others(2006) , we decided to use results from an analysis of air conditioner efficiency characteristics. According to A. Hosoi, T. Sawachi, and others, the following characteristics have been confirmed for air-conditioner efficiency.

- Efficiency is highest at half of maximum output.
- The COP at maximum output falls to about 80 % of the maximum COP.
- Below medium output (about 50 % of rated output) the COP falls sharply.
- Lower outdoor temperatures have lower heating COP. Higher outdoor temperatures have lower cooling COP.

Figure 7 shows a model of these characteristics.

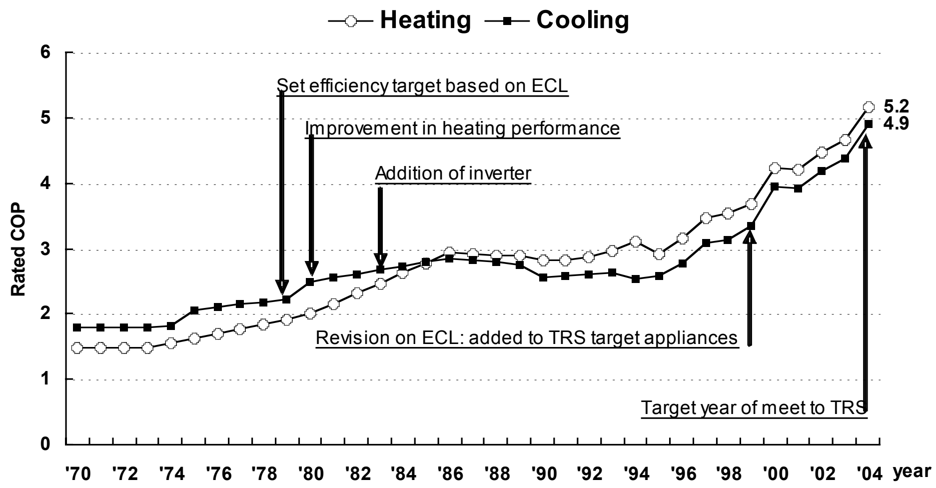
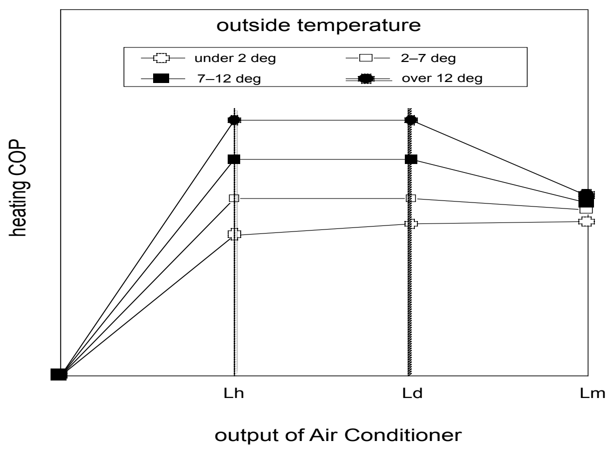


Figure 6. Change in air-conditioner design efficiency over time (average for units shipped).



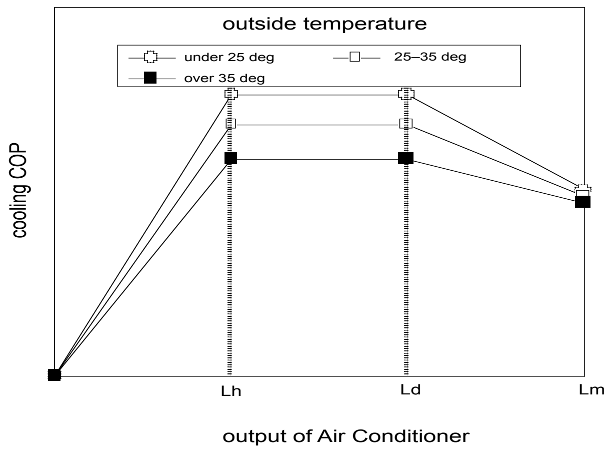


Figure 7. Characteristics of air-conditioner efficiencies. Lh is half of maximum output, Ld is the design, or rated output, and, Lm is the maximum output.

Estimate of energy consumption by air-conditioners during actual operation

We calculate annual air-conditioner energy consumption according to the following steps.

- Decide on the air-conditioning output needed, from the load distribution for the living room. Obtain the maximum output, design output, and design COP for the air-conditioner to be installed.
- Specify the load distribution (*see Figure 4*) based on region and envelope insulation characteristics.
- Calculate annual energy consumption, from the load distribution above and the air-conditioner efficiency characteristics shown in *Figure 7*. We have prepared load distributions and air-conditioner efficiency characteristics for each air-conditioner output and each outdoor temperature range, so we can handle each variation in load size and COP, and can calculate annual energy consumption.
- Do these calculations for every room, to obtain whole house energy consumption.

Here, we show results for a house in Tokyo, meeting the 1999 envelope standards, with a 27.7 m² living room. Maximum load for the living room is 7 kW for cooling and 10 kW for heating, so to supply this load we select a large air-conditioner with 7.2 kW cooling output. These large units have low design efficiencies, and even the most efficient unit currently sold has a cooling COP of only 3.17 and a heating COP of 3.94. Annual energy consumption comes to 1 600 MJ/year for cooling and 3 800 MJ/year for heating, with average COP during actual operation of 2.28 for cooling and 2.20 for heating. These are 72 % and 56 % of the design COPs for cooling and heating, respectively, a large decrease.

The decrease in efficiency during actual use is due to the unit frequently operating at partial load ratio. We calculate the case of a 2.8 kW cooling output air-conditioner installed in the same house. The design COP are 6.51 for cooling and 6.56 for heating. Maximum output for this air-conditioner is 3.4 kW for cooling and 4.9 kW for heating, so from the perspective of load, we've chosen a unit that only meets half the demand, leaving a residual load unsatisfied. Much of this unmet load is in the period after the air-conditioner is started up. In other words, the time until the room is warm gets longer, and during

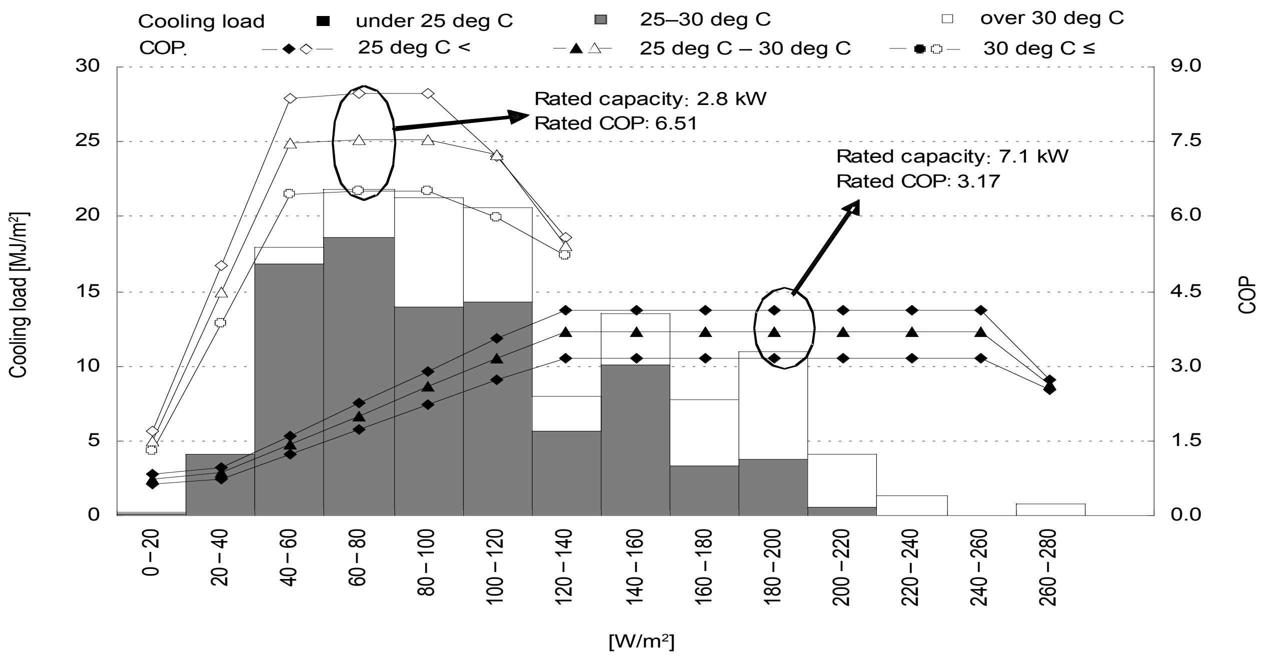


Figure 8. Relation between cooling load and air conditioner cooling efficiency characteristics. (Tokyo, detached house, living room, envelope meets 1999 standards)

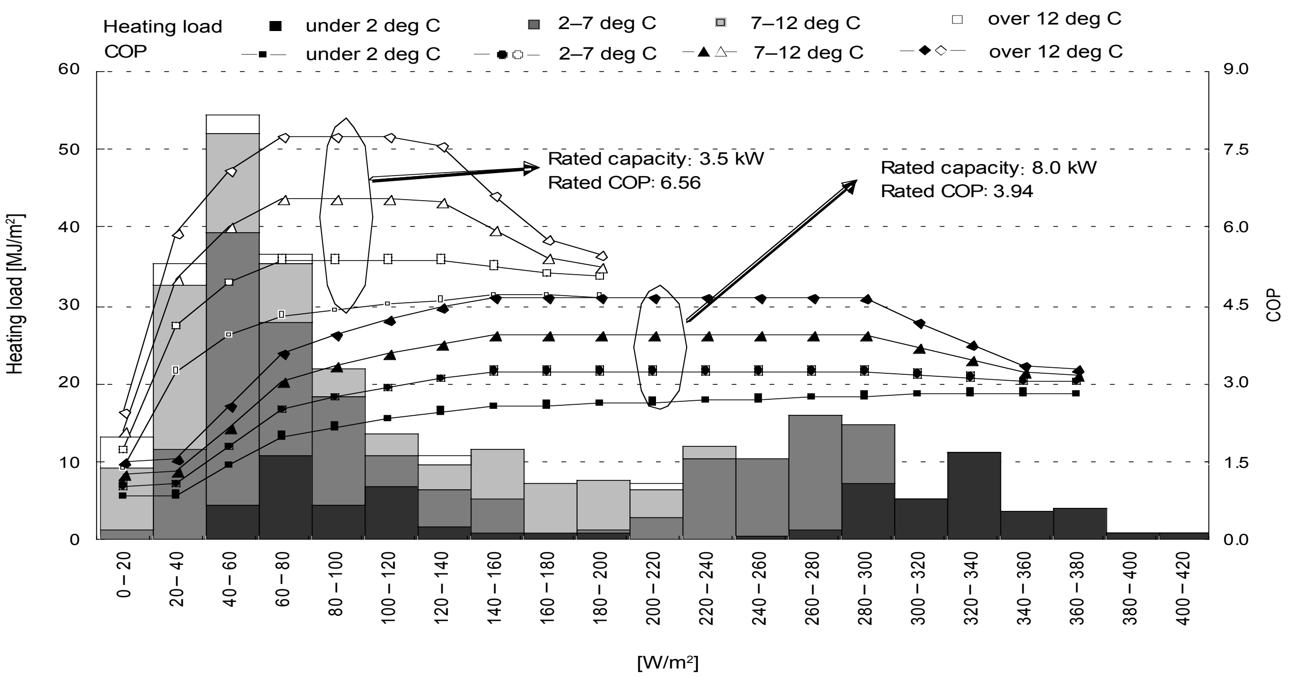


Figure 9. Relation between heating load and air conditioner heating efficiency characteristics. (Tokyo, detached house, living room, envelope meets 1999 standards)

this time the unit runs at maximum output. Of course, the occupant must put up with the air-conditioner not fully heating the room, but we estimate that all of the load can eventually be met, with a time lag. For this case, the energy consumption is 590 MJ/year for cooling and 1 760 MJ/year for heating. The average COP during actual operation are 6.24 for cooling and 4.76 for heating. These are 96 % and 73 % of the design COP for cooling and heating, respectively, generally reflecting the performance characteristics of the air-conditioner.

In this way, in a country like Japan, in which partial, intermittent space conditioning is the general practice, conditioning loads are quite varied and choices of air-conditioner output can cause major changes in actual efficiency.

Table 3. Efficiency of other heating appliances

Heating appliance	Efficiency of appliance	Top Runner Standard
Gas Forced Draught Balanced Flue	0.8	0.82
Oil Forced Draught Balanced Flue	0.85	0.86
Oil Balanced Flue	0.83	0.83
Oil Conventional Flue	0.67	0.69
Other Oil Heater	0.67	0.67

Table 4. Setting of annual water heating loads (MJ/year)

division of regions							
No.1a	No.1b	No.2	No.3	No.4a	No.4b	No.5	No.6
22.5	22.0	20.8	19.8	18.8	17.0	14.5	12.0

Table 5. Energy savings rate for water heating energy efficiency measures

Energy efficiency measure		Energy savings rate(%)
kitchen	sprayer water column	4 %
	easy on-off water column	3 %
bath room	water-conserving showerhead	4 %
	showerhead with stop-water switch	6 %
piping	small diameter piping	5 %

Efficiency of radiant heating

Energy consumption of radiant heating is determined by the heat load, and also by the efficiencies of the heat source, heat panel, and distribution piping. According to analyses of laboratory measurements by Miura and others (2006), these terms are defined as follows.

E=1/eb*(Qr/ep+Cp*Lp)

E: radiant heating rate of energy consumption (W)
eb: heat source efficiency
Qr: radiation from the radiant panel to the room (W)
ep: ratio of panel radiation up and down (for floor heating this depends on the insulation properties beneath the panel)
Cp: rate of heat loss by distribution pipes (W/m)
Lp: length of distribution pipes (m)

Compared to typical heaters, with radiant heating the room temperature can be lower and achieve the same sensible temperature. We calculate Qr below, assuming a 10 % decrease in energy consumption is possible due to this effect.

Qr=L*A*0.9

L: heat load per unit area (W/m^2)
A: living room area (m^2)

Efficiencies of other heating appliances

For efficiencies of other heating appliances, we assume that the appliances meet the TRS, and we allow for decreased efficiency due to energy consumption by things like fans. However, we did not evaluate efficiency of open source combustion appliances, because of the issue of indoor air pollution from exhaust gases.

EVALUATION METHOD FOR WATER HEATING ENERGY CONSUMPTION

To obtain energy consumption for water heating, we need the water heating load and heater efficiency. The water heater efficiency varies, depending on the load and on factors such as mode of use and climate conditions. To find the water heater efficiency, we choose a mode of use, and under those conditions, perform laboratory measurements. From analysing the results, we set an appliance efficiency.

Setting the water heating load and mode of use

We set what becomes the normal mode of use. Setting the mode of use also determines the water heating load. There have been several proposals regarding modes of use. A project by the Ministry of Land, Infrastructure and Transport (National Institute for Land and Infrastructure Management, 2005), *Development of support systems for maintenance of infrastructure for energy and resource self-sufficient housing and cities,* set forth volume of hot water used and a water heating mode, the revised M1 mode, based on measurement results. Here, we use the hot water volume for a 4-person household from these results.

The hot water volume for the revised M1 mode averages 450 L/day. Revised M1 mode set 6 mode depending on, for example, whether it is a regular weekday, a vacation day spent at home, or a vacation day with occupants away, and each there are days of more and less use. The water heating mode stipulates the hot water volume used every five-minute interval for the bathroom sink, kitchen, bath, and shower, for each of the three cases mentioned above. We calculate the annual water heating load using the revised M1 mode hot water volume and the hot water temperature for each region, monthly.

Effective energy efficiency measures for water heating include use of small diameter piping and water conservation equipment. *Table 5* shows estimates of the rate of energy savings from such methods. Also, use of solar water heaters has a

Table 6. Water heater efficiencies

water heater type	division of regions							
	No.1a	No.1b	No.2	No.3	No.4a	No.4b	No.5	No.6
gas on-demand water heater	0.71	0.71	0.72	0.72	0.72	0.73	0.73	0.75
latent heat recovery gas on-demand water heater	0.88	0.88	0.87	0.88	0.87	0.86	0.86	0.85
kerosene on-demand water heater	0.76	0.77	0.78	0.78	0.78	0.79	0.79	0.82
kerosene tank water heater	0.74	0.75	0.76	0.76	0.76	0.77	0.76	0.79
electric water heater	0.76	0.76	0.75	0.75	0.75	0.74	0.74	0.72
CO2 heat pump water heater	-	-	-	2.85	2.92	3.12	3.15	3.52

large energy efficiency effect. Heat obtained from solar water heaters is estimated according to the panel direction and slope, for each region.

Setting water heater appliance efficiencies

According to analyses of laboratory measurements under conditions of the revised M1 mode by M. Mae (2006), we obtain efficiencies for the following types of water heaters: gas on-demand water heater, latent heat recovery gas on-demand water heater, kerosene on-demand water heater, kerosene tank water heater, electric water heater, and CO_2 coolant heat pump water heater. *Table 6* shows these results.

EVALUATION METHOD FOR CO-GENERATION

Two types of residential co-generation systems are sold, gas engine co-generation and fuel cell co-generation. Gas engine co-generation holds the major market share, with 40 000 units purchased in 2005. The government target is 195 000 purchased by 2010, but it appears that diffusion may exceed the target. It is expected that 40 000 fuel cell co-generation units will be purchased by 2010.

Co-generation systems provide electricity and heat, and because they have hot water tanks, their efficiencies are influenced by many factors, such as water heating load, modes of hot water and electricity use, and outdoor temperatures. We set the heating and cooling loads described above, water heating load, and also the electricity used for lighting and plug loads. Based on result and analysis of laboratory measurement of M. Mae (2006), we developed a simple estimate of energy efficiency performance. However, the efficiency of co-generation is greatly influenced by other factors besides changes in load, such as electric power output and efficiencies of electricity generation and waste heat recovery. Therefore, our estimates can only be applied to systems equivalent to the ones we tested in the laboratory.

$Et=C_1Ee+C_2Lw+C_3$

Et: energy consumption of the co-generation system (GJ/year)

Ee: electricity supplied by the co-generation system for heating , cooling, lighting, and ventilation (GJ/year)

Lw: heat load supplied by the co-generation system for water and space heating (GJ/year)

C_1, C_2, C_3: coefficients shown below

	gas engine co-generation	fuel cell co-generation
C_1	0.999	0.995
C_2	1.098	0.261
C_3	0.70	5.35

The co-generation systems for which this equation can be applied are limited to those specified below. If a new type of system is developed, it will have to be tested in the laboratory and undergo the same kind of analysis.

Results of Energy Consumption Calculations

Among houses newly built in 2004, 19 % of detached houses and 12 % of multifamily houses met the 1999 envelope standards. The 1992 envelope standards were met by 46 % of detached houses and 77 % of multifamily houses. A majority are at the level of the 1992 standards. Below, we compare results of energy consumption estimates for a detached house in Tokyo.

For houses meeting the most generally used 1992 standard, energy consumption using normal appliances comes to 68.6 GJ/year. In comparison, a house using the same equipment but meeting the 1999 standards uses 57.2 GJ/year, a 17% energy efficiency effect. This case is simply for meeting current envelope standards, and if high-efficiency equipment and appliances were used, we would expect further energy savings.

For comparison, we show the energy consumption with energy efficient appliances. For energy efficient appliances we used the following: for heating and cooling, the most efficient heat pump air-conditioner; for water heating, hot water conservation equipment, to reduce the load, with either a condensing boiler or a CO_2 heat pump water heater; high-efficiency ventilation system; and a high-efficiency lighting system. We also added a co-generation system. Even though the envelope only meets the 1992 standard, by specifying high-efficiency appliances, whole house energy consumption drops to 52.4 GJ/year, or 8 % less than the current standard level. In other words, although the envelope performance is only typical, by using efficient appliances the whole house energy consumption can be held below the current standard level.

For the case of 1999 envelope standards with efficient appliances, energy consumption is 48.6 GJ/year with the condensing boiler, a decrease of 15 % below the current standard. When the CO_2 heat pump is used for hot water, it is 44.7 GJ/year, or a 22 % savings. When co-generation is used, the PE fuel cell results in 43.2 GJ/year, a 24 % savings, and the gas engine co-generation results in 49.7 GJ/year, or a 13 % savings.

Application to energy efficiency standards

As we stated above, residential energy efficiency standards in Japan address envelope performance, not considering appliance energy efficiency. There are the TRS for appliances, so housing standards and appliance standards exist separately. The housing energy efficiency standards were set in 1999 and partially revised in 2006, but the revision left the envelope standards at 1999 levels. At the time of setting the 1999 standards,

Table 7. Specification of types of co-generation systems subject to evaluation

	gas engine co-generation	fuel cell co-generation
heat source	163 cc gas engine	PE fuel cell
electric power output	1 kW	1 kW
fuel	city gas 13A	city gas 13A
hot water tank volume	150 L	200 L
electric generation efficiency (HHV)	20 %	31 %
waste heat recovery efficiency (HHV)	65 %	40 %
back up boiler	gas on-demand boiler	latent heat recovery gas on-demand boiler
power back to the electric company	can not	can

prescriptive standards (for walls and roof, floor, and window construction) were set for each region and construction type, to implement the highest performance possible. Necessary conditions were that local construction workers could build it, and that incremental cost not be excessive. That is, the highest efficiency standards realistically possible were specified. Accordingly, when the standards are next considered for revision, to improve envelope performance, for example, by making insulation and walls thicker, will involve a large extra cost, making further strengthening of this standard difficult.

On the other hand, it is important to undertake improvements in efficiency by promoting purchases of high-efficiency appliances. The unification of both envelope and appliances in a new energy efficiency standard would contribute to increasing overall efficiency. Here, an issue becomes evaluation methods for appliance efficiency. Current appliance energy efficiency standards govern efficiencies at times of rated and maximum power output. Provided that the standard is set for each appliance, even with the current evaluation methods, by raising the standard values the government can direct the market toward high efficiency appliances. If we evaluate whole house energy consumption, we need to evaluate efficiencies corresponding to appliances' actual operation. This is because when such a standard is used, it will be important to treat those trying to increase space heating efficiencies and, for example, water heating or ventilation efficiencies equally. We have developed a method to evaluate efficiencies during actual operation, using analysis of laboratory measurements and modelling.

By using this evaluation method, it is possible to create a standard for energy efficiency performance that unifies efficiency of residential structures and appliances. For setting such a standard, there are two cases that come to mind. One case takes the current house envelope standards, assumes normal appliances, and sets the estimated reference energy consumption as the standard value. The other case assumes high-efficiency appliances and sets the resulting reference energy consumption as the standard value. In the former case, even if the current envelope standards were not met, by using high-efficiency appliances the overall standard could be met. This case has merit, in that it easily promotes purchase of high-efficiency appliances. For the current situation, in which envelope efficiency increases are hardly progressing, this seems to be a realistic strategy for advancing residential energy efficiency. A problem with this method is that envelope efficiency improvements will stop progressing.

As *Figure 10* shows, by meeting current envelope standards and using high-efficiency appliances, even without measures like co-generation, photocells, and solar water heaters, it is possible to improve energy efficiency by nearly 22 %. If the standard value were taken as the second case, the current envelope standard with high-efficiency appliances, it would probably be possible to make the standard value 10 to 20 % tighter than the current standard.

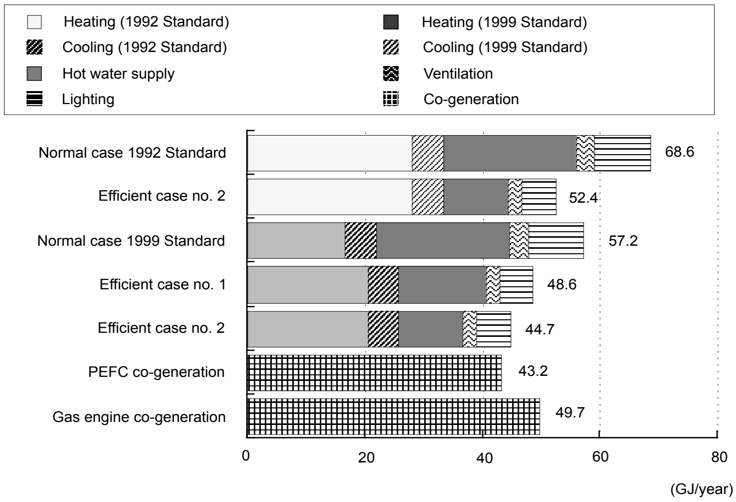


Figure 10. Comparison of energy consumption due to use of efficient appliances (Tokyo, detached house).
Notes: Normal case=normal appliances; Normal case=efficient envelope + normal appliances; Efficient case No.1=most efficient air-conditioner + condensing boiler + efficient ventilation and lighting; Efficient case No.2=most efficient air-conditioner + CO_2 heat pump hot water supply + efficient ventilation and lighting; Electricity conversion rate=9 760 kJ/kWh.

Conclusion

Energy efficiency standards of many countries address a house's envelope and appliances with separate standards. But residential energy consumption is influenced by both the performance of the envelope and the efficiency of its appliances. Therefore, residential energy efficiency standards need to evaluate both envelope and appliances at the same time. Attempts to do this kind of evaluation include HERS and others. Residential energy efficiency standards of Japan also currently evaluate only envelope performance, while appliances are governed by the TRS. While increases in appliance energy efficiency have been progressing under the TRS, compliance with residential energy efficiency standards seems stalled at less than 20 % of new houses. Many experts proposed Government to change the standard as mandatory. But Ministry of Land, Infrastructure and Transport (MLIT) do not plan to change it. Japan's residential energy efficiency standards are at about the same level as those in Europe and America. Because Japan is a temperate region and rooms are only heated or cooled when occupied, and generally not during sleeping hours, heating and cooling energy consumption is comparatively less than in Europe and America. We think this is also a factor in the lack of progress in raising envelope performance. That is, for Japan, the standard level is relatively high. In addition, to promote residential energy efficiency it would be effective to develop a comprehensive standard that includes things like water heating and lighting, besides heating and cooling. I think, it is same situation for European countries. These comprehensive standard would be effect on increase or promote high efficient equipments.

To standardize a method to evaluate whole house energy consumption, there are many challenges to surmount. For space heating and cooling equipment, efficiency characteristics of air-conditioners and combustion appliances differ, so the current standards that evaluate efficiency for operation at rated capacity or maximum combustion cannot be applied. For this reason, there is a need to develop methods that evaluate efficiency during times of actual operation. At the same time, it is also necessary to consider the quantity and distribution of the heat load. Besides analysing data from laboratory measurements to make models of appliance efficiency characteristics, for space conditioning we have also obtained load distributions from simulations of heat load, for water heating we selected a standard mode of use and set water heating loads, and for things like ventilation and lighting we set reference modes of use and appliances. In so doing, we have developed a method for calculating whole house energy consumption.

We hope that in the future this evaluation method can be applied to residential energy efficiency standards and contribute to promotion of energy efficiency.

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