How Do We Measure Resident's Benefits?
Benefits and Costs through Energy-Saving Activities

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ABSTRACT

The energy-saving activities of household members such as disconnecting appliances from the outlet to reduce standby power and adjusting the settings of the cooling temperature of air conditioners are some important methods of reducing energy demand. However, when people try to conserve energy or are encouraged to conserve energy, they generally choose a balance between the benefits and costs that they reap through energy-saving activities. However, people do not necessarily maintain energy-saving activities that reduce their comfort notably. Moreover, people may adopt energy-saving activities that do not reduce energy at all.

To determine energy savings activities that are both effective at decreasing energy consumption and that also maximize the comfort and convenience of consumers an analytic hierarchy process (AHP) was used. AHP is a mathematical technique for estimating the relative importance or effectiveness of various factors in a decision making process using pair-wise comparisons. In this case, energy-saving activities, along with their benefits and costs were classified and presented to residential consumers. The benefits included energy reduction and cost reduction. On the other hand, costs included a user's labor and a reduction in the benefits expected through the use of appliances. The model identifies which energy savings activities should be adopted first in a household, based four evaluation criteria (convenience, environmental benefit, comfort, cost). In addition, the energy-saving potential that can be achieved when people carry out energy-saving activities was calculated based on monitored data and existing literature.

Introduction

In Japan, the number of residential houses and the floor space per house are increasing, and the diffusion of various appliances causes increasing energy demand in the residential sector. In order to meet the Kyoto Protocol, it has become clear that reducing energy demand and consequently CO_2 emission in this sector is vitally important. There are several methods of reducing the energy demand in residential houses such as home insulation and the use of efficient electric appliances. However, energy-saving activities of household members are also important.

A number of studies have been conducted with regards to the methods to induce energy savings by providing household members with information on domestic energy consumption. For example, Egan investigated the relationship between different display formats and the reaction of informants to each (Egan 1999). McClelland carried out a study by employing an electronic device to show consumers electricity information (McClelland 1979). Dobson and Griffin developed the Residential Electricity Cost Speedometer software and installed it into the PCs of 25 homes (Dobson 1992). Newborough analyzed the effectiveness of an appliance-specific display showing the energy consumption for cooking (Mnsouri 1999; Wood 2003a), and classified the features necessary for displaying energy information (Wood 2003b). Brandon analyzed the most effective energy saving technique among several feedback methods using, for example, computers, leaflets, etc (Brandon 1997, 1999).

The authors have developed an on-line Energy Consumption Information System that provided residents with information on end-use electric power consumption, and installed the system into nine houses in a suburb of Kyoto, Japan (Ueno 2006a). In addition, the authors constructed a remodeled on-line Energy Consumption Information System that provided residents with information on city gas consumption and room temperature, in addition to electric power consumption. The system was installed in 10 houses (Ueno et al. 2006b, 2006c) and total energy in houses was reduced by 12% by installation of the system.

However, customers generally do not know such detailed information about energy consumption. And they do not know the actual effect of each energy-saving activity, even though a lot of energy-saving activities are proposed by government and other agencies.

Performing energy-saving activities has several benefits including the reduction of energy consumption, reduction of CO_2 emissions, and lower energy bills; however, there are several costs as well, such as decreases in comfort and the achievement of goals that could have been obtained by the utilization of electric appliances, and increases in time and labor due to energy-saving activities. Since the levels of these benefits and costs vary with the energy-saving activities, when consumers do not properly understand the benefits and costs, they may adopt an energy-saving activity that has a small energy-saving effect relative to the frequency of carrying out the activity, or adopt an energy-saving activity that significantly decreases benefits, and therefore results in a situation that such activities are not maintained as effective energy-saving activities. If the levels of decreases in benefits are almost identical among several energy-saving activities, it is preferred that activities with greater effect be adopted first. Thus, changes in benefits received by household members should not be neglected when considering energy-saving activities.

The authors previously developed a method of selecting appliances that decrease standby power consumption in a household, with consideration given to not only the energy-saving effect, but also the decrease in benefits, i.e., the labor of carrying out the activity as well as the inability to utilize the functions of the appliances (Ueno & Nakano 2006). In the current study, by improving the above method, we propose a method of rationally selecting energy-saving activities in a household with consideration given comprehensively to not only the energy-saving effect, but also the changes in benefits received by household members.

People have different considerations concerning factors affecting their actions, such as environmental problems and comfort. In addition, the values of benefits obtained from using electric appliances and benefits lost by energy saving also differ significantly among individuals. Thus, in this study, we use an analytic hierarchy process (AHP) to enable a variety of consumers with different preferences and lifestyles to select appropriate energy-saving activities.

Development of Selection-Priority Decision Model for Energy-Saving Activities

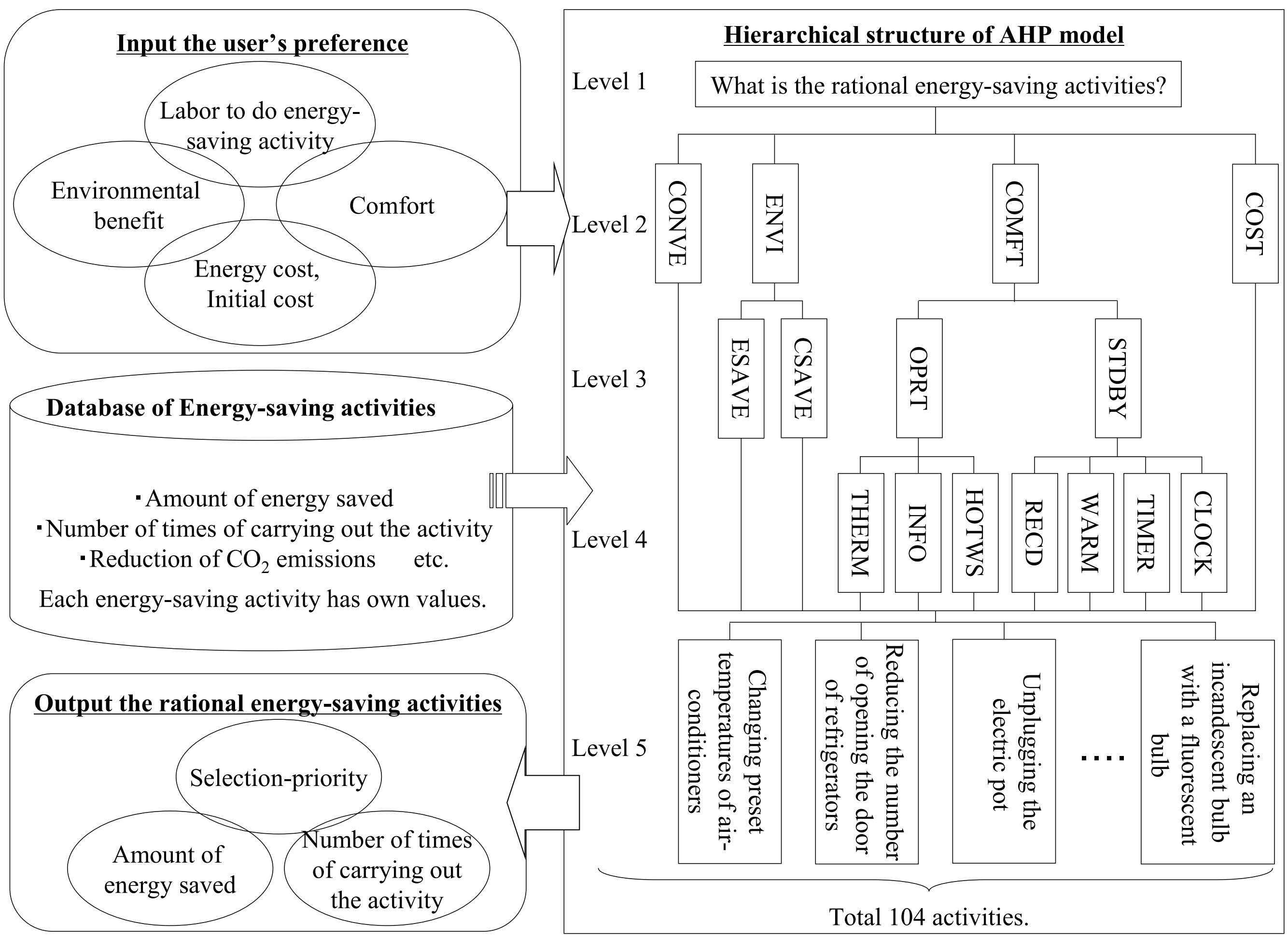
Outline of the Model

AHP is the one of the methods for decision making developed by Saaty (Saaty 1980), and it can be applied to solving the problem containing qualitative elements such as a decision- maker's judgements. The AHP is a systematic method for comparing a list of targets, criteria (stimuli). The decision makers perform paired comparison of the criteria/targets by using the scale value in table 1. Then the weight of each criterion/target is calculated by estimating the eigen vector of the matrix that consists of the scale values.

Figure 1 shows the outline of the model proposed in this study. The purpose of the model is to find, among many energy-saving activities, which activity should be adopted first in a household. Then, at hierarchical level 2 of the hierarchical structure, four evaluation criteria are presented for selecting energy-saving activities: 1) convenience, 2) environmental benefit, 3) comfort, and 4) cost. These criteria are further classified at hierarchical levels 3 and 4. At hierarchical level 5, recommended energy-saving activities to be evaluated are shown. In this study, 104 energy-saving activities are examined. There are a total of 15 evaluation criteria at hierarchical levels 2-4. However, since the evaluation criteria at the upper levels are used only for inter-criteria comparison, only 11 evaluation criteria are directly related to each energy-saving activity, and energy-saving activities have respective evaluation values for these 11 criteria. Selection priority, which is the purpose of the model, is calculated from the evaluation values and the level of importance of each evaluation criterion.

Table 1. Scale Value for Comparing One by One in AHP

Scale Value	Meaning of Scale value
1	Equal importance of both elements
3	Moderate importance of one element over another
5	Strong importance of one element over another
7	Very strong importance of one element over another
9	Extreme importance of one element over another



Abbreviation list

CONVE: Convenience	CSAVE: Amount of CO_2 emission reduction	HOTWS: Hot water supply
ENVI: Environmental benefit	OPRT: Functions under operation	RECD: Picture/sound recording
COMFT: Comfort	STDBY: Functions on standby	WARM: Keeping warm
COST: Cost	THERM: Thermal comfort	TIMER: Start-and-stop timer
ESAVE: Amount of energy saved	INFO: Information acquisition	CLOCK: Clock display

Figure 1. Outline of Selection-Priority Decision Model for Energy-Saving Activities

Calculation Method of Evaluation Values for Each Evaluation Criterion

In the model the evaluation criterion "convenience" refers to the amount of labor required for users to carry out the energy-saving activity. Convenience is evaluated by the annual number of times of performing the action multiplied by labor coefficient. Here, the labor coefficient is a numerical value of the labor required for carrying out the energy-saving activity once. Depending on the type of energy-saving activity or the location of the appliance, the labor required for each activity varies , therefore accurate quantification is difficult. Thus, in this model, in order to determine the labor required for each energy-saving activity while maintaining input simplicity, we classified labor into three levels of "easy, standard, and troublesome," thereby attaching a weight to the labor levels by using AHP.

Activities allocated to each labor level were determined by the authors on the basis of the location of the appliance and the amount of labor for each activity, as shown in Table 2. The decision maker performs paired comparisons regarding the degree of extra labor required for a "standard" or "troublesome" energy-saving activity relative to an "easy" energy-saving activity. In addition, because it is preferred that the annual number of times of performing the action is small, we set the evaluation value for each activity as the value obtained by subtracting the annual number of times the activity is performed from the total annual number of times all the activities are carried out.

Finally, the evaluation value obtained for each energy-saving activity is divided by the maximum evaluation value, which is then used as the evaluation value of convenience. This normalization process is conducted to make the maximum evaluation value equal to 1 for any evaluation criterion, in order to set importance levels equivalently for the different criteria.

Table 2. Meaning of the Labor Coefficient

Labor level	Meanings of the level	Examples of energy-saving activities
Easy	Easier than "Standard" to do.	Turning off the main power switch of the TV, Changing the preset temperature of the air conditioner, etc.
Standard	Harder than "Easy". Activities in their house.	Unplugging the appliances inside house, etc.
Troublesome	Harder than "Standard". Activities outside their house or purchasing new appliance.	Unplugging the appliances outside the house, Replacing an incandescent bulb with a fluorescent bulb, etc.

The evaluation criterion "environmental benefit" is evaluated using the amount of energy saved and the amount of CO_2 emission reduction achieved as a result of the energy-saving activities. The amount of CO_2 emission reduction is calculated as the sum of the annual amounts of reduction in CO_2 emission from using electric power, gas and kerosene achieved as a result of adopting each power-saving activity.

The evaluation criterion "comfort" was set to evaluate the reduction of benefits such as thermal comfort and information acquisition obtained as a result of using appliances. Since the purposes of the utilization of appliances vary significantly, they are classified into the purposes of "functions under operation" and "functions on standby," which are then further classified. Evaluation criteria belonging to "functions under operation" include "thermal comfort," "hot water supply," and "information acquisition." While appliances are utilized in many other ways by residents in households, including cooking, washing and cold storage, the three evaluation criteria above are the most important factors affecting the benefits during the operation of appliances when considering energy-saving activities; this fact has been clarified from our analyses of current general energy-saving activities. The reason for this is speculated as follows: in general, cooking and washing appliances are used only when necessary, so that there is almost no room for energy saving; on the other hand, it is generally considered to be easy to reduce the utilization time of TVs and PCs, and to change the room temperature during air conditioning and the temperature of the hot-water supply.

The evaluation criterion “information acquisition” is evaluated as the amount of reduction in the duration of receiving benefits relating to information acquisition, such as the use of TVs and PCs, namely, the annual amount of reduction in hours. “Thermal comfort” is evaluated by the coefficient of thermal-comfort benefit multiplied by the reduction in the benefit-receiving duration. The coefficient of the thermal-comfort benefit is a numerical conversion factor representing the amount of reduction in comfort provided by air conditioning per unit time. Using the AHP, the amounts of reduction in benefits when users change preset temperatures or turn off appliances, in comparison with their previous utilization of air conditioners, are obtained. The evaluation criterion “hot-water supply” is calculated by AHP the same way as the evaluation criterion “thermal comfort”.

Evaluation criteria for “function on standby” included four items: “picture/sound recording,” “keeping warm,” “start-and-stop timer,” and “clock display.” In the case of “function under operation”, the annual reduction in utilization duration is used as the evaluation criterion; whereas in the case of “function on standby,” the reduction in the annual number of utilization times was evaluated. Namely, the number of times in which functions become unavailable because of conducting energy-saving activities such as unplugging is used as the evaluation criterion.

The evaluation criterion “cost” is evaluated using the annual cost saving due to conducting energy-saving activities, as well as the cost of introducing an appliance. The annual cost saving is the sum of cost reductions of purchasing electric power, gas and kerosene obtained by each energy-saving activity. The cost of introducing an appliance is calculated from the purchase price of the appliance divided by its lifetime in years. The cost of introducing an appliance is applicable to only part of the activities, such as replacing an incandescent bulb with a fluorescent bulb.

Table 3 (next page) shows the calculation method of each evaluation criterion. Refer to figure 1 for abbreviations in Table 3.

Energy-Saving Activities Adopted

The energy-saving activities examined in this study, the amounts of energy reduction provided by these activities and their utilization durations were determined by the authors, with reference to information from Web sites such as the Ministry of the Environment in Japan and other sources (The Energy Conservation Center in Japan, Tokyo Electric Power Company). For several activities, the power-consumption data of single-family houses and multiple-household buildings measured in Kyoto, by Professor Kiichiro Tsuji of Osaka University (Tsuji et al. 2000, 2004; Ueno et al. 2001), were used. Table 4 shows the examples of the energy-saving activities adopted in the calculation of the current model, and their values for the evaluation criteria. In this model, each value is calculated on the assumption that four people live in one house.

Table 5 shows the best three and worst three activities regarding the amount of energy saved and the frequency of performing the action. Tables 4 and 5 shows that characteristics such as the amount of energy saved vary considerably depending on the energy-saving activity. The annual amount of energy saved by each energy-saving activity is considered to differ greatly depending on factors such as the number of residents and the available living area, as well as differences in the lifestyle of residents. Although calculations in the current model are are based on values developed from references and other sources, in the future, we intend to use more appropriate values for each user in the model, by inputting information related to users such as the number of household members and their lifestyle.

Table 3. Calculation Method of Each Evaluation Criterion

Hierarchical Level			Unit	Explanation
Level 2	Level 3	Level 4		
CONVE			-	(Labor coefficient)*1 × (Numbers of action)*2
ENVI	ESAVE		[Wh/year]	Amount of energy saved
	CSAVE		[tCO2/year]	Amount of CO2 emission reduction
COMFT	OPRT	THERM	-	(Coefficient of thermal-comfort benefit)*3 × (Reduction of hours)*4
		INFO	[h/year]	Reduction in the benefit-receiving duration
		HOTWS	-	(Coefficient of hot-water-supply benefit)*5 × (Reduction of hours)*6
	STDBY	RECD	[count/year]	Reduction in the annual number of utilization times
		WARM		
		TIMER		
		CLOCK		
COST			[yen/year]	(Annual cost saving) - (Cost of introducing the appliance) / (Life times in years)
Details	CONVE	*1:Labor coefficient	Numerical value	Easy, Standard, troublesome
		*2:Numbers of action	[count/year]	Annual number of times of performing the action
	THERM	*3:Coefficient of thermal-comfort benefit	Numerical value	Present state, Changing preset temperature, Turning off the appliance
		*4:Reduction of hours	[hour/year]	Reduction in the thermal-comfort benefit-receiving duration
	HOTWS	*5:Coefficient of hot-water-supply benefit	Numerical value	Present state, Changing temperature of hot-water, Changing amount of hot-water
		*6:Reduction of hours	[hour/year]	Reduction in the hot-water-supply benefit-receiving duration

Table 4. Example of Energy-Saving Activities and Evaluation Values

Examples of activities		Changing the temperature of hot-water	Replacing an incandescent bulb with a fluorescent bulb	Unplugging the air conditioner in the off-season	Unit
CONVE	Labor efficient	Standard	Troublesome	Standard	Easy, Standard, Troublesome
	Numbers of action	365	1	2	[count/year]
ENVI	ESAVE	340	3,510	90	[MJ/year]
	CSAVE	17,400	164,200	4,400	[g-CO2/year]
COMFT	Kind of comfort	Hot-water-supply benefit (changing temp.)	-	-	-
	Reduction of hours	550	-	-	[hour/year]
COST	Initial cost	-	1,250	-	[Yen/year]
	Annual cost saving	970	8,190	220	[Yen/year]

Table 5. The Best Three and Worst Three Activities Regarding the Amount of Energy Saved and Numbers of Times of Performing the Action

Ranking		Amount of energy saved		Numbers of action [count/year]	
		Energy-saving activity	MJ /year	Energy-saving activity	count /year
BEST	1	Not leaving the shower running	8,500	Putting the refrigerator away from walls	0.1
	2	Replacing an incandescent bulb with a fluorescent bulb	3,510	Unplugging the heating applications in the off-season	1
	3	Use of a water-saving shower	2,550	Replacing an incandescent bulb with a fluorescent bulb	1.25
WORST	1	Soaking in the bathtub instead of using the shower	0.81	Closing the cover of heated toilet	3,650
	2	Tiding up a room before using a vacuum cleaner	2.08	Uplugging the solar water heater during standby	1,520
	3	Changing the preset temperature of the Kotatsu*1	2.61	Not leaving the shower running	1,460

*1: Kotatsu is a Japanese traditional foot warmer.

Calculation Example of the Model

Calculation Scenario

Calculation results of the current model may differ significantly depending on the level of importance of each evaluation criterion inputted. We consider that input by actual users is performed with a well-balanced selection of importance levels among evaluation criteria based on each user's preference. However, in order to clarify the output characteristics of the model, we assume four cases, in each of which one specific evaluation criterion is strongly emphasized, and show the calculation results for these cases.

Set Values of the Model

We developed four cases in which one of the four evaluation criteria in hierarchical level 2 is rated "extremely important" (see Table 1) compared with the other three criteria, which are set as "equal importance;". Cases in which convenience, environmental benefit, comfort, and cost are each given the highest level of importance are respectively referred to as the convenience-emphasized case, the environmental-benefit-emphasized case, the comfort-emphasized case, and the cost-emphasized case.

The levels of importance of all four cases in hierarchical level 3 and 4 are considered to be equal. In addition, the labor coefficient, the coefficient of thermal-comfort benefit, and the coefficient of hot-water-supply benefit, which are required for the calculation of the evaluation criteria of convenience, thermal comfort and hot-water supply, respectively, were set by the authors as shown in Table 6.

The level of importance of each evaluation criterion in each case is calculated as shown in Table 7. Refer to Figure 1 for abbreviations in Table 7. In Table 7, shaded columns show the most important criterion in each scenario. In the comfort-emphasized case, although the total importance level is 0.75, the importance level of each evaluation criterion is low because there are many evaluation criteria.

Table 6. Calculation of Coefficient by AHP Matrix

(a) The Labor Coefficient

	Easy	Standard	Troublesome	Weight
Easy	1	5	7	1.00
Standard	1/5	1	3	0.26
Troublesome	1/7	1/3	1	0.11

(b) The Coefficient of Thermal-Comfort Benefit

	Present state	Changing preset temperature	Turning off the appliance	Weight
Present state	1	5	7	1.00
Changing preset temperature	1/5	1	3	0.26
Turning off the appliance	1/7	1/3	1	0.11

(c) The Coefficient of Hot-Water-Supply Benefit

	Present state	Changing temperature of hot-water	Changing amount of hot-water	Weight
Present state	1	5	5	1.00
Changing temperature of hot-water	1/5	1	1	0.20
Changing amount of hot-water	1/5	1	1	0.20

Table 7. Weight of Each Evaluation Criterion in Each Case

Hierarchical Level			Case Name			
Level 2	Level 3	Level 4	Convenience-emphasized case	Environmental-benefit-emphasized case	Comfort-emphasized case	Cost-emphasized case
CONVE			0.750	0.083	0.083	0.083
ENVI	ESAVE		0.042	0.375	0.042	0.042
	CSAVE		0.042	0.375	0.042	0.042
COMFT	OPRT	THERM	0.014	0.014	0.125	0.014
		INFO	0.014	0.014	0.125	0.014
		HOTWS	0.014	0.014	0.125	0.014
	STDBY	RECD	0.010	0.010	0.094	0.010
		WARM	0.010	0.010	0.094	0.010
		TIMER	0.010	0.010	0.094	0.010
		CLOCK	0.010	0.010	0.094	0.010
COST			0.083	0.083	0.083	0.750

Calculation Results

Table 8 shows the ranking of the upper 10 energy-saving activities in each case. In the convenience-emphasized case, selections of high priority are activities that reduce the comfort of users but require only a small number of actions, such as changing the preset temperature of the air conditioner. The next activities selected are energy-saving activities requiring frequent actions but only a small effort on behalf of users, such as frequently turning off the main power switch of the TV. In the environmental-benefit-emphasized case and the cost-emphasized case, the amount of energy consumption, CO_2 emission and the annual cost saving of the evaluation criteria emphasized are similar in these two cases because of the characteristics of the original data, therefore the results for the two cases are also similar. Activities such as replacing an incandescent bulb with a fluorescent bulb, and the use of a water-saving shower, which incur purchase costs, are evaluated highly in the cost-emphasized case. In the comfort-emphasized case, energy-saving activities that reduce comfort but are ranked as high priority in other cases, such as changing the preset temperature of the air conditioner, not leaving the shower running, and unplugging the electric pot, are ranked as low priority, and energy-saving activities that do not affect comfort are ranked as high priority.

Table 8. Ranking of Each Case

Ranking	Convenience-emphasized case	Environmental-benefit-emphasized case	Comfort-emphasized case	Cost-emphasized case
1	Changing the preset temperature of water of the heated toilet	Not leaving the shower running	Changing the preset temperature of water of the heated toilet	Not leaving the shower running
2	Changing the preset temperature of seat of the heated toilet	Replacing an incandescent bulb with a fluorescent bulb	Warming only the part of hot carpet where human exist	Replacing an incandescent bulb with a fluorescent bulb
3	Changing the preset temperature of the refrigerator	Use of a water-saving shower	Changing the preset temperature of seat of the heated toilet	Use of a water-saving shower
4	Changing the preset temperature of the heat-pump (in winter)	Unplugging the electric pot	Changing the preset temperature of the refrigerator	Unplugging the electric pot
5	Changing the preset temperature of the air-conditioner (in summer)	Unplugging the heated toilet on standby	Changing the amount of water in the electric pot	Unplugging the heated toilet on standby
6	Changing the preset temperature of the city gas fan heater	Warming only the part of hot carpet where human exist	Using air-conditioner and electric fan together	Warming only the part of hot carpet where human exist
7	Changing the preset temperature of the kerosene fan heater	Changing the preset temperature of water of the heated toilet	Turning off the main power switch of the TV (other rooms)	Changing the preset temperature of water of the heated toilet
8	Warming only the part of hot carpet where human exist	Not using the heated toilet except in winter	Turning off the lights frequently	Changing the preset temperature of seat of the heated toilet
9	Using air-conditioner and electric fan together	Reducing the using hours of oil heater	Not leaving the shower running	Not using the heated toilet except in winter
10	Turning off the main power switch of the TV (other rooms)	Changing the preset temperature of seat of the heated toilet	Turning off the main power switch of the TV (living room)	Changing the preset temperature of the refrigerator

Figures 2 and 3 show the cumulative amount of energy saved and the cumulative amount of energy-saving activities performed, respectively, when energy-saving activities with descending order of selection priority are performed in each case. Here, "amount of energy-saving activities" is the number of times an energy-saving activity is performed multiplied (weighted) by the reciprocal of labor coefficient. Since energy-saving activities that save large amounts of energy are evaluated highly, the curve in figure 2 shows an upward trend. In particular, this tendency is strong in the environmental-benefit-emphasized and cost-emphasized cases. In addition, since activities requiring a small number of actions are evaluated highly, the curve for the convenience-emphasized case in Figure 3 shows a downward trend.

Looking at Figures 2 and 3 from another viewpoint, when the 10 highest-priority energy-saving activities are performed, the amounts of energy saved in the convenience-emphasized case, environmental-benefit-emphasized case, comfort-emphasized case, and cost-emphasized case are 3.1 GJ, 22.8 GJ, 11.6 GJ and 21.9GJ, respectively. The amount of energy saved in the environmental-benefit-emphasized case is over seven times that in the convenience-emphasized case. Here, the amounts of energy saved and the number of times activities are performed are simple sums of each value, but in practice, not all these energy-saving activities can be performed simultaneously in each household. For example, there are several energy-saving activities involving heating applications, but only some of these appliances are used in many houses and few houses use all of these appliances. Therefore, the cumulative values shown in the figures are larger than those that would be obtained by actual energy-saving activities performed in each household.

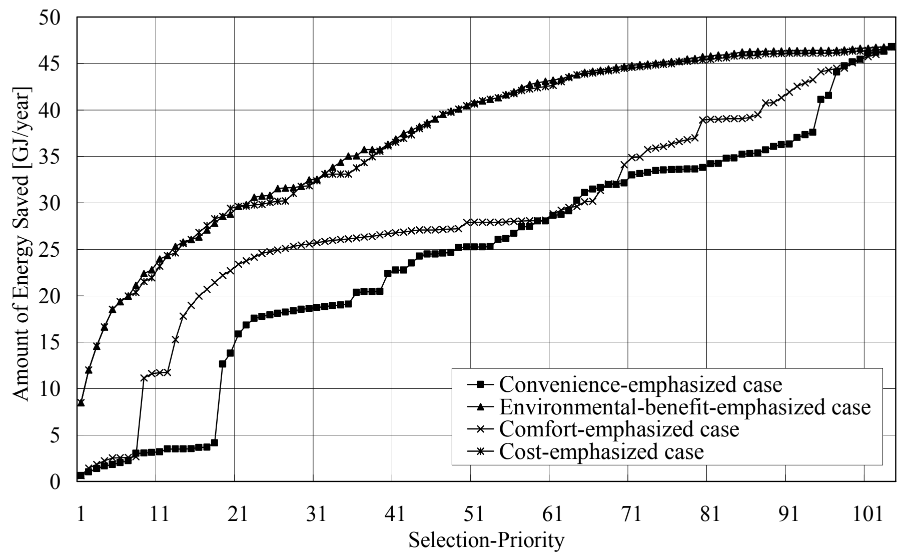


Figure 2. Annual Energy Reduction of Each Case

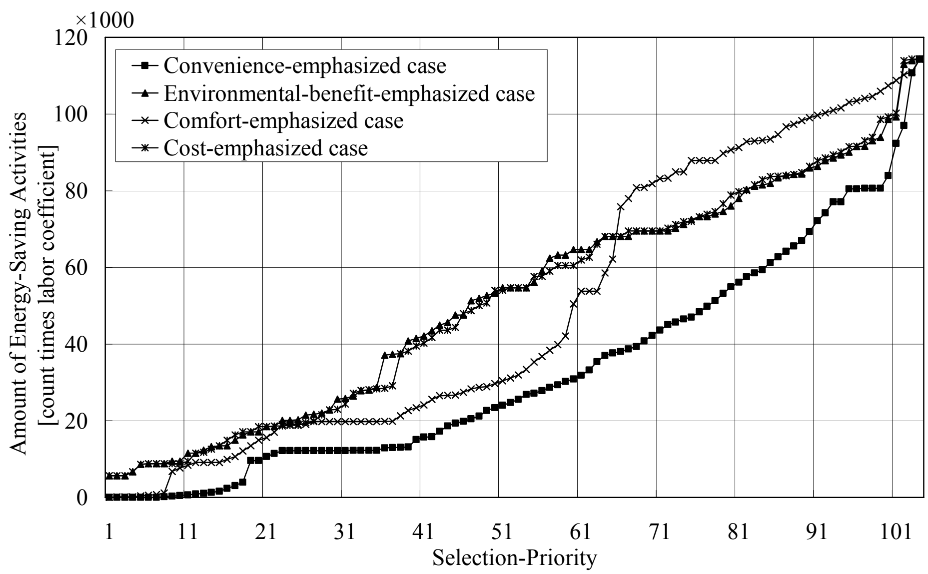


Figure 3. Annual Number of Energy-Saving Activities of Each Case

Conclusion

In this research, a method that requires each customer to rationally select energy-saving activities was used to determine which energy savings activities maximize reductions in energy consumption and minimize the costs or inconvenience of these energy savings activities. In addition, the energy-saving potential that can be achieved when people carry out energy-saving activities was estimated by using this method in conjunction with pre-existing meter data.. Depending on which evaluation criteria is emphasized, the best activities, that is activities that maximize energy savings and minimize costs such as a decrease in comfort, include not leaving the shower running and changing the preset temperature of the heated toilet.

By using the method, people can rationally determine which energy-saving activities to implement in their home. Furthermore, in the near future the method can be used in the algorithms of the systems that induce residents to save energy, such as the energy information systems (Ueno et al. 2006a) or home energy management systems (HEMS).

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