A Support Tool for Ranking Energy-Saving Activities in Office Buildings

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Abstract

In Japan, energy consumption in the commercial sector is still increasing and the promotion of energy-saving measures is needed. With the background of a revision to the Energy Conservation Law and other factors, energy saving for buildings is also an important issue. However, in the case of buildings, several stakeholders are involved, as exemplified by problems between owners and tenants, leading to difficulties in dealing with energy-saving issues. Thus far, in promoting energy saving for office buildings, benefits to the owners and tenants of buildings have been focused on, and the benefits to workers working in the buildings have rarely been targeted. Various energy-saving measures for offices have been proposed; the amount of investment required and the expected benefits, as well as effects on workers in the building significantly differ among these measures. In this study, we developed a decision aiding tool about selection of energy-saving measures for offices, in which the cost and benefits of three stakeholders, that is, building owner, tenants(=employers) and workers(=employees) are considered comprehensively. Among various energy-saving measures for offices (such as measures related to facilities, operations, and worker's activities), measures related to worker's activities are targeted particularly in this study. A questionnaire was conducted to elucidate the rate of adoption of these measures and how workers perceive the adoption of energy-saving measures. Then, a tool to support the selection of energy-saving measures was developed by the analytic hierarchy process, a decision-making technique. An example of case study applying the tool to a model office building is shown and discussed.

Introduction

In Japan, energy consumption in the commercial and residential sectors is still increasing and the implementation of energy-saving measures is needed. The promotion of energy saving for buildings is also an important issue.

Thus far, in the promotion of energy saving for office buildings, the benefits to the owners and tenants (employers) of buildings have been focused on, and the effects on workers (employees) who use the buildings have seldom been targeted. Although various energy-saving measures for offices have been proposed, the amount of investment required and the expected benefits, as well as the effects on workers in the buildings, significantly differ among these measures.

In this study, we developed a tool to support decision making related to energy-saving measures for offices, in which the above factors are considered comprehensively.

Questionnaire-based survey on selection of energy-saving measures for offices

In this section, we describe a questionnaire-based survey of approximately 2,500 workers at general office buildings throughout Japan prior to the development of the above-mentioned support tool. Table 1 gives an outline of the survey. We examined a total of 15 energy-saving measures that might affect the thermal and visual environment and convenience for workers potentially. Fifteen types of energy-saving measures that we analyzed are shown in Figure 1.

Table 1. Outline of questionnaire-based survey

Survey method	Web survey
Candidate for survey	Office workers throughout Japan. Registrant of web questionnaire survey by research organization
Surbey period	March, 2010
The number of effective replies	2,512
Survey item	Attribute of respondent such as gender, ages, position, etc.
	Attribute of office where respondent works such as region, building scale, etc.
	Adoption of each energy-saving measure, approval/disapproval of each energy-saving measure, etc.

Figure 1 shows the percentages of actual adoption for each of the 15 energy-saving measures obtained from the responses to the questionnaire, in decreasing order. For the measure involving the changing of the air-conditioning and heating temperatures, the respondents who answered that they had changed these temperatures to 28 deg-C or higher and 20 deg-C or lower, respectively, were considered as having adopted the energy-saving measures in this study. Note that the office workers and/or tenants have the ability to change the temperature setting in their area of the building and to turn off lights, unlike workers or tenants in office buildings in other jurisdictions where temperature settings and lighting use are generally controlled by building automation systems. The percentages of adoption varied significantly from 15% to 80% among the 15 energy-saving measures. The highest percentages of adoption were for the measures of wearing light clothing in summer and turning off lights in common-use spaces.

Figure 2 shows the percentages of workers who agreed with the 15 energy-saving measures between offices where the measures were adopted and those where the measures were not adopted. Unlike households, offices are affected by various factors; workers may voluntarily adopt energy-saving measures or may have to follow a decision made by their office manager or as part of company policy or a request from the owner of the building in Japanese offices (e.g., including building automation systems). Nonetheless, the percentages of worker agreement at offices where the energy-saving measures had been adopted were higher than those at offices where the measures had not been adopted, except for the measure of changing the air-conditioning temperature. For most of the measures, a clear difference in the percentage of worker agreement was observed between energy-saving measures adopting offices and energy-saving measures not adopting offices.

Figure 3 shows the percentages of worker agreement to the energy-saving measure of turning off the room lights during the lunch break, among different decision makers. The percentage of agreement was high not only when the workers voluntarily turned off the lights but also when they did so following a request from the owner of the building or as part of company policy. From this result, it was considered that in the promotion of energy-saving measures, the understanding of workers of the effect of the measures can be enhanced and their percentage of agreement can be increased by adopting the measures in buildings on a trial basis and providing an opportunity to experience their effect using test equipment.

The percentages of worker agreement were generally higher than those of actual adoption (Figure1, Figure2). This indicates that worker consciousness of the need for energy saving and environmental conservation does not necessarily lead to the adoption of energy-saving measures. Or, the decision makers responsible for energy-saving measures such as the owner of the building tend not to adopt such measures to avoid decreasing the comfort and convenience of workers, even when the workers agree with their adoption.

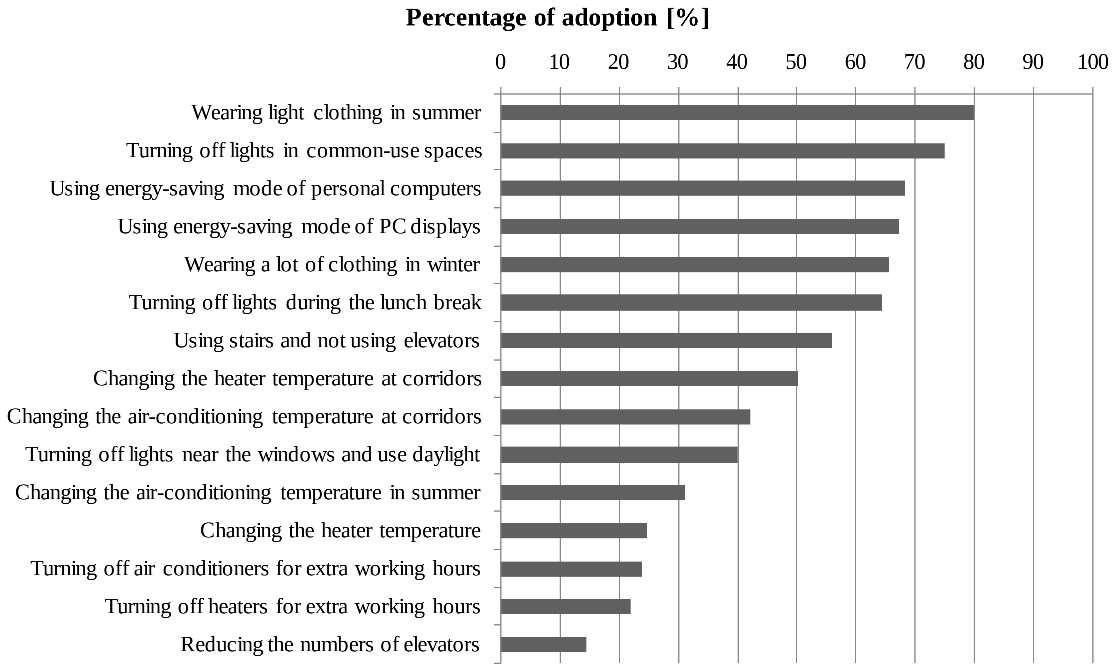

Figure 1. Percentages of adoption of energy-saving measures

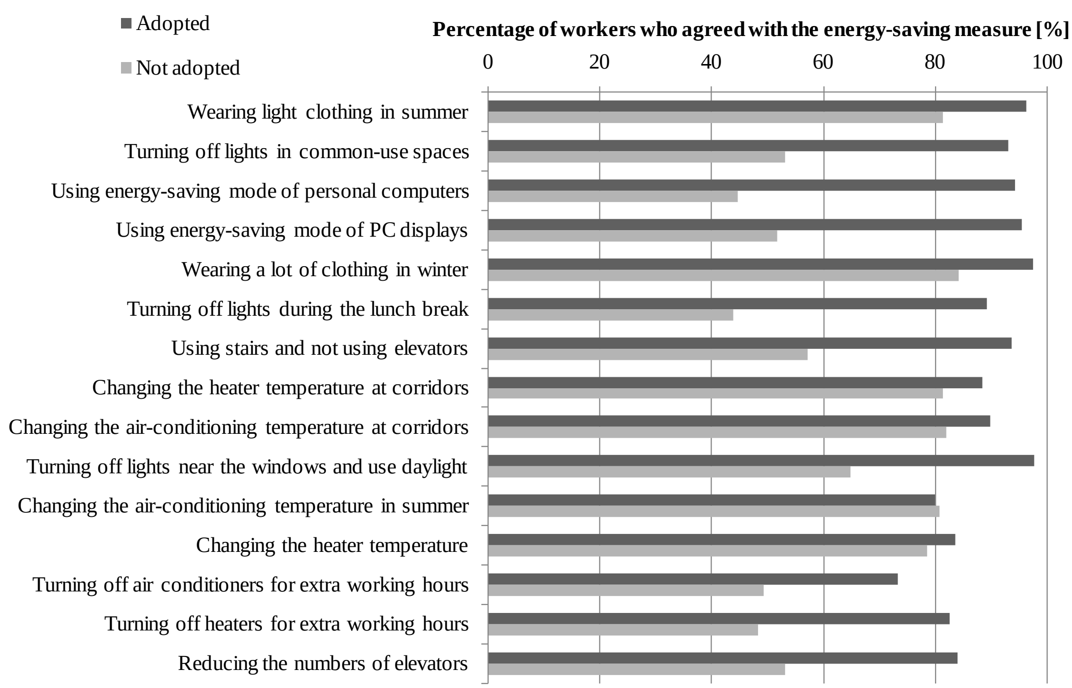

Figure 2. Percentages of worker agreement to energy-saving measures

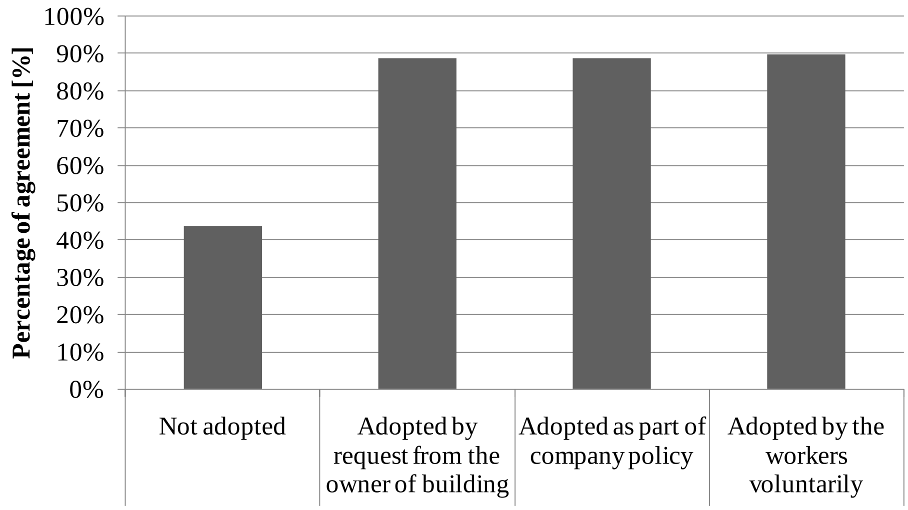

Figure 3. Percentages of worker agreement to the measure of turning off room lights during the lunch break for different decision makers

Figure 4 shows the frequency distribution of the actual air-conditioning temperature set in offices for each type of decision maker about choice of preset temperatures. When the air-conditioning temperature is determined by the owner of the building or the office manager, it was mostly set to 28 deg-C, which is publicly recommended temperature for energy-saving temperature in Japan. At least 60% of the respondents answered 28 deg-C or higher when the decision maker was the owner of the building. When the air-conditioning temperature was decided by the office workers, the percentages of respondents who answered 25 or 26 deg-C were greater than those in the case of other decision makers. The average air-conditioning temperatures were 26.7, 26.2, and 24.8 deg-C when the decision makers were the owner of the building, the office manager, and the office workers, respectively, showing a clear difference in the air-conditioning temperature among the different decision makers.

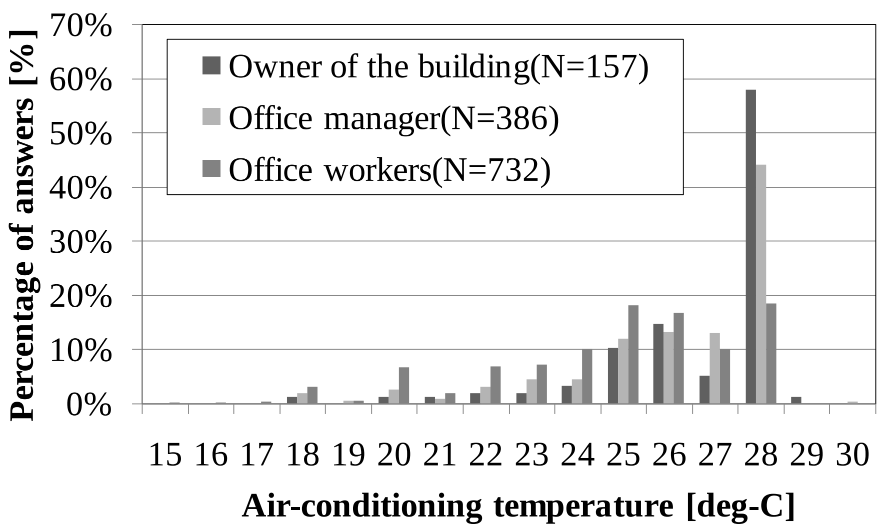

Figure 4. Frequency distribution of actual air-conditioning temperature set in offices for each type of decision maker

Figure 5 shows the relationship between the air-conditioning temperature and workers' comfort based on how hot or cold they felt. In the figure, the position of the center of each circle represents the average comfort level, and the area of each circle is proportional to the number of respondents. The higher the air-conditioning set temperature, the lower the comfort level. However, there was a clear dependence of the comfort level on the decision maker; the comfort level was significantly greater when the decision maker about choice of the air-conditioning temperature was the office workers themselves than when the decision maker was the owner of the building or the office manager.

As mentioned above, the percentages of worker agreement at offices where energy-saving measures had been adopted were high regardless of the decision maker, which is not in agreement with the relationship between the air-conditioning temperature and worker comfort. To promote energy saving in air conditioning load, it is necessary to adopt a policy of setting a recommended temperature while allowing office workers to change the air-conditioning temperature to increase their satisfaction level.

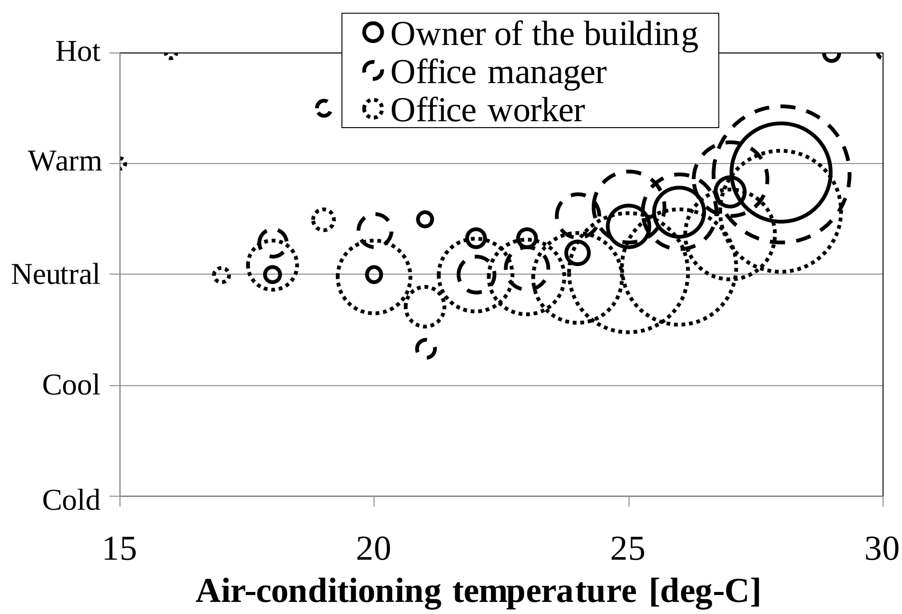

Figure 5. Relationship between air-conditioning temperature and worker comfort

Development of tool to support the selection of energy-saving measures for office buildings

In the selection of energy-saving measures for offices, it is very important to consider the reduction in CO_2 emission and the cost reduction that can be achieved by adopting each measure. However, the effects on office workers such as comfort and convenience should not be ignored, as mentioned in the previous section. The cost required to adopt each measure is also a key factorin selection of energy saving measures.

In the case of office buildings, although it is the workers whose comfort may be reduced by the implementation of energy-saving measures, they are not responsible for the energy cost. If a building owner adopts energy-saving measures that markedly reduce worker comfort, the number of complaints from workers (i.e., the clients of the owners) will increase, possibly resulting in the nonrenewal of tenancies. Therefore, it is preferable to discuss the advantages and disadvantages of energy-saving measures for owners, tenants, and workers before selecting measures.

In this study, we ranked the preference for energy-saving measures using the analytic hierarchy process as known as AHP (Saaty 1980, Saaty 2008, Ueno 2007), a decision-making technique, by considering not only environmental impact and cost reduction but also the effect on workers, and developed a tool to support the selection of energy-saving measures.

Figure 6 shows a diagram of the tool proposed in this study. The right-hand side of the figure shows the hierarchical structure in the AHP, which is the core of the tool. The purpose of the AHP (the top row in the hierarchical structure) is to determine which energy-saving measures should be prioritized at offices (i.e., to rank the preferance of measures). The second row consists of the three decision makers, i.e., building owners, tenants, and workers. The third row consists of four evaluation criteria for selecting energy-saving measures, i.e., environmental impact, reduction of owner's cost, reduction of tenant's cost, and the effect on workers. Among these criteria, the effect on workers is further divided into the four subgroups shown in the fourth row. The bottom row consists of the energy-saving measures evaluated in the proposed tool, which include 15 measures related to workers, seven measures related to operations (not related to workers), and seven measures related to facilities (not related to workers).

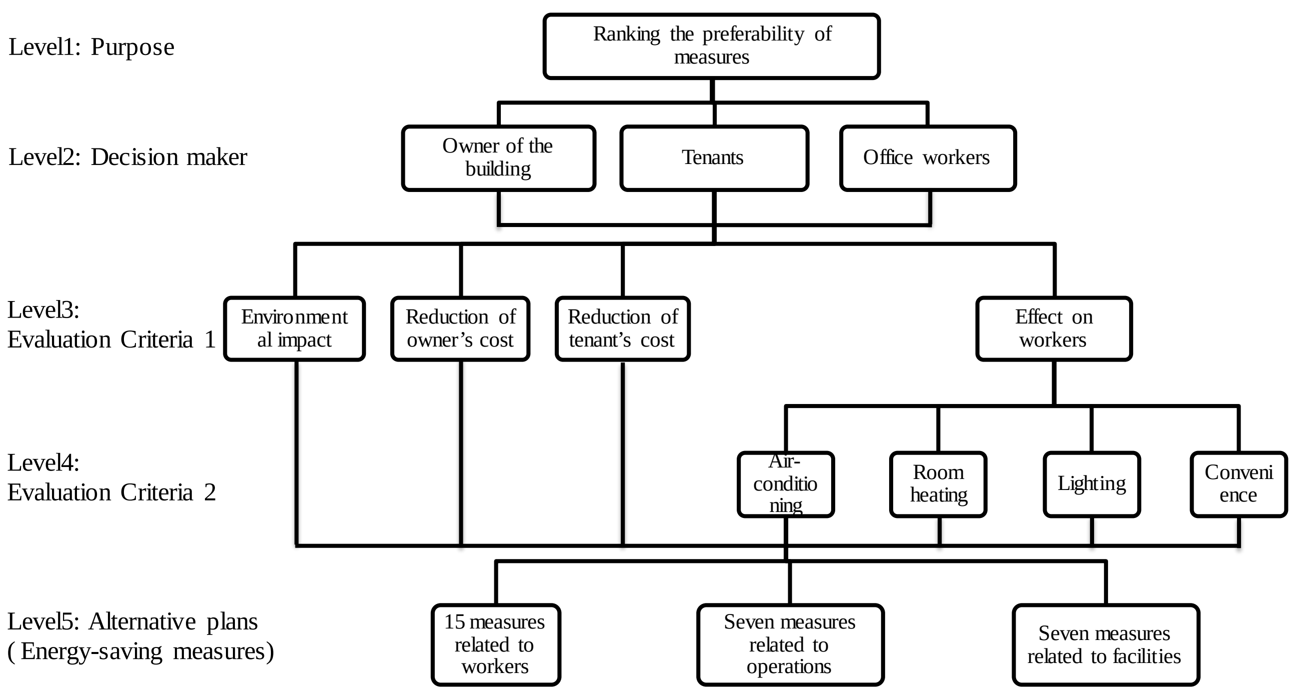

Figure 6. AHP hierarchy diagram

The evaluation criteria were calculated as follows. For environmental impact, the reduction in annual expected CO_2 emission resulting from each energy-saving measure was used. This was calculated from the reduction in the annual power consumption and city gas consumption resulting from each measure.

The reduction of the owner's cost was calculated from the annual expected reduction of the owner's cost resulting from each energy-saving measure, the cost of installing facilities (if applicable), and the maintenance cost required for their operation (if applicable). The cost of installing facilities was converted to an annual cost by dividing the initial cost by the expected number of years of use.

The reduction of the tenant's cost was the annual expected reduction of the tenant's cost resulting from each energy-saving measure.

The effect on workers was considered from the viewpoints of air conditioning, heating, lighting, and convenience. For example, measures related to worker comfort resulting from the use of air conditioners, such as changing the air-conditioning temperature, were evaluated using the response to a question on the decrease in satisfaction resulting from each energy-saving measure in the questionnaire (i.e., the score for worker comfort in a comfortable environment was assumed to be 100 points). We asked the respondents to provide the score for the effect on workers together with the responses to the questionnaire described in the previous section during the survey.

A case study: Evaluation of 29 types of energy-saving measures for model office buildings in Japan by the proposed tool

In this section, we describe the results obtained by calculating the total benefits for model office buildings using the tool outlined in the previous section. Table 2 summarizes the specifications of the model office buildings. To verify the versatility of the tool, we assumed two buildings, i.e., a large building with a total floor area of approximately 12,000 m2 and a small building with a total floor area of approximately 2,000 m2, and two regions, Tokyo (the capital of Japan) and Sendai (a city in the Tohoku region), and determined the specifications of these buildings. The types of air conditioning systems, individual units and centrally controlled systems (unit and central types) were considered for large buildings, while only the unit type was considered for small buildings. A total of six cases (four large buildings and two small buildings) were considered in the calculation of total benefits.

We assumed a total of 29 energy-saving measures, i.e., 15 measures related to workers, seven measures related to operations, and seven measures related to facilities, and calculated the reduction in CO_2 emission, the required cost of implementation, and other factors obtained by adopting each measure, to compare them with those for each case under standard operation.

The reduction of energy consumption, which was used to calculate the reduction in CO_2 emission and energy cost, was calculated using the Energy Specific Unit Management tool, ESUM, developed by the Energy Conservation Center [ECCJ], Japan. Moreover, the initial and maintenance costs required to adopt each energy-saving measure were calculated on the basis of actual data.

Table 2. Summary of specifications of six model buildings

Large building	Small building
Rented building (used as office)	
Ten stories above ground, one story beneath ground level	Eight stories above ground
Total floor area: 12,000 m^2	Total floor area: 2,000 m^2
Story height: 3.8m	
Ceiling height: 2.7m	
Number of elevator: three	Number of elevator: two

We asked the respondents to provide the data required for the developed tool in addition to the responses to the questionnaire described in Section 2. The surveyed items are as follows.

1) Score indicating effect on workers

This score indicates the degree of worker satisfaction when each energy-saving measure was adopted (the extent to which worker satisfaction decreased compared with the case where worker comfort is entirely satisfactory, which is assumed to be 100 points). This score is used as the evaluation criterion for the effect on workers.

2) Weight for evaluation criteria

Weights are applied to the evaluation criteria of the AHP shown in the hierarchical structure in Figure 6. Figure 7 shows the average weight of each criterion for different decision makers obtained by the AHP by asking the respondents to state their job title (i.e., worker, tenant, or building owner) in the questionnaire. The average weights for the workers occupying both company and rented buildings were used. For the tenant opinions, the average weights for respondents who answered that they were responsible for the management of utility costs were used.

No reliable data were obtained from owners. Therefore, the same weights of environmental impact and the effect on workers as used for the tenants' opinions were used for the owners. The weight of the owner's cost used for the tenant opinions was used as the weight of the tenant's cost for the owners, and vice versa.

Also, regarding worker opinions, not only the effect on workers (comfort) but also the reduction of owner's and tenant's costs and environmental impact were taken into consideration in the weighting of the evaluation criteria. Regarding the effect on workers, air-conditioning was given the largest weighting, indicating that workers tend to prefer not to adopt energy-saving measures that reduce their comfort resulting from the use of air-conditioners.

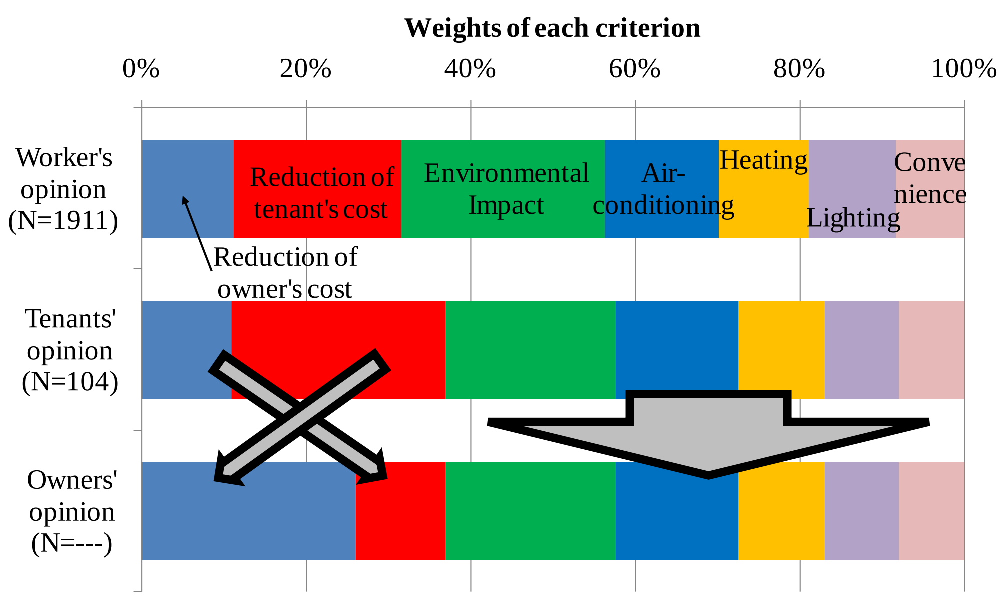

Figure 7. Weights for evaluation criteria for different decision makers

Figure 8 shows the final result of total benefits and annual rates of reduction in CO_2 emission calculated by the tool. In the figure, the averages for the six buildings considered in the calculation are shown, and the energy-saving measures, expressed as a simple sum of the benefits to owners, tenants, and workers, are listed in decreasing order.

In the figure, the current situation represents the case in which no energy-saving measures are adopted, and the energy-saving measures with a positive value for total benefits are considered to be effective. The ranking by total benefits for the energy-saving measures was similar among the six buildings regardless of the size, the type of air conditioning, and the region. The energy-saving measures with high scores for total benefits included the installation of high-efficiency lighting and turning off lights, and a control system for the heat sources (excluding the buildings with the unit-type air-conditioner), and were thus primarily related to lighting for both workers and facilities. In contrast, the measures with low scores for total benefits tended to include those that decrease the thermal comfort of workers, such as turning off air conditioners and heaters for extra working hours and changing the preset temperature.

Note that the results of the evaluation using environmental impact (rate of reduction in CO_2 emission) alone were different from those of the evaluation based on the total benefit.

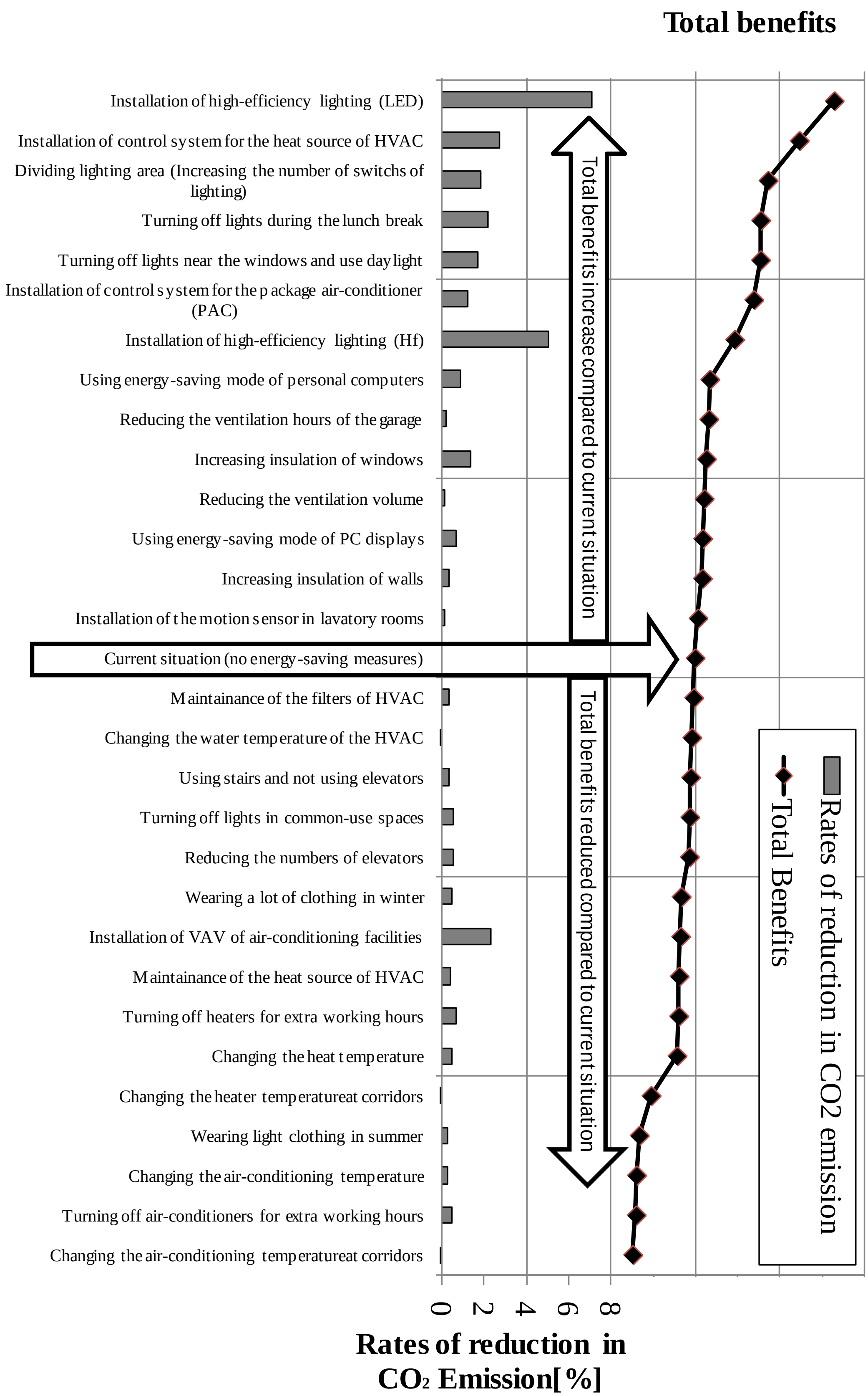

Figure 8. Calculation results of total benefits (average for six model office buildings)

Conclusion

In this study, we carried out a large-scale Internet-based questionnaire of office workers, tenants and owners on the current status of adoption of energy-saving measures and their agreement and disagreement to promote energy-saving measures for office buildings. We also proposed a tool to support the decision-making procedure related to the selection of energy-saving measures using the analytic hierarchy process.

The percentages of worker agreement were generally higher than those of actual adoption. This indicates that worker consciousness of the need for energy saving and environmental conservation does not necessarily lead to the adoption of energy-saving measures. Or, the decision makers responsible for energy-saving measures such as the owner of the building tend not to adopt such measures to avoid decreasing the comfort and convenience of workers, even when the workers agree with their adoption.

.In general, the higher the air-conditioning set temperature, the lower the comfort level. However, there was a clear dependence of the comfort level on the decision maker; the comfort level was significantly greater when the office workers were left to choose the air-conditioning temperature themselves than when the decision maker was the owner of the building or the office manager. The average air-conditioning temperatures were 26.7, 26.2, and 24.8 deg-C when the decision makers were the owner of the building, the office manager, and the office workers, respectively

The percentages of worker agreement at offices where energy-saving measures had been adopted were high regardless of the decision maker, which is not in agreement with the relationship between the air-conditioning temperature and worker comfort. To promote energy saving, it is necessary to adopt a policy of setting a recommended temperature while allowing office workers to change the air-conditioning temperature. Workers tend to prefer not to adopt energy-saving measures that reduce their comfort resulting from the use of air-conditioners.

Based on the modeled results for six buildings, the energy-saving measures with high scores for total benefits included the installation of high-efficiency lighting and turning off lights, and a control system for the heat sources (excluding the buildings with the unit-type air-conditioner), and were thus primarily related to lighting for both workers and facilities. In contrast, the measures with low scores for total benefits tended to include those that decrease the thermal comfort of workers, such as turning off air conditioners and heaters for extra working hours and changing the preset temperature.

The tool is expected to be used to efficiently implement energy-saving measures with agreement among stakeholders while minimizing the decrease in the comfort of workers and maximizing the benefits to owners and tenants.

References

ECCJ, The Energy Conservation Center, JAPAN. http://www.asiaeec-col.eccj.or.jp/index.html

Saaty, T.L. 1980. "The Analytic Hierarchical Process", McGraw-Hill.

Saaty, T.L. 2008. "Relative Measurement and its Generalization in Decision Making: Why Pairwise Comparisons are Central in Mathematics for the Measurement of Intangible Factors - The Analytic Hierarchy/Network Process ", RACSAM (Review of the Royal Spanish Academy of Sciences, Series A, Mathematics) 102 (2): 251–318. http://www.rac.es/ficheros/doc/00576.PDF.

Ueno, T. and Nakano, Y. 2007 "How Do We Measure Residents Benefits? Benefits and Costs through Energy-Saving Activities." In Proceedings of the International Energy Program Evaluation Conference 2007. Chicago, Illinois.