Economic Impact Analysis of Energy Conservation Measures for Building Remodeling

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Abstract— **This paper describes energy conservation measures (ECMs) for building energy efficiency improvement and presents a method and process of economic impact analysis of ECMs in terms of energy and cost savings. ECMs have various measures including operation and maintenance improvements, retrofit activities or renewable energy sources. Most of these measures need investment expense for installation or replacement of facilities. Thus, it is not easy for building owners and energy managers to figure out the detailed cost saving and the payback period. To analyze economic impacts, this paper simulates the energy and cost savings, greenhouse gas emission reduction and payback period and examines the simulation results to verify the effects of ECMs.**

Keywords- energy conservation measure; energy saving; energy efficiency improvement.

I. INTRODUCTION

Buildings consume almost 35% of total energy in the world and building owners spend around 30% of their budget on energy [4][5]. Buildings take up a major share of world energy consumptions, hence energy savings in buildings can lead to both great cost savings and enormous greenhouse gas emission reductions. Much of this energy use can be safely reduced with proper energy conservation measures (ECMs). ECMs are to improve the energy efficiency of buildings including roof and windows, heating, ventilation, and air conditioning (HVAC), utility systems, and renewable energy systems. The aims of ECM are to reduce building energy consumptions to save energy cost, and mitigate the greenhouse gas emissions.

To reduce building energy consumptions in a cost-effective manner, ECMs have three main approaches : energy efficiency improvement, operating time reduction and renewable energy adoption. The energy efficiency improvement approach is to improve energy efficiency by installing new facilities, replacing or upgrading existing ones. The operating time reduction approach is to control the facilities by using monitoring and control including accurate set points and occupancy monitoring. The other approach introduces renewable energy sources like solar, natural gas and wind energy, which substitute for conventional energy resulting in energy cost saving and greenhouse gas emissions reduction.

However, it is not easy for building owners and energy managers to estimate the economic benefits of ECM before implementation and to evaluate actual energy savings after implementation. Recent researches in the field of energy efficiency focus on simulation tools based on database [1-4] and standards [6]-[8]. This paper presents a method and process to analyze the economic impacts of ECM such as energy and cost savings, CO2 emission reduction and payback period. In this paper, we first present how to analyze the economic impacts of ECM in Section II. Afterwards, we describe an economic analysis tool to calculate the economic impacts and discuss how to use the analysis results in Section III. Finally we conclude this paper in Section IV.

II. ECONOMIC IMPACT ANALYSIS

Economic impact analysis is necessary for building owners and energy managers to evaluate the benefits of ECM, which is one of the most important issues before and after ECMs implementations. The benefits of ECMs need to be analyzed in terms of energy saving and non-energy savings including CO2 reduction. Thus, the energy and cost savings, CO2 reduction and payback period need to be analyzed in ECM planning phase and evaluation phase after implementation.

A. Energy Saving

Energy saving is determined by comparing energy uses before and after ECM implementation. To estimate energy saving, baseline energy E_{base} is defined as the amount of the energy that would be consumed without ECM implementation and post installation energy E_{post} as the estimated or measured energy use after the implementation [5-7]. Then, the energy saving E_{save} is given by summation of monthly energy savings as follow.

$$E_{save} = (E_{base} \pm E_{adj}) - E_{post} \qquad (1)$$

where, adjustments E_{adj} compensate for the condition changes in weather, occupancy, or other factors between the baseline and performance periods.

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On the other hand, the energy saving of each ECM can also be estimated. We describe three kinds of ECMs as examples: outer wall, variable air volume (VAV), and solar energy. Table I presents symbols and units of variables related to the ECMs.

TABLE I. SYMBOLS AND UNITS OF VARIABLES

Symbol	Description	Unit
A	outer wall area	m^2
$t_{oper,m}$	operating time in month	hour
$T_{diff,m}$	temperature differences between outdoor and indoor in month	K
$U_{w,pre}$, $U_{w,post}$	thermal transmittance of outer wall	$W/(m^2K)$
P	power consumption	W
N	number of devices	
η	efficiency	

i) Efficiency improvement

Consider an ECM to improve the thermal transmittance of outer wall and refer to the variables in Table I. Then, the estimated annual energy saving of the ECM is obtained by

$$\hat{E}_{save,wall} = \sum_{m=1}^{12} (U_{w,pre} - U_{w,post}) A \hat{T}_{diff,m} \hat{t}_{oper,m} \quad (2)$$

where $\hat{T}_{diff,m}$ and $\hat{t}_{oper,m}$ are the estimated mean temperature differences between indoor and outdoor in month and the estimated mean operating time per month, respectively.

ii) Operating time improvement

Consider an ECM to replace high efficient fans of a variable air volume (VAV) system. Then the operating time can be reduced from $t_{oper,pre,m}$ to $t_{oper,post,m}$. Then the estimated energy saving can be obtained by

$$\hat{E}_{save,fan} = \sum_{m=1}^{12} (t_{oper,pre,m} - \hat{t}_{oper,post,m}) N P_{fan} \eta_{post} \quad (3)$$

where η_{post} and N represent the efficiency and the number of fans, respectively.

iii) Renewable energy

Consider an ECM to introduce solar photovoltaic energy, which generates electricity directly from sunlight via an electronic process. The savings are given by

$$E_{save,pv} = \sum_{m=1}^{12} P_{pv} \hat{t}_{oper,m} . \quad (4)$$

Assuming that a project has N ECMs, then the total annual energy savings can be obtained by summation of energy savings of each measure, as follows

$$\hat{E}_{save} = \sum_{i=1}^{N} \hat{E}_{save,i} . \quad (5)$$

The estimated energy saving $\hat{E}_{save}$ in (5) and the saving E_{save} (1) are logically same.

On the other hand, from the energy saving in (5), cost saving and CO2 reduction can be obtained by considering the associated energy source such as electricity, natural gas and solar energy.

B. Payback Period

Cost saving can be calculated from the energy savings in (5). Let C_{save} and $C_{project}$ be annual cost saving of a project and project expense, respectively. Then the payback period is given by

$$\hat{P}_{payback} = \frac{C_{project}}{\hat{C}_{save}} \quad (4)$$

where, $\hat{C}_{save}$ can be calculated from $\hat{E}_{save}$.

III. SIMULATION

A. Enoomic Analysis Tool

To examine the economic impacts of ECM, we set up an economic analysis tool as shown in Fig. 1. The tool consists of input block, output block, database and ECM impact analysis block. The input block is to enter information on the building to be analyzed including building attributes, energy use and monitoring-based commissioning (MBCx). The baseline energy is determined from the energy use, which is usually performed on an annual basis. The database consists of the information on ECMs, weather, energy price, measurement and verification (M&V) results, etc.

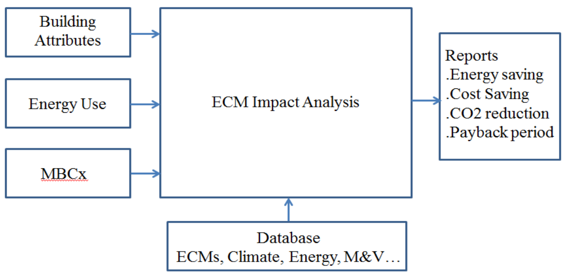

Figure 1. Architecture of economic analysis tool

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The analysis block calculates the economic impacts including energy and cost savings, CO2 reduction and payback period. The output block then displays, saves, or prints out the analysis results.

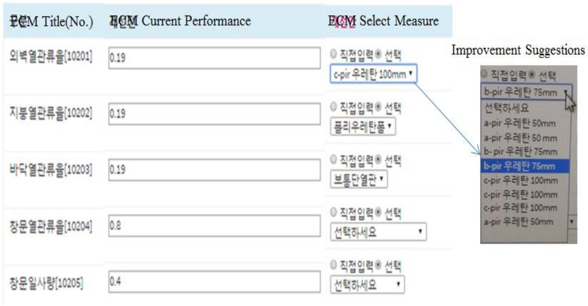

Figure 2. Combo box for detailed measure selection

Fig. 2 shows an example of detailed measure selection of ECM. The tool prepares a lot of typical measures in the ECM database for building owners and energy managers to simply select detailed measures and analyze their economic impacts.

B. *Simulation Results*

We carried out some simulations to examine the economic impacts of ECM. Simulation results can be represented in various forms. Fig. 3 shows the energy saving by comparing post installation energy and adjusted baseline energy. We assumed the baseline energy as the monthly energy use in the last year and the adjusted baseline energy is increased by almost 2.5 % every year after implementation. The post installation energy is obtained by subtracting the estimated energy saving from the adjusted baseline energy in planning phase or obtained by measurement after implementation.

Table II summarizes the annual economic impact analysis results of ECM, which represents energy and cost savings, CO2 reduction, and payback period. It can help the building owners and energy managers determine appropriate ECMs and implementation schedule.

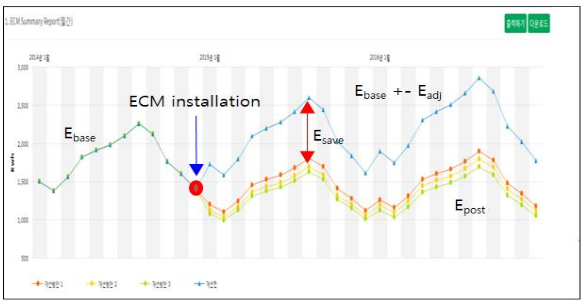

Figure 3. Energy saving impacts by implementing ECMs

TABLE II. ANNUAL ECONOMIC IMPACT ANALYSIS RESULTS

	items	before	N+1 년	N+2 년	N+3 년
baseline energy	energy use(MWh)	1,341	1,374	1,376	1,403
	energy cost($)	116,667	119,538	119,712	122,061
post-installation energy	energy use (MWh)	1,341	1,305	1,307	1,333
	savings(MWh)	-	69	69	70
	CO2reduction(kg)		29,256	29,256	29,680
	Saving ratio (%)	-	5.02	5.01	5.0
	energy cost($)	116,667	113,535	113,709	115,971
	cost savings($)	-	6,003	6,003	6,090
	implementation cost	-	18,969		
	payback period	-	3.16		

Energy cost =87$/MWh, CO2 Emission = 0.424 kg/kWh

Table III shows the monthly energy savings in the first year. Much of energy is used in winter and summer. From the table, we can estimate the effect of user habitat, weather, building use and occupancy and need to examine the efficiency of HVAC and thermal transmittance of the outer wall and roof. Fig. 4 shows the monthly energy consumption categories in the first year after implementation. From the figure, we can see which categories consume how much energy and which categories should be improved.

The economic impacts can be examined through M&V activities that are to verify operation of the installed equipment and systems.

TABLE III. MONTHLY ECONOMIC IMPACT ANALYSIS RESULTS

Month	Baseline (kWh)	Post-installation (kWh)	Energy Saving (kWh)
Jan	136,566	129,564	7,002
Feb	130,523	125,205	5,318
Mar	109,173	106,391	2,782
Apr	105,384	103,453	1,931
May	103,514	101,435	2,079
Jun	110,404	106,810	3,594
Jul	112,839	109,398	3,441
Aug	129,309	124,639	4,670
Sep	107,012	105,602	1,410
Oct	88,700	88,573	127
Nov	98,939	98,493	446
Dec	109,283	105,328	3,955
Total	1,341,646	1,304,891	36,755

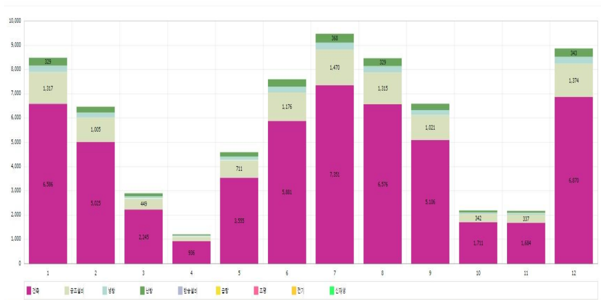

Figure 4. Energy consumption categories per month in the first year after implementation

IV. CONCLUSIONS

In this paper, a method and process to analyze economic impacts of ECM have been presented, which can help build owners, energy managers and facility managers plan ECM strategy. ECMs can save building energy so that building owners can reduce building energy cost and mitigate greenhouse gas emission. For building owners, the economic impact analysis is one of the most important issues since they spend around 30% of their budget on energy. However, it is difficult for a non-expert to select proper ECMs for one's buildings and to estimate economic benefits of ECMs. By proper ECMs much of building energy can be reduced, which leads to not only great cost saving but also enormous greenhouse gas reduction.

To analyze economic impacts, this paper set up an economic analysis tool and carried out simulations on energy and cost savings, CO2 emission reduction and payback period. The analysis results can be used for planning and evaluating ECM implementation. The energy saving is determined by comparing baseline energy and post installation energy. In ECM planning phase, it needs to estimate post installment energy by using an appropriate algorithm to calculate energy saving of each ECM. After implementation, baseline energy is adjusted to compensate for the condition changes including weather, occupancy and activities and the impacts of ECM can be examined through M&V activities.

Further studies are needed to establish a reliable database for ECMs and verify the economic impact analysis results of various buildings.

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