An Optimal Energy Conservation Measure (ECM) Decision Method based on Greenhouse Gas Reduction Target

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***Abstract*— This paper presents an optimal energy conservation measure (ECM) decision method, which is to find optimal ECMs to minimize the initial implementation cost of ECMs for satisfying the target of greenhouse gas (GHG) emission reduction. The method estimates energy savings by implementing ECMs and calculates GHG emission reduction considering both energy savings and carbon dioxide emission factors of each energy source. Then, it decides on the optimal ECMs whose initial implementation cost is minimal while meeting the target of GHG emission reduction. This paper modifies the knapsack algorithm to decide an optimal ECM combination to satisfy the target of GHG emission reduction and presents the simulation results including the optimal ECM list, the amount of GHG emission reduction and implementation cost to verify the optimal ECMs.**

Keywords- energy conservation measure (ECM); greenhouse gas (GHG); building retrofit; building energy.

I. INTRODUCTION

Globally, energy consumption in buildings makes up about 35% of the total energy consumption. Furthermore, the cost of building energy accounts for almost 30% of all building management costs [1]-[2]. For this reason, reducing the amount of building energy is an important issue in terms of global warming and the exhaustion of energy resources, as well as cost reduction. Energy saving in buildings can lead to both enormous cost savings and great greenhouse gas (GHG) emission reductions. Korea has planned to save GHG emission by 37% from business-as-usual (BAU) level by 2030 across all economic sectors. To cope with the twenty-first session of the Conference of the Parties (COP 21), the Korean government has announced a plan to new public buildings to be a zero energy building by 2020 and also expand the plan toward new private buildings by 2025. The number of public buildings in Korea is about 190,000. Thus, it is important to draw up a retrofit budget every year for a number of public buildings to meet the target of GHG emission reduction.

In existing buildings, on the other hand, much of energy consumptions can be safely reduced by the adoption of the adequate energy conservation measures (ECMs). ECMs are to reduce building energy consumptions by reducing operating time, improving energy efficiency and adopting new and renewable energy, which results in both energy cost saving and GHG emission reduction. However, the number of combinations of selectable ECMs is excessively large. Thus, it is difficult for building owners and project managers to select an optimal ECM combination in which the initial implementation cost is minimized while the target of GHG emission reduction is satisfied for a building retrofit.

Energy saving caused by implementing ECMs can be estimated by the measurement and verification (M&V) methodology [6]. The M&V methodology is to monitor and quantify the changes in the performance and operational parameters which are measured or calculated. The values of the parameters are needed to calculate energy savings associated with each ECM implementation. Thus, GHG reduction can be obtained from the energy savings. Recent researches in building retrofit include simulation tools based on various databases and standards [7]-[10].

This paper presents a method to decide the minimal initial implementation cost of a building retrofit for satisfying the target of GHG emission reduction. In this paper, we present how to analyze energy savings and GHG emission reduction in Section II. Afterwards, we describe how to decide the optimal ECMs whose implementation cost is minimized for satisfying the target of GHG emission reduction in Section III. Section IV describes the simulation environment and presents simulation results including an optimal ECM list, estimated GHG emission reduction and initial implementation cost, and finally, we conclude this paper in Section V.

II. GHG EMISSION REDUCTION ANALYSIS

A. Energy Saving

The amount of energy saving can be estimated by comparing the difference of energy consumptions between before and after ECM adoption. In order to determine the energy saving, baseline energy E_{base} and post-installation energy E_{post} are firstly defined as the amount of energy that would be consumed without ECM implementation and the estimated or measured energy consumptions after the implementation, respectively [4]-[5]. Thus, the energy saving E_{save} is obtained as follows:

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

where, E_{adj} represents adjustment energy to compensate for the changes in occupant behavior and weather condition, and for the difference of other factors between the baseline period and performance evaluation period.

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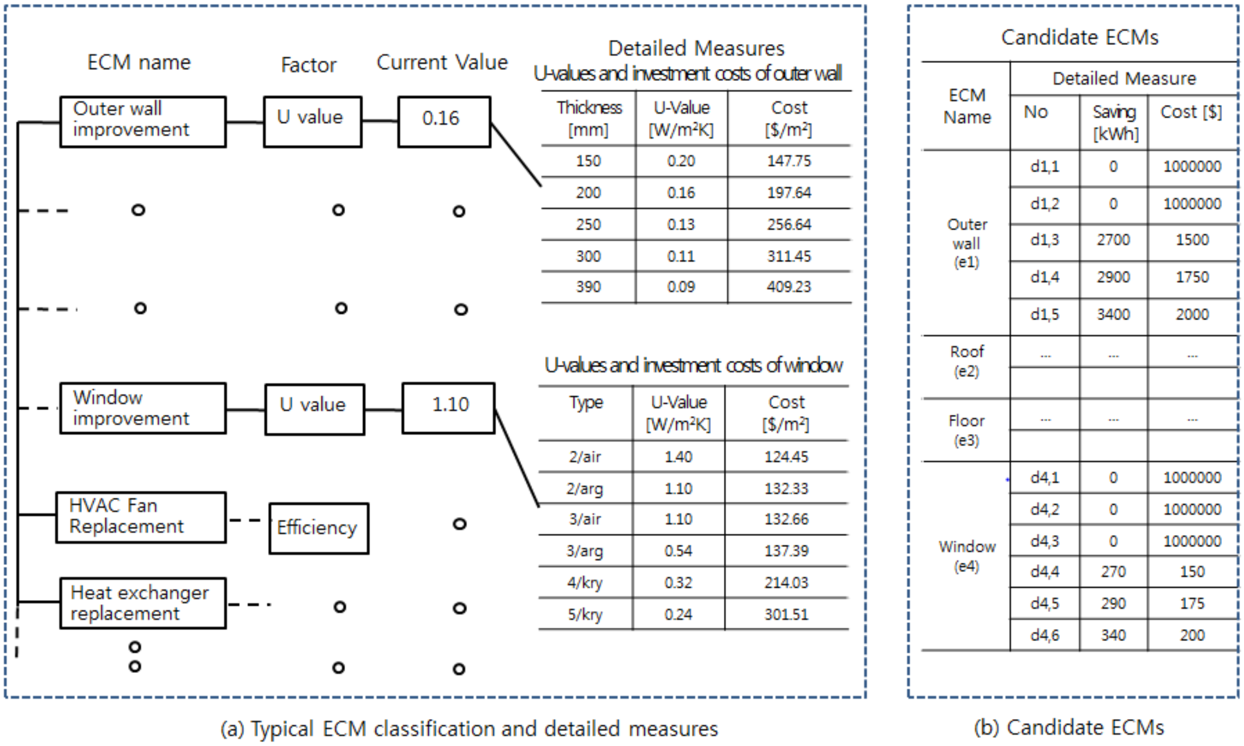

Figure 1. A typical ECM classification and cadidate ECMs of a building to be retrofitted

On the other hand, the energy saving E_{save} of an ECM also can be estimated depending on the ECM factor. A typical classification of ECMs and detailed measures (a) and candidate ECMs (b) are shown Figure 1. ECMs for building retrofit may include various types, such as construction, facility, lighting, and new and renewable energy. In figure 1(a), the ECM for outer wall improvement has five detailed measures with different U-values, thermal transmittance and costs per square meters. When the current thermal transmittance is 1.10, the detailed measures for improving thermal transmittance may be three detailed measures, $d_{1,3}$, $d_{1,4}$ and $d_{1,5}$. The others, $d_{1,1}$ and $d_{1,2}$, can be neglected. Candidate ECMs are composed of the ECMs that are capable of improving energy efficiency in figure 1(b). Candidate ECMs have energy savings and implementation costs of the corresponding building, which are calculated based on the ECM factors, weather condition and building information including location, size and occupant behavior.

A building retrofit includes one or more ECMs. If N ECMs are included in a building retrofit project, the energy savings of the project will be calculated as follows:

$$E_{save} = \sum_{i=1}^{N} E_{save,i} \, . \tag{2}$$

where, E_{save} and $E_{save,i}$ denote the overall energy saving by ECMs and the estimated energy saving of ECM i, respectively, in a building retrofit project.

B. GHG Emission Reduction

Greenhouse gas, like CO2, results from the burning of fossil fuel sources including coal, petroleum and natural gas. Each fuel source has a different GHG emission factor, as shown in Table I [12].

TABLE I. CARBON DIOXIDE EMISSION FACTORS

Fuel	EIA Fuel Code	Factor [kg/MBtu]
Bituminous Coal	BIT	93.3
Distillate Fuel Oil	DFO	73.16
Jet Fuel	JF	70.9
Natural Gas	NG	53.07
Propane Gas	PG	63.07
Waste Coal	WC	93.3
Waste Oil	WO	95.25

* 1 [BTU/h] = 0.29307107 [W]

Then, the amount of GHG emission reduction, $GHG_{reduction}$ is obtained by

$$GHG_{reduction} = \sum_{i=1}^{N} E_{save,i} C_{fuel,i} \tag{3}$$

where, $C_{fuel,i}$ represents the GHG emission factor of the fuel source of ECM i.

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III. OPTIMAL ECM DECISION BASED ON GHG EMISSION REDUCTION TARGET

A problem of zero energy building is expensive. Likewise, a lot of money is required for existing building retrofit to meet the target of GHG emission reduction. Thus, the proposed optimal ECM decision method minimizes the implementation cost of ECMs for satisfying the target of GHG emission reduction, *T_GHG_R*. The implementation cost is obtained by

$$\text{Minimizes} \sum_{i\in T} Cost_i$$

$$\text{Subject to} \sum_{i\in T} GHG\_R_i \ge T\_GHG\_R \quad (4)$$

where, GHG emission related parameters are shown in Table II.

TABLE II. GHG RELATED PAEAMETERS

Parameter	Description
Cost	ECM impementation cost [$]
GHG_R	GHG emission reduction [ton/y]
T_GHG_R	Target of GHG emission reduction [ton/y]

From (3), the proposed algorithm tries to find an optimal combination of ECMs to minimize the implementation cost of the building retrofit, so the algorithm chooses the best possible outcome. We modified the Knapsack algorithm [11] to minimize the amount of implementation cost for the retrofit while still keeping the overall GHG emission reduction larger than or equal to its target. The pseudocode is shown in Figure 2.

We start with a set of candidate ECMs, whose implementation costs and energy savings can be obtained based on the corresponding building information including location, size and occupant behavior.

```
// c: cost;          r:GHG emission reduction;
// T: GHG emission target;     L: ECM list;

GHG_OptimalECM (c, r, n, T)
{
  for (c=0 to C) R[0, c]=0;
  for (i=0 to n)
    for (c=0 to C)
      if (c[i] ≤ c)
        R[i, c] = max{R[i-1, c], r[i] + R[i-1, c - c[i]};
      else
        R[i, c] = R[i-1, c};
      if (R[i, c] ≥ R[i-1, c])
        L[i, c] = L[i-1, c] ∪ {i};
      if (R[i, c] ≥ T)
        Cost = c; List = L[i, c]; Reduction = R[i, c];
        break GHG_optimalECM;
}
```

Figure 2. Psudocode for optimal ECM decision algorithm

The algorithm is to determine whether each ECM will be included in an ECM list for the building retrofit. Therefore, the total GHG emission reduction is larger than or equal to a given limitation while maintaining the total implementation cost is as low as possible.

IV. SIMULATION

To examine the proposed method, we set up an optimal ECM decision tool, as shown in Figure 3, which consists of building information, data base, GHG based optimal ECM decision engine and output unit. The building information includes building attributes, consumptions and energy diagnosis results. The current value of the attribute of each ECM can be obtained from the energy diagnosis results of the corresponding build. The database includes ECM, climate and energy price information.

The tool analyzes energy savings associated with each ECM for a building retrofit and organizes the candidate ECM table with energy saving and implementation cost. An example of a candidate ECM table is shown in Table III. Table IV represents the estimated optimal ECM list, initial implementation cost and GHG emission reduction. If the target of GHG emission reduction is 800 kilograms per year, the optimal ECM combination is {5, 6, 7}, the lowest implementation cost is 4800, and estimated GHG reduction is 820 kilograms per year, respectively.

From the results, we can see the budget required for a building retrofit to meet the target of GHG emission reduction and prioritize which buildings to be firstly retrofitted within an allowable budget.

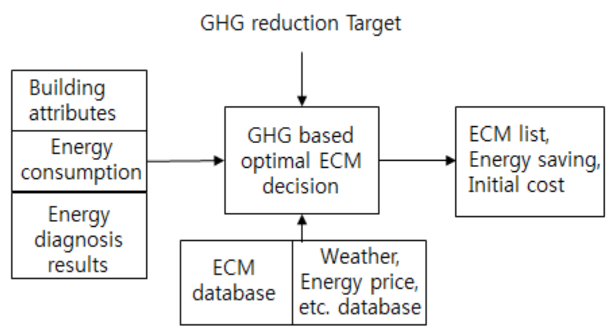

Figure 3. Architecture of the proposed method

TABLE III. AN EXAMPLE OF CANDIDATE ECMS WITH GHG REDUCTION AND COST OF THE CORREPONDING BUILDING

# of ECM	GHG reduction	Cost
1	300	2000
2	100	800
3	80	700
4	120	1000
5	200	1200
6	350	2100
7	270	1500
8	210	1400
9	150	1700

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TABLE IV. OPTIMAL ECM AND IMPLEMENTATION COST FOR GHG REDUCTION TARGET

GHG reduction target	Estimated GHG reduction	Implementation cost [$]	Optimal ECM list
50	80	700	3
100	100	800	2
200	200	1200	5
300	300	2000	1
400	400	2800	1, 2
500	500	3200	1, 5
600	600	4000	1, 2, 5
700	700	4300	3, 6, 7
800	820	4800	5, 6, 7
900	910	5700	3, 6, 7, 8

V. CONCLUSIONS

In this paper, an optimal ECM decision method has been presented, which determines an optimal ECM combination for building retrofit. The optimal ECM combination is a subset of ECMs to minimize the initial implementation cost for satisfying the target of GHG emission reduction. ECMs can reduce building energy so building owners and project managers can decide an optimal ECM combination both to reduce GHG emission and to save energy cost. The proposed method modified the knapsack algorithm to decide an optimal ECM combination among numerous combinations of ECMs. The presented method provides building owners and project managers with the optimal ECM list, estimated implementation cost and estimated GHG emission reduction.

Much of building energy can be reduced with a suitable ECM adoption, which leads to enormous GHG reduction. However, the number of ECM combinations increases exponentially with the number of ECMs and each ECM requests an initial implementation cost. For this reason, it is difficult for building owners and project managers to select a suitable ECM combination for their building retrofits to reduce GHG emission within a limited budget. To estimate the initial implementation cost for satisfying the target of GHG emission reduction, this paper set up an optimal ECM decision environment and performed simulations on GHG emission reduction. The analysis results provide the optimal ECM combination to meet the target of GHG emission reduction while the implementation cost is minimal.

Further studies are necessary to get more data on detailed measures for ECMs and verify simulation results of the optimal ECM decision method for various buildings.

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