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Development of a prediction model for the cost saving potentials in implementing the building energy efficiency rating certification

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HIGHLIGHTS

- This study evaluates the building energy efficiency rating (BEER) certification.
- Prediction model was developed for cost saving potentials by the BEER certification.
- Prediction model was developed using LCC analysis, ROV, and Monte Carlo simulation.
- Cost saving potential was predicted to be 2.78–3.77% of the construction cost.
- Cost saving potential can be used for estimating the investment value of BEER.

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ABSTRACT

Building energy efficiency rating (BEER) certification is an energy performance certificates (EPCs) in South Korea. It is critical to examine the cost saving potentials of the BEER-certification in advance. This study aimed to develop a prediction model for the cost saving potentials in implementing the BEER-certification, in which the cost saving potentials included the energy cost savings of the BEER-certification and the relevant CO_2 emissions reduction as well as the additional construction cost for the BEER-certification. The prediction model was developed by using data mining, life cycle cost analysis, real option valuation, and Monte Carlo simulation. The database were established with 437 multi-family housing complexes (MFHCs), including 116 BEER-certified MFHCs and 321 non-certified MFHCs. The case study was conducted to validate the developed prediction model using 321 non-certified MFHCs, which considered 20-year life cycle. As a result, compared to the additional construction cost, the average cost saving potentials of the 1st-BEER-certified MFHCs in Groups 1, 2, and 3 were predicted to be 3.77%, 2.78%, and 2.87%, respectively. The cost saving potentials can be used as a guideline for the additional construction cost of the BEER-certification in the early design phase.

1. Introduction

South Korea has established its national carbon emissions reduction target (CERT), which aims to reduce its greenhouse gas (GHG) emissions by 37% below its business as usual (BAU) level until 2030, and, particularly, by 25.7% below its BAU level until 2030 in its domestic industry [1]. To achieve the CERT, various policies for reducing GHG emission have been established [2]. Building energy efficiency rating (BEER) certification, as a kind of energy performance certificates (EPCs) system, is one of the representative policies related to the building energy performance in South Korea [3]. The BEER certification was established to promote the voluntary improvement of energy performance for new buildings in terms of the energy savings and the relevant CO_2 emissions reduction in the building sector [4].

It is required to submit the energy simulation results in implementing the BEER-certification, explaining how much energy demand could be reduced compared to the standard housing [5]. Also, it is necessary to consider the additional construction cost for the BEER-certification (which includes the investment cost for the application of the high performance windows and the renewable energy systems) [6]. However, the simulated energy demand would be quite different from the actual energy consumption. Thus, it is important to examine the cost saving potentials in implementing the BEER-certification and in determining its grade in the early design phase.

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Nomenclature

1st-BEER-certified MFHCs	the first-grade of the BEER-certified MFHCs
2nd-BEER-certified MFHCs	the second-grade of the BEER-certified MFHCs
3rd-BEER-certified MFHCs	the third-grade of the BEER-certified MFHCs
ACS	average cost savings
AEA	average enclosed area per household
AECS	average energy cost savings per household
AKCER	average Korea certified emission reduction
AnECS	annual energy cost savings
ANOVA	analysis of variance
BAU	business as usual
BEER	building energy efficiency rating
BOPM	Binomial option pricing model
BS	black and scholes
CEI	CO_2 emission intensity
CERT	carbon emissions reduction target
KCERP	KCER potentials
CSI	cost savings intensity
DT	decision tree
ECS	energy cost savings
EPCs	energy performance certificates
ESP	energy saving potentials
EST	energy saving technique
EUI	energy use intensity
GHG	greenhouse gas
CSP	cost saving potentials
KCER	Korea certified emissions reduction
LCC	life cycle cost
LEED	leadership in energy and environmental development
MCS	Monte Carlo simulation
MFHC	multi-family housing complex
MOLIT	ministry of land, land, infrastructure and transport
NPV	net present value
PDF	probability density function
ROV	real option valuation
SCCI	standard construction cost index
TEA	total enclosed area
TGA	total gross area

Based on this background, this study aims to develop a prediction model for the cost saving potentials in implementing the BEER-certification. The cost saving potentials includes the energy cost savings (ECS) of the BEER-certification and the relevant CO_2 emissions reduction (that is related to the *Korea certified emissions reduction* (KCER)) as well as the additional construction cost for the BEER-certification [7]. The developed model can be meaningful for investors to decide the specific grade of the BEER-certification in the early design phase. The detailed research methodology are presented in Section 3.

2. Review of the building energy efficiency rating (beer) certification

2.1. BEER-certification in South Korea

The BEER-certification was initiated by the governmental organization, Ministry of Trade, Industry and Energy in 2001. The BEER-certification can be used to evaluate how much energy consumption would reduced for the target building compared to the standard building in the early design phase [5]. Thus, it can be expected that the BEER-certified building will consume less energy than the non-certified building. In this regard, if the BEER-certification is effective for reducing the energy consumption of buildings, the monetary value of the energy savings and the relevant CO_2 emissions reduction can be also predicted.

The BEER-certification has two kinds of rating system by building types (i.e., one is the residential building focused on the multi-family housing complexes (MFHCs) and the other is the non-residential building). The MFHC refers to a group of high-rise residential apartments (which consist of multiple housing units, and are over 48% of households in South Korea) [8]. Table 1 shows the historical records of the BEER-certification in residential buildings. This study analyzed the BEER-certified buildings from 2004 to 2013.

2.2. Energy performance evaluation in the BEER-certification

As shown in Table 1, the BEER-certification is divided into five grades (i.e., first, second, third, fourth and fifth grade). It can be established with the energy savings of the certified buildings compared to standard housing, which is calculated by Eq. (1) [9].

$$ES^i = \frac{DHeat^{st} - DHeat^i}{DHeat^{st}} \times 100 + Add.F^i \quad (1)$$

where ES^i is the energy saving ratio of unit housing in the target MFHC i (%); $DHeat^{st}$ is the heating energy demand of unit housing in the standard MFHC (*GJ/y*); $DHeat^i$ is the heating energy demand of unit housing in the target MFHC i (GJ/y); and $Add.F^i$ is the additionally acceptable energy saving ratio (%) in the target MFHC i for 23 categories with 11% of maximum available.

The heating energy demand of unit housing is estimated using the calculation process provided by *Ministry of Land, Infrastructure and Transportation (MOLIT)*, which considers heat gain and loss, ventilation, and heating degree-day of the target MFHCs. The standard housing is modelled using the guideline provided by MOLIT (for the detail guideline of the standard housing, refer to Table S1 in Supplementary Material) [5].

Through the analysis of the BEER-certification, five issues were found in the criteria of standard housing. First, the efficiency of boiler in standard housing is defined as low value (i.e., 80%) compared to the actual efficiency of condensing boiler (i.e., 88–95%) that is generally used in MFHCs in South Korea [10]. Second, the window size of the standard housing is larger than that of the target housing [9]. Third, the façade of standard housing is oriented to east [11]. Fourth, the coefficient of heat transmission in standard housing is fitted to the legal minimum requirement. Fifth, the additional energy saving ratio is available by Eq. (1). In this regard, it can be expected that the conventional MFHCs without the BEER-certification may obtain a certain level of energy savings compared to the standard housing in BEER-certification. Therefore, the validation is required to evaluate the energy saving ratio using the actual energy consumption data.

Several previous studies evaluated the energy performance in implementing the EPCs. While most of the previous studies mainly compared the difference between the simulated energy demand and the actual energy consumption based on the limited cases and conditions, there is still a lack of the efforts for establishing a reliable evaluation process or for assessing the effectiveness of the EPCs [12–23]. In case of the BEER-certification in South Korea, most of studies were focused on the analysis of energy simulation