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Decision support model for establishing the optimal energy retrofit strategy for existing multi-family housing complexes

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H I G H L I G H T S

- The proposed model was developed to establish the optimal energy retrofit strategy.
- Advanced case-based reasoning was applied to establish the community-based CERT.
- Energy simulation was conducted to analyze the effects of energy retrofit strategy.
- The optimal strategy can be finally selected based on the LCC and $LCCO_2$ analysis.
- It could be extended to any other country or sector in the global environment.

A R T I C L E I N F O

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A B S T R A C T

The number of multi-family housing complexes (MFHCs) over 15 yr old in South Korea is expected to exceed 5 million by 2015. Accordingly, the demand for energy retrofit in the deteriorating MFHCs is rapidly increasing. This study aimed to develop a decision support model for establishing the optimal energy retrofit strategy for existing MFHCs. It can provide clear criteria for establishing the carbon emissions reduction target (CERT) and allow efficient budget allocation for conducting the energy retrofit. The CERT for “S” MFHC, one of MFHCs located in Seoul, as a case study, was set at 23.0% (electricity) and 27.9% (gas energy). In the economic and environmental assessment, it was determined that scenario #12 was the optimal scenario (ranked second with regard to NPV_{40} (net present value at year 40) and third with regard to SIR_{40} (saving to investment ratio at year 40). The proposed model could be useful for owners, construction managers, or policymakers in charge of establishing energy retrofit strategy for existing MFHCs. It could allow contractors in a competitive bidding process to rationally establish the CERT and select the optimal energy retrofit strategy. It can be also applied to any other country or sector in a global environment.

1. Introduction

The increase in greenhouse gas (GHG) emissions due to the over-consumption of energy has caused global climate change. To cope with such crisis, the *United Nations Framework Convention on Climate Change* proposed the *Kyoto Protocol* in 1997. Accordingly, leading countries have established long-term targets for their GHG emissions (Chicco and Stephenson, 2012; Wang et al., 2011). The European Union (EU) has established a target of at least 20% GHG emission reduction by 2020 compared to 1990 (EU Action against Climate Change, 2009). The United Kingdom has also set 34% and 80% GHG emission reduction targets by 2020 and 2050, respectively, compared to 1990 (Energy Act, 2008). The Japan has set 15% GHG emission reduction targets, respectively, by 2020 compared to 2005 (Pielke Jr., 2009).

Keeping pace with the global trend, South Korea has also set to reduce 30% of the business-as-usual emissions by 2020 (KME, 2011). While South Korea is currently considered a developing country under the *Post-Kyoto Protocol* (2013–2020), it is expected to be included later in the list of the countries with mandatory GHG emission reduction (SEI, 2011). Of the total energy consumption of South Korea, 96% depends on imports, and only 2.24% is generated from new and renewable energy (NRE). Also, South Korea's total GHG emission in 2011 was 0.61 billion tons, among the highest globally, and its GHG emission increase rate from 1990 to 2011 was considerable at 144% (The 1st National Basic Plan for Energy, 2008). On September 15, 2011, South Korea experienced a

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Table 1
Literature reviews of the building energy retrofits.

Perspective	Technique	Detailed techniques	References
One objective (energy)	ESTs[a]	Double skin facades, building envelope	Choi et al. (2012), Lam et al. (2005), Mwasha et al. (2011), and Ramesh et al. (2012)
		Energy recovery ventilator (ERV), heat recovery ventilator system	Liu et al. (2010) and Yu and Kim (2012)
		Residential heating (small stoves and boilers), radiant floor heating	Junninen et al. (2009) and Seo et al. (2011)
		Light pipe system, artificial and natural lighting	Shin et al. (2012) and Yun et al. (2012)
		Building design and energy end-use	Wan and Yik (2004)
		Building equipment retrofits	Yalcintas (2008)
		Air-side economizers (temperature-based economizer cycle (TEC) and the enthalpy-based economizer cycle (HEC))	Yao and Wang (2010)
	NREs[b]	Heat pump heating system using wastewater, ground-coupled heat pump, solar-ground coupled heat pump, ground source heat pump, geothermal heat pump	Gustafsson and Bojic (1997), Wang et al. (2009), Nagano et al. (2006), Hong et al. (2013), and Yang et al. (2008)
		Thermal photovoltaic system, solar water heating system, nanofluid solar hot water technologies	Bianchi et al. (2012), Golić et al. (2011), and Otanicar and Golden (2009)
		Micro combined heat and power (MCHP)	Dorer and Weber (2009)
		Rooftop photovoltaic system, photovoltaic system, stand-alone photovoltaic systems, building integrated PV systems	Ubertini and Desideri (2003), Xiaoting et al. (2011), Kaldellis et al. (2010), Sumper et al. (2011), and Raugei and Frankl (2009)
Multi objective (energy, economic, comfort, environmental, etc.)	ESTs[a]	Energy-efficient retrofit, retrofitting interventions	Amstalden et al. (2007) and Boeri et al. (2011)
		Building envelope, green roof	Fesanghary et al. (2012) and Chang et al. (2011)
		Orientation, window location and size, glazing type, wall and roof insulation levels, lighting fixtures, appliances, heating and cooling systems, façade, ventilation system	Brecha et al. (2011), Ihm and Krarti (2012), Jaber and Ajib (2011), Kwak et al. (2010), Morrissey and Horne (2011), Ouyang et al. (2009), and Jin and Qiu (2012)
	NREs[b]	PV/wind/diesel hybrid energy system, PV/solar heat/cogeneration system, rainwater harvesting	Ngan and Tan (2012), Oke et al. (2008), and Domènech and Saurí (2011)
	ESTs[a] and NREs[b]	Combinations of energy efficiency measures, thermal comfort measures, and renewable energy systems (wind, solar, geothermal)	Griego et al. (2012) and Habib and Ismaila (2008)
		Basic upgrades (2006 IECC standards), advanced upgrades, building integrated PV systems	Sadineni et al. (2011)

[a] ESTs stands for the energy saving techniques.
[b] NREs stands for the new renewable energies.

short yet massive nationwide blackout, which led to active debates on policies and systems for energy-saving and GHG emission reduction (KMKE, 2011a). In South Korea, 21% of the GHG emissions by energy consumption results from the operation and maintenance phase of buildings, 56% of which are residential buildings (KMKE, 2011b). South Korea conducts regimes such as "*Building Energy Efficiency Rating System*," which target the energy retrofit of residential buildings (KMKE and KMLTM, 2011). The targets of these regimes, however, are limited to new buildings, and minimal effort is being made for saving energy in the existing buildings. "*The Green Home Pilot Project*" of Korea Land and Housing Corporation is an energy efficiency improvement project that targets existing multi-family housing complexes (MFHCs). However, it lacks variety in execution, i.e., there are no specific process and no clear criteria for selecting the target MFHC, establishing the optimal energy retrofit strategy, and allocating the limited budget, thus giving rise to criticisms with regard to the project's inefficiency (KMLTM, 2010). Furthermore, South Korea is promoting various policies for energy retrofits in buildings (Baek and Park, 2012; Chung and Tohno, 2009; KEMCO, 2013a; Song and Choi, 2012; Tae and Shin, 2009). In these policies, it is important to allocate the budget efficiently and to establish the optimal energy retrofit strategy by determining the characteristics and energy consumption patterns of buildings.

Many studies have been conducted on the energy retrofit of residential housing units in various countries. Considering the climate of the country where the study was conducted, these studies analyzed the economic and environmental effects of envelop systems, lighting, HVAC systems, and other energy-saving techniques (ESTs) on residential buildings (refer to Table 1) (Choi et al., 2012; Junninen et al., 2009, Lam et al., 2005; Liu et al., 2010; Mwasha et al., 2011; Ramesh et al., 2012; Seo et al., 2011; Shin et al., 2012; Wan and Yik, 2004; Yalcintas, 2008; Yao and Wang, 2010; Yu and Kim, 2012; Yun et al., 2012). Other studies analyzed the economic and environmental effects of NRE systems, including solar photovoltaic energy, solar thermal energy, and geothermal energy (refer to Table 1) (Baek et al., 2005; Bianchi et al., 2012; Dorer and Weber, 2009; Golić et al., 2011; Gustafsson and Bojic, 1997; Hong et al., 2013; Kaldellis et al., 2010; Nagano et al., 2006; Otanicar and Golden, 2009; Raugei and Frankl, 2009; Sumper et al., 2011; Ubertini and Desideri, 2003; Wang et al., 2009; Xiaoting et al., 2011; Yang et al., 2008). These studies focused on the effect of a single EST or NRE.

In the practical area of MFHC's energy retrofits, however, the energy-saving effect must be maximized not by applying a single EST or NRE but by combining various ESTs or NREs, on which many studies have focused. Several studies have conducted multifaceted analysis of the energy-saving effects, life cycle cost, and life cycle CO_2 of various ESTs or NREs, and of the comfort level of the occupants from the application of such ESTs or NREs (refer to Table 1) (Amstalden et al., 2007; Boeri et al., 2011; Brecha et al., 2011; Chang et al., 2011; Domènech and Saurí, 2011; Fesanghary et al., 2012; Griego et al., 2012; Habib and Ismaila, 2008; Ihm and Krarti, 2012; Jaber and Ajib, 2011; Jin and Qui, 2012; Kwak et al., 2010; Morrissey and Horne, 2011; Ngan and Tan, 2012; Oke et al., 2008; Ouyang et al., 2009; Sadineni et al., 2011). Based on these results, the optimal energy retrofit strategy was selected and applied to a given housing unit. Nevertheless, these studies do not provide detailed criteria for selecting target MFHC projects for energy retrofit. In other words, they failed to consider the appropriate allocation of the limited budget. Furthermore, they do not offer detailed criteria for establishing the CERT or energy-saving target for a given housing unit. Such criteria are essential in terms of practical aspects.

Therefore, this study aimed to develop a decision support model for establishing the optimal energy retrofit strategy for