Energy Policy 68 (2014) 218–231

Contents lists available at ScienceDirect

Energy Policy

journal homepage: www.elsevier.com/locate/enpol

Development of a new energy efficiency rating system for existing residential buildings

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HIGHLIGHTS

- A new energy efficiency rating system for the residential building was developed.
- The incentive and penalty programs were established using an advanced CBR model.
- The new system was established using reasonable and fair standards.
- It allows all residents to voluntarily participate in the energy saving campaign.
- It can be applied to any country or sector in the global environment.

ARTICLE INFO

Article history:
Received 2 September 2013
Received in revised form
26 November 2013
Accepted 30 December 2013
Available online 8 February 2014

Keywords:
Energy efficiency rating system
Incentive and penalty programs
Energy policy

ABSTRACT

Building energy efficiency rating systems have been established worldwide to systematically manage the energy consumption of existing buildings. This study aimed to develop a new energy efficiency rating system for existing residential buildings from two perspectives: (i) establishment of reasonable and fair criteria for the building energy efficiency rating system; and (ii) establishment of comparative incentive and penalty programs to encourage the voluntary participation of all residents in the energy saving campaign. Based on the analysis of the conventional energy efficiency rating system for existing residential buildings, this study was conducted in five steps: (i) data collection and analysis; (ii) correlation analysis between the household size and the CO_2 emission density (i.e., CO_2 emission per unit area); (iii) cluster formation based on results of the correlation analysis using a decision tree; (iv) establishment of a new energy efficiency rating system for existing buildings; and (v) establishment of incentive and penalty programs using advanced case-based reasoning. The proposed system can allow a policymaker to establish a reasonable and fair energy efficiency rating system for existing residential buildings and can encourage the voluntary participation of all residents in the energy saving campaign.
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1. Introduction

The worldwide crisis known as global warming has prompted the enactment of the *United Nations Framework Convention on Climate Change* in Rio de Janeiro, Brazil in June 1992. This was followed by the *Kyoto Protocol* in Kyoto, Japan in December 1997, which regulated the obligatory greenhouse gas (GHG) emissions from industrialized countries (IPCC, 2007; UNFCCC, 1998). It has been reported that in the U.S. and the European Union (EU), two representative countries/regions with GHG emission reduction obligations, about 40% of the total fossil fuel consumption comes from the building sectors (CCC, 2010; DECC, 2012; EIA, 2012; IEA, 2012). Accordingly, the EU approved the *Energy Performance of Building Directive* (EPBD) on December 16, 2002 to strengthen control over the total energy consumption of buildings. In 2007, EPBD adopted a regulation that forces building purchasers and tenants to provide energy performance certificates (EPCs) in the building sale or rental process. The U.K. announced in December 2006 that it would realize its nearly-zero-energy building (nZEB) target on all new homes in the country by 2016 (ECEEE, 2011; GFE, 2010; IRENA, 2012; Sunikka, 2005; ZCH, 2011). The U.S. Department of Energy (DOE) proactively supports research on nZEB (DOE, 2002; NREL, 2006; NSTC, 2008). Thus, the world is enacting building laws related to building energy efficiency or is reforming existing ones for the improvement of the energy performance of buildings (KC, 2012; KME, 2011; MLTM, 2012; NREL, 2009, 2010; RICS, 2009).

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http://dx.doi.org/10.1016/j.enpol.2013.12.068

The *Post-Kyoto Protocol* categorizes South Korea as a non-Annex-I country. As of 2011, however, the main index of South Korea's GHG emissions ranks as high as follows: (i) its annual CO_2 emission was determined to be 0.61 billion tons of CO_2 equiv. (ranked 7th in the world); (ii) the increase ratio of its annual CO_2 emission from 1990 to 2011 was 144% (ranked 6th in the world); and (iii) its annual CO_2 emission per gross domestic product was 0.55 t of CO_2 equiv. per thousand U.S. dollars (ranked 12th in the world) (refer to Table S1). Accordingly, the global society is requesting South Korea to follow the obligatory GHG emission regulation (IEA, 2011; UNDP, 2012).

In keeping with such global trend, South Korea has established GHG emission reduction targets by industry. For the building sector, it has established a 26.9% GHG emission reduction target (business-as-usual) (KG, 2011). To achieve this, the country imposed about 50%, 25%, and 25% of the allocation of emission allowances on its existing buildings, new buildings, and improvement of behavior, respectively (MLTM, 2012). The South Korean government enacted and proclaimed in February 2012 the '*Act on the Promotion of Green Buildings*,' based on the country's national vision, '*Low Carbon and Green Growth*.' This move was aimed at the distribution of green buildings that have high new renewable energy use and lower GHG emissions. Having been in effect since February 23, 2013, this act focuses on controlling the GHG emissions of existing buildings. Based on this act, the South Korean government created a new green-building division under the Ministry of Land, Transport, and Maritime Affairs (MLTM) (MLTM, 2012).

Besides the EU, the U.S. and U.K., South Korea is also establishing a building energy efficiency rating system to systematically control the energy consumption and GHG emissions of its existing buildings. However, for such a system to be effective, it should generally satisfy two conditions: (i) the building energy efficiency rating system should be set up based on reasonable and fair standards; and (ii) its implementation should be coupled with the voluntary participation of all the residents. Therefore, this study analyzed the conventional energy efficiency rating system for existing residential buildings based on these two conditions. Based on the analysis results, this study aimed to develop a new energy efficiency rating system for existing residential buildings from two perspectives: (i) establishment of reasonable and fair criteria for the building energy efficiency rating system; and (ii) establishment of comparative incentive and penalty programs to encourage the voluntary participation of all residents in the energy saving campaign. Towards these objectives, the multi-family housing complex was selected as the representative type of existing residential building in South Korea.

2. Conventional energy efficiency rating system for existing residential buildings

2.1. Building energy efficiency rating system

The EU announced EPBD in 2002 to minimize the GHG emissions of its buildings. EPBD defined not only a clause that made the evaluation of the energy performance of new and existing buildings compulsory, but also a clause that made the attachment of EPCs on contract documents during the sale or rental of buildings compulsory. The building energy efficiency rating system defined by EPBD is generally divided into two types: (i) asset rating calculated by the energy demand calculation method based on the characteristics of a building (mainly for new buildings); and (ii) operational rating based on the building's actual energy consumption (mainly for existing buildings).

EBPD is considered a representative green-building policy worldwide. Based on the EBPD guideline, the U.K., Germany, France, etc. established and operated building laws related to building energy efficiency (DCLG, 2012a, b, 2008; IEEP, 2011).

In the case of the EPCs in the U.K., the asset rating based on the government's standard assessment procedure (SAP) for the energy rating of a dwelling is applied for new residential buildings. For existing buildings, however, both the asset rating based on the reduced-data SAP (RdSAP) and the operational rating based on the actual energy consumption are used. Meanwhile, for public buildings, the U.K. issues display energy certificates (DECs), which are applied to the operational rating. DECs offer a standardized value (0–150) for a building's CO_2 emissions, which is categorized into seven grades from A to G (refer to Fig. 1) (CA EPBD, 2011a; Cho, 2010; Song et al., 2010).

As for the EPCs in Germany, both the asset rating and the operational rating are used selectively. Since 2010, all new buildings and large rehabilitation projects of existing buildings have been required to use the asset rating. For large residential buildings, either the asset or operational rating can be selected. Compared to those of other countries, the EPCs of Germany are not represented in a stepped scale but in a continuous scale, resembling the speed meter. For example, the EPC of a residential building is presented in the range of 0–400 $kWh/m^2 \cdot year$. It consists of several types of buildings from the passive house, which is the standard for energy efficiency in a building, resulting in ultra-low energy buildings that require little energy for space heating or cooling (Passive House, 2013), to single-family home which is not refurbished. Also, the EPC of a non-residential building is presented in the range of 0–1000 $kWh/m^2 \cdot year$ (refer to Fig. 2) (CA EPBD, 2011b; Cho, 2010).

Regarding the EPCs in France, the operational rating based on the actual energy consumption is mainly used. It is divided into four types: (i) sale of existing buildings; (ii) rental of residential buildings; (iii) new buildings; and (iv) public buildings. While the EPCs of residential buildings are divided into seven grades from A to G, those of non-residential buildings are divided into nine grades from A to I (CA EPBD, 2011c; Cho, 2010).

The South Korean government hopes to achieve national energy savings and its GHG emission reduction target by promoting

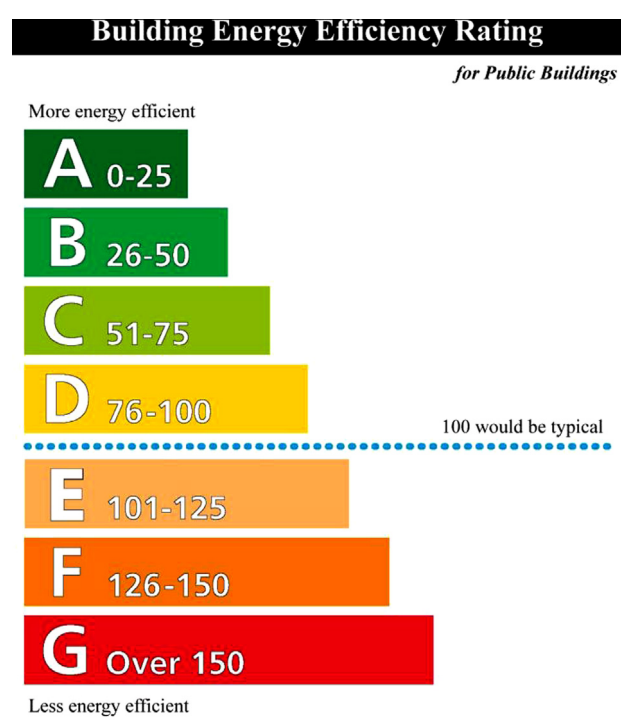

Fig. 1. Building EPCs for the operational rating in the UK.

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