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Analysis of a Building Energy Efficiency Certification System in Korea

Duk Joon Park [1], Ki Hyung Yu [2], Yong Sang Yoon [2], Kee Han Kim [2] and Sun Sook Kim [1,*]

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[1] Department of Architecture, Ajou University, Suwon 443-749, Korea; pdj33@hanmail.net
[2] Building and Urban Research Institute, Korea Institute of Civil Engineering and Building Technology, Ilsan 411-712, Korea; raytrace@kict.re.kr (K.H.Y.); ysyoon@gasd.kr (Y.S.Y.); keehankim@kict.re.kr (K.H.K.)
* Correspondence: kss@ajou.ac.kr; Tel.: +82-31-219-3571; Fax: +82-31-219-2945

Abstract: The Korean government has established a national plan for the promotion of zero energy buildings to respond to climate change and energy crises. To achieve this plan, several energy efficiency policies for new and existing buildings have been developed. The Building Energy Efficiency Certification System (BEECS) aims to promote the spread of high energy-efficient buildings by evaluating and certifying building energy performance. This study discussed Korean building energy efficiency policies and analyzed especially the influence of the BEECS on the actual energy consumption of a residential building and calculated energy performance of non-residential buildings. The BEECS was evaluated to have influence on gas and district heating consumption in residential buildings. For non-residential buildings, a decreasing trend was shown in calculated primary energy consumption in the years since the BEECS has been enacted. Appropriate improvements of the certification system were also discussed by analyzing relationship between building characteristics and their energy consumptions.

Keywords: building energy policy; building energy conservation code; building energy performance certification; building energy efficiency certification

1. Introduction

Buildings are a major end-use in global energy markets and will continue to be a source of increasing energy demand in the future [1]. The building sector, comprising both the residential and services sub-sectors, accounts for 35% of global final energy consumption [2]. The IEA has identified the building sector as one of the most cost-effective sectors for reducing energy consumption and released 25 energy efficiency policy recommendations in an effort to reduce energy consumption and CO_2 emissions [3,4]. If the recommendations are implemented worldwide, 7.6 GT of CO_2 emissions could be saved annually by 2030, which is 1.5 times the current CO_2 emissions of the United States; 1950 Mtoe in annual energy consumption could also be saved [3].

Since there are numerous barriers to energy efficiency in the building sector, many countries have introduced building energy policies that are imperative to achieve a CO_2 emissions reduction in the building sector [3,5]. Building energy codes and minimum energy performance standards have been enforced and regularly strengthened for new and existing buildings. Many countries also set targets for zero energy buildings to reduce greenhouse gases (GHG) in the building sector. In addition, over the last few decades, energy performance certification has also been introduced to the commercial and residential building sectors as a key policy instrument that can assist governments in reducing energy consumption in buildings [6]. This certification provides consumers with information on buildings, either in relation to achieving a specified level of energy performance or in comparison to other reference buildings [6,7]. In Denmark, the mandatory energy performance certification system was launched for commercial and residential buildings in 1992 and 1993, respectively [8]. Since the European Union's Energy Performance of Buildings Directive (EPBD) in 2002 created a common framework to improve the energy performance of buildings [8], mandatory energy certification policies have been enacted and implemented in member countries over the next decade. Although Europe has been leading the efforts in this area, mandatory or voluntary certification systems have also been introduced in many countries throughout the world [5–10]. While the certification is mandatorily required for all buildings that are constructed, sold, or rented by legislative instrument in the EU, the US involves private companies for certification which seems to be a more market driven approach. In Korea, the Building Energy Efficiency Certification System (BEECS) was enacted in 2001 and has been implemented as a policy tool to promote reduction of building energy consumptions by providing customers information on building energy use [11].

As the building energy certification system has been implemented for years and energy performance data have been collected in databases, countries have been making various attempts to evaluate its influence on actual energy consumptions and real estate markets and to assess the efficacy of the certification as a policy tool for reducing energy consumptions in the building sector. Fuerst *et al*. [7] investigated the relationship between UK EPC ratings and sale prices of dwellings and suggested that energy efficiency labels have a measurable and significant impact on housing prices in England. Majcen *et al*. [12] examined actual and calculated household energy consumption and found out their discrepancies in respect to the targets set for reductions in energy consumption for the residential sector in the EU and the Netherlands. In Ireland, Curtis and Pentecost [13] also examined the relationship between residential buildings' energy efficiency labels and household energy expenditure and found out that each rating decline along the scale is associated with a reduction in energy expenditure of 1.6%. In Greece, Dascalaki *et al.* [14] analyzed the 360,000 certificates issued since the certification system started in 2011 in terms of energy labels and calculated primary energy consumptions per unit floor area by building types, end-users, climate zones, and construction periods. In Germany, Murphy [15] conducted a survey of energy performance certificate recipients and non-recipients and analyzed the influence of certificate descriptively and statistically to enhance the efficacy of the policy. However, even though the Korean BEECS has been implemented for more than 10 years, few studies have been conducted on analyzing the result and influence of the policy.

The aim of this research is to overview the Building Energy Efficiency Policies in Korea, especially the BEECS, and to investigate the influence of the certification system by analyzing energy performance in certified buildings. For residential buildings, the relationship between the results of the energy performance calculation and the actual energy consumption was analyzed. For non-residential buildings, calculation results and energy performance of building components were analyzed. In addition, the outlook for this policy was discussed.

2. Building Energy Use in Korea

In 2013, final energy consumption was about 210.2 Mtoe and 42.01 Mtoe (20.0%) was consumed in the building sector [16] which includes residential and commercial (17.8%), and public services (2.2%) [17]. Over the last few decades, building energy consumption has been increasing continuously, as shown in Figure 1 [16]. Considering that the building sectors of most Organization for Economic Cooperation and Development (OECD) countries use an average of 40% of each country's total energy consumption [18], it is expected that the energy consumption of the building sector in Korea could increase in the future as the country shifts from a heavy energy consumption industrial structure to a low energy consumption industrial structure.

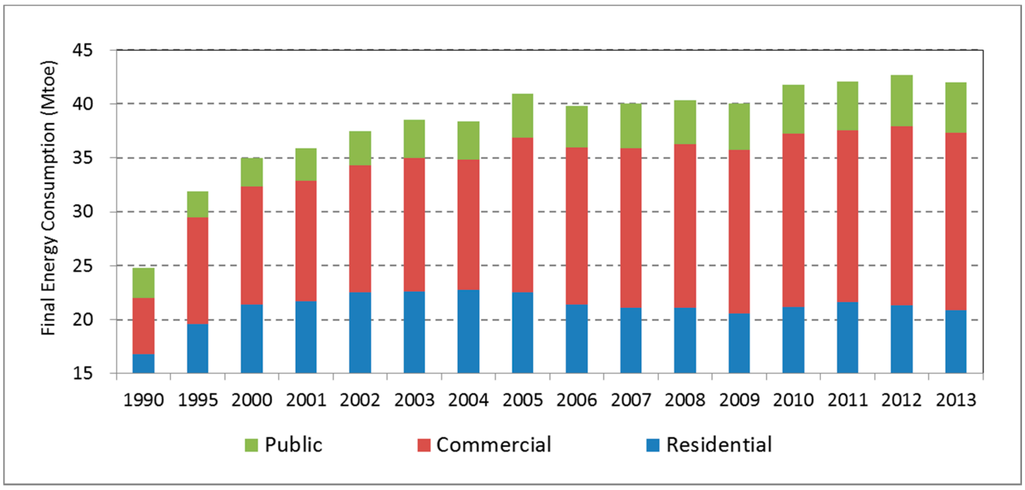

Figure 1. Final energy consumption by building sub-sectors.

According to the Korean energy consumption survey [19] which has been conducted every three years by the Korea Energy Economics Institute (KEEI), residential energy consumption per household was 1.214 toe in 2013. Residential energy consumption per capita was 0.440 toe, which was lower than U.S. (0.809 toe) or Germany (0.701 toe) but higher than Japan (0.368 toe) [19]. Figure 2 shows that gas (53.4%) was the most important final energy source for residential buildings, followed by electricity (25.1), coal (11.2%), and district heating (8.3%). Gas, coal, and district heating are usually used for space heating, domestic hot water, and cooling, while electricity is used for space cooling, lighting, and appliances. In Figure 2, petroleum includes gasoline, kerosene, diesel, LPG, *etc.* The portion of energy consumption by commercial and public services has also increased gradually, from 6.1% in 2001 to 9.5% in 2013. Space heating and water heating were the main end uses with a portion of 34.5%, followed by space cooling with 24.2%, food preparation and others with 19.2%, lighting with 11.9%, and motors for vertical transport and plumbing system with 10.3%. Electricity (65.8%) accounts for considerable portion of final energy sources for commercial and public buildings. The average prices for electricity and gas are about 0.1 US dollar/kWh and 0.02 US dollar/MJ, but for electricity, fees are charged on a graduated scale.

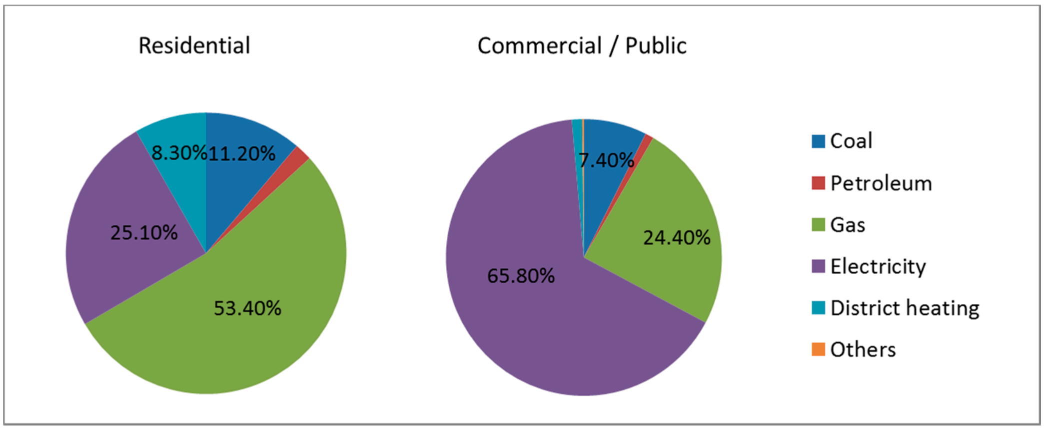

Figure 2. Energy consumption by sources in the building sector.

Table 1 shows energy use of 933 large buildings which consumed more than 2000 toe from the complete survey conducted in 2013 [20]. Figure 3 shows energy consumption by end uses of these buildings in the commercial and public sector.

Table 1. Energy consumption indicators of large buildings with more than 2000 toe of energy use.

Parameter	Office	Retail	University/ Institute	Hotel	Hospital	Data Center	Apartment	Others
Number of buildings	164	174	148	61	80	55	221	30
Average building floor area (m^2)	110,205	92,399	195,216	114,221	91,735	28,812	227,463	106,618
Total final energy (ktoe)	344.7	319.6	471.5	203.9	267.1	146.1	545.9	70.8
Final energy use intensity(kWh/m^2)	221.7	231.2	189.8	340.2	423.3	1071.9	126.3	257.2

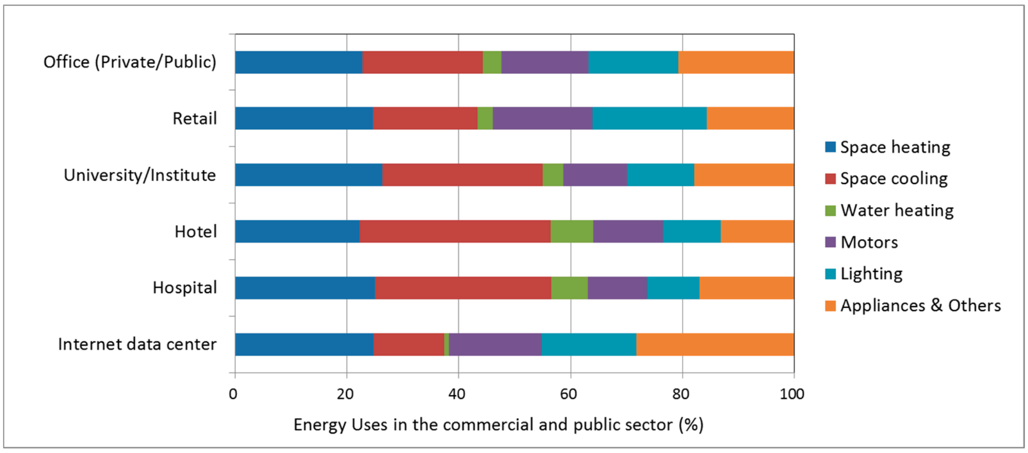

Figure 3. Energy consumption by end uses in the commercial and public sector.

Considering past and prospective trends in building energy consumption, the Korean government established the second energy master plan in January of 2014 [21] which includes a vision for the country's energy policy through 2035. Since the residential sector and commercial and public service sector are collectively referred to as "the buildings sector" internationally [2,17], energy demands for 2035 were also expected by sectors including industry, transportation, and building, as shown in Table 2. The portion of final energy demands for residential buildings are expected to decrease from 10.5% in 2011 to 9.8% in 2035, and increase for commercial and public buildings from 9.9% in 2011 to 13.5% in 2035. In particular, because the annual incremental rate for commercial buildings is expected to be 2.4% (which is much higher than for other types of buildings), it is important to focus particular attention on this building type's energy consumption. In addition, since the residential sector energy use is expected to increase by 15% from 2011 to 2035 despite its share of final energy decreases, energy conservation measures and policies also need to be implemented to improve the energy efficiency of residential buildings.

Table 2. Prospective energy demand by sector for 2035.

Sector		Energy Demand (Mtoe)				Annual Avg. Rate of Increase (%)
		2011	2025	2030	2035	
Industry		126.9	151.6	152.3	148.4	0.66
Transportation		36.9	44.0	45.5	46.5	0.97
Building	Residential	21.6	24.2	24.6	24.9	0.59
	Commercial	15.9	23.6	26.0	28.1	2.39
	Public	4.6	5.4	5.8	6.2	1.31
Total		205.9	248.7	254.3	254.1	0.88

3. Building Energy Policy in Korea

The Korean Government also has made a significant effort to develop and enforce policies regarding regulations, certification system, financial support, and technical development. Since the 1980s, a number of policies have been adopted to improve building energy conservation in Korea, including the Building Energy Conservation Code (BECC) in the 1980s, the Regulations for Energy Efficiency Labeling and Standards in the 1990s, the Green Building Certification program and the BEECS in the early 2000s. The Korean government announced several major government projects in August of 2008, including their provision of a million green houses, in an effort to further their new vision of Low Carbon and Green Growth [22–24]. This Green Growth aims at establishing a new paradigm that is expected to shift the current conflictive relationship between environmental protection and economic growth to one of cooperation; this will be accomplished by creating a new job market (and accomplishing other related goals) that responds to climate change and the current energy crisis [25]. This policy of Low Carbon and Green Growth hopes to switch the human population from a vicious to a virtuous cycle in terms of energy, the economy, and the world's climates and ecosystems; it aims to develop a new paradigm of balance between economic development and environmental conservation [22–24]. To further these goals, the Korean government's Ministry of Land, Infrastructure, and Transport (MOLIT) announced an "Activation Plan for Green Building" in November of 2009. The government's aim is to keep updating building codes gradually such that by 2025 all newly constructed buildings will be zero-energy buildings [24]. This is one significant reason why energy conservation policies in the building sector should now be consistently followed.

The Activation Plan for Green Building, announced in 2009, carries an especially important meaning for green buildings and building energy policy. This was the first plan to integrate a number of policies designed to promote the spread of green buildings and building energy conservation in Korea into a national vision for general conservation. Before this plan, each building's energy conservation policy was implemented on an individual basis. MOLIT proposed a refined policy for promoting green buildings in 2011, and then enacted the Green Building Development Support Act in 2012; it was first enforced in February of 2013. MOLIT also furthered green building policies by establishing the Green Architecture Division in March of 2012, and designating the Korea Energy Agency (KEA), the Korea Institute of Construction Technology (KICT), the Korea Infrastructure Safety and Technology Corporation (KISTEC), the Korea Appraisal Board (KAB), and the Korea Research Institute for Human Settlements (KRIHS) to act as green building centers for the development and execution of a number of related policies. In addition, the Korean government announced its first green building master plan in December of 2014, which includes a five-year plan containing strategies for promoting the development of green buildings. By 2020, the government expects this plan to reduce the country's production of greenhouse gases in the building sector by 26.9% [24].

Among various policy measures, a regulation and certification system can be both representative and fundamental because the regulations lead second movers in construction markets to meet minimum requirements for building energy conservation, and the certification system encourages improvements in energy efficiency by supporting energy efficient buildings in the construction market [26]. Therefore, the BECC as a regulation and the BEECS as a certification system were briefly overviewed in this part.

3.1. Building Energy Conservation Code

The BECC is a mandatory regulation to specify minimum requirements for building energy performance. The BECC has both prescriptive and performance approaches. In its prescriptive approach, the Code specifies a set of mandatory design criteria for the four main building sections (building envelope, mechanical systems, electrical systems, and renewable energy systems) as well as an evaluation of the Energy Performance Index (EPI) [27]. In its performance approach, buildings are not yet mandated to meet the established criteria but it is recommended that builders evaluate the energy consumption levels of their designs according to ISO 13790 when constructing office buildings above 3000 m^2 total floor area. In order to obtain a construction permit, a building energy conservation plan complying with specific design criteria, an EPI evaluation sheets, and energy consumption calculation results must all be submitted according to building type. The target building types for submissions have been expanded year by year, as shown in Figure 4. Even though a public bath and a swimming pool were not common typologies, they were included in the target building types due to high energy consumptions. A dormitory was also considered separately from a multifamily residential building since its energy consumption profile was much more similar to lodging. Since September 2013, obligation to submit energy conservation plans have been expanded to all types of residential and non-residential buildings above 500 m^2 total floor area.

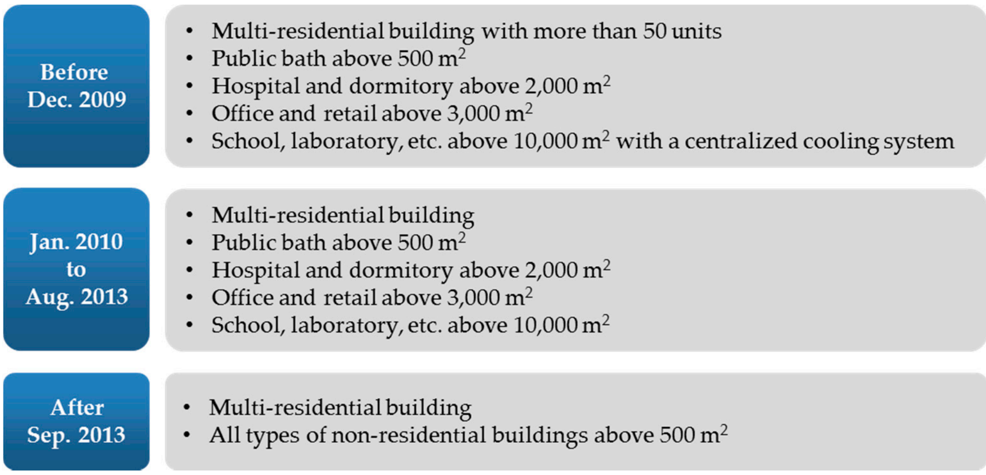

Figure 4. Expansion of building types for submission of building energy conservation plans.

Each relevant institution has an assigned role. MOLIT announces the BECC, and KEA manages the practical aspects of the system by analyzing data, maintaining online review systems, developing guidelines, advertising, educating mandating authorities and architectural firms, and examining review outputs from other review institutions. The review process for building energy conservation plans is shown in Figure 5.

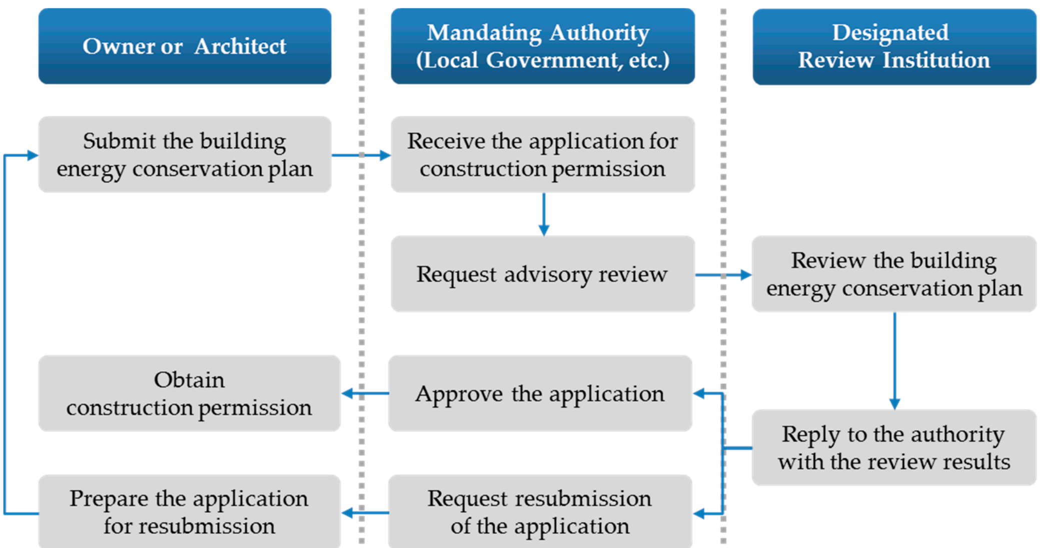

Figure 5. Review process of a building energy conservation plan.

The building energy conservation plan consists of three paths: energy conservation design criteria, EPI evaluation, and energy consumption calculation. All building types described in Figure 4 should comply with the first two prescriptive paths. Office buildings with above 3000 m^2 of total floor area are required to comply with not only the prescriptive paths but also the performance-based energy consumption calculation.

First, nineteen criteria that comprise the architectural, mechanical, and electrical sectors of the building are obliged to meet specific design criteria. An example of the detailed list can be found in Table 3. According to the heating degree-days, insulation criteria for building envelope are classified into three climate zones; the central zone, the southern zone, and Jeju Island [27]. The U-value for each part of the building envelope is required to meet certain criteria, unless insulation beyond a certain thickness and of a certain performance quality is installed. In order to avoid heat loss from excessively large window areas, the criteria also regulate the average U-value for the whole building envelope. In Korea, because most residential buildings have underfloor radiation heating systems, the regulations also require the installation of insulation on the floor between the bottom of hot water pipes and the material beneath in order to minimize heat loss downwards. Moreover, an automatic standby power cut-off device must be installed for more than 30% of electric outlets, and whole house-off switches must be installed either by floor or by zone. For public buildings, shading devices are required, and more than 60% of total cooling systems capacity should be covered by alternative power cooling systems such as gas turbine cooling systems, small cogeneration systems, or renewable energy systems instead of electricity. The requirement for alternative power cooling systems was originally applied for public buildings above 3000 m^2 and was extended to buildings above 1000 m^2 in 2013. It was intended to promote the use of alternative power cooling systems for ensuring that power supply problems were not incurred by peak load in summer.

Secondly, the Energy Performance Index (EPI) is also a prescriptive compliance path which comprises 50 evaluation criteria within the architectural, mechanical, electrical, and renewable sectors. The EPI score is calculated as the sum of the credits obtained from each sector, with corresponding weighting. This type of evaluation method is also used for Korean green building certification systems, Green Standard for Energy and Environmental Design (G-SEED). The mechanical sector has the greatest number of evaluation criteria, followed by the electrical, architectural, and renewable sectors, in that order. However, the architectural sector offers the most possible credits, followed by the mechanical, electrical, and renewable sectors, in that order.

In order to get a construction permit, more than 65 of the 120 total credits must be obtained (this was 60 until September 2013); for public buildings, the minimum is 74. According to the analysis of office building samples from the submitted building energy conservation plan from 2008 through 2013, 57 percent of the buildings were able to obtain slightly more than 60 credits, and 25 percent of the buildings were able to obtain above 70 credits (see Figure 6). The reason for this could be either that the buildings were designed to be barely beyond the baseline necessary to obtain a construction permit, or the buildings were already beyond the baseline for the permit so the building owners simply did not apply for the additional credits they could have obtained.

The most current of this information is used for inputs when running building energy simulations for the BEECS. The BECC has been enacted since the 1980s to minimize the energy consumption of newly constructed buildings. It has regularly been strengthened to target zero-energy buildings that will be built after 2025. In 2009, the Korean government announced that after 2017, they would require building envelope criteria to be up to the level of passive buildings. Accordingly, the criteria have been strengthened every two years. In addition, the government plans to revise the criteria to determine a rational thickness for insulation in building envelopes, as well as provide integrated criteria such as thermal bridge, airtightness, and solar control devices.

Table 3. Mandatory energy design criteria of building energy conservation plan.

Sector	Mandatory Criteria
Architecture	Comply with U-value for walls, roofs, floors, windows, doors, *etc.* Comply with area-weighted average U-value for walls, windows, and doors Comply with insulation method for underfloor heating/installation of vapor barriers Install airtight windows Install solar control devices (only for public buildings)
Mechanical system	Comply with design outdoor temperature and humidity for HVAC load calculation Install Korean Standard (KS)-certified pumps or high-efficiency pumps Comply with insulation requirements for ducts and pipes Install alternative power cooling system (only for public buildings above 1,000m^2)
Electrical system	Install high-efficiency transformers Install power-factor improvement condensers Install high-efficiency lighting/circuits for partial lighting Install certified high-efficiency LED lighting for parking lots and for emergency exit signs Install automatic illumination control systems in entrances of each residential unit Install whole house-off switch Install automatic standby power cut-off devices for more than 30% of electric outlets

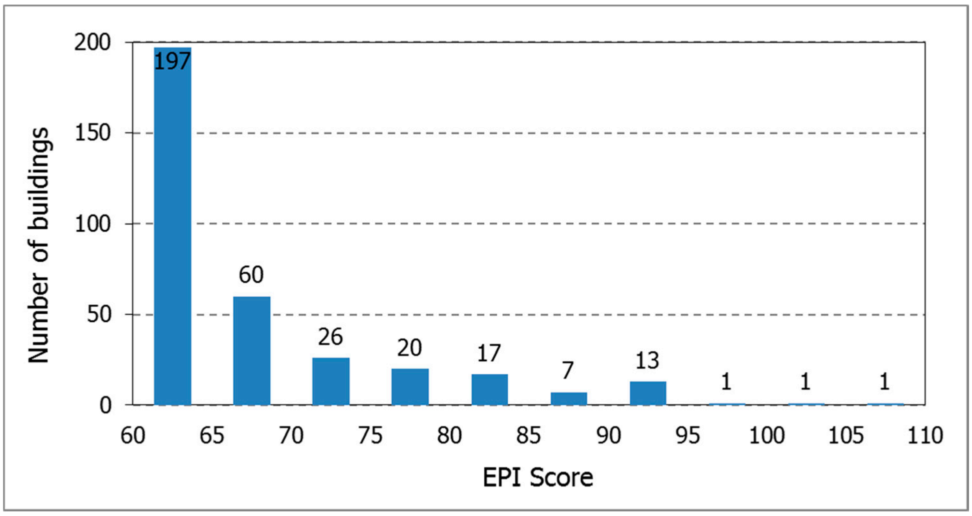

Figure 6. EPI scores of office buildings in 2008–2013 (Number of samples = 343).

Lastly, in order to make up for the weak prescriptive approach of the building energy code, a performance approach has been test-operated for office buildings with above 3000 m^2 of total floor area. It is mandatory for these buildings to submit the calculated energy consumption for heating, cooling, domestic hot water, ventilation, and lighting by use of an official building energy simulation program, ECO2-OD [28]. Until now, there is no specific requirement for calculated energy consumption, but its performance criteria are due to be suggested in near future. Additionally, this approach is expected to be expanded to various types of buildings.

3.2. Building Energy Efficiency Certification System

Figure 6 shows that most of the buildings were designed to be barely beyond the baseline of the mandatory design criteria. In order to promote the spread of high energy-efficient buildings, the system that could evaluate and certify energy performance of buildings other than the minimum design criteria should be required. Therefore, the BEECS was established to promote energy conservation in buildings and encourage energy efficient technologies by providing information on building energy consumption and GHG emission. The Ministry of Trade, Industry, and

Energy (MOTIE) began the certification process in 2001 for new multifamily residential buildings. The certification system was expanded to new office buildings in 2010, and then to all types of buildings in 2013.

The first version of calculation tool for the BEECS was developed for multifamily residential buildings only. It was based on the variable heating degree-days method which has a similar concept with a heating degree days, but considers internal heat gains as well as a balance point temperature, the outdoor temperature required for space heating. This method has been widely adopted in other evaluation systems as well for calculating heating energy demand in residential buildings, including ISO 9164, SAP (Standard Assessment Procedure) in the United Kingdom, and HERS (Home Energy Rating System) in the United States.

The evaluation was performed by comparing the calculated heating energy consumptions of a residential building complex with those of the reference residential building complex. Through this comparison, a preliminary certification could be issued according to the energy saving ratio of the applied complex against the reference complex. Equations (1)–(3) show how to calculate energy saving ratio of a household, a residential building, and a residential building complex that applied for the certification.

$$ERh = \{(Eref - Eh) / Eref + ERah \tag{1}$$

$$ERb = \sum (ERh \times Ah) / Ab + ERab \tag{2}$$

$$ERt = \sum (ERb \times Ab) / At \tag{3}$$

where,

ER_h: energy saving ratio of a household in a residential building (%)
ER_b: energy saving ratio of a residential building (%)
ER_t: total energy saving ratio of a residential building complex (%)
E_{ref}: calculated heating energy consumption for a household in a reference residential household (GJ/year)
E_h: calculated heating energy consumption for a household that applied for the certification (GJ/year)
ER_{ah}: additional energy saving ratio of a household by use of designated energy conservation measures (%)
ER_{ab}: additional energy saving ratio of a residential building by use of designated energy conservation measures (%)
A_h: floor area for a household (m^2)
A_b: total floor area for a residential building (m^2)
A_t: total floor area for a residential building complex that applied for the certification (m^2)

The preliminary certified residential building complex could be evaluated again to obtain a final certification after the completion of construction by confirming whether the energy saving measures were applied to the buildings appropriately and examining the infiltration rate (ACH) of a representative household through the blower door test. The energy saving ratio calculated from the equations above was used for determining the certification label, and the criteria was changed in 2010 as shown in Figure 7. From 2001 to 2009, buildings with energy savings ratios above 33.5% could earn Label 1, but the minimum requirement for Label 1 has been strengthened to 50% of energy savings ratios since 2010.

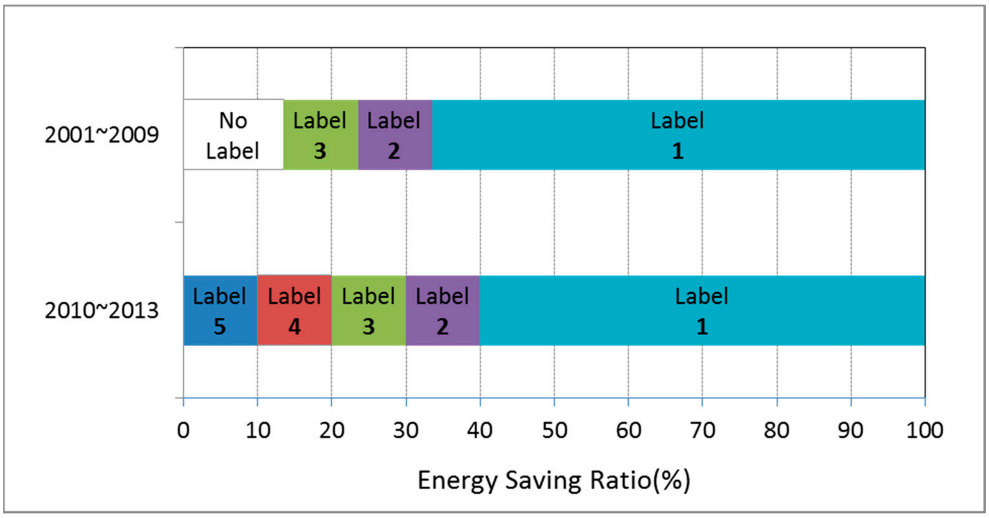

Figure 7. Previous criteria of the BEECS for residential buildings.

However, this method was not suitable for non-residential buildings since it only focused on heating energy consumption and could not reflect actual energy consumption in buildings in detail. Consequently, a new calculation software program, ECO2, was developed in 2010 to calculate energy consumptions for heating, cooling hot water heating, lighting, and ventilation in non-residential buildings [10]. Since May 2013, this method replaced the previous variable heating degree-days method for residential buildings as well.

In this program, building energy consumption is estimated by monthly calculation methodology in accordance with the ISO 13790 [29], which is considered sufficiently accurate for application in energy certification [30]. First, heating and cooling energy needs are calculated by considering various parameters regarding building envelopes, internal loads, user schedules, air change rates, *etc.* Heating and cooling energy needs are defined as heat to be delivered to or extracted from a conditioned space to maintain the intended temperature conditions during a given period of time [29]. Secondly, annual energy use for heating and cooling of buildings can be calculated considering HVAC systems and renewable energy systems (PV, solar thermal, and geothermal systems). Finally, annual primary energy consumptions are derived from annual energy use by the application of primary energy conversion factors in Korea: electricity 2.75, gas 1.1, district heating 0.728, and district cooling 0.937.

With the adoption of this new calculation method and software, the labelling criteria were also modified as shown in Table 4. There are ten labels of certification from 1+++ to 7, according to the total primary energy consumption from heating, cooling, domestic hot water, lighting, and ventilation by building types.

Since 2004, the Korean government has required new multifamily residential buildings constructed by public institutions to acquire a certificate, and since 2008, those certificates were required to be at least Label 2. In 2010, the mandatory requirement was expanded to public office buildings, and since September of 2014, all public buildings above 3000 m^2 of total floor area must acquire at least a Label 1 certificate. Multifamily residential buildings constructed by public institutions are obligated to have at least a Label 2 certificate.

Table 4. Modified Criteria for the BEECS.

Label	Annual Primary Energy Consumption (kWh/m^{2}a)	
	Residential Building	Non-Residential Building
1+++	Under 60	Under 80
1++	More than 60 and under 90	More than 80 and under 140
1+	More than 90 and under 120	More than 140 and under 200
1	More than 120 and under 150	More than 200 and under 260
2	More than 150 and under 190	More than 260 and under 320
3	More than 190 and under 230	More than 320 and under 380
4	More than 230 and under 270	More than 380 and under 450
5	More than 270 and under 320	More than 450 and under 520
6	More than 320 and under 370	More than 520 and under 610
7	More than 370 and under 420	More than 610 and under 700

The BEECS is supervised by a partnership of the MOLIT and the MOTIE. The KEA provides executive management and accredited nine certification bodies conduct the assessment and issue the certificate. The certification is divided into two steps, a preliminary and a final. The energy efficiency label of the preliminary certification is determined by an evaluation of the design documents during either design or construction phases, while that for the final certification is determined through an evaluation of the as-built documents and a field inspection after completion. The certification process is shown in Figure 8.

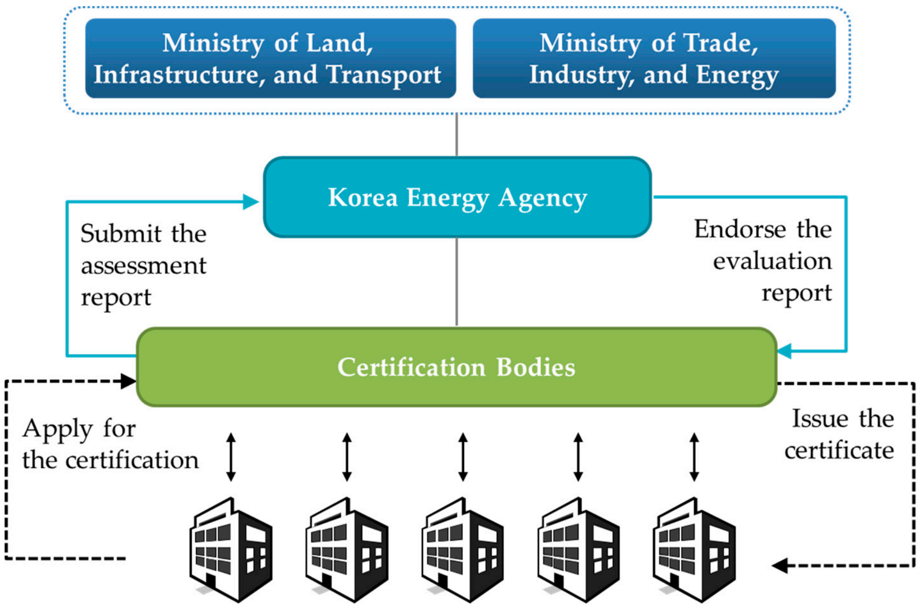

Figure 8. Building Energy Efficiency Certification process.

An owner or constructor can benefit from the certification. First, depending on the energy efficiency label, there may be local tax exemptions for the acquisition tax and the annual property tax on ownership of the building. An owner can be exempt from 5% to 15% of the acquisition tax (this began in January of 2010), and from 3% to 15% of the property tax (this began in January of 2011). Second, a preliminary certificate can mitigate the regulations affecting the building design. Local government regulations, such as a limitation on the maximum floor area ratio, landscaping area, and building height, can be mitigated by 4%–12%. In this case, the label of the final certification should be equal to or higher than the label of the preliminary certification. Third, construction companies can earn an additional point in the prequalification evaluation of bidders for public construction works ordered by the Public Procurement Service, which is responsible for purchasing goods and services including construction works on behalf of public organizations in Korea.

4. Evolution of Certified Building Stock

From 2001 to 2014, preliminary certificates were issued for 1380 residential and 632 non-residential buildings, and final certificate were issued for 630 residential and 272 non-residential buildings. Most of the issued certificates for residential buildings were for multifamily residential buildings, as shown in Table 5. Approximately 54% of the certified buildings were constructed by government or public institutions due to mandatory requirement for public residential buildings. However, buildings constructed by private companies also acquired a large number of certificates, even though they were not obligated to do so. The reason for this is either that the certificates could be used for promotional purposes or that builders were required to acquire certificates in order to get approval for construction in newly development residential areas. The government has a plan to strengthen the baseline for grades of residential buildings in the latter half of 2015 because the government judges that the certification system is acceptable to construction markets.

Table 6 shows the number of certified residential and non-residential buildings by year. In the initial phase of the certification system, few buildings acquired a certificate, but the number of certified buildings has increased annually since 2007. This is due to that the certification system was suggested as one of the most important building energy policies, and the government began to provide incentives and benefits for certified buildings in 2007. With regard to non-residential buildings, the number of certified buildings has also increased year by year since 2010. As shown in Table 7, 84% of non-residential buildings were constructed by government or public institutions, which is a much higher percentage than that of residential buildings. Ninety-nine percent of certified non-residential buildings received certificates above Label 1 due to the mandatory requirement for the buildings constructed by government or public institutions. Since the BEECS is still not a mandatory system but a voluntary system for private buildings, it can be found that the number of certified private buildings was much less than that of certified public buildings. The number of buildings above 10,000 m^2 total floor area increased to a greater extent than buildings below 10,000 m^2 as shown in Figure 9.

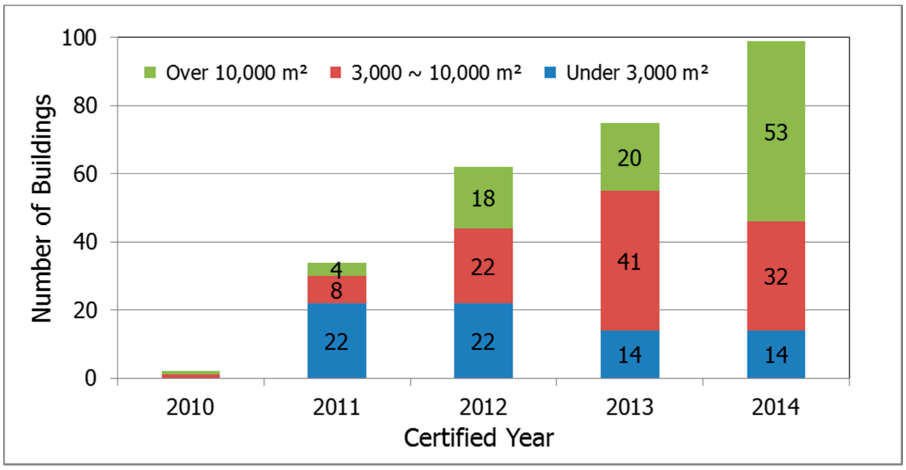

Figure 9. Number of certified non-residential buildings by year (final certification).

Table 5. Number of certified residential buildings by type.

Step	Apartment		Mixed Residential and Commercial		Row House		Official Residence		Total	
	Public	Private	Public	Private	Public	Private	Public	Private	Public	Private
Preliminary	664	600	2	66	8	5	31	4	705	675
Final	361	222	1	22	3	2	11	8	376	254

Table 6. Number of certified residential and non-residential buildings by year.

Step	Type	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	Total
Preliminary	Res.	1	2	6	8	28	14	68	63	127	83	141	212	360	267	1380
	Non-Res.	-	-	-	-	-	-	-	-	-	68	132	92	101	239	632
Final	Res.	-	-	-	2	2	2	6	29	39	63	92	90	105	200	630
	Non-Res.	-	-	-	-	-	-	-	-	-	2	34	62	75	99	272

Table 7. Number of certified non-residential buildings by year and construction authority.

Step	2010		2011		2012		2013		2014		Total	
	Public	Private	Public	Private	Public	Private	Public	Private	Public	Private	Public	Private
Preliminary	65	3	126	6	84	8	74	27	166	73	515	117
Final	1	1	33	1	59	3	68	7	81	18	242	30

5. Energy Performance of Certified Buildings

The energy performance of certified buildings was analyzed in a different way for residential and non-residential buildings because their enforcements were initiated in different years and evaluation methods were different as well. For residential buildings, enough actual energy consumption data was obtained since 2001 when the certification system was enforced; thus the relationship between calculated energy saving ratios and actual energy consumptions was analyzed. However, it was difficult to obtain enough actual energy consumption data for non-residential buildings since the certification system for those wasn't enforced until 2010. Therefore, the trend of energy performance of the buildings in architectural design phase was analyzed in this study by comparing the calculated energy consumption and thermal properties of buildings that were designed after the certification system was initiated.

The certified residential buildings constructed in 2008 through 2012 in the same climate zone (the central climate zone) were selected for this study. These residential buildings were comprised of 86,138 households in 89 multifamily residential building complexes. Among them, 19 complexes are located in Seoul, 14 complexes in Incheon, and 58 complexes in Gyeonggi Province. With regard to the heating systems, 13 complexes (14.6%) are equipped with individual heating systems, and 76 complexes (85.4%) with district heating systems. For the complexes with individual heating systems, gas and electricity consumption data were collected. In these cases, gas was used for space heating, hot water heating, and cooking. For the complexes with district heating systems, district heat, gas, and electricity consumption data were collected respectively. In these cases, district heating was used for space heating and hot water heating, and gas was used for cooking. For both cases, electricity was used for lighting, cooling, and household appliances. The consumption data of electricity, gas and district heating were collected for two years from 2012 through 2013, and their average was used in the analysis. Using the data, relationships between energy saving ratios and actual energy consumptions for each type of heating system, and actual energy consumptions according to the unit floor area of each complex were analyzed. The unit floor area of each complex was calculated by dividing the total floor area of a complex by the number of households in that complex. Therefore, higher average unit floor areas indicate more households with larger floor areas. For non-residential buildings, calculated annual average primary energy consumption, cooling and heating energy demands, and average U-values of walls and windows were analyzed for buildings certified between 2010 and 2014.

5.1. Analysis of Energy Performance of Certified Residential Buildings

Figures 10 and 11 show mean annual gas and district heat consumptions per unit floor area according to energy saving ratios for certified multifamily residential complexes equipped with individual heating systems and district heating systems, respectively. In both complexes with individual heating and district heating systems, it was found that district heat and gas consumptions (district heating), or gas consumptions (individual heating) per unit floor area seemed to decrease as the energy saving ratios increased, but the decreasing trends were not clear. It might have been caused by the fact that the energy uses for cooking and hot water heating were included in the energy consumption data, which were not considered in calculating energy saving ratios. Overall, it was expected that actual energy consumptions in residential buildings would decrease, if the BEECS were mandatory and strengthened over time.

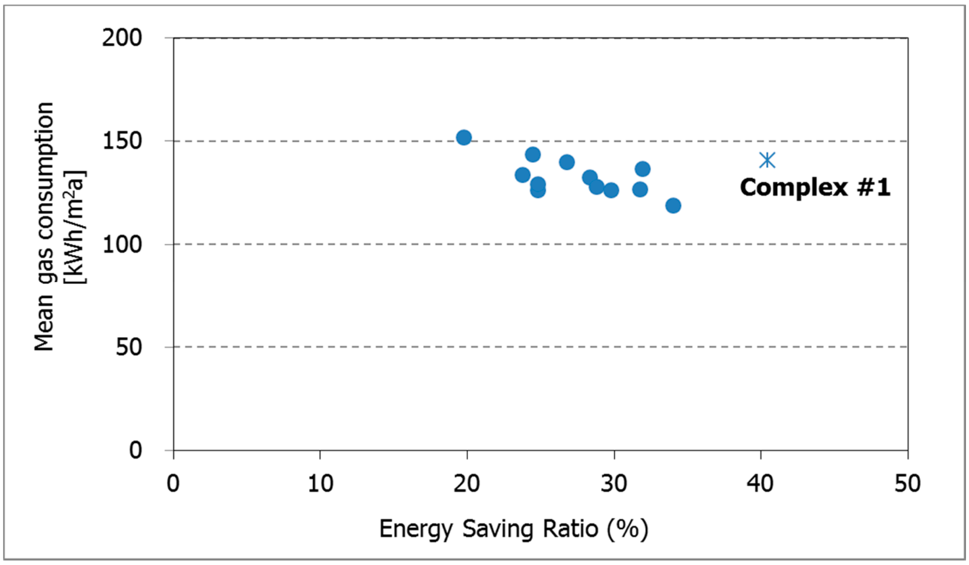

Figure 10. Energy saving ratios and gas consumptions in the individual heating complexes.

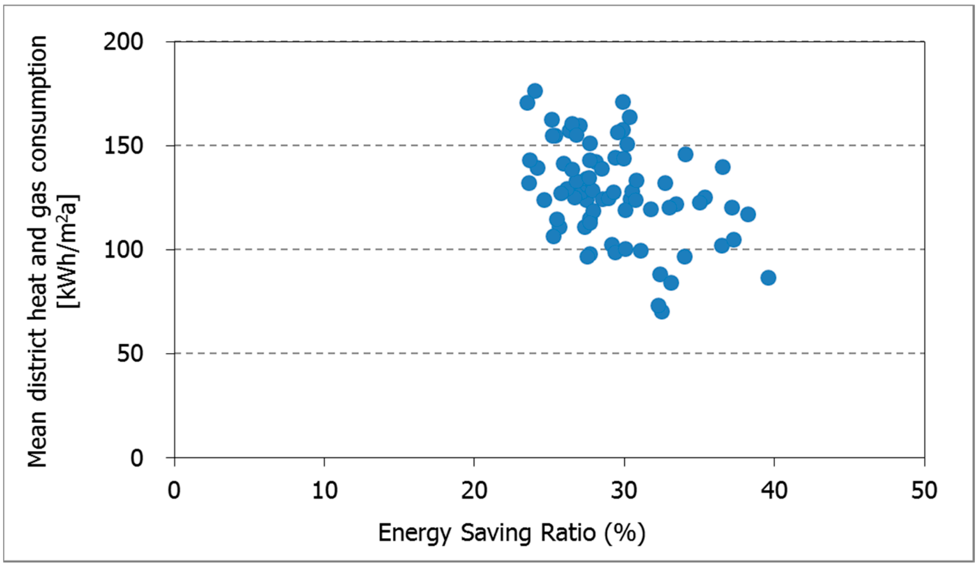

Figure 11. Energy saving ratios and district heat and gas consumptions in the district heating complexes.

On the other hand, in Figure 10, Complex #1 showed comparatively high gas consumption in spite of the highest energy saving ratio of 40.45% in the evaluation for certification. This may have been caused by the occupants' characteristics in this residential complex. Complex #1 is a considerably luxurious multifamily residential building complex consisting of households with large floor areas, and the occupants might have less interest in energy savings. Usually, building energy performance evaluation does not consider the energy consumption determined by the occupants' lifestyle and behavior. Consequently, actual energy consumption in buildings can vary widely by occupants even though the building was constructed to be energy efficient. This result suggests that not only the wide spread use of high energy-efficient buildings but also the education for occupants should be integrated into building energy policies.

Figure 12 shows mean annual electricity consumptions and energy saving ratios of certified multifamily residential complexes. It was found that electricity consumptions per unit floor area were not much influenced by the energy saving ratios. This means that evaluations by calculating space heating energy saving ratios in current certification systems cannot be used for evaluating electricity consumption. Therefore, it is necessary to modify and improve the evaluation method so as to consider factors related to electricity consumption such as space cooling, lighting, appliances, *etc.* Average electricity consumption was about 45.9 kWh/m^{2}a, while average gas and district heat consumption was 128.5 kWh/m^{2}a. The portion of electricity consumption and gas and district heat consumption was consistent with statistical survey data [19] regarding the share of different final energy sources, as mentioned before.

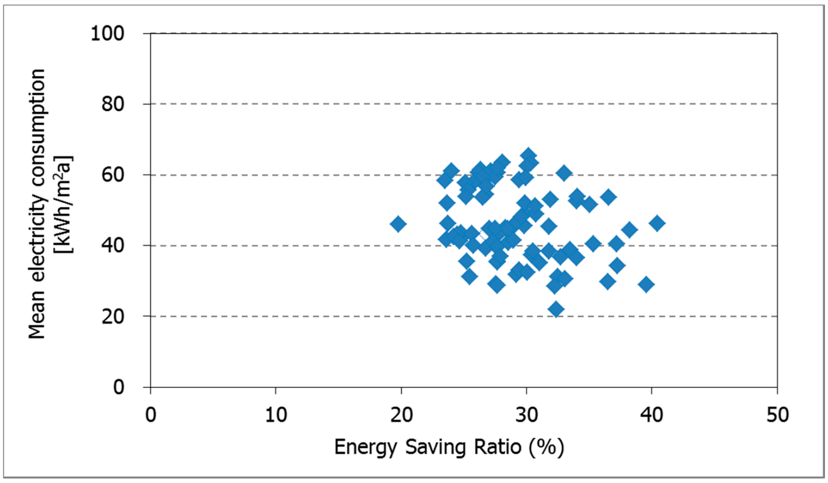

Figure 12. Energy saving ratios and electricity consumptions in the residential complexes.

Figures 13 and 14 show mean annual gas and district heat consumptions per unit floor area according to household average floor area for multifamily residential complexes equipped with individual heating systems and district heating systems, respectively. Figure 15 shows mean annual electricity consumptions and household average floor areas. While noticeable variation trends were not found in Figure 13, gas consumptions per unit floor area tend to decrease as average floor area of a household increases in Figure 10. This difference might be caused by the dearth of samples with individual heating systems. If there were more samples, the trend may be apparent as shown in samples with district heating. The decreasing trend was also found in electricity consumptions in Figure 15.

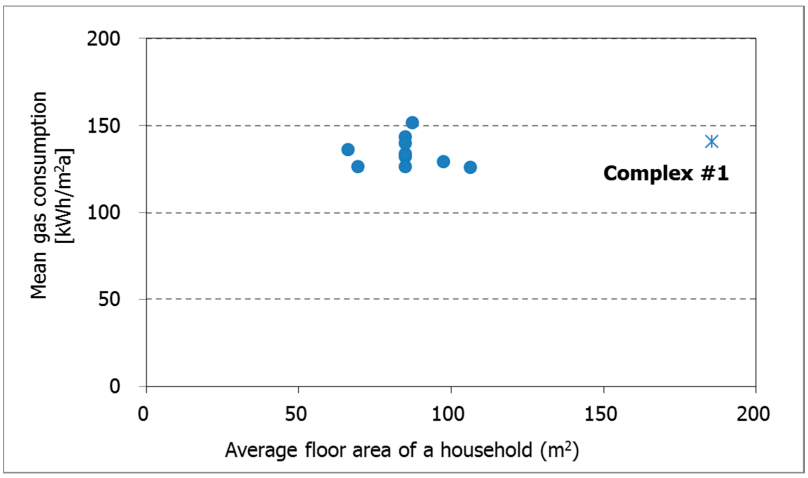

Figure 13. Household floor areas and gas consumptions in the individual heating complexes.

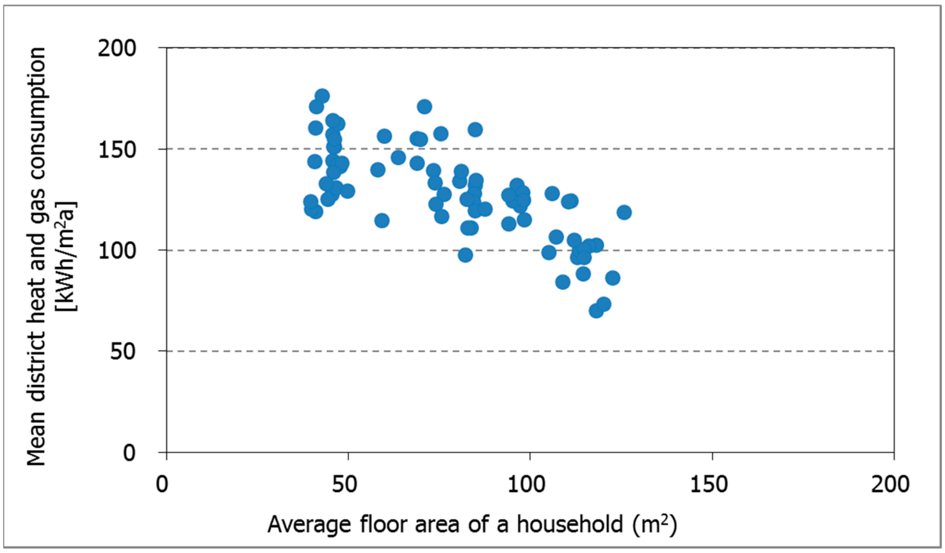

Figure 14. Household floor areas and district heat and gas consumptions in the district heating complexes.

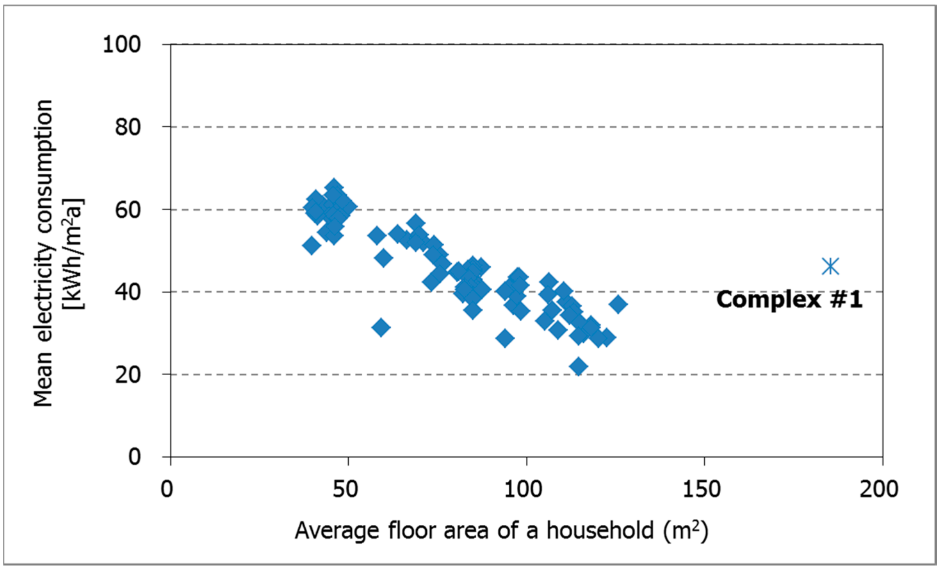

Figure 15. Household floor areas and electricity consumptions in the residential complexes.

This decreasing trend does not mean that smaller households consume much energy, and larger households consume less energy. This may be caused by the calculation method of energy use intensity by dividing mean annual energy consumption by the floor area of a household. The problem of “small house penalty” [31] has also been demonstrated in various energy benchmarking reports [32,33]. Another way to look at this problem is that households use energy for hot water and cooking regardless of size, which is essentially independent of household floor area. In case of a small household, the energy consumption is divided by a small number, making it seems to have poor performance [31]. Complex #1 located in the rightmost part of Figure 13 shows irregular consumption compared to other complexes due to its characteristics as mentioned above.

5.2. Analysis of Energy Performance of Certified Non-Residential Buildings

The calculated mean annual primary energy consumptions of certified non-residential buildings were investigated and analyzed for each year, as shown in Figure 16. The highest value was shown in 2010 at 265.5 kWh/m^{2}a, and the lowest in 2014 at 224.8 kWh/m^{2}a. The decreasing trend in primary energy consumption through the years seems to prove the effect of the building energy policies.

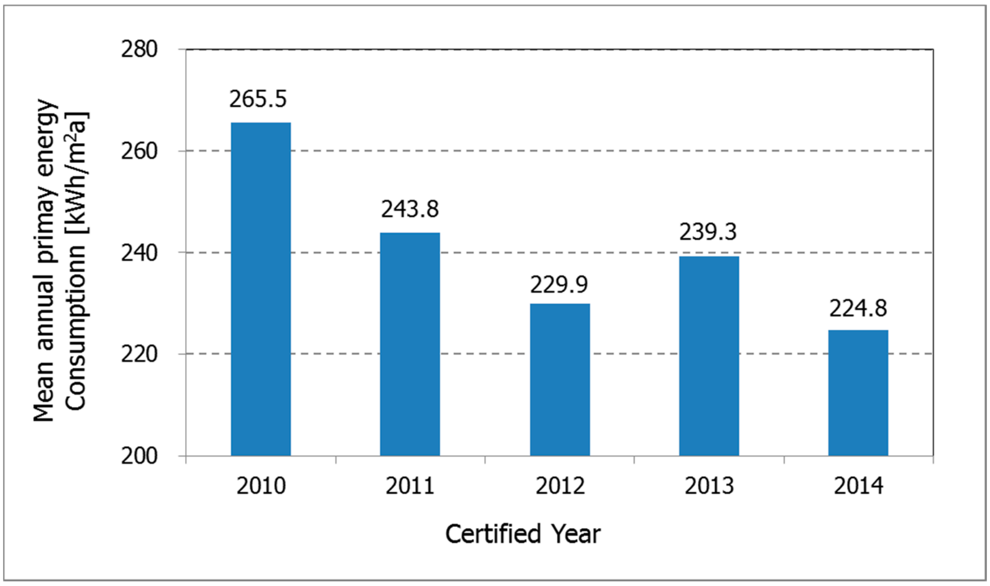

Figure 16. Calculated primary energy consumptions of certified non-residential buildings.

Figure 17 shows space heating and space cooling energy demands of certified buildings. The heating energy demand shows a distinct decrease by year, as compared to the cooling energy demand. In 2010, heating energy demand was higher than cooling energy demand, but heating energy demand was lower than cooling energy demand after 2012. The difference might be caused by energy policies that strengthened the regulations for building envelope insulation and window-to-wall ratio.

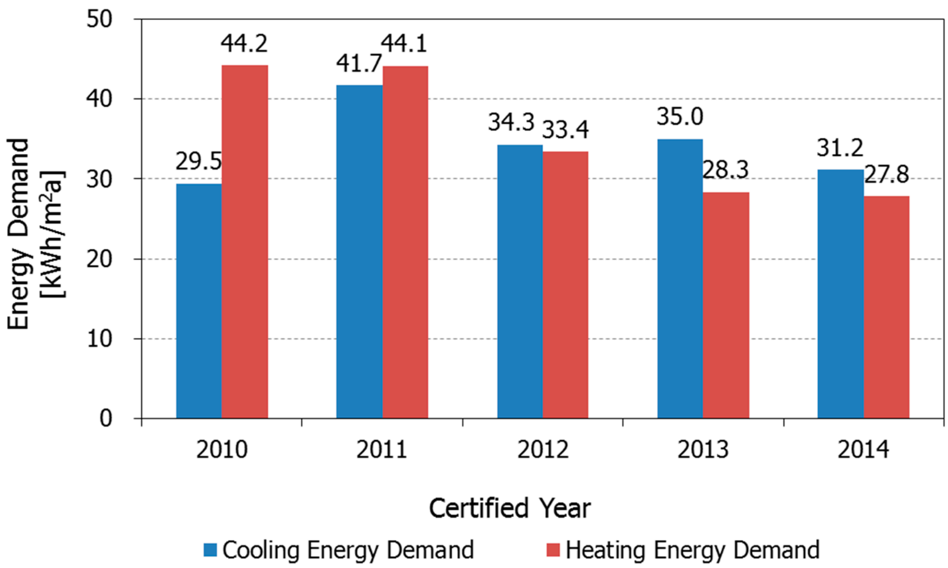

Figure 17. Heating and cooling energy demands of certified non-residential buildings.

Lastly, the average wall and window U-values of certified non-residential buildings were also investigated. As shown in Figure 18, average wall U-value has decreased each year; it had its highest value in 2010 at 0.475 W/m^{2}K and lowest value in 2014 at 0.261 W/m^{2}K. Average window U-value also shows decreasing trends even though there is a slight fluctuation through the year.

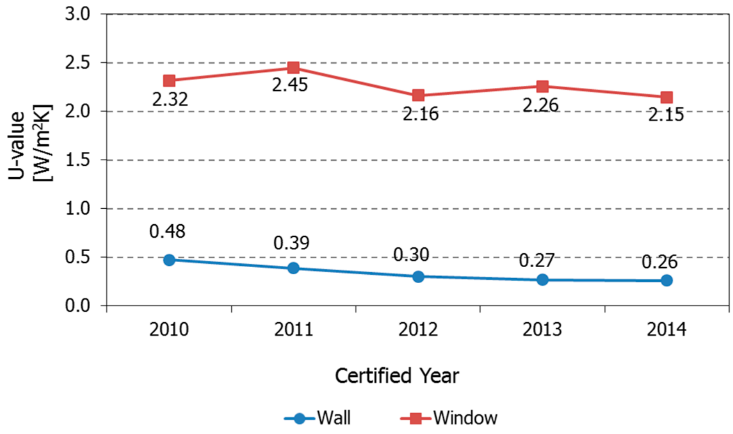

Figure 18. Average U-values of wall and window for non-residential buildings by year.

Based on the results from this study, the evaluation method for certifying residential buildings was modified to include not only heating energy consumption but also cooling, lighting, ventilating, and hot water heating energy consumptions at the end of 2013, as mentioned before. Although ISO 13,790 does not contain total electricity consumption such as appliances, elevator, *etc.*, the BEECS was improved to evaluate total energy performance of buildings, including electricity consumption.

Since the BEECS is the only system that quantitatively evaluates whole building energy performance and issues official certificates, it has led to improvements in the energy efficiencies of buildings, cooperating with other related energy policies in Korea. In addition, since the BEECS was developed according to international standards, it has been used as a standard for evaluating the building energy performance of other building evaluation schemes such as the Green Building Certification System.

The BEECS is a leading energy policy for promoting highly energy-efficient buildings. The building energy simulation program developed for this system is currently being used nationwide for the evaluation of buildings, and its incorporation into the Korean Standard for use in analyzing the evaluation algorithm is under consideration. Since only zero-energy buildings can be newly constructed in Korea after 2025, the calculation program, ECO2, will be upgraded regularly to enable it to evaluate zero-energy buildings through an analysis of the evaluation results produced by the BEECS.

6. Conclusions

In this study, two current representative energy policies in Korea, the BECC and the BEECS, were introduced and investigated. The BECC was first introduced in the 1980s, and has led construction markets to meet minimum requirements for building energy conservation. Lastly, to make up its prescriptive approach, a performance based procedure has been test-operated for office buildings with above 3000 m^2 of total floor area. This approach is expected to be expanded to more various types of buildings. The BEECS started in 2001 and about 670 final certificates have been issued for residential and non-residential buildings according to the energy consumption calculation methodology. Even though the BEECS in Korea has been in effect for new construction for more than ten years and many certified buildings have been occupied and operated, there were few studies on analyzing its result and influence. This study describes the first findings from the analysis of energy performance of certified buildings.

According to the actual energy consumption data from the certified residential buildings, evaluation result was shown to have influence on energy consumption, in particular in gas and district heating consumption. It was found that gas and district heat consumptions decreased as energy saving ratios increased, and energy consumptions (*i.e.*, gas, district heating, and electricity consumption) per unit floor area decreased in larger floor area households. Additionally, it was a desirable decision to improve the certification system to evaluate total energy consumption, including energy for hot water heating, lighting, and ventilation since the previous certification system that evaluated heating energy consumption only had no significant relationship between energy saving rate and electricity consumption. For non-residential buildings, the decreasing trend in calculated primary energy consumption through the years proved the efficacy of the BEECS.

Since, unlike Europe or the US, the BEECS in Korea is mandatory only for public buildings, the number of certified private buildings was much less than that of certified public buildings. Also, only a small percentage of the total number of multifamily residential buildings has acquired certificates. Therefore, the Korean government needs to establish a long-term and continuous energy conservation policy, and investigate comprehensive solutions for improving the practical effects of the system from various aspects such as strategies, technologies, education, and supporting incentives. The BEECS will be upgraded over time in future by analyzing energy consumption pattern in terms of various aspects and developing new technologies towards zero energy buildings that will be required after 2025. Also, the database of certified buildings in Korea will be more deeply analyzed to extract and provide more and better results regarding the impact of building regulations and certification on building energy performance.

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