Development of Reference Building Energy Models for South Korea

Deuk Woo Kim[1], Yu Min Kim[1], Sang Hoon Lee[2], Won Young Park[2], Young Jin Bok[3], Sung Kyun Ha[3], Seung Eon Lee[1]

[1]Korea Institute of Civil Engineering and Building Technology, South Korea

[2]Lawrence Berkeley National Laboratory, United States

[3]Greenhouse Gas Inventory and Research Canter, South Korea

ABSTRACT

It is important for South Korea to set a roadmap for the reduction of greenhouse gas emissions to keep pace with the newly established target from the United Nations Framework Convention on Climate Change. Building energy consumption is a major source of nation's greenhouse gas emissions. Hence, there is a rising interest in developing reference buildings which can be used as a roadmap simulator to represent energy consumption of building stocks. The paper introduces development of eleven reference building energy models for South Korea based on the national statistics. Input data preparation and model validation are given. Finally, it is shown that the reference models reflect the real building stock with a deviation margin about 20% for residential and 10% for commercial buildings.

INTRODUCTION

The Conference of the Parties (COP21) signed a legally binding and universal agreement on climate change, with the aim of keeping global warming below 2°C in December 2015. Each of the parties (189 countries) should therefore put their best efforts to maintain the global mean temperature below the pre-industrial level. The parties publicly outlined post-2020 climate actions and have to make extensive efforts to keep the temperature rise below 2°C.

In South Korea, energy use in the building sector is about 41,000 thousand tonnes of oil equivalent, accounting for 20.5% of the total (KEEI, 2015). South Korea pledged to achieve a cut of about 26.9% (compared to 2020 BAU) in the building sector at the Copenhagen meeting in 2011, but now, it is expected that more stringent reduction targets will be set from the result of COP21.

There needs a roadmap to provide systematic energy savings in the building sector, which has the most significant contribution to greenhouse gas reduction. Energy models serve an important role to express the energy performance of Korean building stocks, and they enable predicting and responding to the energy saving roadmap from simulations for diverse policy scenarios. The aim of this study is to develop building energy models that can represent building stocks of South Korea

In the case of the United States, there are reference building energy models for 15 commercial buildings and one midrise multifamily apartment. The models were developed based on the statistical data and energy consumption survey. These reference models represent about 70% of building stocks of United States (Deru et al., 2011). In Europe, the TABULA project was carried out for 2009-2012 (IEE 2012) to develop a typology of residential buildings and a framework for reference building development. Thirteen countries (Germany, Greece, Slovenia, Italy, France, Ireland, Bulgaria, Poland, Austria, Belgium, Sweden, Czech Republic and Denmark) participated and proposed representative building types for each country (Ballarini et al., 2014). The developed reference buildings are used for analysis of energy consumption reduction by energy conservation measures and adoption of more stringent energy standards.

The research on the development of RB in South Korea has not been widely conducted so far. The main reason is the lack of basic statistics (e.g. gross floor area, building structure, energy consumption, etc.). Recent activities, 'Open Data 3.0'(MOI, 2013) have led to the rapid release of rich building-related datasets in South Korea. This paper introduces a new effort to develop reference building energy models (RBs) to represent buildings stocks in South Korea and validate them against the national energy consumption statistical data.

METHODOLOGY

Table 1 shows eleven types of RBs developed from the study. These models represent residential, commercial, and public buildings. The residential models include three building types considering typical housing styles: detached house, high-rise apartment, and townhouse. Commercial and public sectors have eight types considering typical building uses: retail, accommodation, restaurant, private office, public office, hospital, university, primary school, and secondary school.

Table 1: Eleven reference buildings by use type

Sector	Reference Buildings
Residential	Detached house, High-rise apartment, Townhouse
Commercial	Retail, Accommodations, Restaurant, Private office
Public	Public office, Hospital, University, School

It is important that the output (simulated energy consumption) of RBs is close to the total energy consumption of the national building sector. Thus, the end-use energy use intensity (EUI) in kWh/㎡ of each RB is inversely calculated based on the dataset from national statistics. The developed model for each building type is calibrated using the corresponding end-use EUI. Figure 1 shows overview of the development process.

For the reference model development, a single-zone modelling approach was used for the consistency among reference models as zone data for diverse space types was limited for different buildings. The models reflect standardized operation profiles of occupants, lighting, equipment and HVAC. EnergyPlus 8.1 (Crawley et al., 2001) was used for the development of reference models.

REFERENCE BUILDING

A reference building energy model is an analytical model that represents whole building descriptions, standardized building operation and activity, and climate location of a building stock. It needs a reasonable basis when develop reference models and classify their development methods (European Commission, 2012). Modelling approaches vary depending on the expertise and resolution, availability of statistical data, and model fidelity (Corgnati et al., 2013; Ballarini et al., 2014). RB is classified into three as shown in Table 2.

Table 2: Classification of reference buildings (Corgnati et al., 2013; Ballarini et al., 2014)

Type	Based on	Comments
Example Building	Expert judgement	An actual building selected by expert judgement. When reliable statistical data are not available, this method is chosen.
Exemplary Building	Expert judgement and basic statistics	An actual building selected from the building stock considering its average characteristics. For this method, well-constructed national statistics is required.
Virtual Building	Expert judgement, basic statistics, and building component database	A synthetic building having statistically average characteristics. For this method, a detailed national database for building components (envelope, lighting, materials, etc.) is required.

Example Building and *Exemplary Building* in Table 2 are specific buildings, which are selected from actual building stock. On the other hand, *Virtual Building* is a synthetic building, which is created by combining an average level of materials, systems, and forms. *Virtual Building* is used to derive the 'representative' energy use of the target building stock (Corgnati et al., 2013).

The reference models for the study were created using the *Virtual Building* approach. The developed RBs can be used as a supplementary material for the development of future codes and standards (Ballarini et al., 2014; Lee et al., 2015; DOE, 2016), and as a tool when predicting greenhouse gas reduction by innovative energy conservation technologies (Tommerup and Svendsen 2006; Kurnitskia et al., 2007; Olofsson and Mahlia, 2012).

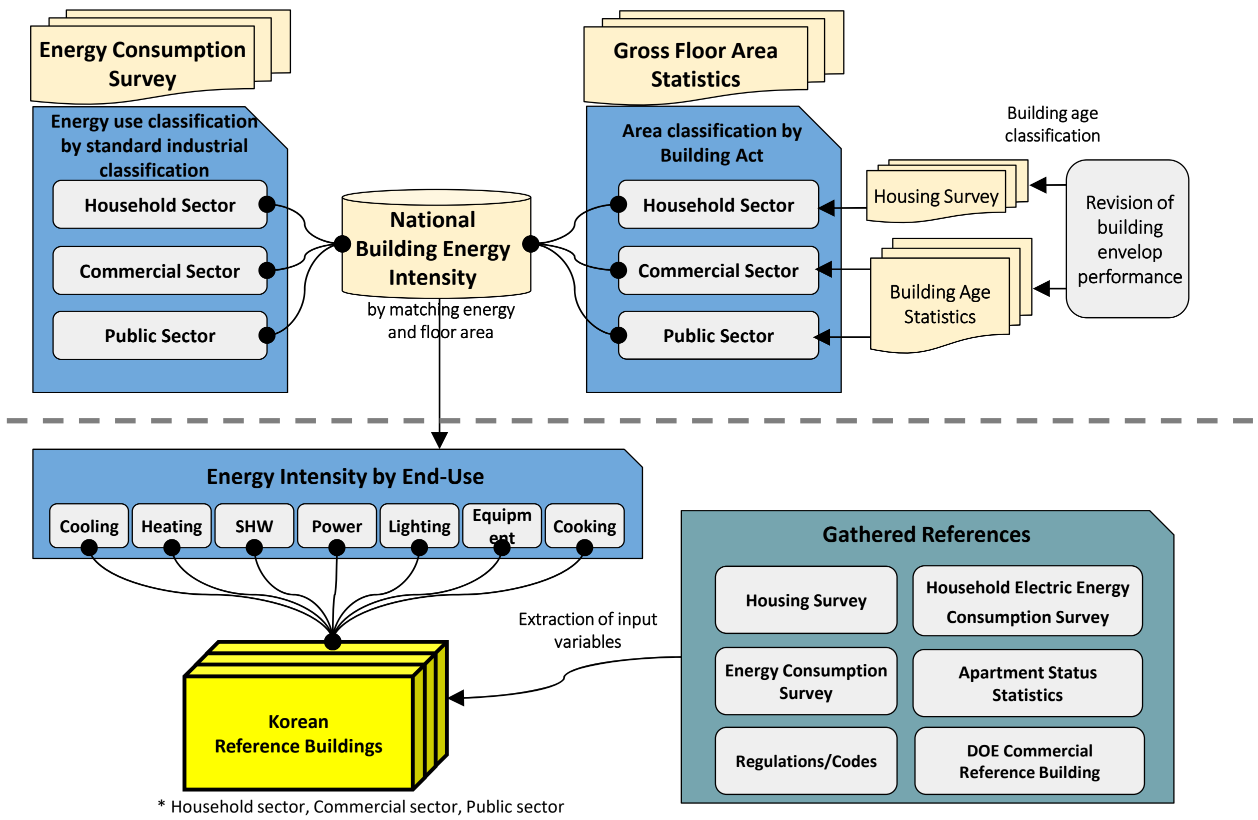


Figure 1: Overview of reference building energy model development

MATCHING ENERGY AND GROSS FLOOR AREA STATISTICS

Currently, two different government ministries separately manage the statistics of energy consumption (The Ministry of Trade, Industry and Energy, MOTIE) and building gross floor area (The Ministry of Land, Infrastructure and Transport, MOLIT) in South Korea. Therefore, mapping of two datasets was needed to derive EUI (e.g. kWh/㎡) for each building type. The study uses the end-use EUI as an indicator for validation.

- MOTIE publishes national energy consumption statistics every three years (KEEI, 2015). In these statistics, the building sector is divided into three categories: residential, commercial, and public sectors. In commercial and public sectors, the total end-use energy consumption (heating, cooling, service hot water, lighting, cooking, equipment) is surveyed according to "*industry classification*" rather than by "*building use type*" (e.g. hospital, office, restaurant, etc.). Because of this, the additional classification work is needed to match between energy consumption and floor area statistics. However, in the residential sector, because the total energy consumption already is subdivided by *building use type* not by *industry classification*, therefore the additional classification work is not needed to match energy statistics and area statistics. It should be noted that unfortunately, for the residential sector, KEEI (2015) only provides *total energy consumption* by fuel type, not by *end-use consumption*. It hinders to verify each end-use output of the residential RBs precisely (Table 3).
- MOLIT provides annual statistical data on the status of building gross floor area by region and *building use type* (EAIS, 2016). The dataset includes building use types into 29 categories (sales building, office buildings, educational building, etc.) according to building codes rather than by *industry classification*. The statistics of national gross floor area are thus based on such categorization criteria.

As the categorization criteria of two ministries are different, the matching works for two different statistical data set were carefully conducted. Table 3 shows the EUI data for the eleven building types from the matching task, which can be used for validation against the reference models simulation results.

The total gross floor areas (Table 3) can be considered as weighting factors, which help infer the number (or gross area) of each reference building in each location. In other words, the weighting factors allow information from the individual reference buildings to be expanded to represent all buildings or the whole country (Deru et al., 2011).

MODEL DEVELOPMENT

After the matching work, the model inputs were derived inversely based on the end-use EUI (Table 3) or estimation (by expert judgement, trial-and-error method). As shown in Table 3, there is differences in the level of detail of the gathered statistics in the residential and non-residential (commercial and public) RBs due to the availability of statistical data. Therefore, the preparation of model inputs of each RBs are different.

The EUI of the non-residential sector was divided according to the end-use energy for the commercial and public RBs, which was used to estimate model inputs (e.g. power density, W/㎡) for operation hours. For residential buildings, only the total energy consumption by carrier (electricity, gas, etc.) was available, which makes difficult to calculate the input variables inversely. Therefore, the inputs for residential buildings were estimated relying on

Table 3: End-use EUI (kWh/㎡) derived from MOTIE and MOLIT statistics

Sector	Reference building	Total	Heating	SHW	Cooling	Lighting	Power	Equipment	Cooking	Total Gross Floor Area (unit: one million ㎡)
Residential	Detached house	179.9	n/a	n/a	n/a	n/a	n/a	n/a	n/a	474.8
	Apartment	149.7	n/a	n/a	n/a	n/a	n/a	n/a	n/a	961.7
	Townhouse	200.3	n/a	n/a	n/a	n/a	n/a	n/a	n/a	138.4
Commercial	Private office	380.5	118.5	12.2	93.6	51.0	44.7	72.7	11.4	174.0
	Retail	358.7	142.0	10.0	107.7	39.4	39.1	30.6	1.5	136.5
	Restaurant	591.5	140.8	29.6	140.3	87.8	4.0	218.6	194.3	76.7
	Accommodation	337.6	186.3	25.7	73.9	37.6	7.8	31.9	21.7	45.8
Public	Hospital	263.8	94.6	17.1	68.9	19.5	18.9	61.9	21.3	44.1
	Public office	220.5	75.5	7.7	61.0	21.2	11.2	51.8	0.7	28.8
	School (primary/secondary)	164.6	97.0	6.7	18.9	15.2	12.6	20.7	8.0	82.9
	University	150.4	51.7	6.2	40.2	18.3	15.2	25.0	4.7	34.8
Other	Excluded	8.1	0.5	n/a	0.4	0.2	6.4	0.5	n/a	955.4

relevant statistics, expert judgement, and trial-and-error estimation comparing the total energy consumption.

The operation data such as schedules and activity levels are based on the DOE RBs (Deru et al., 2011), which allows minor modifications considering Korean usage patterns.

Building size and form

According to the Housing Survey (MOLIT, 2014), it was found that the average household size is about three people. In addition, the occupied area per person was 29.7 ㎡ for detached house residents, and 36.5 ㎡ for multi-unit buildings (Apartment and Townhouse). Finally, the size of residential buildings was decided based on the above-mentioned facts, but the building shape was decided based on the expert judgement due to a lack of shape statistics.

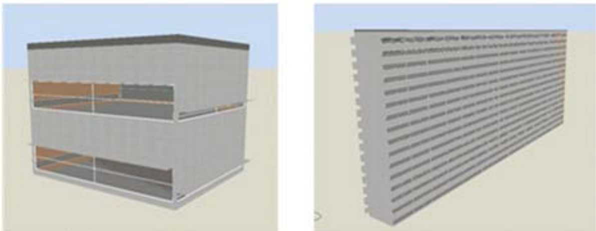


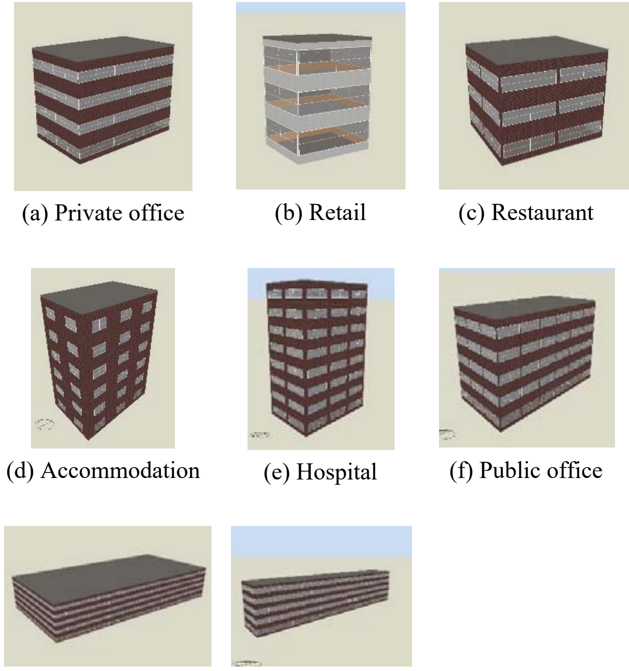
Figure 2: Modelled Detached house and Apartment

For the commercial and public RBs, it is not possible to determine the building size based on the occupied area per person or the average household. However, according to the benefit of the building status statistics (EAIS, 2016), the average gross floor area (㎡/bldg.) can be derived by simple arithmetic (Table 4); the total number of buildings in each sector divided by the total gross floor area.

Table 4: Size and form of the non-residential RBs

Reference building	**Number of bldgs.** (unit: one thousand)	**Average gross floor area** (㎡/bldg.)	**Average number of floors**	**Aspect ratio** a) b)	**WWR (%)** b)
Private office	216.8	802	4	1.6	40
Retail	274.2	498	3	1.2	50
Restaurant	162.7	472	3	1.2	40
Accommodation	38	1,205	6	1.5	25
Hospital	21.8	2,024	8	1.5	35
Public office	12.6	2,280	5	2	40
University	1.5	22,568	5	2	50
School	11.6	7,163	5	6	50

a) Ratio of the longest dimension of the building footprint to the narrowest dimension.
b) As there are no statistics, this was decided by expert judgement



(a) Private office (b) Retail (c) Restaurant
(d) Accommodation (e) Hospital (f) Public office
(g) University (h) School

Figure 3: Modelled non-residential RBs

Insulation of building envelope

In South Korea, the standards/codes for building insulation have been legislated since 1979 (MOLIT, 1980). Because the building insulation performance should follow such standards/codes, model inputs should use the classified values based on standards. In this study, the insulation level was classified into four categories regarding the major revision of the standards/codes, as shown in Table 5.

Table 5: Insulation levels of the RBs

Building age	**U-value of wall/roof/floor/window**		**SHGC** a) (glazing)
	Residential	Non-residential	
Before 1981	1.05/1.05/1.05/5.00	1.05/1.05/1.05/5.00	0.83
1981-1988	0.58/0.41/0.58/4.19	0.58/0.58/0.58/4.19	0.76
1989-2002	0.58/0.41/0.58/4.19	0.58/0.58/0.58/4.19	0.76
2003-2013	0.47/0.29/0.35/3.84	0.47/0.47/0.47/3.84	0.76

a) Solar heat gain coefficient (SHGC) of window systems have not been addressed so far in the Korean standard. The values in table were estimated based on assumption that a single glazing window was used for Before 1981, and a double pane window was used the rest of the period in general.

Infiltration and ventilation

Air change per hour (ACH) is the rate at which the amount of air in the zone (㎥) is replaced by outdoor air per hour due to infiltration and ventilation. It is very difficult to determine the ACH which is caused by infiltration and ventilation, as they vary greatly depending on occupant behaviour, construction type, renovation, opening and closing of windows and doors, and weather conditions. Infiltration and ventilation airflow rates are highly unknown and uncertain parameters for energy modelling (Hyun et al., 2008).

All residential RBs (Detached house, Apartment, Townhouse in Table 3) were calibrated through a process of trial and error in the range from 0.2 to 0.5 ACH depending on the building age. For the Detached house, the final estimated values are 0.50, 0.44, 0.38 and 0.25 ACH, and for the Apartment/Townhouse, the final estimated values are 0.40, 0.35, 0.30 and 0.20 ACH, for before 1981, 1981-1988, 1989-2002 and 2003-2013 respectively.

Likewise, the ACH of the commercial and public RBs were also estimated from parametric studies for input values with a range, and selected values are summarized in Table 6.

Table 6: Estimated ACH of the RBs by building age

Reference building	Before 1981	1981-1988	1989-2002	2003-2013
Detached house	0.50	0.44	0.38	0.25
Apartment/Townhouse	0.40	0.35	0.30	0.20
Private office	1.20	1.10	1.00	0.90
Retail	1.04	0.87	0.87	0.80
Restaurant	2.70	2.50	2.40	2.20
Accommodation	1.20	1.10	1.00	0.90
Hospital	0.50	0.45	0.35	0.30
Public office	1.00	0.90	0.85	0.80
University	0.80	0.60	0.50	0.30
School	1.20	1.00	0.90	0.80

In the case of a restaurant, the estimated amount of ACH (by trial and error) is somewhat high at about 2.2-2.7 ACH, considering the use of ventilation devices such as exhaust hood. On the other hand, for hospitals, the value of ACH was estimated to be somewhat low, 0.3-0.5 ACH, considering the pressurization of wards. For other buildings, the values of ACH were estimated as 0.8-1.2 ACH.

Internal heat gains (people, lighting, and equipment)

The number of occupants was set to three per household based on Housing Survey (MOLIT, 2014). The amount of activity was set as a general rest (95W). Family members consist of a dual-income couple and one child (student). It is assumed that the household are not occupied from 7:00 to 17:00 on weekdays, and from 11:00 to 17:00 on weekends based on the survey (Statistics Korea, 2014).

It is not easy to derive the occupants density (people/㎡) for Korean non-residential RBs due to the lack of data and references. The DOE reference models (Deru et al., 2011) were considered to derived occupancy related inputs. However, it is inappropriate to use these as is because the population density of South Korea is ten times higher than that of United States. In addition, occupancy density is one of the key uncertain parameters for Korean buildings, and extended occupancy schedule and working characteristics have a direct impact to the energy performance as well. In the estimation process, the value of the DOE RBs was considered as an initial guess. Table 7 shows the best estimated values that are carefully derived after a series of consultations by experts.

Table 7: Occupant variables of the RBs

Reference building	Density (people/㎡)	Activity	Schedule
Detached house	0.03	Seated	Expert judgement
Apartment/Town house	0.03	Seated	Expert judgement
Private office	1.20	Standing/walking	DOE retail
Retail	1.04	Eating/drinking	DOE restaurant
Restaurant	2.70	Seated quiet	DOE small hotel
Accommodation	1.20	Seated quiet	DOE hospital
Hospital	0.50	Office work	DOE medium office
Public office	1.00	Office work	DOE medium office
University	0.80	Writing	DOE school. For vacation periods, Notification of Korean government was referenced.
School	1.20	Writing	

According to KPE (2013), the average lighting power per household is 550W/household. Therefore, the average lighting power densities (LPD) of Detached house are set to 6.19W/㎡ (=550W/89 ㎡), and Apartment and Townhouse are set to 5.03W/㎡ (=550W/109 ㎡) respectively.

Meanwhile, as mentioned previously, the average LPD in the non-residential RBs can be calculated inversely; the end-use lighting energy intensity (Table 3) was divided by total operation time (Table 8). The information on the operation time is derived from the DOE RBs (Deru et al., 2010). In this study, it is assumed that the usage profiles do not differ greatly from that of US except for the university and school RBs. For university and school, representative Korean vacation profiles were implemented.

Table 8: Lighting power density in non-residential RBs

Reference building	Energy Intensity (kWh/㎡)	Operation time (hours)	LPD (W/㎡)
Private office	51	3,235	15.8
Retail	39	3,849	10.2
Restaurant	88	6,461	13.6
Accommodation	38	3,598	10.5
Hospital	19	3,901	5
Public office	21	3,235	6.5
University	18	3,685	5
School	15	3,333	4.6

KPE (2013) report provided valuable information for input values of power intensities of common household appliances (electric rice cooker, general refrigerator, TV, computer, vacuum cleaner, hair dryer, etc.) as well as supply rate, rated power of each appliance, and the survey of hourly profiles for weekday and weekend. In the case of the residential RBs, all of the appliances' rated power was summed up, and input into the model. Next, a weighted schedule was used. To create this weighted schedule, each hourly usage profile of the appliances was averaged based on the appliances' rated power. Table 9 provides equipment power densities for non-commercial buildings.

Table 9: Equipment power density in the non-residential RBs

Reference building	Energy Intensity (kWh/㎡)	Operation time (hours)	EPD (W/㎡)
Private office	61.3	4,744	12.9
Retail	29.1	4,663	6.2
Restaurant	33.1	2,154	15.4
Accommodation	7.3	2,302	3.2
Hospital	40.5	5,352	7.6
Public office	51	4,744	10.8
University	20.3	3,922	5.2
School	12.8	3,939	3.2

Service hot water

According to MOE (2016), a household uses about 203 litres of water per person daily. The water consumption can be divided into 25% for toilet, 21% for sink, 20% for washing machine, 16% for bath, 11% for toilet, and 7% for other uses.

In this study, it is assumed that a half of the sink and the bath is used as hot water (37.5% of 203 litres). In this case, the amount of hot water supply is about 76.1 litre/day/person, the supply and main pipe temperatures are 45 ℃, 15℃ respectively, and the number of use days is 365.

For the non-residential RBs, daily hot water supply (litre/㎡/day) was calculated inversely using the conversion coefficient as shown in Equation 1 and Table 10. The conversion coefficient, C_{shw}, (litre/kJ/day) is calculated as:

$$C_{shw} = e \;/\; (\rho \cdot C \cdot dT \cdot d) \div 3 \quad (1)$$

where, e is boiler efficiency (75%), ρ is water density (1,000kg/m³), C is specific heat water (4.2kJ/kgK), dT is difference between the supply and main pipe temperature, d is the number of use days, *1/3* is the ratio of hot water usage time during the day.

Table 10: Inputs of service hot water in the non-residential RBs

Reference building	Energy Intensity (kWh/㎡)	Conversion Coefficient (litre/kJ/day)	Daily unit volume (litre/㎡/day)
	=a	=b	=a*b*(3.60E+03)*
Private office	12.2	5.40E-06	0.237
Retail	10.0	5.40E-06	0.195
Restaurant	29.6	5.40E-06	0.575
Accommodation	25.7	5.40E-06	0.499
Hospital	17.1	5.40E-06	0.333
Public office	7.7	5.40E-06	0.150
University	6.2	5.40E-06	0.120
School	6.7	5.40E-06	0.131

** 1kWh = 3.60E+03kJ*

Temperature set-point

The set-point temperature for heating and cooling is one of the influential factors that has the greatest effect on HVAC energy consumption. The set-point temperature is highly uncertain because it is dependent on personal preference, customer satisfaction, energy cost, etc. which will differ in each of the RBs. In this study, it was decided based on the government's indoor temperature guidelines, expert judgement, and trial and error estimation (Table 11). The estimated cooling and heating set-point temperatures are about 24-26ºC and 19-21ºC, respectively.

Table 11: Set-point temperatures of the RBs

Reference building	Cooling	Heating
Detached house	26	20
Apartment/Townhouse	26	21
Private office	24	21
Retail	24	19
Restaurant	24	19
Accommodation	24	20
Hospital	24	20
Public office	25	19
University	24	20
School	24	20

Heating and cooling system efficiency

Various types of heating and cooling systems for example, boiler, turbo/absorption chiller and cooling tower, package air conditioner, heat pump, and fan coil unit can be used in buildings. To develop a reference model, it is important to use the average performance value based on statistical data of the HVAC system type, supply rate, and efficiency applied to each building.

In order to know the *average efficiency* of such systems, overall statistics on the type of equipment, supply rate, and specific efficiency are needed, but there is no such statistical data available in South Korea. For this reason, all heating and cooling related systems were modelled as *Ideal Loads Air System* in EnergyPlus, and then the results are divided into *overall system efficiency* to derive final energy consumption. Here, the definition of the overall system efficiency is a lumped coefficient that considers the consumption energy not only of the primary (e.g. chiller or boiler) system but also of secondary systems such as the cooling tower and the pump working together. The average efficiency values for heating and cooling system performance are as shown in Table 12. It should be noted that these values will be further calibrated in the near future using an in-depth simulation or field study.

Table 12: Overall efficiency of heating and cooling systems by age

SYSTEM	Reference building	Before 1981	1981-1988	1989-2002	2003-2013
For heating	Detached house	0.82	0.85	0.87	0.89
	Apartment and Townhouse	0.86	0.88	0.9	0.92

	Non-residential RBs	0.7	0.72	0.76	0.8
For cooling	Residential RBs	3.5	3.5	3.5	3.5
	Non-residential RBs	1.96	1.96	1.96	1.96

In the residential sector (e.g. Detached house, Apartment, and Townhouse), the overall system efficiency was decided based on the national supply rate and installation status of heating and cooling systems (central heating, district heating, heat pump, etc.). For example, based on such information, the number of the households of each RBs (Detached house, Apartment and Townhouse) was weighted to derive the overall system efficiency respectively.

MODEL VALIDATION

The comparison between simulation results and energy consumption statistical data is shown in Table 13. Error rates in the residential sector varied from -27 to 16%. Error rates in the non-residential sector varied from -13% to -2%, which are comparatively small.

The reason for the large deviation in the residential sector is caused by the difference in the procedure used for extracting model inputs. The non-residential reference models used the information on end-use energy consumption survey data and other parameter values were combined using the gathered statistics (Table 3), the model inputs were calculated inversely. However, input variables for the residential reference models were estimated based on the lifestyle survey (Housing Survey, Household Electric Energy Consumption Survey) due to the lack of information on end-use energy consumption. Also, there is a potential deviation on occupancy input due to the high degree of freedom of occupants in residential buildings.

The differences in ratio of the end-use consumption are examined to verify the plausibility of all RBs. However, as mentioned above, the Energy Consumption Survey (KEEI, 2015) does not provide statistics depending on the end-use consumption for the residential sector. Therefore, only simulation outputs (average of Detached house, Apartment, and Townhouse) were compared to the values of the existing report (Lee 2010) to judge whether or not the ratio is reasonable. The report (Lee 2010) provided the estimate ratio of the end-use energy in the residential sector in the year of 2008. Compared with the report, the result of residential RBs is relatively good as shown in Table 14. Finally, Table 15 below shows a summary of the error rate (= [simulation - statistics] / statistics x 100) in the non-residential sector.

Table 13: Comparison of total energy use intensity (kWh/m^2) between simulation and national statistics

Reference building	Simulation	Statistics	Deviation (%)
Detached house	208.4	179.9	16
Apartment	131.6	149.7	-12
Townhouse	146.4	200.4	-27
Private office	360.3	380.5	-5
Retail	341.6	358.7	-5
Restaurant	559.5	591.5	-5
Accommodation	329.3	337.6	-2
Hospital	250.5	263.8	-5
Public office	216.2	220.5	-2
University	137.9	150.4	-8
School	142.5	164.6	-13

Table 14: Comparison of end-use ratio (%) in the residential sector

End-use	Detached house	Apart ment	Town house	Average of RBs	Lee (2010)
Heating	53.0	32.0	40.0	41.8	44.2
Cooling	1.0	2.0	1.0	1.1	2.0
SHW	21.0	28.0	25.0	24.7	23.8
Cooking	6.0	11.0	16.0	11.1	9.0
Lighting	2.0	3.0	3.0	2.8	1.7
Appliances	16.0	25.0	14.0	18.4	19.2
Total	100.0	100.0	100.0	100.0	100.0

CONCLUSION

This paper explores a practical methodology to develop the RBs to represent building stocks in South Korea. Eleven RBs were developed for residential, commercial, and public sectors. The model parameters values were derived by statistical inference by pre/post-processing and matching the energy and gross floor area statistics.

The reliable statistical data on building energy consumption survey are critical to develop more accurate reference models. The developed models were calibrated against the energy consumption survey data. The reference models reflect the real building stock with a

Table 15: Summary of the error rate (%) of the end-use ratio in the non-residential reference buildings

End-use	Private office	Retail	Restaurant	Accommodation	Hospital	Public office	University	School
Heating	-7.7	-15.7	-13.1	-12.2	-14.2	-18.8	-35.2	-23.5
Cooling	-12.8	-2.7	-7.7	0.6	-7.7	7.6	-2.5	-21.4
SHW	-5.8	1.0	1.2	-5.7	-1.0	-5.6	-5.1	-5.3
Power	1.4	1.4	1.2	1.4	1.4	1.4	1.4	1.8
Lighting	0.9	6.8	2.6	-4.6	-0.4	6.5	19.7	13.5
Equipment	0.2	-0.1	-5.8	-5.4	5.2	1.8	-3.6	-2.4
Cooking	1.3	1.5	-3.2	15.2	1.4	1.5	1.4	1.4
Total	-5.3	-4.8	-5.4	-2.4	-5.0	-1.9	-8.3	-13.4

deviation margin about 20% for residential and 10% for commercial buildings. However, since there are some relatively large deviations, currently Bayesian calibration is in progress.

It is expected that the reference models can be rigorously applied to predict the greenhouse gas emission reduction resulting from national legislative code and standard revisions, which promote the application of innovative technologies.

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