Development of an assessment method for energy performance of residential buildings using G-SEED in South Korea

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ABSTRACT
A new assessment method for the “Energy Performance” issue in the Green Standard for Energy and Environmental Design (G-SEED) was developed in this study. First, the corresponding issues in green building rating systems in advanced countries were reviewed and analysed, and then a new assessment method that uses dynamic building energy simulation programs was developed. The most important part of the new method was developing guidelines for modelling a reference building using simulation programs. Therefore, details of the simulation inputs for a reference building model were provided, and new guidelines were developed in this study. To evaluate the new assessment method, it was applied to a multi-residential building in Seoul, South Korea, and the results were compared to those from the current assessment method in G-SEED.

1. Introduction

The energy consumption in buildings accounts for almost a third of total energy consumption in the world (Han et al. 2013; Energy Information Administration 2010). In addition, the energy consumption in South Korea in the residential and commercial sectors that include energy consumed in homes, offices and other types of buildings for heating, cooling, cooking and other appliances account for 19% of the total energy consumption in South Korea (Seok and Park 2017), and has recently been increasing by about 1% every year (KEA 2017). Consequently, the government of South Korea has put lots of effort toward reducing building energy consumption by enacting the “Green Building Promotion Act” and promoting other related programs such as the Green Standard for Energy and Environmental Design (G-SEED) (MOLIT 2012).

G-SEED is a green building rating system managed by the government of South Korea. G-SEED includes eight different categories, including “Land use and transportation”, “Energy and environmental pollution”, “Material and resources”, “Water circulation management”, and so on. Among them, “Energy performance” is one of the issues that belong to the “Energy and environmental pollution” category, which is directly related to improvements in energy efficiency in buildings based on the promotion of sustainable designs for building envelopes and various energy-related mechanical and electrical systems. In addition, “Energy performance” is a mandatory issue that must meet certain criteria to be certified in G-SEED.

In the current version of G-SEED (G-SEED 2016 2016), the “Energy performance” has no unique assessment method, but relies on results from the other existing programs, which include: the “Energy Performance Index (EPI)” provided in the “Energy Conservation Plan” (that should be submitted to obtain a building permit for new construction), the “Building Energy Efficiency Rating” program, and the “Energy Conservation Standard for Green House Construction” program. This connection with the other programs eliminates the need to perform additional assessments to be certified G-SEED. However, there are difficulties in strengthening the standards of G-SEED, such as time-lag, which occurs when assessing the equivalence with other related programs. Therefore, G-SEED, which plays a leading role in green buildings, needs a new assessment method to efficiently respond to today’s need for green building and to be domestically and internationally applicable as a green building rating system.

Based on this background, this study focussed on the “Energy performance” issue of G-SEED. We performed a thorough analysis and comparison with the other green building rating systems in advanced countries to assess the current status of G-SEED. Afterwards, the overall framework for the future “Energy performance” was established, and a new assessment method was developed. In addition, the new assessment method and current method were applied to an
existing multi-residential building in Seoul, South Korea. These results were compared and analysed to evaluate the new method developed in this study. It is not clear whether this assessment method will be implemented in the future, but it is expected that this study will be a useful basis for materializing this method.

2. Green building rating systems: domestic and foreign

2.1. "Energy Performance" of green building rating systems abroad

Green building rating systems in the world were well summarized by Doan et al. (Doan et al. 2017), and we have selected systems among them for further study corresponding to the “Energy performance” issue in G-SEED. Table 1 summarizes the issues in six different green building rating systems from around the world, including the Leadership in Energy and Environmental Design (LEED) system used in the United States (USGBC 2016), the Building Research Establishment Environmental Assessment Method (BREEAM) International used in the United Kingdom (BRE 2016), the Deutsche Gesellschaft Für Nachhaltiges Bauen (DGNB) used in Germany (DGNB 2018), the Green Star used in Australia (Green Star 2017), and the Comprehensive Assessment System for Building Environmental Efficiency (CASEE) used in Japan (CASBEE 2014), the Green Mark used in Singapore (BCA 2015), the Global Sustainability Assessment System (GSAS) used in Qatar (GSAS 2019), and the LOTUS used in Vietnam (VGBN 2015).

2.1.1. LEED

LEED is a standard developed in 1998 by the US Green Building Council (Egbu et al. 2009; Tkner and Burt 2004; Lee and Kim 2008). The “Energy and atmosphere” category in LEED includes “Minimum energy performance (mandatory) and “Optimized energy performance” (optional) related to “Energy performance” in buildings. These two issues are assessed through energy reduction for the target building against a reference building using dynamic building energy simulation programs approved by LEED. The reference building must be modelled according to Appendix G of ASHRAE Standard 90.1 (ASHRAE 2010). The “Minimum energy performance” issue should satisfy the standard at a minimum of 5% energy reduction compared to the reference building, while the “Optimize energy performance” issue offers different credits depending on the energy reduction from 6% to 50%.

2.1.2. BREEAM international

BREEM is the first green building rating system in the world developed by the Building Research Establishment (BRE) (Alyami and Rezgui 2012; Lee 2013). “Energy performance” in BREEAM International is assessed by the “Ene 01. Reduction of energy use and carbon emissions” issue in the “Energy” category. The two assessment methods used in BREEAM International are the “Use of approved building energy calculation software” and “Energy-efficient design features.” The former method is similar to LEED in that a building energy simulation program is used to give different credits depending on the energy demand, primary energy demand, and CO₂ emission reductions of the target building compared to the reference building. The latter method (“Energy-efficient design features”) is only used if the former assessment method is not available, and it offers credits depending on whether the components of the target building (i.e., lighting, hot water heater efficiency) meet certain criteria. Details of comparison analysis between BREEAM International and G-SEED were conducted by Kim et al. (Kim et al. 2018) prior to this study.

2.1.3. Green Mark

Green Mark is a standard developed in 1999 by the Building and Construction Authority (BCA) under the Ministry of National Development of Singapore (Babu, Lamanoo, and Pawar 2017). “Energy performance” in Green Mark is assessed based on the “Thermal performance of building envelope” issue in the “Energy” category. It is designed to minimize heat gains through the building envelope to be suitable for hot and humid

| Country      | System         | Issue                                                                 |
|--------------|----------------|----------------------------------------------------------------------|
| USA          | LEED           | - Minimum Energy Performance                                         |
|              |                | - Optimize Energy Performance                                        |
| UK           | BREEAM International | - Reduction of Energy Use and Carbon Emissions                      |
| Germany      | DGNB           | - Life Cycle Assessment Primary Energy                                |
| Australia    | Green Star     | - Greenhouse Gas Emissions                                            |
| Japan        | CASBEE         | - Efficiency in Building Service System                               |
| Singapore    | Green Mark     | - Energy Efficiency                                                  |
| Qatar        | GSAS           | - Energy Demand Performance                                           |
| Vietnam      | LOTUS          | - Energy Delivery Performance                                         |
|              |                | - Fossil Fuel Conservation                                           |
|              |                | - Total Building Energy Use                                           |
climate characteristics in Singapore. Specifically, it focuses on the building envelope performance rather than the energy performance of the whole building. However, assessment using building energy simulation programs is required to obtain “Platinum” and “Gold Plus”, which are the highest rating levels of Green Mark. In this assessment, the target and reference buildings are modelled using a building energy simulation program that meets “ASHRAE 140: Standard method of test for the evaluation of building energy analysis computer programs” (ASHRAE 2014), and the energy reduction of the target building against the reference building is calculated. In the case of “Platinum”, energy reduction of the target building should be at least 30% compared to the reference building, and at least 25% for “Gold Plus”. In addition, reference buildings should be modelled according to the guidelines developed by the government of Singapore.

2.1.4. GSAS

GSAS is a green building ratings system used in Qatar. The building energy performance assessment includes “Energy demand performance” issue, which assesses the energy demand under specific conditions, and “Energy delivery performance” issue, which assesses the amount of energy used in mechanical and electrical systems to satisfy the energy demand. It is categorized into “Fossil fuel conservation” issue focusing on reducing fossil fuel consumption.

2.2. Comparison of “Energy performance” issues in domestic and foreign green building rating systems

Table 2 summarizes the domestic and foreign assessment methods of “Energy performance”. As mentioned previously, “Energy performance” in G-SEED is assessed by three assessment methods, all of which use the prescriptive methods except for “Building Energy Efficiency Rating”, which uses the performance method using ECO2 program. Generally, the prescriptive methods are designed to improve energy efficiency in buildings through the use of building materials and equipment that meet certain standards. However, they offer the least possible flexibility for building designers, unlike the performance methods, which require that a building as a whole performs to a certain standard. Although “Building Energy Efficiency Rating” using ECO2 program in G-SEED is assessed using the performance method, the energy predictions are based on steady-state calculations. The ECO2 program calculates monthly primary energy consumption per unit area of a target building and evaluates it according to the range of consumptions. Therefore, for a season with severe temperature changes such as the summer season, the energy predictions are relatively inaccurate compared to dynamic building energy simulations. Thus, dynamic building energy simulation programs are often used to predict the energy consumption of the target and reference buildings in the world, including LEED in the United States, BREEAM International in the United Kingdom, and Green Mark in Singapore. Therefore, it is necessary to introduce dynamic building energy simulation to assess the energy performance of buildings more accurately and introduce them to G-SEED evaluation, as well as to apply the assessment method to various types of buildings both domestically and internationally.

3. Development of a new assessment method for “Energy performance” issue

3.1. Review of “Energy performance” assessment methods using dynamic building energy simulations

Advanced green building rating systems in other countries use dynamic building energy simulation programs to model and perform energy simulations for both the target and the reference buildings. The energy reduction of the target building is calculated relative to the reference building, and a higher rate means better building energy performance, which
results in higher credit allocations. The energy simulation of the target building can be modelled relatively easily based upon design drawings such as floor plans, elevations, mechanical and electrical plans. However, it is somewhat difficult to perform an energy simulation of the reference building.

Basically, a reference building refers to a building with minimum specifications that meets the energy code of a given country. However, the simplicity of the building defined as the reference is largely up to the simulation users if there are no guidelines on how to model. For example, a target building may have shading to reduce cooling load by blocking summer solar radiation. The decision whether to include the entire shade includes only part of it, or exclude it in the model of a reference building may differ from one simulation user to another, and this decision greatly affects the energy reduction of the target building. Therefore, the development and provision of guidelines for modelling reference buildings are critical in building energy performance assessments. In addition, after setting up the modelling guidelines for a reference building, balancing the equity between the assessment methods, newly developed and current will be conducted in section 4.

A number of studies on modelling a reference building has been conducted in South Korea (Jeong et al. 2014; Jung, Jeong, and Huh 2015; Kim et al. 2017). However, most of them are based on previous years’ building statistics, which could define the average envelope performance and equipment efficiency for modelling a reference building that does not exist in reality. Currently, there is no research on how to model a reference building based on the target building. Furthermore, only a few countries around the world have developed guidelines for how to model a reference building, and ASHRAE Standard 90.1: Appendix G (ASHRAE 2010), which was developed by the American Society of Heating, Refrigerating and Air-Conditioning Engineers, is the most reliable one. Nonetheless, the ASHRAE Standard 90.1: Appendix G was developed based on regional energy codes in the United States, and its application to building energy performance assessment in South Korea would be inadequate. Therefore, in this study, the data for modelling reference buildings were collected and compiled to develop guidelines based on energy codes in South Korea, which include “Energy Conservation Standard for Building Design” for commercial and “Energy Conservation Standard for Green House Construction” for residential buildings.

3.2. Guidelines for modelling a reference building using dynamic building energy simulation programs

The most important guidelines for modelling a reference building using dynamic building energy simulation programs are summarized in Figure 1. This study included the fundamentals that must be addressed in the guidelines, and further details will be developed in the authors’ future work. In addition, the developed guidelines are limited for residential and commercial buildings in this study. The expansion of the guidelines to cover other types of buildings is also part of the authors’ future work.

3.2.1. Selection of simulation program

According to ASHRAE Standard 90.1 (ASHRAE 2010), a given dynamic building energy simulation program should be a computer-based program that can be used for performing a minimal functional evaluation of building energy with the ability to calculate and analyse energy consumption. In addition, the program should meet several other requirements such as the capability to perform building energy calculations for 8,760 hours per year, the ability to model more than 10 thermal zones, and a high accuracy of predictions. In addition, Singapore’s Green Mark uses the criteria and methods for verification of building energy simulation programs provided in ASHRAE 140 (ASHRAE 2014). Therefore, it is necessary to identify simulation programs that are qualified for building energy performance analysis and to develop a clear approval

Figure 1. Contents of the guidelines for modelling a reference building.
process for selecting other simulation programs according to the guidelines of G-SEED. Currently, DOE-2.1e, EnergyPlus, eQUEST, ESP-r, IDA ICE, TRACE and TRNSYS (Crawley et al. 2005) are the programs that meet the criteria. In addition, it is important to use the same program to model both the target and reference buildings (ASHRAE 2010). On the other hand, the fact that using a building energy simulation takes a lot of time and effort of the user is a part to be supplemented in the future. It is necessary to study how to use time more efficiently in the authors’ future work, such as using parametric building performance simulation tools.

3.2.2. Selection of standard weather file
Dynamic building energy simulation programs perform simulations using standard weather files that contain the hourly temperature and solar radiation data (along with other data) representing climatic conditions of the area under consideration. Standard weather files are one of the most important factors influencing a building’s energy performance. Thus, it is necessary to select weather files appropriately. First, South Korea has four major climate zones, including two central regions, a southern region and Jeju Island. The standard weather data for the four zones are provided by “The Korea Solar Energy Society” and the “Passive House Institute Korea”. Most large cities in the climate zone have hourly weather data measured by the Korea Meteorological Administration, but in some suburban areas does not. In this case, weather data of cities close to the area, similar in climate, and belonging to the same climate zone should be used. In addition, the same weather file should be applied for both the target and reference building simulation (ASHRAE 2010).

3.2.3. Guidelines for modelling a reference building: general, building envelope, lighting and equipment density, hot water and HVAC system
The first thing that should be considered when modelling a reference building using building energy simulation programs is obtaining rating levels equivalent to the current “Energy performance” assessment methods in G-SEED. Currently, the G-SEED rating system is done in such a way that a given building can obtain the same rating levels regardless of the assessment methods applied. Therefore, we must make the new assessment method equivalent to one of the existing assessment method, the results from the ECO2 program. Thus, it is necessary to identify the settings and modelling conditions of ECO2 (KEA 2016) first (ECO2 is a computer-based program used for “Building Energy Efficiency Rating”), and then apply them to the development of guidelines for modelling reference buildings in the new assessment method.

Several modelling conditions were set in the ECO2 program, including lighting, internal heat gain for equipment and occupants, heating and cooling set points, minimum infiltration and hot water supply on a daily or monthly basis according to 20 types of space uses. The available space uses are: living room, small office (less than 30 m²), large office (more than 30 m²), conference/seminar room, auditorium, cafeteria, restroom, other space (lounge, locker room, etc.), annex space (lobby, corridor, staircase, etc.), warehouse and mechanical room, computer room, kitchen, ward, hotel guest room, classroom (primary and middle school), classroom (college), store (shop, department store), exhibit hall (gallery, museum), reading room (library), and sports facility (please see Table 4). Similarly, modelling conditions and space use using dynamic building energy simulation programs should be set according to those of the ECO2 program. If there is a space that does not correspond to any of the options in the space uses above, the best fitting type should be chosen.

With this in mind, the guidelines for modelling a reference building using a dynamic building energy simulation program were developed based on the following categories: (1) general, (2) building envelope, (3) light and equipment density, and (4) hot water and HVAC system.

3.2.3.1. General of a reference building. The general information about the building to be included in the modelling of a reference building is shown in Table 3. Briefly, the number of the floors, the floor area, building

| Target building (TB) | Reference building (RB) |
|----------------------|-------------------------|
| Use the same dynamic building energy simulation program for both the TB and RB | Same as TB |
| Use the same standard weather file for both the TB and RB | Same as TB |
| Number of building stories | Reflectance: 0.30, emittance: 0.90 |
| Building size (eg areas of walls, roofs) | Same as TB |
| Shape of building | Same as TB |
| Orientation of building | Same as TB |
| Reflectance and emittance of roofs | Same as TB |
| Space use in the building (eg office) | Same as TB |
| Thermal zone in building | Same as TB |
| Modelling assumptions | Same as TB |
| Shadings of adjacent buildings and topography | Same as TB |
shape and orientation, and all the space uses within the building should be modelled in the same manner as the target building. However, the measures for improving the energy efficiency of the target building should not be included in the reference building model (ASHRAE 2010).

3.2.3.2. Building envelope of a reference building.

The building envelops of a reference building should be modelled to meet the U-value of multiple layers of materials provided by the “Energy Conservation Standard for Green House Construction” and “Energy Conservation Standard for Building Design” for residential and commercial buildings, respectively.

For residential buildings, the window-to-wall ratio of a reference building should be set to the smallest ratio between the target building and the ratio in Appendix 4 in the “Energy Conservation Standard for Green House Construction.” Whereas, the window-to-wall ratio of a reference building for commercial building should be set to the smaller of the ratio of the target building and a 40% ratio (ASHRAE 2010). After the overall window-to-wall ratio of a reference building is determined, the window-to-wall ratio on each wall surface for the reference building should be determined according to the ratio of the target building on each wall surface. In addition, there should be no shading installed in the reference building. The skylight ratio of the reference building should be set to the smallest ratio between that of the target building and a 5% skylight ratio. The skylight orientation and inclination should be modelled the same as the target building (ASHRAE 2010).

In addition, the U-value of the window for a reference building should be set according to Appendix 4 in the “Energy Conservation Standard for Building Design”, and the Solar Heat Gain Coefficient (SHGC) of a window for a reference building should be set to 0.48 and 0.40 for residential and commercial buildings, respectively. The SHGC for residential buildings was calculated from windows that have U-0.9 as shown in Appendix 1 in the “Energy Conservation Standard for Green House Construction”, and the SHGC for commercial buildings was set to have the value provided in the “National Calculation Methodology (NCM)” (EPC Expert 2014).

3.2.3.3. Lighting and equipment density of a reference building.

As mentioned previously, it is important to refer to the ECO2 program settings when modelling the reference building using dynamic building energy simulation programs. However, for most dynamic energy simulation programs, energy calculations for lighting and equipment are based on a 24-hour operation schedule. In the ECO2 program, the calculations are based on the daily lighting hours and heat gains from equipment. Hence, lighting schedule and equipment density from the ECO2 program could not be directly used in dynamic building energy simulation programs.

As the purpose of this study was to develop guidelines for modelling a reference building using dynamic building energy simulation programs, the daily-based lighting and equipment density and operation schedule for each space used in the ECO2 program (MOLIT 2012) were applied to model a reference building using a dynamic simulation program. To do that, the average lighting and equipment density provided in a report from the National Renewable Energy Laboratory (NREL) (Deru et al. 2011) were modified to match those in the ECO2 program. Table 4 shows the

| Table 4. Lighting and equipment densities for a reference building. |
|---------------------------------------------------------------|
| **Space use** | **Lighting density (W/m²)** | **Equipment density (W/m²)** |
|----------------|-----------------------------|------------------------------|
| Living         | 10.00                        | 3.4                          |
| Small office (less than 30 m²) | 10.76                        | 4.0                          |
| Large office (more than 30 m²) | 10.76                        | 11.0                         |
| Conference/seminar room | 13.99                        | 2.2                          |
| Auditorium     | 9.68                         | 1.8                          |
| Cafeteria      | 12.91                        | 0.8                          |
| Restroom       | 9.68                         | 0.0                          |
| Lounge, locker room, etc. | 9.68                        | 0.8                          |
| Lobby, corridor, staircase, etc. | 5.38                        | 0.0                          |
| Warehouse/mech. room, etc. | 9.68                        | 0.0                          |
| Computer room  | 15.06                        | 75.0                         |
| Kitchen        | 12.91                        | 200.0                        |
| Ward           | 7.53                         | 1.3                          |
| Guest room     | 11.84                        | 5.0                          |
| Classroom (primary and middle) | 15.06                        | 1.5                          |
| Classroom (college) | 15.06                        | 1.8                          |
| Store (shop, department store) | 18.29                        | 1.9                          |
| Exhibit hall (gallery, museum) | 13.99                        | 0.0                          |
| Reading room (library) | 13.99                        | 0.0                          |
| Sports facility | 15.06                        | 0.0                          |
lighting and equipment density of a reference building. The operation schedules of the lighting and equipment will be discussed in detail in Section 3.2.4.

3.2.3.4. Hot water and HVAC system of a reference building. According to the ASHRAE Standard 90.1 (ASHRAE 2010), the energy source for hot water systems in the reference building model should be the same as the target building. In addition, the efficiency of the hot water heater was set to 83.0% for residential and 83.5% for commercial buildings based on the efficiency of the average heaters calculated from the EPI report (KEA 2000).

The HVAC system of the reference building should be modelled in basically the same manner as the target building; however, the system control method should be deferred based on the size or conditions of the thermal zone of the conditioned floor area of the target building. For the target building with a small conditioned floor area (i.e., less than 2,000 m² or a single thermal zone), the reference building should have a constant air volume (CAV) system. For a target building with a large conditioned floor area (i.e., more than 2,000 m² or multiple thermal zones), the reference building should have a variable air volume (VAV) system. Regarding the system performance (e.g., equipment efficiency and capacity, etc.), the same input values should be used for both the target and reference buildings (KIER 2001). In addition, if the target building used a district heating system, the same system should be applied to the reference building. As such, most HVAC systems in the reference building were set to be almost identical to the target building. Thus, the strategy of using high-efficiency HVAC systems in the target building did not result in an energy reduction of the target building against the reference building. However, there are not enough data to establish the relevant standard in South Korea at present (Kim et al. 2017), and this part will need to be continuously supplemented through future data accumulation.

Heat source systems such as boilers and refrigerators in the reference building (e.g., type, capacity, number of equipment, etc.) should be basically the same as the target building in the model with the exception of the equipment efficiency. The boiler efficiencies of 83.5% and 83.0% were set for residential (individual boiler) and commercial (central boiler) reference buildings, respectively, and refrigerator efficiency (COP of absorption refrigerator) of 1.1 was set for both the residential and commercial reference buildings. These efficiencies were set based on the averages calculated from the EPI report (KEA 2000). In a manner similar to the case of HVAC systems, only the efficiency of the limited equipment was considered in the guidelines because there is currently a lack of accumulated data in South Korea such as information for compression refrigerators, heat pump systems, etc. However, this should be revised as related data are accumulated in the future.

3.2.4. Operation schedule for a reference building

Generally, it is appropriate to apply the same operation schedule for lighting, equipment, heating and cooling set points of both the target and the reference buildings. However, if the target building uses special schedules for improving building energy efficiency such as a dimming control lighting system, these should be applied differently in the reference building, and the details of the applied schedules should be specified in the documents to be submitted. In addition, if the target building does not have any operation schedule, both the target and the reference buildings are required to apply the operation schedule developed in this study.

The operation schedules for all the space uses have been developed in this study; however, only the 24-hour operation schedule for a large office (i.e., more than 30 m²) is presented in Figure 2. The developed schedules were based on ECO2 program settings, which include building occupancy, equipment, heating and cooling set points, minimum infiltration, hot water supply and lighting schedule. When more operation schedules are needed, the simulation user should set them accordingly.

As mentioned previously, the operation schedules were developed through some modifications of lighting, equipment and other schedules reported by NREL (Deru et al. 2011) to match the daily or monthly outputs of ECO2 program (MOLIT 2012). In addition, not only the outputs of the ECO2 program, but also the operation schedule was modified to suit the situation in South Korea. The detailed modifications for each space use are shown in Table 5. In brief, the operation schedules according to the space uses developed by NREL were modified in consideration of the commute time, the recommended set-point temperature of the heating and cooling system, the current status and the usage time of equipment, etc. in South Korea.

3.2.5. Document submission

The organization of documents to be submitted is another important part. It is practically impossible for the reviewer to evaluate all the simulation inputs in the model. Therefore, the submitted documents must be in a certain order to ensure that the target and the reference buildings were modelled properly. In this study, the documents were organized according to ASHRAE Standard 90.1 (ASHRAE 2010), as shown in Table 6.

4. Balancing the equity of a new assessment method

As mentioned previously, the new assessment method calculates and evaluates the energy reduction
between a target building and a reference building, but the current assessment method using the ECO2 program calculates the primary energy consumption per unit area of a target building and evaluates it according to the consumption ranges. Thus, it is impossible to compare the results of the two assessment methods directly, and we performed balancing the equity of the two assessment methods. To balance the equity of the new assessment method, “Energy performance” of a residential building was assessed using the current method (ie ECO2 program) and the newly developed method (ie a dynamic simulation program) in this study. A residential building located in near Seoul, South Korea was selected that obtained an “Excellent” rating level in G-SEED certification in 2016. Details of the target building are summarized in Table 7, and Figure 3 shows the floor plan and the energy simulation model for the target building that was used for the comparison of both methods. Same as the most newly constructed multi-residential buildings in South Korea, there is no cooling system, but the underfloor heating system installed.

4.1. Current assessment method using ECO2 program

For the current assessment method, the target building was modelled and simulated using ECO2 program based on the design drawings such as floor plans, mechanical and electrical plans. As mentioned previously, the ECO2 program uses the monthly steady-state method to calculate primary energy consumption per square meter of a building, and a rating level can be determined accordingly. The specification of the building envelope is summarized in Table 8, which was also used for modelling a dynamic energy simulation program later. Besides the inputs, the operation schedule in ECO2 program (ie schedule for occupancy, equipment, heating and cooling set points, minimum infiltration, hot water and lighting) was checked if it is correct, and whether file in ECO2 program was checked as well if outdoor air temperature and solar radiation data were same with the weather file used for a dynamic simulation. The percentage


Table 5. Modifications made for each operation schedule.

| Operation schedule          | Modification |
|-----------------------------|--------------|
| Occupancy                   | The 24-hour schedule of occupancy rate (%) by the space use provided in the NREL report (Deru et al. 2011) was applied. However, the schedule was recalculated to be the same as the occupant heat gains in the ECO2 program through the calculations of occupant heat gains according to Table 6.3 in the ASHRAE Handbook: Fundamentals (ASHRAE 2001). |
| Equipment                   | The equipment density in Table 4 was used to calculate the heat gains generated from equipment, and then the operation schedule of rate (%) in the NREL report (Deru et al. 2011) was recalculated to be the same as the equipment heat gains in the ECO2 program. |
| Heating and cooling Set point | The 24-hour schedule provided in the NREL report (Deru et al. 2011) was applied with some modifications (ie multiplying 1.07 and 1.03 for heating and cooling, respectively) to match the heating and cooling temperature settings in the ECO2 program. |
| Minimum infiltration        | The minimum infiltration rate (%) provided in the NREL report (EPC Expert 2014) was used. However, the operation schedule was recalculated to be the same as the minimum infiltration (m³/h/m²) in the ECO2 program. |
| Hot water                   | From the 24-hour schedule in the NREL report (Deru et al. 2011), the energy consumption per unit area was calculated for each space used, and the operation schedule from the NREL report was modified to match the hot water settings in the ECO2 program using the Equation (1) below: 

\[ Q_{\text{heating}} = \rho_v \cdot \dot{V}_w \cdot (T_{hw} - T_o) / 3600 \] (1)

Where, \( Q_{\text{heating}} \) is net energy needs for domestic hot water (kWh), \( \rho_v \) is water density (1000 kg/m³), \( \dot{V}_w \) is specific heat capacity of water (4.2 kJ/kgK), \( V_{\text{Dom}} \) is domestic hot water consumption (m³), \( T_{hw} \) is domestic hot water temperature (45°C), and \( T_o \) is domestic cold water temperature (15°C). |
| Lighting                    | The lighting schedule in rate (%) in the NREL report (Deru et al. 2011) was modified (multiplying 1.08) to match the daily lighting hours in the ECO2 program. |

Table 6. List of documents.

| Document                          | Content                                                                 |
|-----------------------------------|-------------------------------------------------------------------------|
| Project summary                   | This document included all the measures used to improve building energy performance, the name and version of the dynamic building energy simulation program used, and the simulation results (the results of the target and reference buildings, and the degree of improvement in the energy performance of the target building in comparison to the reference building). |
| Project overview                  | The document contained general information on the project such as the number of floors (above and underground), floor size, space uses (ie office, cafeteria, parking lot), and thermal conditioned area. |
| List of technologies applied in the building design | To improve the energy performance of the target building, all inputs to the target building and the reference building should be specified. An example is the installation of the dimming control lighting system for a target building. The document specifies whether the target building complies with the “Energy Conservation Standard for Green House Construction” and “Energy Conservation Standard for Building Design” in the case of residential and commercial buildings, respectively. |
| Compliance with building energy codes | The document contains all the calculations and assumptions made to obtain the key inputs for building materials (such as the calculation of the U-value for the building envelope). |
| List of modelling assumptions     | At a minimum, list the inputs and results of the simulation, including energy consumption of lighting, equipment, hot water heater, heating and cooling systems, fans and so on. |
| Input and output report           | This document contains all the assumptions made to obtain the key inputs for building materials (such as the calculation of the U-value for the building envelope). |
| List of special calculation Methods | The document must clearly describe the accuracy of the theoretical or empirical aspects of the method used. |

Table 7. Description of target building.

| Building type         | Location                  | Stories | Conditioned floor area (m²) | Cooling system | Heating system               |
|-----------------------|---------------------------|---------|-----------------------------|----------------|-----------------------------|
| Multi-residential     | Yongin, South Korea (about 50 km south from Seoul) | 33      | 84                          |                | Underfloor heating using district heating |

The difference of annual outdoor temperature between two files was 0.3°C, and solar radiation was 0.3 W/m², which were acceptable. As a result, the primary energy consumption for the target building was 146.4 kWh/m²-year (83.9 kWh/m²-year for heating, 30.1 kWh/m²-year for hot water and 32.4 kWh/m²-year for lighting), which placed in 2nd rating level in “Energy performance” issue in G-SEED.

4.2. New assessment method using a dynamic energy simulation program

For newly developed assessment method, first, the target building was modelled and simulated using DesignBuilder program based on the design drawings, taking care to use as many of the same inputs with ECO2 program as possible. The DesignBuilder is a dynamic building energy simulation program that uses the EnergyPlus engine, and it is a highly reliable program that is also used for LEED evaluation. In order to model the target building using the DesignBuilder, the specification of the building envelope in Table 8 were entered into the program. In addition, 24-hour operation schedule that we developed to match with the schedule in the ECO2 program (described in section 3.2.4), and weather file was used in the simulation. Primary energy consumption of the target building was calculated from the simulation results by
4.3. The method, the Table assessment simulation

After building was modelled using the DesignBuilder program as well to calculate the energy reduction of the target building against the reference building. The reference building was modelled according to the guidelines developed in this study. Table 9 shows the 12.6% of primary energy reduction of the target building.

4.3. The equity of new assessment method

As mentioned above, in this study, the results of using the ECO2 program, which was the current assessment method, and the results of using a dynamic energy simulation program, which was a newly developed assessment method, were set at the same rating level. The results of the ECO2 program on the target building show that the primary energy consumption per unit area is 146.4 kWh/m²-year, which was the second-highest of the four levels in the “Energy performance” issue in G-SEED. Therefore, the energy reduction, which was the result of the new assessment method, was set as the second rating levels in the “Energy performance” issue in G-SEED. In fact, this result is not enough as it is compared to only one building currently, but we plan to supplement this part by carrying out several other cases in the future.

5. Conclusions

The purpose of this study was to develop a new assessment method that uses a dynamic building energy simulation program to assess “Energy performance” issue in the “Energy and environmental pollution” category of G-SEED. The findings from the study are as follows:

1. A comparison and analysis of the “Energy performance” assessment methods used by different rating systems showed that most of the green building rating systems in advanced countries use dynamic building energy simulation programs to model both the target and the reference buildings to calculate energy reduction in the

Table 9. Energy reduction in the target building.

| Primary energy consumption | A target building | A reference building | Energy reduction |
|----------------------------|-------------------|----------------------|------------------|
| Heating                    | 72.5 kWh/m²-year  | 79.6 kWh/m²-year    | 8.9%             |
| Hot water                  | 29.6 kWh/m²-year  | 29.6 kWh/m²-year    | 0.0%             |
| Lighting                   | 18.6 kWh/m²-year  | 28.8 kWh/m²-year    | 35.5%            |
| Total                      | 120.6 kWh/m²-year | 138.0 kWh/m²-year   | 12.6%            |
target building. Therefore, this most common assessment method was necessary for G-SEED to effectively promote building energy efficiency both domestically and internationally.

2. Our study showed that the provision of guidelines (in the new assessment method) on how to model a reference building and how to organize the required documents is crucial for the reviewer to efficiently identify whether the simulation model complies with the guidelines. Therefore, guidelines for modelling a reference building were developed, and all the details included in the reference building model were analysed.

3. Furthermore, to standardize the developed method with the current assessment method, 24-hour operation schedules for dynamic building simulation programs were developed based on the ECO2 program, which is currently used in the “Energy performance” assessment of G-SEED.

4. Lastly, the equity of the developed method was balanced by comparing the results of the “Energy performance” assessment with an existing multi-residential building using the current and new assessment method.

Although the overall framework of a new “Energy performance” assessment method was established in this study, there are still many areas that need further investigation and data collection to develop more integrated guidelines. This requires the contribution and cooperation of all researchers involved in green building rating systems in South Korea, and it will be a focus of the authors’ future work. In addition, although this study considered the equity with the current assessment method for only one case study building, more buildings will be conducted, and the assessment method developed through this process will be more firmly verified in the future.

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