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Study on Policy Marking of Passive Level Insulation Standards for Non-Residential Buildings in South Korea

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Abstract: This study presented a methodology and process to establish a passive level for policy making of building energy in South Korea. A passive level in Korea specified in the 2017 Roadmap for non-residential buildings, which was 15 kWh/m^2·year, was defined as the heating energy requirement to strengthen the building energy saving design standards, which were typical building energy regulations in Korea. This study also presented insulation standards of roofs, floors, outer walls, and windows in Pyeongchang, Seoul, Gwangju, and Jeju, which were represented cities of four zones in Korea (Middle 1, Middle 2, Southern, and Jeju). Furthermore, the study results were extended to 66 cities around the nation to calculate the heating energy requirements and a severely cold region was added to existing three regions (Middle, Southern, and Jeju) to extend this to four regions (Middle 1, Middle 2, Southern, and Jeju). Afterwards, insulation standards for four represented regions were presented to derive a measure that minimized an energy loss through outer walls or windows in buildings. Finally, this study derived that a return of investment can be achieved in 10 years, which was determined through the comprehensive economic feasibility analysis due to strengthening insulation performances, proving the rationalization of the legal strengthening.

Keywords: passive building; building energy policy; insulation standards; building energy; building energy requirement; energy benefit

1. Introduction

The energy and environmental improvements have become the national goals and tasks as exhibited in the provision of a new greenhouse gas reduction system and the national establishment of a greenhouse gas reduction plan by 2030 (the Paris Agreement in December 2015) after the Kyoto Protocol, which will expire in 2020 [1]. South Korea has planned to reduce greenhouse gas emissions by 37% from business-as-usual (BAU) levels by 2030 and decided to reduce 18.1% in the building sector only [2]. The insulation standards have been strengthened continuously in a stepwise manner for the gradually changing market since the mandatory zero-energy building (by 2025) was announced in the Green Building Promotion Measure (the Sixth Green Committee Report: November 2009) [3]. Although voluntary participation has been induced through constant education about energy cost saving of buildings through advertisement of the need to reduce greenhouse gases and insulation improvements, the initial building cost burden has increased due to rising construction costs of using highly efficient building materials (insulators and high-efficiency insulation windows), which has prevented the voluntary participation by building owners. To overcome these realistic limitations, it is necessary to strengthen the insulation standards to provide superior energy performance while ensuring acceptable policies with minimized burdens on citizens. The passive buildings in Germany are defined as buildings whose annual primary energy consumption is 10 kWh/m^2 or smaller and annual heating energy consumption is 15 kWh/m^2 or smaller. The core of the standards is to strengthen insulation performance thereby minimizing the heating energy requirements and to reduce the role of active facilities such as boilers [4,5]. It will contribute to building energy saving by reducing volumes of active facilities and minimizing basic energy loads through increases in insulation performance of envelopes, which are the largest heat loss areas from the initial design phase. Yoon et al. [6] analyzed a difference in heating energy requirements through the PHPP (Passive House Planning Pakage) program in Germany assuming that demonstration buildings in South Korea are constructed in seven regions, thereby studying the effect of climate characteristics on building energy performance. Lee et al. [7] proved that the adoption of energy saving elements in the passive house standards in detached houses was useful in terms of energy saving. Ko et al. [8] aimed to identify the characteristics of the passive technology according to climates with regard to techniques used in terrain and layout shape and structures according to climates, floor plan, and envelope plan, and material composition.

The passive house concept in Germany is to satisfy thermal comfort requirements without radiation imbalance by preventing drafts or dew condensation in buildings through increases in thermal performance in outer walls and windows. Accordingly, the heating energy requirement standard is specified to 10 kWh/m^2·year [9], and passive houses are defined as buildings whose heating energy requirement in Central Europe is 15 kWh/m^2·year or smaller generally. In addition, for the coefficient of overall heat transmission (U-value) for each part specified in the Passive House, it is specified as 0.15 W/m^{2}K for the covering and as 0.8 W/m^{2}K for the window considering [10] the climate in Central Europe as a criterion. Generally, for the definition, the layout of buildings, envelope thermophysics, building geometry and infiltration and air-tightness are taken into consideration [11].

However, the standards of the passive houses in Korea and other nations are based on detached houses, whereas national mandatory passive standards are not yet presented for non-residential buildings. In addition, no studies have been conducted to establish passive insulation conditions for national policy making that satisfies the passive standards in different types of weather. Thus, this study aims to provide a methodology that presents an insulation level of buildings to satisfy the passive standard (15 kWh/m^2·year of heating energy requirements for non-residential buildings by applying Korean use profiles of non-residential buildings, thereby proposing the insulation standards and measures that take construction cost increase and energy cost saving into consideration comprehensively in case the standards are strengthened.

2. Building Energy Policy in Korea

2.1. Building Energy Roadmap in Korea

Korea has changed the national policy direction from passive response to greenhouse gas reduction in the past to a pro-active response called Low Carbon Green Growth, and the Basic Act of Low Carbon Green Growth took effect in 2010 and green growth has been started and promoted in earnest. Thus, the Ministry of Land, Infrastructure, and Transport in Korea has the goal of lower energy consumption in buildings in 2012 compared to the energy consumed in houses in 2009, and further reduction using passive building levels by 2017, as shown in Figure 1. According to the Green Building Act, and the press release of Measure or Early Promotion of the Response to Climate Change and Zero-Energy Buildings the energy level reduction of buildings will be strengthened step by step due to mandatory zero energy regulations by 2025, which sets the goal as mandatory zero energy performance [3].

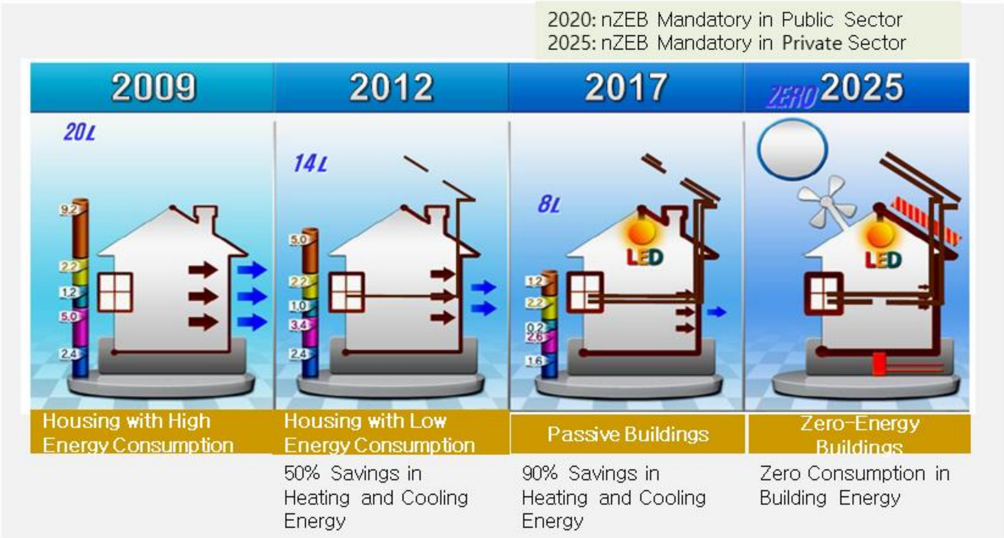


Figure 1. Building energy roadmap in Korea [3].

In addition, a short-term goal of greenhouse gas reduction was set to have a policy goal that reduced the greenhouse gas emitted in the building sector by 26.9% by 2020 compared to that of 2014, which was announced as the First Basic Plan for Green Buildings [3]. As part of the policies, the government has strengthened various energy reduction policies gradually such as building energy efficiency rating certification standards and building energy saving design standards to reduce building energy consumption.

2.2. Design Standard of Energy Saving in Buildings

The Building Energy Conservation Code (BECC) is a standard of mandatory energy-related minimum requirements to specify mandatory and energy performance indices of energy saving design including heat loss prevention and energy saving facility use for efficient energy management of buildings. The Korea Energy Agency has started investigation on an energy saving plan document based on the ordinance enacted by local governments in 2003. The energy saving planning document is submitted in accordance with the BECC (notified by the Ministry of Land, Infrastructure, and Transport) and the Green Building Creation Support Act at the time of new building permit application over 500 m^2 for this regulation. The main details of this standard are divided into: (i) building sector—energy saving designs including mean thermal transmittance, air-tight windows, rooftop landscaping, (ii) mechanical and electrical sector: adoption of high-efficiency certified products and energy saving control techniques, and a (iii) new and renewable sectors: cooling and heating, hot water, and electric capacity into new and renewable energy. Based on the above details, a building permit is determined if 65 or higher points out of 120 full mark in the energy performance index (EPI) are acquired (74 points for public institutions) and all mandatory items are adopted. Table 1 summarizes the mandatory items of the standards in buildings, machines and electric parts [12]. In particular, it presents thermal transmittance for building an outer wall and window in the middle, southern, and Jeju regions that are divided based on the Heating Degree Days (HDDs) in relation to passive condition-related insulation standards, and a mean thermal transmittance is presented to limit a ratio of window area, which is excessively large.

The BECC Standards of Thermal Transmittance for Building Parts by Region regulate and strengthen the envelope thermal transmittance according to a building type and region. The thermal transmittance for walls was strengthened from 0.58 W/(m^2·K) in 1987 to 0.26 W/(m^2·K) in 2016 and thermal transmittance for windows from 3.37 W/(m^2·K) to 1.5 W/(m^2·K) on the basis of the middle region.

Table 1. 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(Heating, Ventilation and Air-Conditioning system) 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 1000 m^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

2.3. Process to Determine Building Energy Policies in Korea

A number of processes are needed to determine policies to make building energy-related regulations mandatory in the Ministry of Land, Infrastructure, and Transport. In these processes, technical levels of building material suppliers, construction costs rise in case of standard strengthening, energy cost reduction is comprehensively taken into consideration, and the acceptability of the amendment is increased through an advisory conference with building companies, related experts, and material suppliers to facilitate the regulation compliance by the regulated (citizens). Thus, a revision draft is provided after reflecting discussion contents comprehensively based on expert advisory conferences and industry meetings, and regulation examinations such as cost analysis and verification and self-regulation examination (including cost–benefit analysis) are conducted followed by seeking the consultation of related institutions' administrative notices about the revised draft. Finally, opinions of stakeholders such as related institutions are fully gathered through public hearings and the act is amended.

3. Simulation Configuration

This study calculated an insulation level that satisfies a heat quantity required to maintain an indoor temperature constantly according to the regional monthly mean outdoor air temperature based on envelope conduction heat loss, ventilation conduction heat loss, internal heat generation acquisition, and solar heat gain with regard to heating energy requirements as a methodology to calculate building energy requirements of ISO 13790 [13]. Figure 2 shows the process to meet the insulation level required for passive heating requirements. This process is conducted as follows: first, reference building conditions are set according to building use, characteristics, and envelope conditions and then the insulation level that satisfies 15 kWh/m^2·year, which is a heating energy requirement of passive insulation level, is obtained by reflecting the meteorological data by region. In fact, ISO 13790 is an international standard, which is unlikely to produce errors. However, it is also true that it can produce a significant difference in energy results depending on the local use conditions. This study does not aim to evaluate performances of individual buildings in detail conceptually. This study conducts simulations at the standard set conditions in Korea by utilizing statistical data of energy efficiency rating certification and SEUMTER (SEUMTER is the National Standard Information System to apply for permission through the digitized construction administrative system for all construction administrative works in the Republic of Korea), an administration system for building-related public services, for represented regions by region. Thus, it may produce a difference in measurement results of individual buildings. However, these errors compared to actual measured data will be reduced once the local-based set data are constructed constantly in the future.

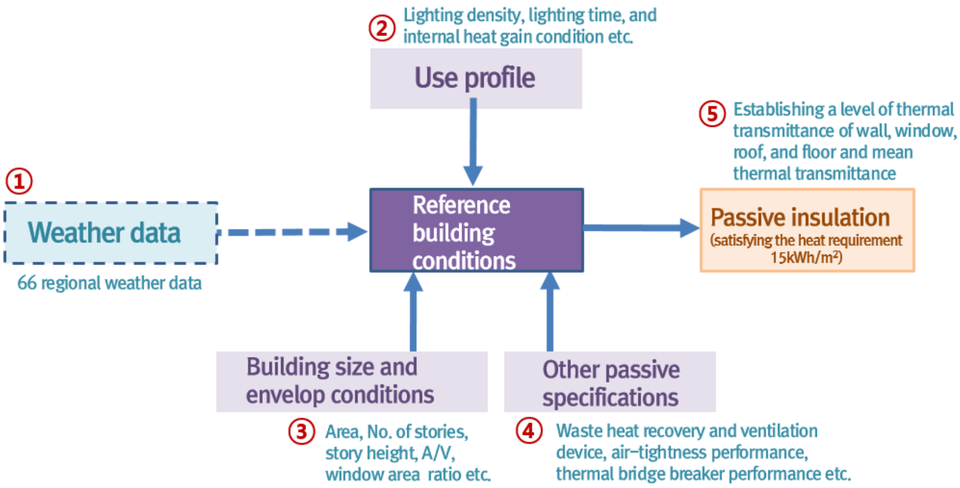


Figure 2. Process to calculate an insulation level to satisfy the passive heating requirement.

3.1. Meteorological Data Conditions

The methodological data used in this study employed 66 data sets [14] in Korea constructed with dry bulb temperature, humidity, solar radiation, and wind volume based on ISO 15927-4 to present thermal transmittance that satisfied the passive level in each of the regions.

3.2. Buiding Sizes, Envelope Conditions, and Other Passive Specifications

An envelope conduction loss and solar heat gain vary in buildings according to building characteristics (size, envelope conditions, and a ratio of envelope area with floor area, etc.). In particular, they are also affected by the parameter zone condition according to a ratio of envelope area with floor area. There is a difference in energy requirements in buildings ultimately due to a sum of heat loss and gain of internal heat generation, envelope loss, and solar radiation according to the characteristics of buildings. This is illustrated in Figure 2. Accordingly, 34,000 buildings that had a permit of the BECC from January 2014 to August 2018 were analyzed to determine the reference conditions of non-residential buildings constructed in Korea and building size and envelope conditions were defined. Note that since a simulation model configuration that satisfied all mean values of the certification data was impossible, some of the variables were referred from existing study 10 based on the certification data. For other passive specifications, passive house standards and DIN (Deutsche Industric Normen) standards in Germany were followed. Table 2 summarizes them.

Table 2. Building sizes, envelope conditions, and other passive specifications.

Building Size and Envelop Conditions		Other Passive Specifications	
No. of stories	4.27 [stories]	Waste heat recovery and ventilation device	75 [%]
Story height (mode)	3.6 [m]	Air tightness performance	0.6 [times, based on n50]
Heating area of ground floor	7060 [m^2]	Thermal bridge	0.1 [W/m·K]
Based on outside insulation Wall area ratio to (A)	0.577 [-]	Area ratio of roof	0.2365 [-]

3.3. Use Profile

Since lighting hours, heat generation by residents, and indoor heat generation can vary according to the use profile due to room configuration of buildings, internal heat generation acquisition is determined for the inside of buildings. The standard setup conditions were produced by calculating the area weight use profile according to a room configuration ratio through building investigations on 881 cases of preliminary certification of building energy efficiency rating in 2016 and 2017 to calculate the conditions of the reference building in Figure 3. Accordingly, this study reflected the use profile according to DIN 18599 [15] in Germany and their setup conditions are presented in Table 3.

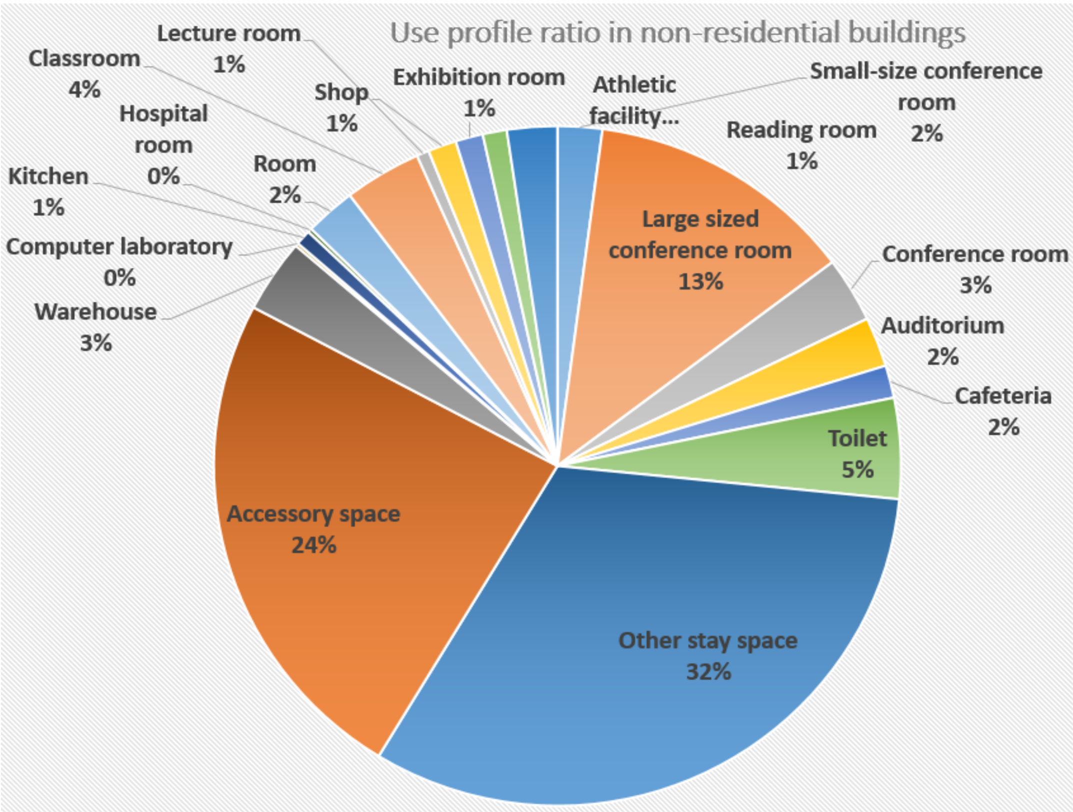


Figure 3. Room configuration ratio through building investigation on 881 cases.

Table 3. Setup conditions of non-residential buildings according to room configuration ratios.

Category	Unit	Buildings Other Than Residential Purpose	Business Facility (Efficiency Grade)	Business Facility (Total Energy Consumption)
Minimum outdoor air volume	[$m^3/(m^2 \cdot h)$]	6.15	5.93	5.66
Lighting time	[h]	10.25	10.4	10.14
Person	[$Wh/(m^2 \cdot day)$]	58.3	59.3	57.02
Work auxiliary equipment	[$Wh/(m^2 \cdot day)$]	38.4	42.4	49.18
Indoor heat emission amount	[$Wh/(m^2 \cdot day)$]	96.7	101.7	106.2

4. Study on the Insulation Standard Level by Region

4.1. Heating Energy Requirment by Case Region According to the Current Energy Saving Design Standards

The heating energy requirement in DIN 18599 is marked as a sum of envelope conduction heat loss, ventilation heat loss, internal heat generating acquisition, and solar radiation acquisition, and it indicates a heat generating value that maintains a temperature according to the set indoor temperature in the condition of monthly mean outdoor air temperature during the heating period.

This study analyzed the annual heating energy requirements using four regional meteorological data of Pyeongchang, Seoul, Gwangju, and Jeju by applying thermal transmittance of the aforementioned reference building conditions and current energy saving design standards [16] (2016) in the building parts by region. In Figure 4, each of Pyeongchang, Seoul, Gwangju and Jeju represent a city in the zone of Middle 1, Middle 2, Southern and Jeju. Pyeongchang, though in the same latitude as Seoul, shows the coldest regional characteristic as the mountainous climate due to the Taebaek mountain range. Seoul, Gwangju and Jeju show the characteristics of a warm climate as they go southward.

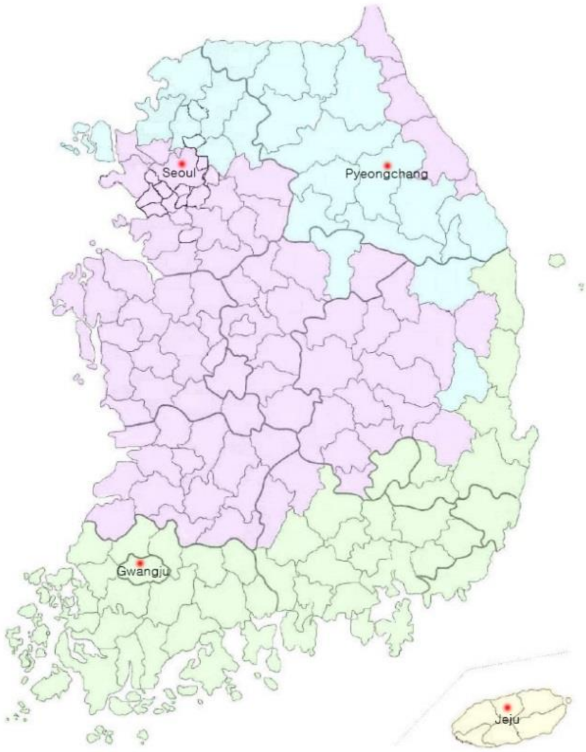


Figure 4. Location of representative cities by area.

The comparison results of regional heating energy requirements in Table 4 showed that, as an outdoor air temperature was decreased, the requirements in most regions were increased. However, despite higher outdoor air temperature in Jeju in April than that of Seoul, a small heating energy requirement was generated. This result indicated that a solar energy gain [16] in Jeju was small due to the meteorological characteristics of Jeju Island despite the high mean temperature, which affected the heating energy requirements. The comparison results of annual heating energy requirements by region showed that Pyeongchang had the highest annual heating energy requirement followed by Seoul, Jeju, and Gwangju. Despite the difference in thermal transmittance in building parts by region due to the insulation performance of the current energy saving standards, buildings in Gwangju and Jeju were close to the passive building level, whereas Pyeongchang and Seoul had relatively high annual heating energy requirements. In particular, Pyeongchang had the same middle region standards applied to Seoul although Pyeongchang was a very cold place whose outdoor air temperature was significantly different from that of Seoul region, which was why Pyeongchang had a higher heating energy requirement than that of Seoul. A very cold place such as Pyeongchang needed improvements in thermal transmittance of more than existing insulation performance for building parts to satisfy the passive level or balance between regions.

Table 4. Heating energy requirements according to monthly outdoor temperature by region.

	Category		January	February	March	April	October	November	December	Heating Requirement kWh/(m^2·Year)
Pyeongchang (Middle 1)	Outdoor air temperature	°C	−9.0	−5.0	−0.3	7.7	8.8	1.9	−4.3	29.8
	Heating energy requirement	kWh/(m^2·month)	9.9	5.5	3	0.1	0.1	3.5	8.0	
Seoul (Middle 2)	Outdoor air temperature	°C	−1.5	2.3	5.1	13.1	15.2	8.3	1.9	17.5
	Heating energy requirement	kWh/(m^2·month)	7.0	3.0	1.7	0	0	1.2	4.4	
Gwangju (Southern)	Outdoor air temperature	°C	1.1	3.9	8.3	14.2	15.7	10.2	2.8	14.4
	Heating energy requirement	kWh/(m^2·month)	5.8	2.4	0.9	0	0	0.4	5.0	
Jeju	Outdoor air temperature	°C	5.5	6.6	9.7	13.8	18.3	12.5	8.5	16.7
	Heating energy requirement	kWh/(m^2·month)	6.3	3.7	1.6	0.3	0	0.8	4.1	

Building Insulation Conditions That Satisfy the Passive Condition

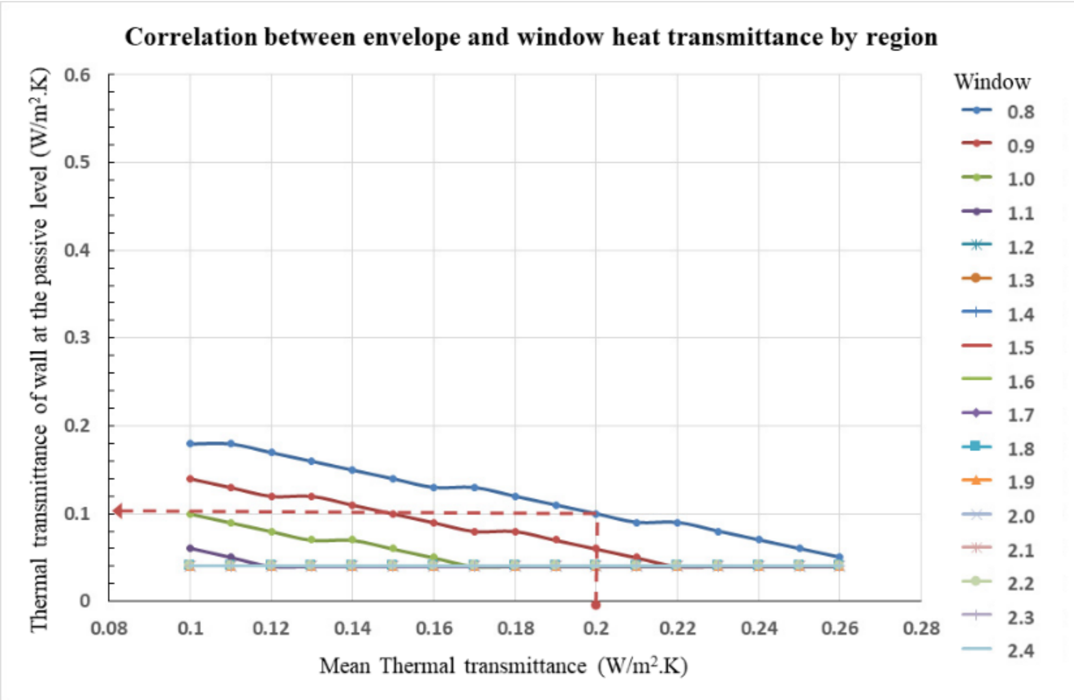
Among heat losses that make up the building energy heating requirements, a part of envelope conduction occurs at roofs, floors, windows, and walls of building overall. Thus, it is important to consider an insulation level in each of the parts compositely that satisfies 15 kWh/m^2·year, which is a heating energy requirement of passive standard for reference buildings. Figure 2 shows the correlation of thermal transmittance between window and envelope by region that satisfies the passive level. For Pyeongchang and Seoul, when a mean thermal transmittance 0.2 W/m^2K of roof and floor, which is close to the current energy saving standard level, is satisfied, the heat loss through envelopes is large due to low outdoor air temperature in the case of Pyeongchang. Thus, the minimum window thermal transmittance shall satisfy 0.9 W/m^2K at least and thermal transmittance of walls shall be lower than 0.1 W/m^2K to satisfy the passive level. For Seoul, this belongs to the middle region, although Seoul has a lower outdoor air temperature than that of Pyeongchang, when thermal transmittance of roof and floor is 0.2 W/m^2K and window thermal transmittance is 1.5 W/m^2K, which is the current middle-region standard, the wall thermal transmittance shall be lower than 0.14 W/m^2K to satisfy the passive standard. This result implies that additional regional segmentation is needed for places where outdoor air temperature is significantly different even if those regions belong to the same middle region. In contrast, Gwangju satisfies the passive standard already even in terms of the current regulation. For Jeju, when a mean thermal transmittance of roof and floor is 0.25 W/m^2K, which is close to the current standard, and a window thermal transmittance is 2.4 W/m^2K, the minimum of the wall thermal transmittance of the passive level should be at least 0.34 W/m^2K. Thus, better thermal transmittance than 0.43 W/m^2K, which is the current legal standard, is required.

Thus, it is important to strengthen each of the levels that can be acceptable in the market by taking insulation standards of roof, floor, window, and wall into consideration by region compared to the current standards in order to present an insulation standard for building parts in consideration of heating energy requirements with regard to the passive building level.

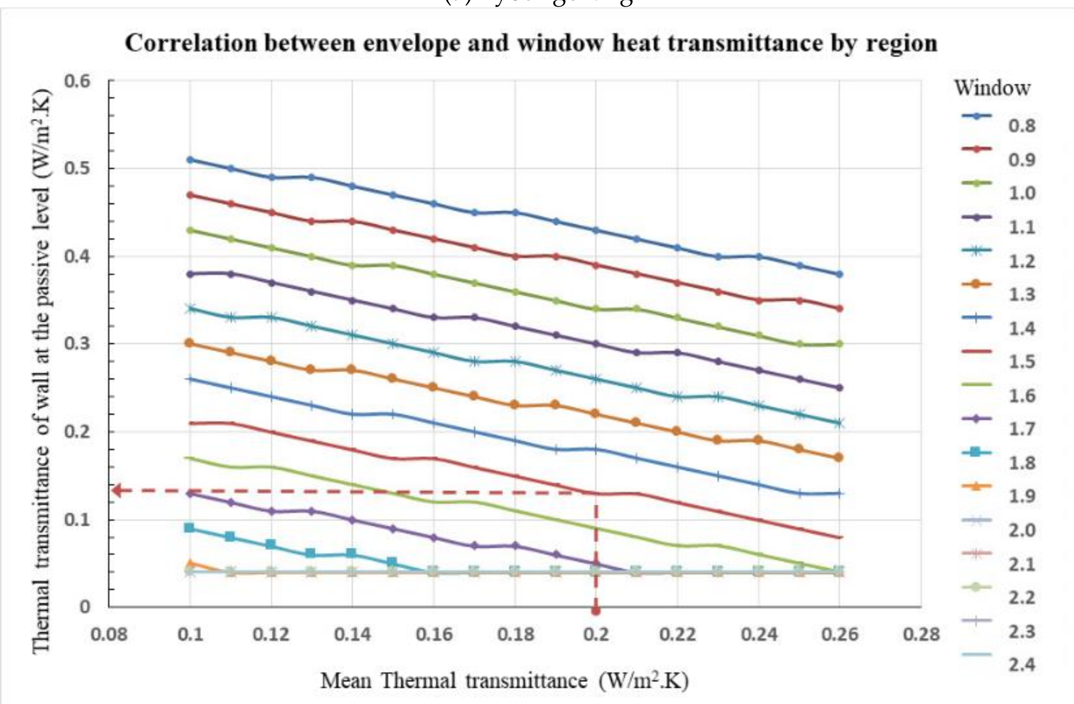
4.2. Study on the Passive Building Level by Region

4.2.1. Regional Heating Energy Requirement According to the Current BECC

Figure 5 shows the regional heating energy requirements that satisfy the current insulation standards based on the 66 regional standard meteorological data, which indicate the HDDs in the *y*-axis. Table 5 presents the cities and fractions that satisfy the regional passive standards according to Figure 5. The purpose of this study is to provide a measure that satisfies a certain level and minimizes energy loss through outer walls or windows of buildings by applying the insulation standard of the passive building level with regard to all buildings around the nation. As a result, Figure 5 shows that the annual heating energy requirements are not met based on the current insulation standards for regions where outdoor air temperature is low (the HDDs are large).

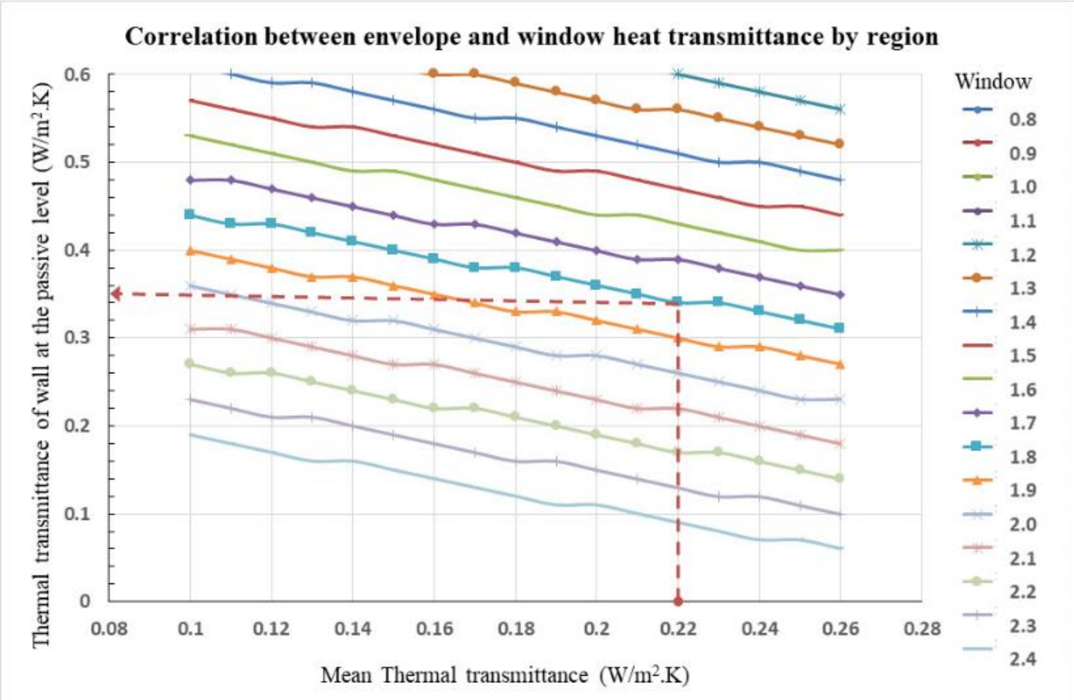


(**a**) Pyoungchang

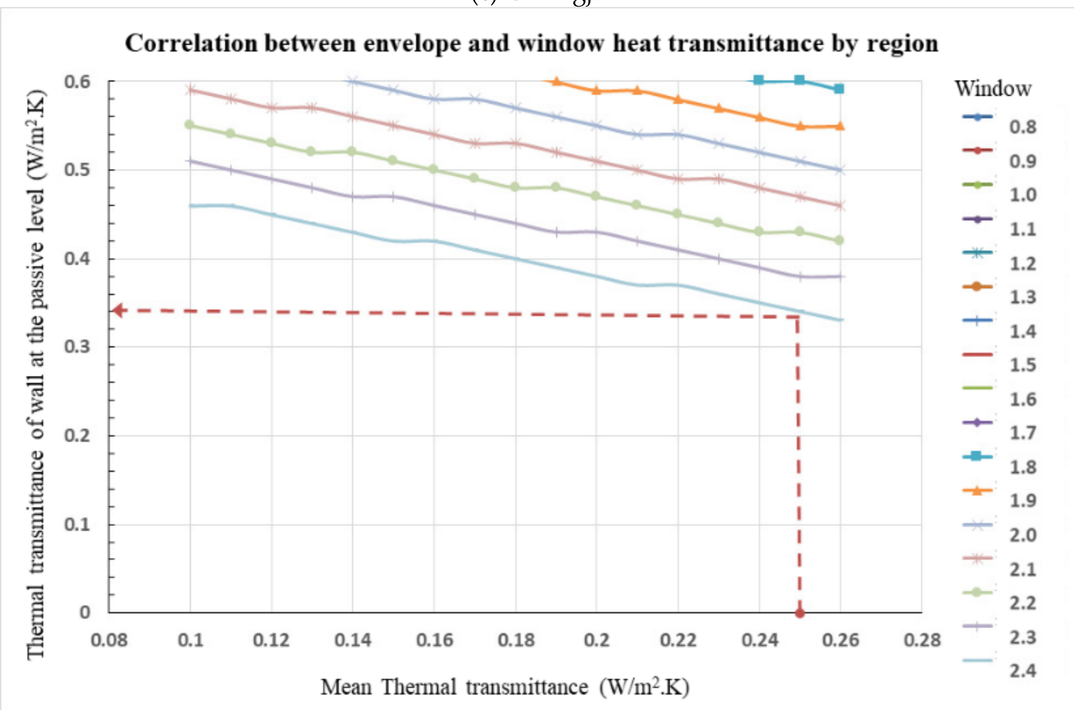


(**b**) Seoul

Figure 5. *Cont.*



(**c**) Gwangju



(**d**) Jeju

Figure 5. Correlation between envelope and window thermal transmittances by region that satisfies the passive level.

Table 5 presents that a proportion of cities that satisfy the passive level in Middle 1 region is 0%, and 10 cities satisfy the passive level out of 31 cities in Middle 2 region (32%), and 18 out of 21 cities (86%) satisfy the passive level in the Southern region. The results in Table 5 indicate that the insulation standards for Middle 1 and 2 regions where an outdoor air temperature is low should be strengthened more, while most of the southern regions except for Jeju satisfy the passive level, which implies that the current standard seems relatively reasonable.

Table 5. Fraction that satisfies the passive conditions for buildings except for apartments by region according to the current insulation standards.

No. of Cities in Region	Middle 1	Middle 2	Southern	Jeju
No. of cities that satisfies the passive conditions	12	31	21	1
Passive fraction	0	10	18	0

4.2.2. Insulation Level by Building Part That Satisfies the Passive Condition by Region in Korea

Figure 6 shows a graph of mean thermal transmittances of window, floor, and roof according to the level of wall thermal transmittance for each region. Using the above method, Table 6 presents the revised version to make Middle 1 and 2 regions satisfy the passive level around 50% based on the current insulation standards [17] and most of the southern and Jeju regions satisfy the passive level, in which a strengthened ratio for each of the thermal transmittances is summarized. Overall, an insulation standard in the Middle 1 region was strengthened by 17% to 35% and that in Middle 2 and Jeju regions by 5% to 8% while the southern region maintained the current level. The thermal transmittance for roofs facing the outdoor air was not strengthened. This was because the thermal transmittance of existing roofs has already been strengthened due to the effect of cold radiation of perforation or winds compared to that of the floor and nearly reached the passive level already. Thus, cities that satisfied the passive level according to the proposed thermal transmittance by building parts exhibited 50% for Middle 1, 47% for Middle 2, 95% for Southern, and 100% for Jeju in Table 7.

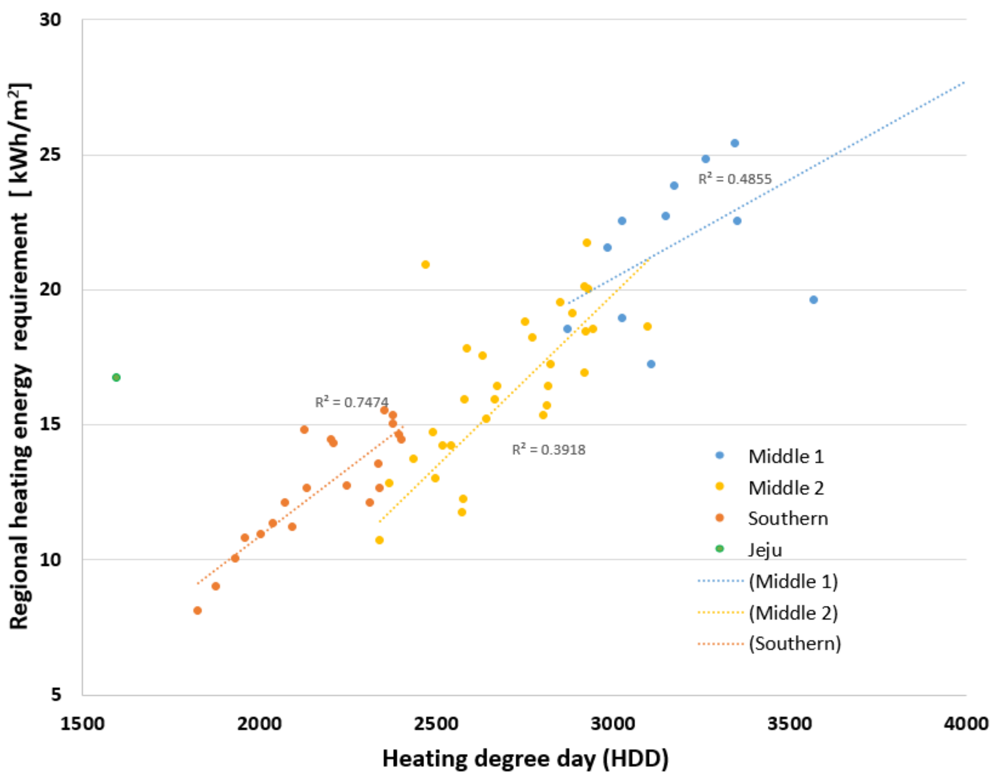


Figure 6. Regional heating energy requirement by region according to the current insulation standard.

Table 6. Strengthened level of insulation standards.

		Middle 1	Middle 2	Southern	Jeju
Existing buildings Thermal transmittance [W/m^2·K]	Windows facing the outdoor	1.5		1.8	2.4
	Roof facing the outdoor	0.15		0.18	0.25
	Floor facing the outdoor	0.22		0.22	0.33
	Outer wall	0.26		0.32	0.43
Revised Thermal transmittance [W/m^2·K]	Windows facing the outdoor	1.2	1.5	1.8	2.2
	Roof facing the outdoor	0.15	0.15	0.18	0.25
	Floor facing the outdoor	0.15	0.17	0.22	0.29
	Outer wall	0.17	0.24	0.32	0.41
Strengthening ratio [%]	Windows facing the outdoor	20%	0%	0%	8%
	Roof facing the outdoor	0%	0%	0%	0%
	Floor facing the outdoor	17%	6%	0%	0%
	Outer wall	35%	8%	0%	5%

Table 7. Fraction that satisfies the passive conditions for buildings except for apartments by region according to the strengthening of the insulation standards.

	Middle 1	Middle 2	Southern	Jeju
No. of cities in region	12	32	21	1
No. of cities that satisfy the passive conditions	6	15	19	1
Passive fraction	50%	47%	95%	100%

5. Analysis on the Effect of Regulation According to the Passive Level

In South Korea, when a citizen's right is regulated legally, whether the regulation is reasonable or not has to be examined through many procedures by the nation. The energy cost–benefit obtained through the direct cost added due to the standard strengthening and energy reduction rate is compared and regulation examination is recommended to have a net benefit within 10 years.

5.1. Cost–Benefit Analysis for Regulated General Citizens

Based on the aforementioned conventional and proposed insulation conditions, costs due to strengthening insulation standards on walls, roofs, floors, and windows were calculated by region. All costs are expressed in US Dollars.

5.1.1. Envelope Insulation

A ratio of the envelope area to the total area was referred to from 2016 building statistical data of building energy efficiency rating certification, and added material cost per unit area [18] was calculated by referring to the consumer price information and supplier's quotes. For the cost calculation of the insulators used due to insulation strengthening, the use of Graphite Expandable Polystyrene (G-EPS) foam (Rating A) was assumed. Table 8 presents the rising cost added due to insulator construction per 1000 m^2 of total floor area.

Table 8. Calculation of rising construction costs of added insulators per 1000 m^2 of total floor area.

Item	Area	Additional Construction Cost ($)			
		Middle 1	Middle 2 (Existing Middle)	Middle 2 (Existing Southern)	Jeju
Wall	575.5	2.3	0.4	1.2	0.2
Roof	236.5	0	0	0.6	0
Floor	231.6	0.6	0.2	0.5	-

5.1.2. Window Insulation

By referring the above efficiency rating statistical data, additional costs were calculated with regard to a window facing the outdoor air directly (if an indirectly-faced window is applied, additional construction costs are reduced. Thus, this study chose a window facing the outdoor air directly in the conservative calculation). Table 9 presents the additional construction cost calculated based on the strengthened window thermal transmittance.

Table 9. Applied values of additional construction cost according to the window insulation levels per 1000 m^2 of total floor area.

Item	Additional Construction Cost Per 1000 m^2 ($)		
	Current	Revision	
	Window Specifications	Window Specifications	Additional Construction Cost
Middle 1	28T low-e double glazing AL insulation bar window	42T low-e argon triple glazing AL window	6326
Middle 2 (Existing Southern)	24T low-e double glazing AL window	28T low-e double glazing AL insulation bar window	11,678
Jeju	22T double glazing AL window	24T low-e double glazing AL window	2433

5.1.3. Calculation of Total Cost

Table 10 presents the added construction cost with regard to rising construction cost per 1000 m^2 of total floor area based on the previously calculated results in Table 9. This can be converted to the cost that occurred nationally as follows: the government of Korea has developed a database of building permits every year by operating SEUMTER by the Ministry of Land, Infrastructure, and Transport. The additional cost for the whole regions was calculated based on the mean building permit area data for seven years (2010 to 2016), which were statistically processed by building use among the data in SEUMTER. The derived equation is as follows:

$$\text{Middle 1 region } 7{,}576{,}271\ \text{m}^2 \times \$9.3 + \text{Middle 2 region (previously Middle region) } 41{,}121{,}076\ \text{m}^2 \times \$0.6 + \text{Middle 2 region (previously Southern region) } 18{,}564{,}911\ \text{m}^2 \times \$41 + \text{Jeju region } 2{,}498{,}341\ \text{m}^2 \times \$2.7 = \$424{,}845{,}000$$

Table 10. Calculation of rising construction cost per 1000 m^2 of total floor area.

Item	Additional Construction Cost ($)				
	Middle 1	Middle 2	Middle 2	Southern	Jeju
Windows	6325.8	-	11,678.4	-	2433.0
Outer wall	2319.3	356.8	1248.8	-	178.4
Roof	-	-	574.4	-	-
Floor	646.1	215.4	502.6	-	71.8
Subtotal	9291.2	572.2	14,004.2	0	2683.2

5.2. Reduction in Heating Cost Due to Energy Requirement Reduction

The heating cost reduction benefit was calculated according to the energy cost saving by building owner as a result of improvements in new building energy performances. The benefit analysis was conducted based on buildings constructed in accordance with the conventional design standards. The energy reduction of the building was calculated using the calculation method of heating energy requirements in ISO 13790, and the setup conditions were referred to through the use profile in the building energy efficiency rating certification scheme. Table 11 presents the comparison results after calculating the heating energy requirements according to the strengthened insulation standards based on the buildings located in Middle 1, Middle 2, Southern, and Jeju regions. A unit cost per 1 Mcal was referred to from the Korea Energy Handbook published by the Korea Energy Agency [19].

Table 11. Comparison results after calculating the heating energy requirements according to the strengthened insulation standards based on different region.

Item	Additional Construction Cost ($)				
	Middle 1	Middle 2	Middle 2	Southern	Jeju
Windows	6325.8	-	11,678.4	-	2433.0
Outer wall	2319.3	356.8	1248.8	-	178.4
Roof	-	-	574.4	-	-
Floor	646.1	215.4	502.6	-	71.8
Subtotal	9291.2	572.2	14,004.2	0	2683.2

The results showed that the annual energy usage per unit area in non-residential buildings in Korea was 258 kWh/m^2·year and a ratio of heating energy was 35.5% approximately according to the 2014 Energy Consumption Survey [19]. Accordingly, the energy savings per unit area by zone, and the resulting savings are summarized in Table 12.

Table 12. The energy savings per unit area by zone, and the resulting savings.

	Middle 1	Middle 2	Middle 2 (Existing South)	Southern	Jeju
Energy savings per unit area-year [Kwh/m^2·year]	21.9	3.6	26	-	8.9
Energy saving amount per unit area-year [$/m^2]	1.4	0.2	1.7	-	0.6
Amount saved by region [$]	$13.207 billion US	$11.656 billion US	$38.458 billion US	-	$1.765 billion US

The average national building permit area from 2010 to 2016 was 101,558,000 m^2. Accordingly, the energy reduction benefit of buildings except for apartments can be calculated for buildings that satisfied the passive level insulation standards based on the areas of the regions presented in Section 5.1.3 considering a discount rate for 30 years of building service life as follows: $13,207,000,000 for Middle 1, $11,656,000,000 for Middle 2 (previously Middle), $38,458,000,000 for Middle 2 (previously Southern) and $1,765,000,000 for Jeju. Thus, a total of $65,086,000,000 can be reduced.

5.3. Analysis on ROI

The return on investment (ROI) for the Middle 1 region was analyzed when the passive level insulation standards are satisfied as follows: for the payback period, assuming that the moving-in starts two years after meeting the passive-level insulation criteria, the initial payback period by applying the discount rate and the generated annual cost savings per zone of residential/non-residential buildings since moving into the buildings (2020) are as shown in Table 13.

The relative ratio of average building permit area in 2010 to 2016 is as follows: Middle 1: 7.79%, Middle 2 (previously Middle): 43.36%, Middle 2 (previously Southern): 19.57%, Southern: 26.68%, and Jeju: 2.60%. The national average ROI is 6.2 years after residents move.

Table 13. The energy savings per unit area by zone, and the resulting savings.

	Middle 1	Middle 2	Middle 2 (Existing South)	Southern	Jeju
Cost Saving Effect [$]	$1.0576 billion US	$0.9334 billion US	$0.3080 billion US	-	$1.4 million US
Increase of Amount in Construction Cost [$]	$7.5778 billion US	$5.8074 billion US	$28.1859 billion US	-	$0.7282 billion US
Payback period	10.2 years	6.6 years		-	6.2 years

6. Conclusions and Policy Implications

This study calculated energy requirements that satisfied the insulation standards of the BECC for building parts by region according to regional climate conditions using the methodology of ISO 13790 and presented the insulation standards that satisfied the passive building standards for each of the regional climate conditions. The conclusions of the study results are summarized as follows:

(1) The regional monthly heating energy requirements had a close correlation mostly with the monthly average outdoor air temperature during the heating period (October to March). The heating energy requirement for each region was as follows: 29.8 kWh/m^2·year in Pyeongchang, 17.5 kWh/m^2·year in Seoul, 14.4 kWh/m^2·year in Gwangju, and 16.7 kWh/m^2·year in Jeju.

(2) The thermal transmittance of building part by region should take the outdoor air condition of the region into consideration compositely to satisfy the passive level of buildings. For Pyeongchang and Seoul, which belonged to the same middle region, when a thermal transmittance of roof/floor of buildings was 0.2 W/m^2K, the minimum window thermal transmittance should satisfy 0.9 W/m^2K and the minimum wall thermal transmittance should satisfy 0.1 W/m^2K in the case of Pyeongchang. On the other hand, the minimum window thermal transmittance should satisfy 1.5 W/m^2K and the minimum wall thermal transmittance should satisfy 0.14 W/m^2K in the case of Seoul. Buildings in Gwangju, which belonged to the Southern region, satisfied the passive level already. For Jeju regions, the minimum wall thermal transmittance should satisfy 0.34 W/m^2K to meet the passive level of buildings if the roof/floor and window thermal transmittances were close to the level specified in the current BECC.

(3) This study investigated the regional meteorological conditions based on 66 meteorological datasets to strengthen energy saving up to the passive building level by region in Korea and proposed a requirement of 50% or higher passive insulation standards for Middle 1 and 2 regions, and nearly 100% passive insulation standards for Southern and Jeju regions considering the market and technical conditions.

(4) The energy benefit obtained through the additional direct cost and energy reduction rate was analyzed due to the strengthening of the insulation standards that satisfied 0.17 W/m^2K for Middle 1, 0.24 W/m^2K for Middle 2, 0.32 W/m^2K for Southern region, and 0.41 W/m^2K for Jeju in the case of outer walls, and 1.2 W/m^2K for Middle 1, 1.5 W/m^2K for Middle 2, 1.8 W/m^2K for Southern region, and 2.2 W/m^2K for Jeju in the case of windows. The results showed that the national average ROI was approximately 6.2 years after moving to new building.

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