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Influencing of the Building Energy Policies upon the Efficiency of Energy Consumption: The Case of Courthouse Buildings in South Korea

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Abstract: As Korea has declared to realize a net-zero emission by 2050 in the Paris Agreement, the country has begun to implement national energy efficiency policies through the Green Standard for Energy and Environmental Design (G-SEED) certification and revision of building insulation thickness standard. However, some studies have reported the ineffectiveness of G-SEED certification and insulation thickness standard in reducing the energy consumption in certain buildings. Therefore, this study investigated the effectiveness of G-SEED certification and the revision of buildings' insulation thickness standard, and evaluated the energy consumption of courthouse buildings. In addition, this study investigated the total annual energy consumption (electricity, gas, and heating energy) per gross floor area of courthouse buildings located in the central and southern regions of South Korea. Although many studies about the energy consumption analysis of non-residential buildings have been performed previously, a study evaluating the effectiveness of green certification and building insulation thickness standard on the energy consumption of courthouse buildings was performed for the first time. The results revealed that the revision of building insulation thickness standard and G-SEED certification resulted in an energy consumption efficiency of 34.61 and 31.14%, respectively. These results indicated the effectiveness of G-SEED certification and the revision of the building insulation thickness standard for enhancing energy efficiency in Korean courthouse buildings. However, some negative results were observed in the southern area, indicating that it is essential to increase the effectiveness of the building insulation thickness standard and G-SEED certification implementation.

Keywords: energy consumption; G-SEED; building insulation thickness standard; energy efficiency; government public buildings

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1. Introduction

Climate change, global warming, gas emissions, and energy shortage are the most critical global environmental issues presently [1]. In 2018, Korea was ranked the third highest country in energy consumption per gross domestic product (GDP) among other International Energy Agency (IEA) member countries [2]. Owing to these environmental issues, countries globally, including Korea, declared the initiation of a net-zero emission by 2050 as per the Paris Agreement with an increase in energy consumption [3]. Among several sectors contributing to these global environmental issues, the building sector has been identified as a major contributor over the last decades [4]. Particularly, poorly planned buildings consume more energy [5], which can increase energy production demand and results in global warming and climate change. IEA [2] has reported the steady annual increase in the energy consumption of Korea's buildings. Currently, existing buildings account for more than 30% of the total global energy consumption [6]. Therefore, the building sector exerts a large-scale effect on the total global energy consumption. As the building sector is largely responsible for global energy consumption, it is necessary and pivotal to analyze the energy consumption of buildings [7].

Public buildings, as well as residential buildings, consume enormous energy. In 2019, the Global Alliance for Buildings and Construction [8] revealed that public buildings contributed 8% of the total energy consumption of the building sector. Accordingly, the energy consumption of buildings has emerged as a genuine concern since 2002 [9], and it will continue to be in the future [10]. To reduce the energy consumption of buildings, Korea has implemented a building certification system known as the Green Standard for Energy and Environmental Design (G-SEED) as a certification mark for the performance of green building practices, and for providing rewards for buildings complying to this certification requirement [11]. One of the methods to accomplish this certification assessment is via the energy consumption analysis of buildings. Therefore, analyzing the energy consumption of Korean public buildings is essential to achieve the comprehensive implementation of national net-zero energy.

Previous studies have reported that high-level green building certification and building insulation thickness standard contribute to the minimization of the energy consumption of buildings; thus, this study focused on these two policies [12,13]. In Korea, despite the increasing popularity of G-SEED and building insulation thickness standard, there is a need to enhance the quality of these standards to fully realize national and international policies regarding the net-zero energy of buildings. Moreover, several studies have reported the inadequacy of green certification and revision of building insulation thickness standard in reducing the energy consumption of buildings. For example, a previous study reported that 28–35% of green commercial buildings in the United States utilized more energy than their non-green building counterparts [14]. For the insulation thickness standard, a previous study analyzed the effect of the revision of Korea's building insulation thickness standard on the energy consumption of residential buildings, and found that the implementation of the revised building insulation thickness standard did not exert a decreasing effect on the gas energy consumption of these buildings [15]. Therefore, to confirm the effectiveness of G-SEED certification and the revision of the building insulation thickness standard, this study verified and analyzed the energy consumption of public government buildings. Moreover, as the nature of the system covers a wide range of buildings, studies on the verification of the effectiveness of the G-SEED certification and the revision of the building insulation thickness standard on the energy consumption of public government buildings in Korea are insufficient.

Most of recent references focused on green building system development rather than evaluating the actual energy consumption of green certified buildings. For example, improvement plans for the G-SEED certification of maintenance, re-maintenance, and existing buildings through an analysis of other domestic and foreign green certification systems have been carried out [16,17]. Analyzing the primary building materials to enhance the non-residential G-SEED certified building systems was also performed previously [18]. In addition, studies about building insulation thickness mostly inspected the optimum insulation thickness, which concentrated on a certain insulation thickness material, before simulating them into a model [19–21] rather than analyzing the energy consumption of buildings based on actual historical data to assess the effectiveness of insulation thickness. On top of that, many current studies are focused on analyzing the energy consumption of residential buildings. For example, Aydin et al. [22] investigated the optimum insulation thickness of residential buildings by lifecycle cost analysis in Turkey. Choi et al. [23] analyzed the energy consumption and CO_2 emissions performance by comparing G-SEED certified against G-SEED non-certified apartments in Korea. Additionally, Kim and Park [24] investigated the G-SEED certification systems based on the energy consumption of G-SEED certified apartments. Although many studies about the energy consumption of non-residential buildings have been performed, a study about evaluating and assessing the energy consumption of green certificated buildings and insulation thickness standard within the courthouse buildings was performed for the first time. Furthermore, to obtain the reliable and solid results as each type of building has its own energy consumption pattern, analyzing the similar type of building is necessary [25]. Considering the prior recent studies, this paper evaluates whether or not the G-SEED certification and insulation thickness standard have achieved efficiency in energy consumption in Korean courthouse buildings.

Several national policies have been implemented to reduce the energy consumption of buildings [26–28]. For example, the G-SEED certification has been implemented to achieve the energy efficiency of buildings. Additionally, the application of the building insulation thickness standard to building envelopes can be used to further increase energy efficiency. G-SEED was implemented in 2002 [29] and the building insulation thickness standard was made mandatory in 1977 [30], and both standards have been actively continuously developed. For example, there was a policy amendment and revision of the building insulation thickness standard in 2017 [31]. Therefore, this study aimed to analyze and examine the effect of the revision of the building insulation thickness standard and G-SEED certification on the energy consumption of government courthouse buildings in Korea. More importantly, this study aimed to identify the effectiveness of the recent energy efficiency policies for future studies. To this end, the research questions (RQs) of this study are as follows:

1. RQ1: Do G-SEED certified courthouse buildings exhibit effectively reduced energy consumption compared with G-SEED non-certified courthouse buildings?
2. RQ2: Is the current revision of the building insulation thickness standard effective in reducing the energy consumption of courthouse buildings compared with the previous revision of the building insulation thickness standard?

This study is divided into five parts, including the introduction in Section 1, which explains the background and objectives of this study. Section 2 contains a review of the existing literature and standards, such as energy consumption analysis in public buildings, Korea's G-SEED, and the revision of the building insulation thickness standard that can support the basis of this study. Section 3 includes the methodology of this study, which describes the consecutive steps employed in this study from data preparation to the analysis method used to achieve the study results. Section 4 present the results of the study, showing the findings of the analyzed data and the discussion of the results. Section 5 describes the conclusions of the analysis presented in previous sections and suggestions on important things observed in the study to be considered for further improvements.

2. Review of Existing Literature and Standards

2.1. Previous Studies on the Energy Consumption Analysis of Public Buildings

To improve the standard and policies, the analysis of the energy consumption of public buildings has emerged as a genuine concern and a crucial task owing to the significant energy-saving potential of public buildings. Public building energy consumption is defined as the energy consumption of air conditioning (A/C), heating, lighting, elevator, office equipment, and others, which utilize electrical, gas, and heating energy [13].

There are some factors affecting the energy consumption of buildings, such as the climate conditions in the geographic location of the building. The energy consumption of public buildings in severely cold regions has been analyzed, and the results have revealed that hotels, commercial, office, and school buildings exhibit the highest energy consumption [32]. In addition, economic analysis has revealed that centralized heating exhibits the largest energy cost. In addition to climatic factors, the influence of the COVID-19 pandemic on changes in the energy consumption of public buildings has been investigated using statistic correlation analysis, and the results revealed that the electrical and gas energy consumption in most public buildings tends to decrease by an average rate of −4.46 and −10.35%, respectively [33].

The comparative energy consumption analysis of public buildings has been an active research topic in recent years. The energy consumption characteristics of buildings can be analyzed using statistical methods based on the types of public buildings to identify specific buildings with the highest energy consumption [34]. For example, green school building and non-green school buildings have been compared using statistics and analysis of variance (ANOVA) to determine whether there is a significant difference, and the results revealed that green school buildings consumed 32% less energy compared with non-green school buildings [35]. Another study employed statistics to develop an energy efficiency benchmark using a case study approach, and found that university buildings with an energy consumption of 72.5 kWh/m^2/year can be considered as an energy-efficient building [36]. In addition, the energy consumption of green public buildings has been evaluated, and G-SEED certified and G-SEED non-certified public buildings have been analyzed using comparative analysis based on data from an open public portal, and the results revealed that the energy consumption intensity of G-SEED certified public buildings was 35.5–48.9% lower than that of the non-certified counterparts [37].

2.2. Korea's G-SEED

G-SEED was introduced in 2002 by the Ministry of Land, Infrastructure, and Transport (MOLIT) and the Ministry of Environment [29]. G-SEED is a representative green building certification system that assesses the performance of a building to reduce building-related environmental loads by reducing the energy consumption and carbon dioxide emissions of the building, which can occur during the building's life cycle [38].

The evaluation items and criteria of G-SEED are similar to that of the Leadership in Energy and Environmental Design (LEED) certification of the United States [37,39]. The G-SEED certificate grades the energy efficiency of buildings into Green 1 to Green 4 based on derived scores. G-SEED assessment points areas are comprised of nine categories. Among the categories, a building with the highest point weight can be described as an energy-efficient building, and thus can be considered as a G-SEED building.

In addition, G-SEED provides some advantages to building owners, and a G-SEED certified building is expected to be a green building. In addition, buildings that are assigned as G-SEED certified or have achieved a high score in the energy performance evaluation will be granted with incentives, such as tax reductions, floor area ratio concession, and building height reduction by the government [40]. Studies on the analysis of the energy consumption of G-SEED certified buildings have been conducted previously, and have demonstrated the low energy consumption of these buildings. For example, Kim et al. reported that the energy-saving effect of G-SEED certified office buildings is 50% higher than that of G-SEED non-certified office buildings [11].

However, there are some obstacles that affect G-SEED evaluation. From an economic perspective, the application of the "Design Standards of Green Buildings" in residential buildings for G-SEED certification typically results in increased construction costs according to level-upgrade adjustments to achieve an excellent rating from G-SEED, but mandatory design items were reduced [41]. Additionally, from the perspective of building management, residential buildings become non-compliant to G-SEED certification when occupied by tenants despite the previous G-SEED certification of the building [42]. Therefore, there is a need to improve the G-SEED effectiveness in all perspectives to encourage building owners to pursue excellent G-SEED rating.

2.3. Revision of the Building Insulation Thickness Standard

Insulation of building envelopes is the most effective method to increase the thermal resistance and reduce the energy consumption for the cooling and heating of an internal area. It is one of the most essential features of building energy efficiency, which is a proven technology, and diverse insulation methods have been investigated to evaluate its performance, such as the environmental effects of insulation thickness and layer configuration [43]. Balancing the energy-saving effects requires the consideration of the appropriate selection of insulation material and implementation of the optimum insulation thickness [44]. Therefore, the building insulation thickness standard plays an important role in the energy consumption of buildings.

Korea's national building insulation thickness standard was regulated in the "Energy Conservation Design Criteria for Buildings" [11], and has been continuously strengthened until 2017. The revised standard was officially implemented in 2018 [45]. The details of the revision of the building insulation thickness standard are shown in Tables 1 and 2. The insulation classification is divided into four grades (a, b, c, and d) based on the result of the thermal conductivity test of the insulation material, where grade 'a' to 'd' describes the smallest to the largest thermal conductivity values within a certain range [31]. The revision of the building insulation thickness standard affects buildings located in the central and southern areas of Korea. According to Table 1, all of the building insulation thickness standards of public buildings (non-residential) in the central area have been revised, except the ceiling of the highest level or roof of a building, which is directly exposed to the outside air. Moreover, as shown in Table 2, for buildings located in the southern area, the revision of the building insulation thickness standard only increased the thickness of the non-underfloor heating of the highest level of building, which is directly exposed to the outside air.

Table 1. 2017 revision of the building insulation thickness standard for the central region buildings.

Category of Building Envelopes			**Before Revision**				**After Revision**			
			Allowed Thickness (mm)				**Allowed Thickness (mm)**			
			a	**b**	**c**	**d**	**a**	**b**	**c**	**d**
Walls	Direct outside exposure	Non-residential buildings	125	145	165	185	135	155	180	200
		Residential buildings	155	180	210	130	190	225	260	285
	Indirect outside exposure	Non-residential buildings	85	100	115	125	90	105	120	135
		Residential buildings	105	120	140	155	130	155	175	195
Ceilings of the highest level or roof	Direct exposure to the outside air		180	220	260	295	330	220	260	295
	Indirect exposure to the outside air		120	145	170	195	220	155	180	205
Floors of the highest level	Direct outside exposure	Underfloor heating	175	205	235	260	190	220	255	280
		Non-underfloor heating	150	175	200	220	165	195	220	245
	Indirect outside exposure	Underfloor heating	115	135	155	170	125	150	170	185
		Non-underfloor heating	105	125	140	155	110	125	145	160

Table 2. 2017 revision of the building insulation thickness standard for the southern region buildings.

Category of Building Envelopes			**Before Revision**				**After Revision**			
			Allowed Thickness (mm)				**Allowed Thickness (mm)**			
			a	**b**	**c**	**d**	**a**	**b**	**c**	**d**
Walls	Direct outside exposure	Non-residential buildings	100	115	130	145	100	115	130	145
		Residential buildings	125	145	165	185	145	170	200	220
	Indirect outside exposure	Non-residential buildings	65	75	90	95	65	75	90	95
		Residential buildings	80	95	110	120	100	115	135	150
Ceilings of the highest level or roof	Direct exposure to the outside air		180	215	245	270	180	215	245	270
	Indirect exposure to the outside air		120	145	165	180	120	145	165	180
Floors of the highest level	Direct outside exposure	Underfloor heating	140	165	190	210	140	165	190	210
		Non-underfloor heating	130	150	175	195	130	155	175	195
	Indirect outside exposure	Underfloor heating	95	110	125	140	95	110	125	140
		Non-underfloor heating	90	105	120	130	90	105	120	130

There are three classifications of the building insulation materials in Korea. The classifications of insulation materials that are often used in Korean buildings include organic (expanded polystyrene, extruded polystyrene, rigid urethane foam, phenolic foam) inorganic (glass wool, mineral wool), and composite (low emissivity) [46]. Moreover, along with the development of technology, there are various ways to reduce energy consumption. Rehman et al. [47] proved that inorganic salt hydrates and zeolite composites can improve the performance of solar heat storage using thermochemical heat storage systems (TCMs). The organic integration of conjugated monomer 3,6-dibromopyridazine (DBP) with carbon nitride containing urea precursor (CNU) can also improve the performance of the semiconductor in the solar energy by promoting the photoreduction of carbon dioxide (CO_2) and hydrogen (H_2) evolution from water [48].

The main purpose of the revision of the Korea's building insulation thickness standard is to reduce the energy consumption of buildings. Choi et al. analyzed the impact of the revision of the building insulation thickness standard on the energy consumption of public buildings [49], and found that the energy consumption of Korean military barracks buildings in the central and southern areas decreased by 11% and 10%, respectively, after the implementation of the revised insulation thickness standard compared with buildings that applied the 1987 building insulation thickness standard. Therefore, continuous revision of the building insulation thickness standard is necessary to ensure the effectiveness of building energy efficiency.

3. Methodology

This study was conducted to analyze and examine the effectiveness of the revision of the building insulation thickness standard and G-SEED certification on the energy consumption of public government courthouse buildings. The steps followed in this study are shown in Figure 1. Prior to the data collection, previous literature was first reviewed to obtain the effect of G-SEED certification and the revision of the building insulation thickness standard on the energy consumption of public buildings, after which the review was summarized and used as a basis for the analysis of this study.

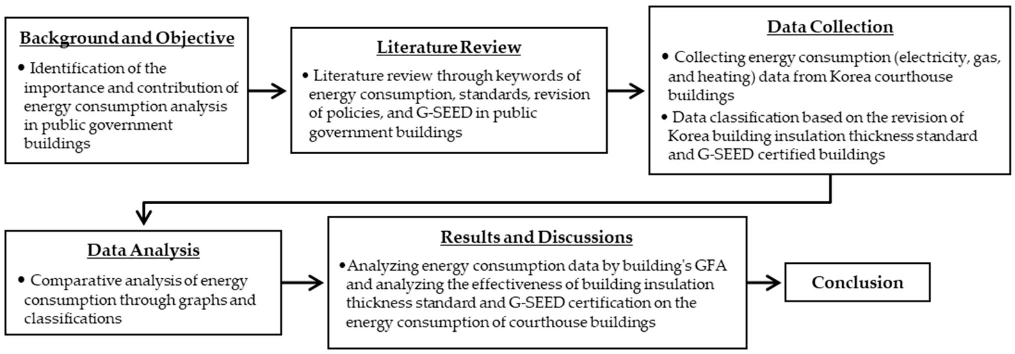

Figure 1. Research flowchart.

Next, the energy consumption data (gas, electricity, and heating) of Korean courthouse buildings in various regions were collected and organized based on the data classifications to achieve the goals of the study. To answer the research questions of this study, a comparative analysis was performed by plotting graphs and classifying the collected data. The impact of the revision of the building insulation thickness standard and G-SEED certification on the energy consumption of buildings was demonstrated by analyzing the collected data to achieve three aims: draw conclusions, achieve a comprehensive understanding, and suggest future policy improvements in building energy efficiency.

3.1. Data Collection

The data used in this study include the electrical, gas, and heating energy consumption data of buildings constructed before and after 2017. Table 3 shows the information of the research data that was analyzed and classified based on the following: year of completion of construction, G-SEED certified and G-SEED non-certified buildings, before and after the revision of the building insulation thickness standard, and GFA of the buildings in square meter (m^2) unit. Six of the nine courthouse buildings have already achieved a G-SEED certificate (Grade Green 2) and three buildings were yet to obtain a G-SEED certificate. These nine buildings are located in the central and southern areas, and were also classified based on "before and after the revision of building insulation thickness standard".

Table 3. Collected data information.

Categories		Name of Courthouse	Year of Completion	GFA (m^2)	G-SEED
G-SEED certified and after revision	Central area	Suwon family court	2020	18,164	certified
		Suwon district court	2019	89,441	certified
	Southern area	Jeonju district court	2019	38,934	certified
G-SEED certified and before revision	Central area	Cheonan branch court	2017	24,130	certified
		Seoul Eastern district court	2017	45,181	certified
	Southern area	Busan district court	2017	26,430	certified
G-SEED non-certified and before revision	Central area	Seoul family court	2012	41,669	non-certified
		Incheon district court	2002	36,801	non-certified
	Southern area	Ulsan district court	2014	35,174	non-certified

3.2. Data Conversion

The most consumed energy of the buildings includes gas, electrical, and heating energy. Therefore, in this research, data for the consumed gas, electrical, and heating energy were collected and analyzed using comparative analysis based on the classification of the courthouse buildings located in the central and southern areas. Energy consumption data include monthly electrical, gas, and heating energy consumption for 2021. The actual obtained total energy consumption data of each building were defined into three units, which are shown in Tables 4–6. The units of each energy consumption include kilowatt-hour (kWh) for electricity, mega-joule (MJ) for gas, and giga-calorie (GCal) for heating energy.

Table 4. Collected energy consumption data (G-SEED certified and after insulation thickness standard revision).

Category	Suwon Family Court			Suwon District Court		Jeonju District Court	
	Heating	Gas	Electricity	Heating	Electricity	Gas	Electricity
January 2021	133	4945	110,574	422	394,598	505,045	273,480
February 2021	72	7551	77,616	262	317,171	328,205	209,622
March 2021	33	9176	62,478	130	328,259	206,953	162,577
April 2021	7	10,265	49,896	31	268,115	128,567	143,367
May 2021	5	10,597	70,758	37	285,875	120,773	134,003
June 2021	5	178,714	95,616	358	398,963	360,351	183,180
July 2021	4	374,374	101,070	820	517,859	572,782	241,353
August 2021	4	423,987	101,376	701	492,467	524,828	251,419
September 2021	3	200,225	63,702	255	344,003	349,794	221,255
October 2021	4	44,828	63,972	60	293,123	181,632	158,189
November 2021	28	9819	77,868	117	321,299	134,235	151,768
December 2021	82	13,162	90,468	358	399,539	427,123	212,678

Table 5. Collected energy consumption data (G-SEED certified and before insulation thickness standard revision).

Category	Cheonan Branch Court		Seoul Eastern District Court		Busan District Court	
	Heating	Electricity	Heating	Electricity	Heating	Electricity
January 2021	182	107,920	200	280,590	121	105,567
February 2021	125	83,800	168	287,106	81	86,896
March 2021	65	73,684	95	214,026	56	91,552
April 2021	17	59,248	31	189,510	14	84,240
May 2021	13	56,985	41	178,472	40	86,812
June 2021	67	90,892	226	218,205	162	110,467
July 2021	144	120,412	371	246,357	248	142,254
August 2021	128	116,861	295	302,841	249	145,147
September 2021	70	91,563	177	270,945	146	108,070
October 2021	26	64,851	37	198,549	52	91,858
November 2021	62	79,359	88	207,225	13	88,055
December 2021	157	125,925	175	238,206	80	112,547

Table 6. Collected energy consumption data (G-SEED non-certified and before insulation thickness standard revision).

Category	Seoul Family Court		Incheon District Court		Ulsan District Court	
	Gas	Electricity	Gas	Electricity	Gas	Electricity
January 2021	1,453,245	243,903	1,837,082	281,496	709,005	162,984
February 2021	2,457,053	240,874	1,338,151	212,832	977,778	182,208
March 2021	1,544,465	269,496	889,360	246,600	711,792	147,192
April 2021	734,748	153,577	346,764	210,432	370,961	159,888
May 2021	244,616	137,453	151,613	275,232	218,876	141,192
June 2021	168,271	178,503	534,161	314,736	191,968	142,104
July 2021	520,734	208,655	1,820,255	336,648	466,488	188,688
August 2021	960,034	248,615	1,914,146	333,000	665,509	223,824
September 2021	1,129,775	233,733	932,983	265,440	716,233	215,448
October 2021	531,662	166,447	316,390	188,520	476,719	180,752
November 2021	205,939	155,009	353,367	217,392	264,157	156,096
December 2021	436,365	192,675	887,443	262,296	302,821	150,840

For the comparative analysis of energy consumption, all obtained gas and heating energy data were converted into a single kWh unit; according to the requirement of the United Nations [50], the unit of energy consumption of the heating (1 kWh = 0.00086 Gcal) and gas (1 kWh = 3.6 MJ) energy was converted to kWh. Therefore, before the data were analyzed, all of the gas (MJ) energy and heating (Gcal) energy values were converted into kWh. Subsequently, the total energy consumption per GFA (kWh/m^2) every month was analyzed through comparative analysis. The converted total energy consumption of each Korean courthouse building for comparative analysis in this study is shown in Tables 7–9.

Table 7. Total energy consumption of Korean courthouse buildings (G-SEED certified and after insulation thickness standard revision).

Category	Total Energy Consumption (kWh/m^2)		
	Suwon Family Court	Suwon District Court	Jeonju District Court
January 2021	14.76	9.90	10.62
February 2021	9.04	6.96	7.72
March 2021	5.72	5.36	5.66
April 2021	3.37	3.41	4.60
May 2021	4.39	3.69	4.30
June 2021	8.36	9.11	7.27
July 2021	11.6	16.46	10.29
August 2021	12.38	14.63	10.20
September 2021	6.79	7.17	8.18
October 2021	4.49	4.06	5.36
November 2021	6.26	5.12	4.86
December 2021	10.47	9.12	8.51

Table 8. Total energy consumption of Korean courthouse buildings (G-SEED certified and before insulation thickness standard revision).

Category	Total Energy Consumption (kWh/m^2)		
	Cheonan Branch Court	Seoul Eastern District Court	Busan District Court
January 2021	13.26	11.35	9.31
February 2021	9.49	10.67	6.85
March 2021	6.16	7.18	5.92
April 2021	3.30	4.98	3.81
May 2021	3.00	5.00	5.04
June 2021	7.01	10.64	11.31
July 2021	11.93	15.01	16.29
August 2021	11.00	14.29	16.45
September 2021	7.15	10.54	10.51
October 2021	3.96	5.34	5.77
November 2021	6.26	6.87	3.90
December 2021	12.79	9.77	7.78

Table 9. Total energy consumption of Korean courthouse buildings (G-SEED non-certified and before insulation thickness standard revision).

Category	Total Energy Consumption (kWh/m^2)		
	Seoul Family Court	Incheon District Court	Ulsan District Court
January 2021	18.43	21.52	10.24
February 2021	26.27	15.88	12.91
March 2021	19.88	13.41	9.82
April 2021	10.18	8.34	7.48
May 2021	5.84	8.62	5.75
June 2021	6.41	12.58	5.56
July 2021	10.06	22.89	9.06
August 2021	14.66	23.50	11.63
September 2021	15.58	14.25	11.79
October 2021	8.94	7.51	8.91
November 2021	6.04	8.58	6.53
December 2021	8.93	13.83	6.68

4. Results

4.1. Effect of the Revision of Building Insulation Thickness Standard

The revision of the insulation thickness standard contains the increase in insulation thickness building envelopes. The results revealed that increasing the insulation thickness contributed to the energy consumption efficiency of the Korean courthouses buildings, as shown in the comparison graph in Figure 2. The dotted lines in Figure 2 represent the energy consumption of the buildings constructed prior to the revision of the building insulation thickness standard, and the solid lines represent the energy consumption of buildings constructed after the revision. The gray lines (both dotted and solid lines), which represent the buildings in the central area, revealed that the increase in the building insulation thickness significantly contributed to the energy efficiency of the buildings (particularly at the beginning of the year from January to April), although the provided efficiency was high during the summer season. Figure 3 shows the bar chart of the comparison of the energy consumption of the courthouse buildings in the central regions. Generally, as shown in Figure 3, the increase in the building insulation thickness effectively enhanced the energy consumption of courthouse buildings.

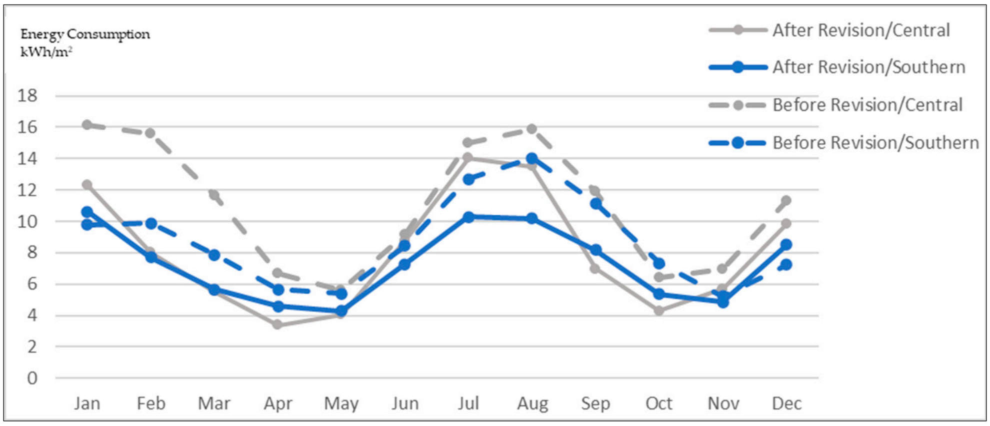

Figure 2. Line chart of the energy consumption of the courthouse buildings based on region and the revision of the building insulation thickness standard.

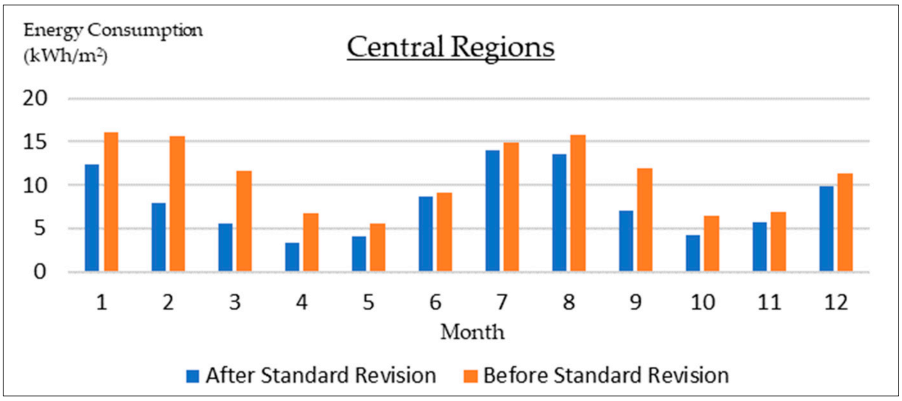

Figure 3. Bar chart of the monthly energy consumption of courthouse buildings in the central region based on the revision of the building insulation thickness standard.

Based on Tables 1 and 2, there were major revisions to the standard thickness for buildings in the central regions. Meanwhile, the revisions for the non-residential building in the southern regions were minor. Before the revision, we can see that the energy consumption of the courthouse buildings is fairly high compared with that after the revision. The results of this study also illustrate that the thickness of building insulation plays a major role in increasing room temperature during cold weather; as we can see in Figure 2, the comparison of energy consumption before and after revision in the central regions is significantly different in the cold weather (the first months of the year). In contrast, the minor revisions for the southern region's buildings are slightly effective in August. It can be seen that the differences in building insulation thickness result in dissimilar energy consumption of courthouse buildings.

The blue lines (both dotted and solid lines) in the image represent the buildings in the southern area, which reflects the positive impact of the revision of building insulation thickness standard on the energy consumption of courthouse buildings in this area. However, compared with the increase in the energy consumption efficiency of the courthouse buildings during winter, the efficiency in January and December decreased. As shown in Figure 4, in the winter season, courthouse buildings that implemented the revised insulation thickness standard consumed 8.51 and 10.62 kWh/m^2 of energy in December and January, respectively, whereas buildings where the standard was not applied consumed 7.23 and 9.78 kWh/m^2 of energy, respectively. These results indicated that the revision of the building insulation thickness standard was not very effective for buildings in the southern area, particularly in the winter season from December to January.

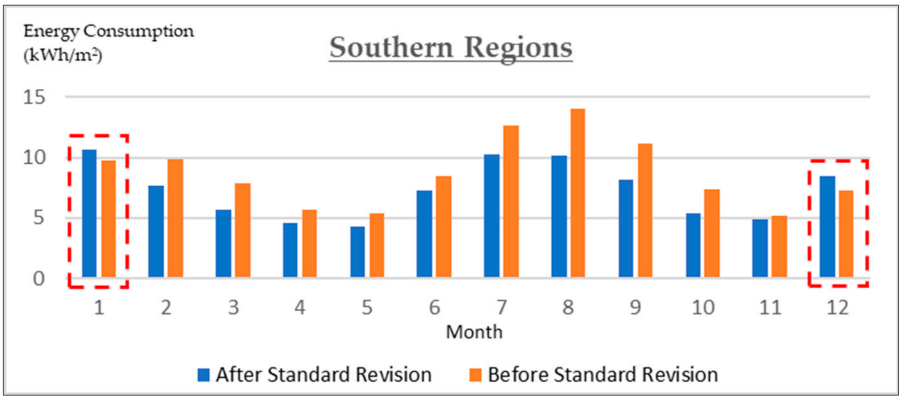

Figure 4. Bar chart of the monthly energy consumption of courthouse buildings in the southern region based on the revision of the building insulation thickness standard.

4.2. Effect of G-SEED Certification

G-SEED certified buildings exhibited effective energy consumption compared with the non-certified buildings. Figure 5 illustrates the positive effects of the G-SEED certification for reducing the energy consumption of buildings in the central area (the gray lines). However, in the summer season, the energy consumptions of the G-SEED certified buildings in the southern area (the blue lines) were higher than those of non-certified buildings. These findings indicated that the G-SEED assessment process in the southern area did not consider the energy consumption during the summer season.

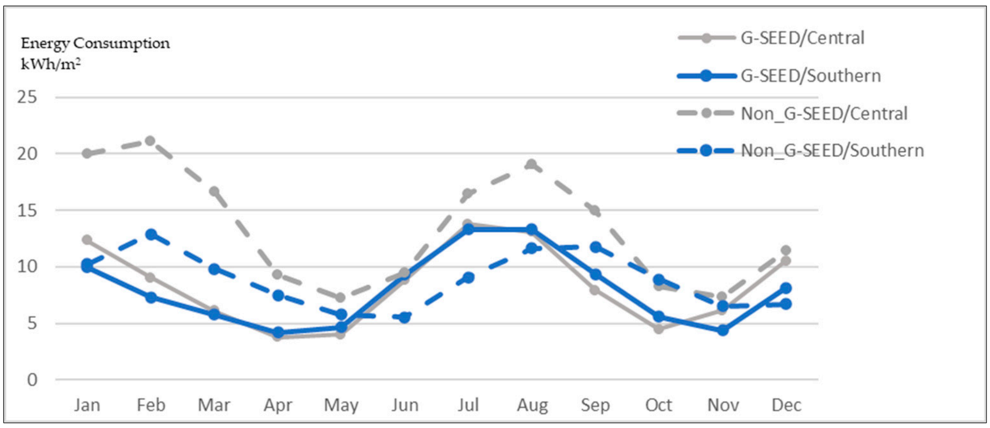

Figure 5. Line chart of the energy consumption of the courthouse buildings based on region and G-SEED certification.

Figures 6 and 7 show bar charts showing the comparison between the energy consumption of G-SEED certified (blue) and G-SEED non-certified (orange) buildings. In the central region (Figure 6), the monthly energy consumption of the G-SEED certified buildings was satisfactory. As shown in Figure 7, the energy consumptions of the G-SEED non-certified buildings in the southern areas from June to August were 5.56, 9.06, and 11.63 kWh/m^2, respectively, and 6.68 kWh/m^2 in December. However, those of the G-SEED certified buildings from June to August were 9.29, 13.29, and 13.33 kWh/m^2, consecutively, and 8.15 kWh/m^2 in December. These results indicated the ineffective energy consumption of the G-SEED certified buildings in the Southern area from June to August and in December.

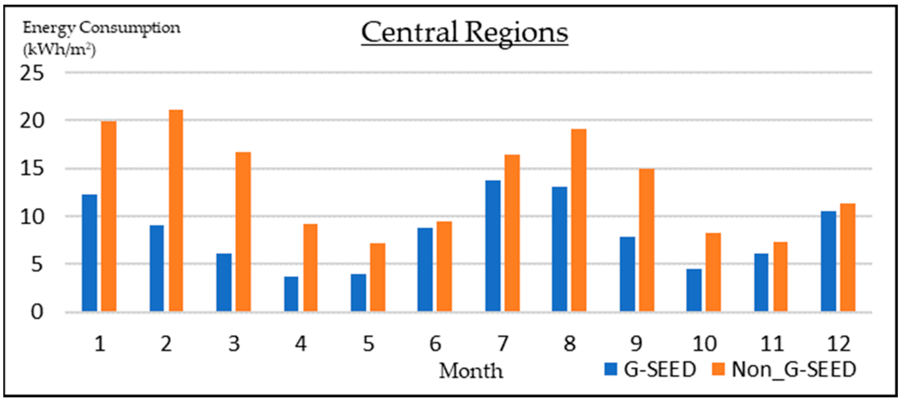

Figure 6. Bar chart of the monthly energy consumption of the courthouse buildings in the central region based on G-SEED certification.

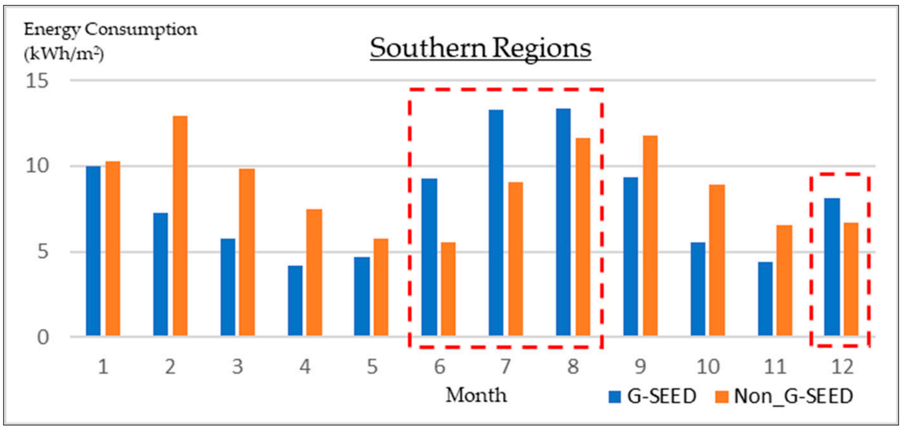

Figure 7. Bar chart of the monthly energy consumption of the court house buildings in the southern region based on G-SEED certification.

4.3. Comparison of the Energy Efficiency

The monthly energy consumption of courthouse buildings that implement the revised building insulation thickness standard and have G-SEED certification was calculated. The calculation results were compared to those of buildings that did not implement the revised building insulation thickness standard and are G-SEED non-certified to obtain the energy-efficiency percentage.

The result of this research revealed that both G-SEED certification and the revision of the building insulation thickness standard contributed positively to the energy consumption efficiency of courthouse buildings annually. Table 10 shows that the revision of the building insulation thickness standard and G-SEED certification was effective for the reduction in the annual energy consumption of courthouse buildings located in the central area compared with courthouse buildings in the southern area. The negative values depicted a contradiction of the expected result. The overall column shows the effects of the revision of the building insulation thickness standard and G-SEED certification implementation on the energy efficiency of all the buildings located in both the central and southern regions. In addition, the results verified that the G-SEED certification of buildings in the southern area cannot guarantee efficient energy consumption, as it only resulted in an energy consumption efficiency of 10.44%. This result is closely related to the findings of Menassa et al. [51], who found that the electrical energy saving of some United States Navy LEED-certified buildings was only 15% less than that of their non-certified counterparts per year. In conclusion, this study revealed that the highest energy-saving outcome both from G-SEED certified buildings and buildings that implemented the revised building insulation thickness standard was observed in February, March, and April. Although negative values were observed in certain seasons, the adequacy of G-SEED certification and the revision of building insulation thickness standard can potentially decrease the energy consumption of courthouse buildings in Korea.

Table 10. Effectiveness of the revision of the building insulation thickness standard and G-SEED certification on energy consumption of courthouse buildings.

Category	Building Insulation Thickness			G-SEED		
	Central	**Southern**	**Overall**	**Central**	**Southern**	**Overall**
January 2021	23.61%	−8.64%	29.71%	38.34%	2.69%	31.06%
February 2021	48.64%	21.86%	56.92%	57.11%	43.57%	53.93%
March 2021	52.48%	28.08%	61.17%	63.32%	41.04%	58.25%
April 2021	49.40%	18.51%	56.23%	59.34%	43.78%	54.87%
May 2021	28.05%	20.30%	38.74%	44.40%	18.78%	37.11%
June 2021	4.64%	13.81%	−0.77%	7.53%	−67.09%	−9.37%
July 2021	6.29%	18.82%	8.71%	16.54%	−46.69%	2.90%
August 2021	14.86%	27.35%	25.27%	31.47%	−14.57%	20.72%
September 2021	41.25%	26.64%	46.80%	46.95%	20.74%	39.52%
October 2021	33.59%	26.98%	45.15%	45.74%	37.54%	42.86%
November 2021	17.98%	6.81%	23.22%	16.18%	32.92%	21.35%
December 2021	13.55%	−17.70%	4.55%	7.40%	−21.93%	0.75%
Total	**27.19%**	**16.32%**	**34.61%**	**37.98%**	**10.44%**	**31.14%**

5. Discussion

The analysis and examination of the effectiveness of the revised building insulation thickness standard revealed its ineffectiveness for the reduction of the energy consumption of courthouse buildings located in the southern areas during the winter season. This was attributed to the fact that there was no revision for the insulation thickness standard for non-residential buildings in the southern areas, except areas of the highest-level floor, which applied non-underfloor heating building (the thickness is 150 mm and then was changed into 155 mm), directly exposed to the outside air (Table 2). A previous study revealed that, to reduce heating and A/C energy consumption, increasing the thickness of the insulation layer is a direct method to improve the thermal qualities of the external wall of public buildings [52]. Therefore, it is imperative to consider and evaluate the insulation thickness standard not only for residential buildings, but also for non-residential buildings, particularly in the southern areas, which exhibit high energy consumption in the winter season. Moreover, the recent insulation thickness standard for non-residential buildings must be a concern to minimize building energy consumption comprehensively.

Additionally, in the summer season, the G-SEED certified buildings in southern areas consumed more energy compared with G-SEED non-certified buildings, and can only save less than 15% energy per year. Further, compared with the G-SEED non-certified buildings, the G-SEED-certified buildings utilized more energy from June to August. As the climate of the southern area is warmer than that of the central area, the result of the analyzed data indicated that the energy consumption of the G-SEED-certified buildings increased in the summer season. A previous study observed that the green university buildings in southeast Australia are more likely to be set up a warm environment [53]. This indicates that the energy consumption of the G-SEED-certified courthouse buildings in southern areas during the summer season can be attributed to the potentially high utilization of A/C during this season. During the summer season, the behavior of the occupants of a building will change because of a high indoor temperature. Occupants will generally use A/C at 30 °C and turn it off at 26.9 °C. In Korea, the indoor temperature is relatively higher than the temperature people are comfortable with, which increases the use of A/C, particularly in office buildings as electrical fees are provided by the employers [54]. In addition, the work productivity of occupants in Korea office buildings can be affected by the work environment, which includes indoor temperature, and maximum productivity occurs at a certain temperature [55]. Therefore, the results of this study may indicate that occupants in the southern courthouse buildings prioritize the comfort temperature of their work environment regardless of the "G-SEED-certified building" label.

It could be suggested that the controversial results for the energy consumption of courthouse buildings in this case study may have been triggered by the poor green building management in the actual operation after the complete construction of the buildings. As there are relations between occupants' workplace culture and the energy consumption of buildings, it is essential to consider the post-occupancy evaluation of buildings [56]. Additionally, when comparing certified green buildings against the non-certified buildings, occupants' awareness is an important factor to consider and selecting the random occupants in the green building assessment process may give unbiased results [57].

6. Conclusions

In order to improve the national building energy efficiency policies comprehensively such as green building certification and insulation thickness standard building, it is crucial to evaluate the energy consumption of public government buildings, which are classified as non-residential buildings. In this study, a comparative analysis of the monthly electrical, gas, and heating energy consumption of nine courthouse buildings in 2021 was performed to investigate the energy efficiency of courthouse buildings in the central and southern region of South Korea. The analysis of the energy consumption parameters was based on compliant and non-compliant to G-SEED certification, and the construction of building prior to and after the 2017 revision of the building insulation thickness standard. This study was conducted to answer the following research questions: whether G-SEED certification and the revision of the building insulation thickness standard are genuinely effective for reducing the energy consumption of courthouse buildings.

Generally, the results of this study verified that G-SEED certification and the revision of building insulation thickness standard are quite effective for reducing the energy consumption of courthouse buildings. The results revealed that the revision of building insulation thickness standard resulted in an energy consumption efficiency of 27.19 and 16.32% in the central and the southern area, respectively, which is a total of 34.61% per annum. In addition, G-SEED-certified buildings in the central and southern area exhibited energy saving of 37.98 and 10.44%, respectively, which is a total of 31.14% per annum. These results indicate that the energy consumption of courthouse buildings, which are classified as public government buildings, can be a good representative and example for the private sector. Particularly, for the implementation of national energy efficiency policies, as Chung et al. [58] reported the decline in the energy efficiency of private office buildings over the years.

In addition, the results of this study revealed the dissimilarity in the energy consumption patterns of each region owing to climate and location factors, such as temperature, humidity, and altitude [59–61]. Accordingly, future studies should analyze the coefficient between regional or location factors in order to reduce the energy consumption of non-residential buildings with the aim to maximize the effectiveness of the building insulation thickness standard and G-SEED certification implementation. Moreover, this study is limited as it is only focused on the GFA parameter and does not consider other parameters that affect energy consumption. Hence, further studies should include other parameters, such as temperature, number of floors and occupants, and occupant behaviors, as these parameters are essential for the analysis of the energy consumption of private and public buildings.

Other than that, this study is limited to only being focused on the evaluation of actual energy consumption of courthouse buildings. There is a lack of data about the insulation materials that were applied in the Korean courthouse buildings. As every insulation material has different characteristics of thermal conductivity and volumetric heat capacity and these thermophysical properties strongly influence the energy performance [62], further studies are needed, especially for the most suitable insulation materials of government public buildings, which can be implemented for further energy efficiency policies and standard improvements. In addition, this study has limitation that didn't consider cost efficiency [63,64]. Considering energy resource economics and cost-benefit will be needed for further studies.

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