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Article

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Research paper

The study on the Energy Consumption of middle school facilities in Daegu, Korea



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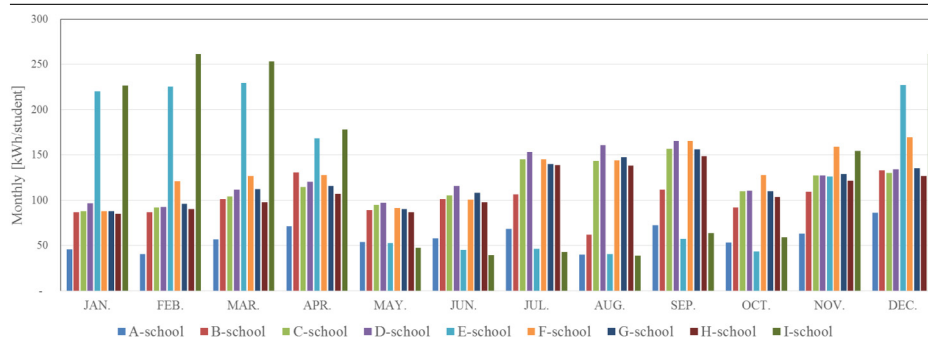
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HIGHLIGHTS

- It is difficult to find actual data on energy consumption of school facilities.
- This study investigated the effects of asbestos-containing slate.
- The energy consumption per unit area of the surveyed schools is approx. 67–240 kWh/m²/yr.
- It is recommended to estimate the school size based on the population density.

GRAPHICAL ABSTRACT



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ABSTRACT

Recently, Korea has upgraded the luminance standard of classrooms and started to introduce the air-conditioning system in order to enhance pleasantness of the learning environment. In addition, as use of auxiliary equipment, such as TV, VTR and computer, is increasing and due to school meals, energy consumption is increasing in school facilities. Despite the increase of energy consumption of school facilities, however, it is difficult to find actual data on energy consumption. Therefore, in this study, the actual conditions of energy consumption are researched, and the relation between the facility area, the number of classes and students, and the cooling and heating facilities is analyzed. And then, the basic data required for energy-saving strategies at school facilities are prepared.

In conclusion, the energy consumption of the surveyed schools is increasing. The total annual energy consumption of each school is estimated to be 400–1750[MWh/yr], which varies between schools depending on the scale. The electric power consumption accounted for approx. 82% of the total energy consumption of the surveyed schools, and LNG and kerosene accounted for 14% and 4%, respectively. The schools using fans for cooling had significantly lower energy consumption than the schools with Electric Heat Pump(EHP). The annual energy consumption per unit area of the surveyed schools is approx. 67–240[kWh/m²/yr], and the annual average energy consumption per unit area is 133[kWh/m²/yr]. However, there is no significant difference in energy consumption per student. These results can be caused by various reasons, but are especially related with the size of school and the number of classes.

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1. Background and objectives of the study

Recently, global warming, destruction of the ozone layer, destruction of natural habitat and loss of ecological environment have attracted attention to the natural environment (Santamouris et al., 2015; Hassid et al., 2000; Stathopoulou et al., 2008; Santamouris et al., 2001; Pantavou et al., 2013). Most of the advanced countries have seen continuous increase of energy consumption since the Industrial Revolution, and energy consumption is increasing also in the building sector, such as office buildings, houses and school facilities (González-Mahecha et al., 2018; Luccon et al., 2014; Han and Kim, 2017). Therefore, many countries are attempting to implement Zero Energy Building (ZEB) and Zero Energy House (ZEH) in order to reduce energy consumption in the building sector, and are pursuing the eco-school plan for the educational facilities (Wiik et al., 2018; ZEB, 2017; Moore, 2014; Katafygiotou and Serghides, 2014; Sekkia et al., 2017). Korea is also recommending institutional improvements and use of renewable energy in order to reduce the energy consumption, and is developing the relevant technologies (MOTIE, 2014).

Korea was required to expand the educational facilities for the baby boomer after the Korean War, and the education policy aimed at accommodating students rather than improving quality of educational facilities (Hwang and Jung, 2011; Yoon, 2016). Since 1990s, Korea was required to improve the quality of educational facilities through various spatial constructions rather than to expand educational facilities. Especially, since the 7th curriculum was started in 1997, elevation, floor plan and roof design of school facilities were improved in consideration of educational activities. In addition, Korea raised the classroom luminance standard from 150 lux to 300 lux to create pleasant learning environment (Yang and Jeong, 2004; Choi and Park, 2009; Kim and Park, 2017), and started to install air-conditioners to improve the thermal environment (Park et al., 2012, 2003). With the changes in curriculum, usage of TV, VTR, computer and electric goods was increased (Yang and Jeong, 2004). Since 2000s, with the start of school meal, energy consumption has been increased further due to cooking (Seo and Kim, 2017; Jeon and Kim, 2014; Cho, 1999). According to Korea Energy Economics Institute, energy consumption per classroom has been increasing steadily since 1970s, and especially since 2000s due to expansion of air-conditioning system in the school buildings for improvement of educational environment (Institute, 2010). Despite the ever-increasing energy consumption in school facilities, it is difficult to find substantial data on energy consumption in educational facilities, and no specific plan has been established for eco-school and use of renewable energy.

Therefore, this study aimed at researching the energy consumption in middle schools of Korea, and providing the basic data for energy saving plan of school facilities through analysis of relation between the facility area, the number of classes and students, and the cooling and heating facilities.

2. Survey method

2.1. Overview of surveyed schools

Table 1 shows the overview of surveyed middle schools, and Table 2 shows the total area of surveyed schools and air-conditioning area ratio and demand for study area ratio. Table 3 shows the annual school hours and academic calendar. There are 123 middle schools and 3019 classes in Daegu, Korea. 9 representative schools were surveyed in this study for area of school facilities, academic calendar, number of students, number of classes, if school meal is provided, energy source, if air-conditioning system is installed, overview of system and energy

consumption of each school. The average number of students per class of the surveyed schools is 33. Assuming 34 school weeks per year and 45 min per class, they have 1156 class hours per year. Some schools open school facilities for supplementary lessons or for activities of the community residents during summer and winter vacations. The size of classrooms varies depending on use, the average size was 9 m x 7.5 m and the ceiling height was 2.7 m. There are no ventilation facilities in the classrooms, and students or teachers open windows for ventilation.

2.2. Outline of classroom electric appliances and air-conditioner

Table 4 shows the cooling and heating facilities of the surveyed schools. In addition to cooling and heating facilities, each classroom has 16 fluorescent lamps (32 W per lamp), 1 TV, 1 VTR and 1 computer. There are one or two cooling and heating facilities in a classroom, and most of which are electric heat pumps (EHP). However, out of the surveyed schools, E-school and I-school use electric fans in summer and individual oil heaters in winter. The rated power of an individual oil heater is 520 w, and the amount of kerosene used is 1.8 liters per hour. Kitchens for school meals use LNG as the energy source. No survey has been conducted for the energy source for night-duty rooms and other facilities.

2.3. Conversion of energy unit

In order to compare the energy consumption of different buildings, it is required to convert different energy sources into a single unit. For this purpose, it is common to represent the energy consumption of each building as the primary energy consumption (Hwang and Jung, 2011). However, the total calorific value for the primary energy factors (based on conversion into the primary energy) varies between countries. In this study, the primary energy factors of Korea for kerosene, LNG and power were used. Table 5 shows the primary energy conversion standard in Korea. For this study, the energy consumption was converted into [kWh].

3. Result

The surveyed schools use electricity, kerosene and LNG as the energy sources. The annual energy consumption for each energy source and the annual gross energy consumption were surveyed. Figs. 1–3 show the consumption of electric power, LNG and kerosene, respectively, of each school. Fig. 4 shows the annual gross energy consumption of each school. As mentioned in 2.3 above, the primary energy conversion standard of Korea was used as the unit of energy consumption.

As shown in Fig. 1, electric power consumption is increasing at all the surveyed schools. The average increase in electric power consumption was 9%, and it was 19% for B-school, which is the highest increase in the last 5 years. The average increase in electric power consumption for C, D, F, G and H-school was around 5%. The annual power consumption varies between schools. The annual electric power consumption of E-school and I-school was approx. 180 [MWh/yr]. For D-school and F-school, it was approx. 450–520 [MWh/yr]. Korean education policies have increased classrooms for special education in accordance with the changes in curriculum. Thus, each classroom has installed air conditioning and heating systems; as a result, the amount of energy consumption each year has been increased.

The LNG consumption was 50–250 [MWh/yr], showing a considerable difference between schools. For C, E, H and I-school there was little change in LNG consumption for 5 years, but it was decreasing in other surveyed schools. Since LNG is normally used as the energy source for cooking and water-heating for school

Table 1
Overview of surveyed middle schools.

School	Result of survey					
	Building area (m ²)	Gross area (m ²)	No. of classrooms	No. of classes	No. of students	No. of students per class
A-school	3600	11,939	47	32	1120	35
B-school	2823	9,221	52	21	672	32
C-school	1781	7,641	52	18	600	33
D-school	3772	10,819	45	30	950	31
E-school	771	3,575	21	9	305	34
F-school	5056	7,170	51	33	1089	33
G-school	3304	7,412	51	26	910	35
H-school	3176	7,590	52	22	748	34
I-school	1180	3,540	20	9	292	32

Table 2
Total area of surveyed schools and air-conditioning area ratio and demand for study area ratio.

School	Classification		
	Total area (m ²)	Air-conditioning area ratio (%)	Demand for study area ratio (%)
A-school	11,939	26	18
B-school	9,221	38	15
C-school	7,641	41	16
D-school	10,819	28	19
E-school	3,575	39	17
F-school	7,170	48	31
G-school	7,412	46	24
H-school	75,90	46	20
I-school	3,540	38	17

means, the consumption of LNG is deemed to fluctuate depending on the amount of food supplied.

Fig. 3 shows the annual kerosene consumption by school. A-school used kerosene, but changed the energy source to LNG in 2012. No data on kerosene consumption in 2012–2015 was available for C-school. B-school and D-school use kerosene for floor heating of the night-duty room only. For other schools, kerosene is used for water-heating, cooking, and auxiliary heaters in classrooms and offices. It is also used for oil heaters in special classrooms without cooling/heating facilities.

Fig. 4 shows the annual gross energy consumption by school. The annual gross energy consumption is the sum of consumption of electric power, LNG and kerosene. The energy consumption was on the rise for all the surveyed schools. The annual gross energy consumption of the surveyed schools was estimated to be 400–1750 [MWh/yr]. The annual gross energy consumption varies between schools depending on the size of the schools. The electric power consumption accounted for approx. 82% of the total energy consumption of the surveyed schools, and LNG and kerosene accounted for 14% and 4%, respectively.

Fig. 5 shows the average monthly energy consumption by school. For 7 schools, the energy consumption is decreased in May, June and September when heating/cooling system is not in operation. For A-school and B-school, the energy consumption in August (vacation) is decreased more when compared to other schools. 5 schools showed no decrease of energy consumption even during the summer vacation (July and August). This is because the facilities were used for supplementary lessons or for

activities of the community residents. E-school and I-school are not equipped with air-conditioning system, and show considerably lower energy consumption when compared with other schools. These 2 schools use electric fans in the classrooms.

4. Discussion

4.1. Comparison of energy consumption

Fig. 6 shows the annual energy consumption per unit area by school. The annual energy consumption per unit area by school is approx. 67–240 [kWh/m²/yr], which varies considerably between schools. Especially, F-school showed more energy consumption than A-school by approx. 3.6 times. The annual average energy consumption of the surveyed schools is 133 [kWh/m²/yr]. Wang (2016) reviewed the existing studies on the school energy consumption, and compared the results with those reported from other countries. The data provided by Ref. Wang (2016) reported that the annual energy consumption per unit area of elementary, middle and high schools in Taiwan was 17, 16 and 26 [kWh/m²/yr], respectively, and the that of universities was 79 [kWh/m²/yr]. It also reported that the annual energy consumption per unit area of schools was 55–405 [kWh/m²/yr] in the global terms.

The middle schools in Korea are estimated to consume more energy per unit area per year than those in Taiwan by 8.3 times. The Ref. Wang (2016) also includes the annual energy consumption per unit area of elementary schools (405 [kWh/m²/yr]), reporting the highest energy consumption among the existing survey results. Korea's average annual temperature is 13.0 degrees between the year of 2012 and 2016; the average temperature in summer is 24.4 degrees; and the average temperature in winter is about 1 degree. The highest temperature in Daegu area was 38.1 degrees in August (summer) in 2016, and the lowest temperature in January (winter) was –13 degrees (Korea Meteorological Administration). On the other hand, the average annual temperature in Taiwan is 22.7 degrees; the lowest temperature is 16 degrees; and the highest temperature is 29 degrees. Therefore, while Korea uses air conditioning and heating systems during the summer and winter time, Taiwan consumes less energy than Korea because it uses only air conditioning in summer (Wang, 2016). In this

Table 3
Annual school hours and academic calendar.

Curriculum	Grade	Annual school hours	Academic calendar	
Middle school	Grade 1	1156 hours	First semester	March ~ 20th of July every year
	Grade 2		Summer vacation	21st of July ~ 20th of August every year
	Grade 3		Second semester	21st of August ~ 20th of December every year
			Winter vacation	21st of December ~ 15th of February every year
		Spring vacation	15th of February ~ 28th of February every year	

Table 4
Classroom cooling and heating facilities.

School	Result of survey				
	Contracted power (kW)	Cooling/heating area (m ²)	Cooling facilities	Heating facilities	Remark
A-school	400	3173		47 units	Combined heating and air-conditioning equipment: EHP Rated output:2500 Wh
B-school	700/30 (night)	3510		72 units	
C-school	400	3510		42 units	
D-school	700	3038		58 units	
E-school	250	1418	16 fans	Individual oil heating	520 W (Rated power) + 1.8 L/h Rated power per fan: 55 W
F-school	450	3443		55 units	Combined heating and air-conditioning equipment: EHP Rated output:2500 Wh
G-school	300	3443		29 units	
H-school	300	3510		52 units	
I-school	400	1350	16 fans	Individual oil heating	520 W (Rated power) + 1.8 L/h Rated power per fan: 55 W

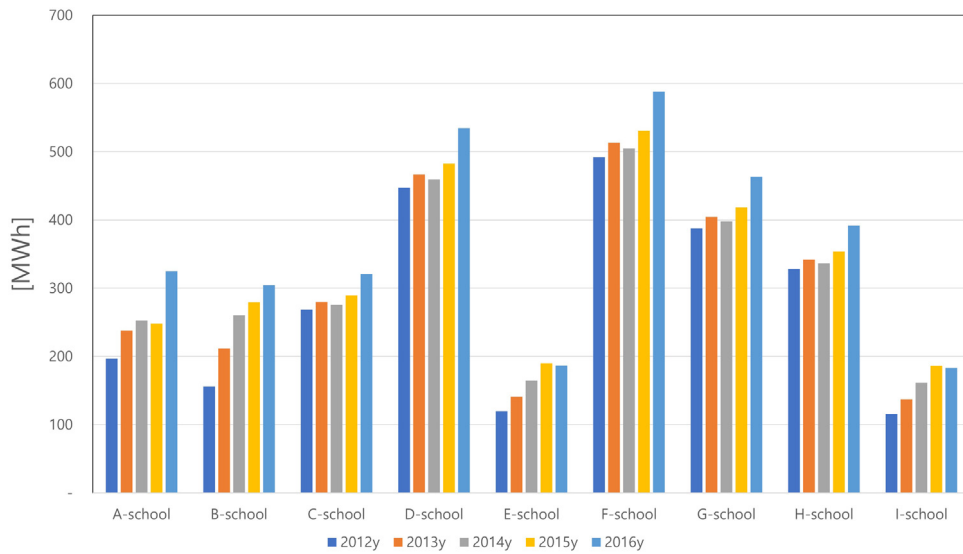


Fig. 1. Annual electric power consumption by School (2012–2016).

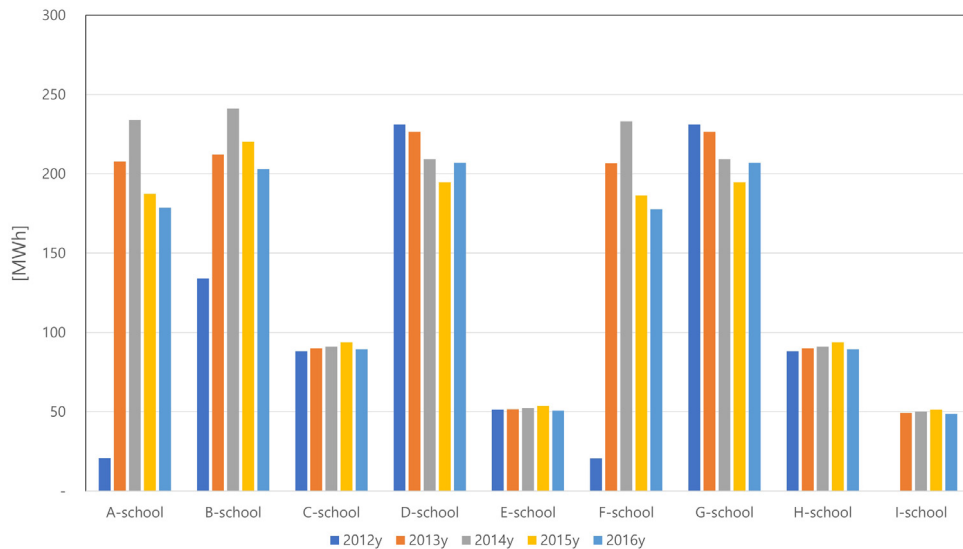


Fig. 2. Annual LNG consumption by School (2012–2016).

study, the surveyed middle schools showed lower annual energy consumption than elementary schools (Kim et al., 2012) despite that middle schools have more school days and class hours. The middle schools investigated by this study showed lower annual

energy consumption than the elementary schools despite the fact that the middle schools have more school days and class hours. However, since the energy consumption of elementary schools was surveyed, it is hard to compare with the findings of the

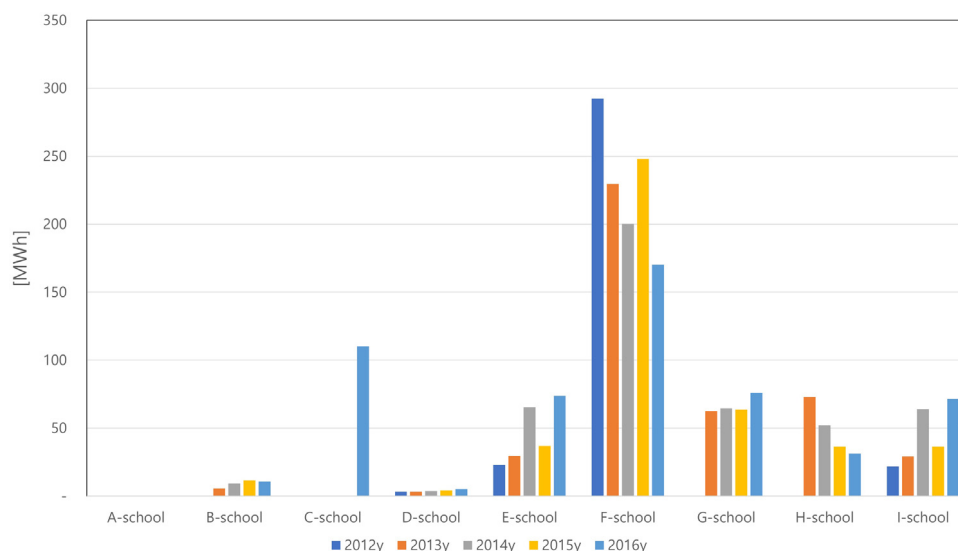


Fig. 3. Annual kerosene consumption by School (2012–2016).

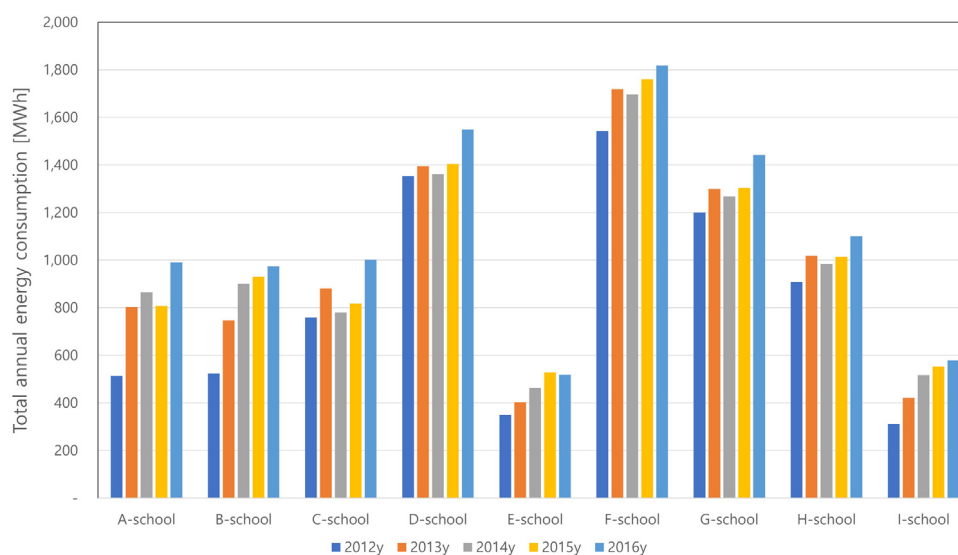


Fig. 4. Annual gross energy consumption by School (converted to 1st energy) (2012–2016).

current study. In recent years, many schools are increasingly aware of the use of highly efficient equipment, and users are also aware of energy savings; therefore, further study on energy consumption of elementary schools should be conducted. Fig. 7 shows the annual energy consumption per student by school. Although the annual energy consumption per unit area by school varies considerably between schools, there is no significant difference in energy consumption per student. F-school with the highest energy consumption per unit area showed similar trend with other schools. I-school showed the highest annual energy consumption per student. In case of A-school, the annual energy consumption per student was about 710 [kWh/student/yr] which is the smallest among the schools surveyed. According to the information in Table 4, C-School was similar to A-school with regard to the cooling and heating area and air-conditioning equipment power. However, the annual energy consumption per student of C-School was 1420 [kWh/student/yr], which was twice the A-school. These results suggest as follows. The Korean government and the local education committee recommend schools to equip air conditioning and heating facilities for the enhancement

Table 5

Primary energy conversion standard in Korea.

Type	Total calorific value Korea
Kerosene	37.5 MJ/L (0.895)
Liquefied Natural Gas (LNG)	44.2 MJ/m ³ (1.055)
Electricity	9.0 MJ/kWh (0.215)

of learning efficiency. However, the manuals for the use of air-conditioning equipment are provided by each school. This study does not have any information on whether A-school has manuals on ways and running-time to use air-conditioning equipment, and how to set the room temperature. If A-school has these manuals, other schools should refer to the manuals that A-school used to reduce energy consumption. For the future study, research on the learning environment and learning efficiency of the A-school should be concurrently carried out.

Table 4 shows that E-school and I-school use individual oil heaters, and others use EHP (Electric Heat Pump). The annual energy consumption per student is estimated to be 700–1800

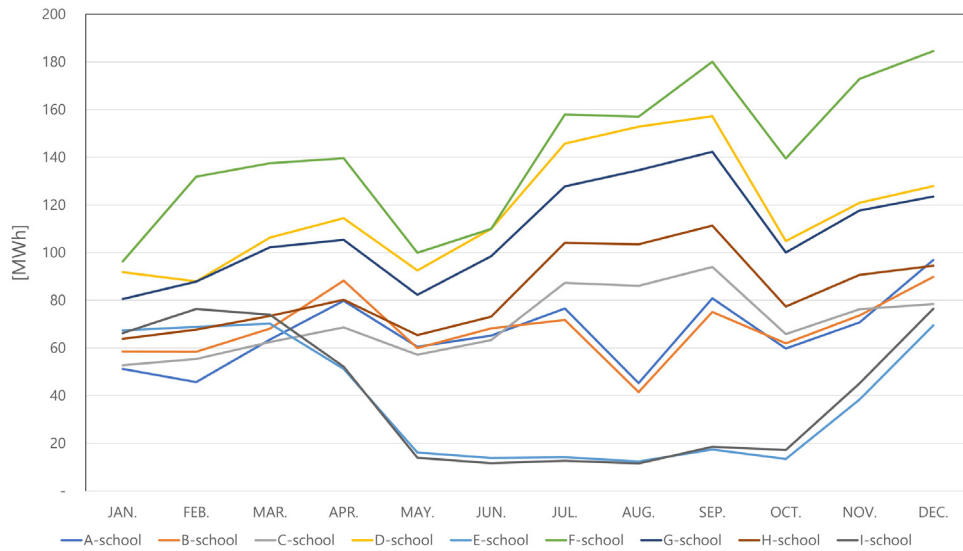


Fig. 5. Average monthly energy consumption by School (average value of 2012–2016).

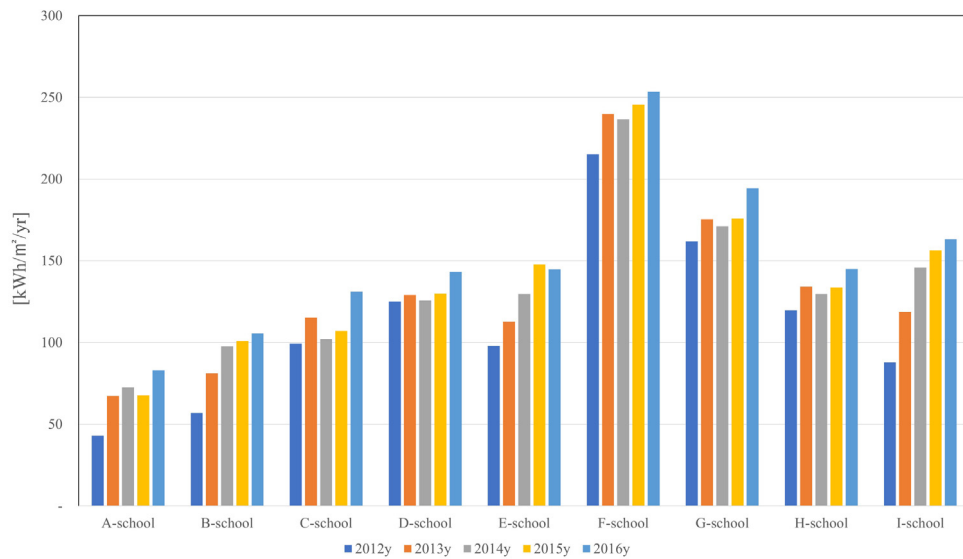


Fig. 6. Annual energy consumption per unit area by School.

[kWh/student/yr]. The energy consumption of the school facilities is expected to vary depending on the number of students, but accurate data could not be obtained from the schools. In the following study, it is necessary to investigate indoor heating and cooling load and ventilation.

Fig. 8 showed the monthly energy consumption of the schools. E-school and I-school use more energy than other schools during the heating season (from November to April). As they use oil heater in the classrooms, loss of heat caused by frequent ventilation might raise the energy consumption. Other schools that do not use oil heaters use combined heating/cooling EHP (rated output: 2500 Wh). All the schools under the investigation utilized natural ventilation through windows. E and I schools are expected to open and close windows more often than any other schools because they use diesel (oil) heater for heating. Therefore, introduction of mechanical ventilation equipment is expected to reduce heat loss through ventilation and ensure air quality in the classroom. The heating/cooling area of the schools is 3038–3510 [m²], and there is no significant difference of the area between schools. The number of EHP units used varies between schools. B-school uses 72 units of EHP, and C-school and H-school,

which have the same heating/cooling area with B-school, use 52 units and 42 units, respectively. The standardized cooling and heating equipment introduced in Daegu area is as following: the cooling capacity is 11.0 kW and the heating capacity is 13.2 kW per 100 square meters respectively. As shown in Fig. 8, there is no difference in energy consumption between these schools during the heating/cooling period. For school facilities in Daegu, the summer cooling period is from July to September, and the winter heating period is from December to February. In addition, air condition system is not used from March to June, and October and November. This may be due to various factors, but is considered to be attributable to the relationship between the school size and the number of classes. B-school shows a low classroom utilization rate as it has 52 classrooms but only 21 classes. This is the same for C-school and H-school. Considering the above result, the energy consumption of schools is considered to be related with the heating/cooling method, the use area, and most of all, the number of students that decides the number of classes. Schools need to increase classrooms or to build new buildings as the local population grows. However, designing schools without consideration of the number of students can increase the facility

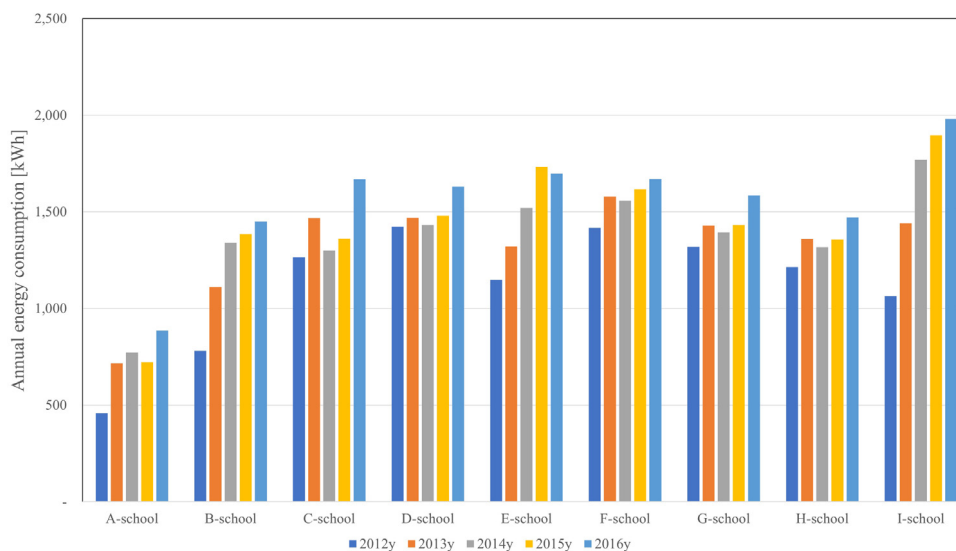


Fig. 7. Annual energy consumption per student by School.

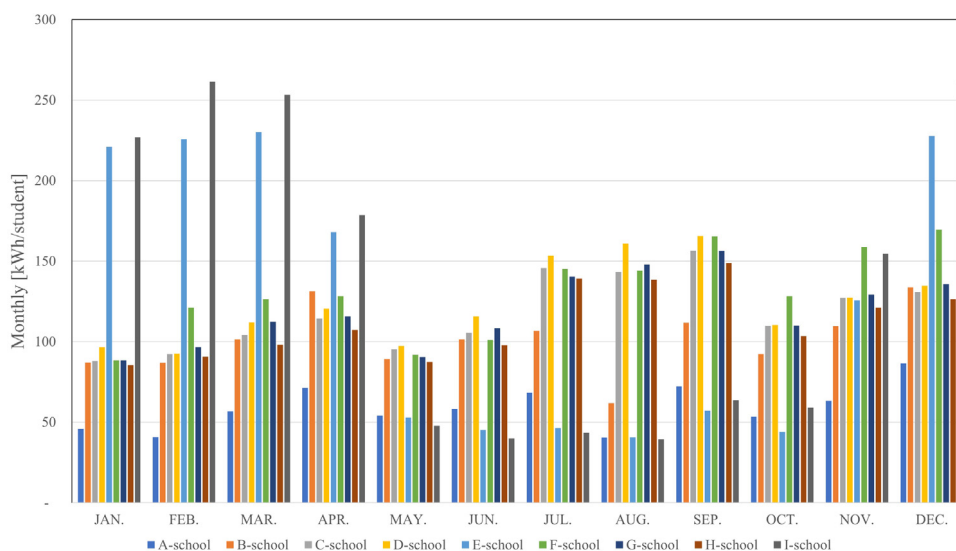


Fig. 8. Monthly energy consumption by School.

management cost and the initial investment cost. Therefore, it is recommended to estimate the school size based on the population density, the number of students, and the local environment, rather than relying on the government's design plan for schools.

5. Conclusion

Korea was required to expand the educational facilities for the baby boomer after the Korean War, and the education policy aimed at accommodating students rather than improving quality of educational facilities. In recent years, however, in order to create pleasant learning environment, attention has been paid to the indoor air quality, luminance and thermal environment. Use of electric appliances, such as TV, VTR and computer, and cooking in school for school meals also contribute to increasing trend of school energy consumption. Despite the ever-increasing energy consumption in school facilities, it is difficult to find substantial data on energy consumption. Therefore, this study aimed at researching the energy consumption in schools, and providing the basic data for energy saving plan of school facilities

through analysis of relation between the facility area, the number of classes and students, and the cooling and heating facilities.

In conclusion, the energy consumption of the surveyed schools is increasing. The total annual energy consumption of each school is estimated to be 400–1750 [MWh/yr], which varies between schools depending on the scale. The electric power consumption accounted for approx. 82% of the total energy consumption of the surveyed schools, and LNG and kerosene accounted for 14% and 4%, respectively. The schools using fans for cooling had significantly lower energy consumption than the schools with EHP. However, it is required to conduct an assessment on the thermal environment for the classrooms using electric fans. If these classrooms show worse thermal environment than those with EHP, it is required to consider installation of EHP in these classrooms for equal learning environment.

The annual energy consumption per unit area by school is approx. 67–240 [kWh/m²/yr], which varies considerably between schools. Especially, F-school showed more energy consumption than A-school by approx. 3.6 times. The annual average energy consumption of the surveyed schools is 133 [kWh/m²/yr]. However, there is no significant difference in energy consumption per

student. This may be due to various factors, but is considered to be attributable to the relationship between the school size and the number of classes. Therefore, it is recommended to estimate the school size based on the population density, the number of students, and the local environment, rather than relying on the government's design plan for schools.

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