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The Relationship between Energy Consumption and Factors Affecting Heating and Cooling

Kwon Sook Park and Seiyong Kim
PhD Student, Department of Architecture, Korea University
Professor, Department of Architecture, Korea University

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Abstract Energy consumption in university building has steadily increased over the last decade, and a strong upward trend in recent years. This study was undertaken to analyze the relationship between energy consumption and their affecting factors, six academic buildings were considered. The factors limited to heating and cooling, which is the main end use (nearly 60 per cent of total energy consumption in university buildings), encompassing system and operating schedules (user activity) and area use. To understand how to building is used, operated and managed, walk-through assessment was conducted as well as interview with university staff. The results show that the energy consumption of the humanities building was somewhat smaller than the consumption of the science and engineering building, and its range was from 31.26kgoe/m^2 to 23.52kgoe/m^2, depending on heating and cooling system and area use. And the energy consumption of the science and engineering building was related to operating schedules (user activity) as well as laboratory equipment characteristics. More analysis on a larger number of buildings is required in the future, including building form and material performance level to generalize the significant factors influencing building energy consumption.

Keywords: Academic Building; Heating and Cooling; System; Operating Schedule; Area Use

1. INTRODUCTION

According to the Korea Energy Management Corporation's statistics, Korea's total final energy consumption grew by 28.83 per cent from 2004 to 2014, with an average annual increase of 2.69 per cent and a maximum increase of 7.43 per cent from 2009 to 2010. The residential and commercial sector relating to buildings accounts for less than 20 per cent of the total energy use for all of Korea, but this proportion is greatly increased in major cities—except some industrial cities (e.g., approximately 60 per cent in Seoul city).

Based on an energy analysis by building type in 2014, about 16.6 per cent (386 kilotonnes of oil equivalent [KTOE]) of building's energy consumption was consumed in apartments, 15.7 per cent (365 KTOE) was consumed in commercial buildings, 14.2 per cent (331 KTOE) was consumed in school buildings, 12.2 per cent (283 KTOE) was consumed in hospitals, and 11.3 per cent (262 KTOE) was consumed in department stores. Of these building types, only energy consumption in school buildings has steadily increased over the last decade. In particular, universities have shown a strong upward trend and consumed a significant amount of energy in recent years. For example, 21 universities (39 per cent of 54 universities in Seoul city) were included in the top 100 energy consuming buildings, of which six universities were managed under a Greenhouse Gas (GHG) and Energy Target Management System, which is operated by the Ministry of Land, Infrastructure and Transport.

Corresponding Author: Seiyong Kim
Department of Architecture, Korea University, Seoul, Korea
email: kksy@korea.ac.kr

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According to the 2014 Energy Consumption Survey, in university buildings, space heating and cooling is the main end use, comprising close to 60 per cent of total energy use. This is followed by lighting, with 12.2 per cent, office equipment and others, with 16.6 per cent, electric power, with 10.1 per cent, and hot water, with 4.2 per cent. Thus, most previous studies pertaining to demand reduction in building energy systems have focused on the status of building envelope and heating and/or cooling system and improving their efficiency (Park and Kim, 2011; Cheong and Park, 2016). These studies examined this by applying a building performance simulation and/or analysing energy consumption patterns compared with campus-wide scale actual energy billing data obtained from utility companies or field-measured data from selected rooms (or entire buildings).

The important elements influencing building energy consumption have been defined through numerous studies such as physical characteristics, e.g., orientation, building form (surface area to volume ratio, and percentage of glazing facing) and building performance level (architectural material and mechanical and electrical equipment) and usage pattern, e.g., zoning, internal load, hours of operation, thermostat setting (Huang and Franconi, 1999; Pacheco et al., 2012). Among physical characteristics, the building performance level can be classified based on the year a building was constructed because construction of academic buildings has complied with the minimum requirements of Building Design Criteria for Energy Saving. Energy savings can be achieved by conserving energy when operating heating and cooling systems, lighting and plug loads as well as improving the building design, as aforementioned (Alajmi, 2012). However, until now, the available information on the internal conditions and operational patterns with the greatest influence on energy usage was insufficient to understand energy usage patterns (Pérez-Lombard et al., 2008). Davis III and Nutter (2010), Masoso and Grobler (2010) and Gul and Patidar (2015) conducted studies to assess the relationship between energy demand profile and occupancy behaviour; however, they neglected other conditions. In contrast, this paper analyses the data to understand the building envelope, system and usage pattern related to operating cooling and heating systems, and their complex interactions with building energy requirements.

2. METHODOLOGY

2.1. Case study building

The studied buildings shown in Table 1 were selected based on: (1) location (buildings were located on the main campus of Korea University [KU] located in the northeast district of Seoul); (2) data availability, with individual meter use that recorded energy consumption; (3) operating system type (a central heating and cooling system); (4) building use (academic buildings—the most common type of building on a university campus contains mainly learning and study facilities, and a faculty office).

2.2. Data collection

2.2.1. Energy consumption data

For this study, the facilities management division at KU provided monthly data from January 2011 to December 2015 on electrical, gas and water consumption in the studied buildings. Water consumption data were excluded from the analysis because it is not related to energy consumption. In this paper, energy consumption is expressed in units of a tonne of oil equivalent (TOE) using the following conversion factors: liquefied natural gas—1.043 and electric energy consumption—0.230.

2.2.2. Heating and cooling systems

The operation of the central heating and cooling systems was investigated via walk-through assessments and interviews with university staff. Heating and cooling were examined, respectively, from the end of October to mid of March, and from early July to the end of September, with a different daily schedule related to room activities (discussed in Section 3.3). Meters were installed to record electricity and gas consumption in each building. The university used speed control fan motors within a fan-coil unit, vacancy control with a room temperature capacitance sensor (with a minimum maintenance level of 15 degrees Celsius for heating and 28 degrees Celsius for cooling) and temperature control (heating and cooling set point of 25 plus/minus 0.5 degrees Celsius) to reduce energy consumption.

2.2.3. Room activities

Each building had up to six general usage areas classified based on Post-secondary education facilities inventory and classification manual: classroom, study facility, laboratory facility, office facility, general use facility, and 'other'. Classrooms were general purpose classrooms, seminar rooms, and other rooms for scheduled non-laboratory instruction. Facilities used for research or non-scheduled instructional activities were divided into study and laboratory facilities, depending on whether they used special-purpose equipment. Office facilities were used for the academic and administrative operations of the university. General use facilities (such as lounges, meeting rooms, and recreational facilities) were public spaces bounded by internal walls or partitions to building users, managed by the university. 'Other' referred to the most communal open spaces (e.g., gathering and circulation areas) for visitors and faculty, students and staff. Small areas—defined as building services, mechanical equipment, and utility and structural services—were excluded from this study.

The room activity was estimated by counting the total number of hours each room was occupied. In general, the operating hours for most facilities were weekdays from 8.00 am to 6.00 pm in summer and 7.00 am to 8.00 pm in winter. However, the classroom occupancy was more unpredictable than the other rooms. Therefore, the schedules for the classrooms in the case study

Table 1. General information for selected university buildings

Building Code	Academic function	Year built	Total area (m^2)	No. of floors	Orientation	Area use (%)					
						Classroom	Study	Lab.	Office	General use	Other
CLASS 1	Business	2003	14,121	6/BF1	SE	28.42	14.88	0	1.16	12.04	43.05
CLASS 2	Politics and economics	1984	8,203	6/BF1	SE	20.07	32.12	0	4.45	13.68	29.50
CLASS 3	Business	2013	15,465	5/BF4	SE	22.75	5.59	0	0	12.48	59.17
CLASS 4	Architecture	1996	18,649	7/BF1	ENE, SSE	11.55	42.61	5.79	5.30	6.73	28.02
CLASS 5	Information security	2011	5,058	7/BF1	SE	5.78	37.04	17.10	2.81	9.11	28.17
CLASS 6	Engineering	2003	18,179	8/BF3	ENE	12.61	44.62	9.71	1.39	4.27	27.41

buildings were downloaded from the KU website timetables.

3. RESULTS AND DISCUSSION

3.1 Annual energy consumption

Although the CLASS 5 building (using energy from August 2011) consumed less than 20 per cent of other years, total energy consumption was highest in 2011—except the CLASS 3 building constructed in 2013. In 2012, energy consumption was beginning to decline as result of enhanced policy due to the large scale blackout (serious imbalance in electricity supply and demand) in Korea and Fukushima nuclear accident in Japan in 2011; however, energy consumption somewhat increased in the last year because extreme weather events are becoming more frequent and the university plans to relax restrictions on temperature limited.

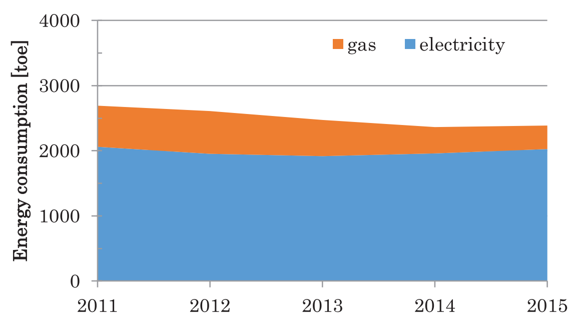


Figure 1. Change in annual energy consumption, 2011-2015

3.2. Comparison of energy consumption

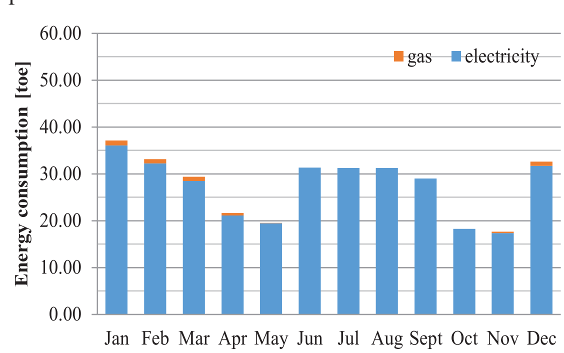
Table 2 shows that the energy consumption of the science and engineering buildings (CLASS 4, 5, and 6) was somewhat larger than the consumption of the humanities buildings (CLASS 1, 2, and 3). A possible reason for this difference pertained to whether the space included a laboratory. Among the buildings with similar academic functions, CLASS 2 and 4 buildings built before 2001—announced the Building Design Criteria for Energy Saving, which requires strengthening thermal insulation—had the highest Energy Use Intensity (EUI). However, when comparing EUI and building constructed since 2001, the results showed no clear connection in this study. In addition, unlike previous studies, the results showed no clear correlation between building size and energy consumption.

Table 2. Energy use and sources

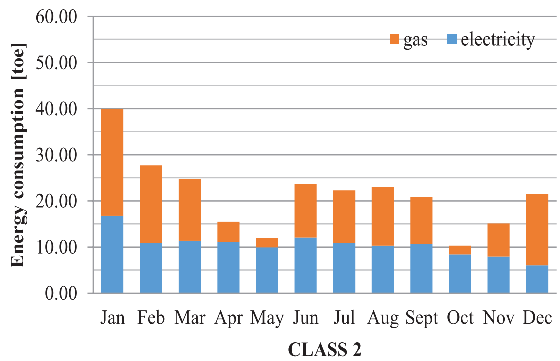
Building Code	EUI (kgoe/m^{2}yr)	Electrical (%)	Gas (%)
CLASS 1	23.52	98.66	1.36
CLASS 2	31.26	49.27	50.73
CLASS 3	28.43	83.13	16.87
CLASS 4	49.42	88.45	11.55
CLASS 5	39.48	100	0
CLASS 6	37.26	82.29	17.71

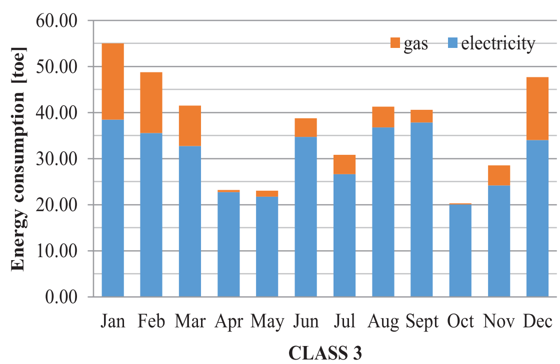
In academic buildings, energy system (especially for heating and cooling), user activity and area use have a huge effect on the amount and pattern of energy consumption. For example, the EUI of the CLASS 1 building was significantly lower (23.52 kgoe/m^{2}yr) than other studied buildings because it used underground water for a heating and cooling plant (after removing absorption chiller heater) and supplied energy per area use per floor level (heating and cooling equipment was located at both ends of the L-shaped building). In contrast, the CLASS 2 building used a gas engine drive heat pump system and had higher EUI (31.26 kgoe/m^{2}yr) for limited space scheduling when compared to the other humanities buildings (CLASS 1 and 3 had 23.52 kgoe/m^{2}yr and 28.43 kgoe/m^{2}yr, respectively). The building could not prevent overloading of the power distribution network without the heating and cooling equipment room, and individual equipment was widely used to solve temperature complaints (distinctly different effective temperature depending on the distance from the central heating and cooling equipment). The CLASS 5 building used an electrical heat pump and consumed significant amounts of electricity energy per square meter (37.26 kgoe/ m^{2}yr). Unlike in typical academic buildings, a considerable number of occupants were research-based graduate students and professors who needed to use the study and laboratory facilities, which comprised a large portion of area use (37.04% and 17.10% of area use, respectively) and did not have specific hours unlike classroom users (the areas were used continually).

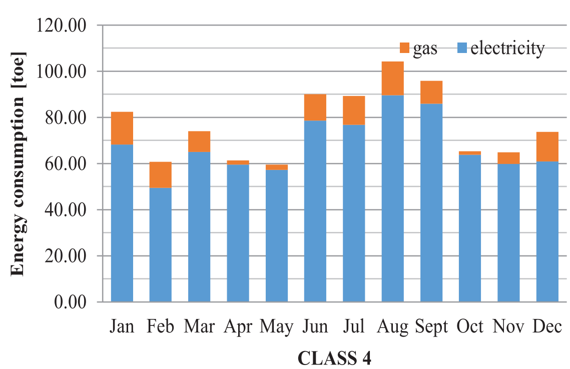
In addition, an absorption chiller heater (fan-coil unit) was widely used in some KU buildings (e.g., CLASS 3, 4, and 6). The percentages of each energy source were similar (approximately 85% for electricity and 15% for gas); however, the building had different energy consumptions. The CLASS 3 building had higher EUI (28.43 kgoe/m^{2}yr) than the other business faculty building (CLASS 1), which had a significant occupant load all day (from 9.00 am to 9.00 pm). Nearly 60 per cent of area use was open space, of which about 19 per cent was void (all floors were linked by a central staircase), and the heating and cooling system operated inefficiently (one heater covered a maximum of four floors). The CLASS 4 and 6 buildings had the highest energy consumption, which was mainly due to laboratory equipment (especially the thermos-hygrostat in the clean room) and the heat gains from equipment that led to more cooling being required in the summer. Among these buildings, the CLASS 4 building consumed the most energy. A possible explanation for this may be that class scheduling was more than twice that of the CLASS 6 building (fewer classes during regular semesters and no classes during vacations) as well as laboratory equipment characteristics.

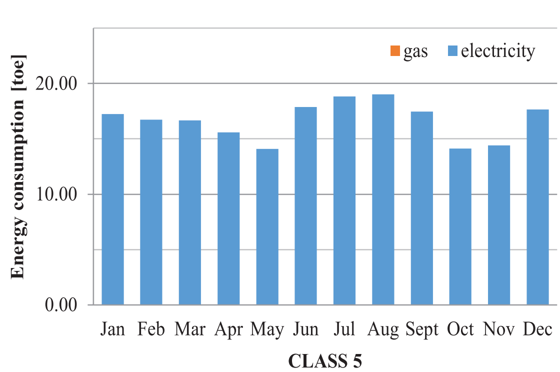


CLASS 1









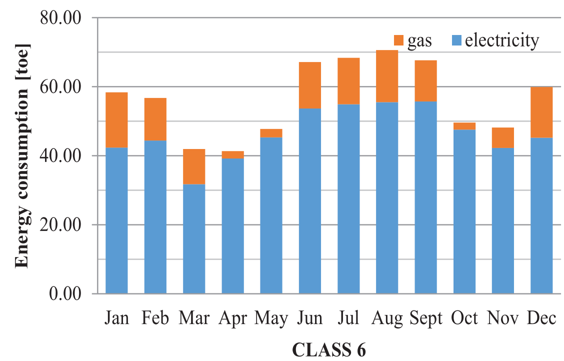


Figure 2. Monthly energy consumption, 2015

4. CONCLUSIONS

The main purpose of this study was to explore the relationships between energy demand profiles and their affecting factors for an academic building. To gain an insight into energy efficiency and reduction in buildings, this study investigated and analysed these factors by organising similar buildings into various groups based on the year built, building size, faculty characteristics, system type and configuration, area use and activity. The studied factors were limited to heating and cooling—a significant part of the energy used in university buildings during the operational period, as indicated in Fig. 2.

Overall, this study evidences that, for all academic buildings, regardless of faculty characteristics, the buildings constructed after introducing thermal insulation criteria consumed less energy than the other buildings. However, as the criteria became consistently tighter, they did not have a significantly different effect on energy efficiency improvements. This study indicates that there is also no clear correlation between building size and energy consumption.

Important factors that can greatly influence heating and cooling loads include system characteristics, area use and area activity. Generally, the humanities buildings without laboratory equipment consumed less energy than did the science and engineering buildings. However, buildings with a similar pattern of area use and activity revealed distinctly different energy consumption according to the system type and configuration (space-efficient layout in terms of operating system). This energy use was particularly affected during the winter months. As expected, a considerable amount of energy consumed in the science and engineering buildings (roughly 50 per cent of area use) was related to research, including laboratory equipment and supplies. These buildings' energy consumption differed according to activity (occupant, class scheduling and so forth). Unlike the humanities buildings, peak electricity demand was recorded during the hottest day of summer.

This study has provided an understanding of the various building factors and their interaction with energy requirements in actual academic buildings. The results obtained could help develop optimum building design, operation and management to reduce energy consumption under a limited budget. Future studies may be extended to other types of buildings (administration, library, classrooms, and laboratory building; clubs and societies; convenience facilities, such as food and retail services) and encompass a larger number of buildings in order to generalize about the significant factors influencing building energy consumption.

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