PRELIMINARY FINDINGS FROM AN ANALYSIS OF LIGHTING ENERGY USE OF OFFICE BUILDING IN KOREA

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Abstract

In Korea, energy consumption information for existing building is provided to primary energy consumption by fuel types (electric, gas, and district heating) from energy service utilities. To be more effective building energy management nationally, it should be to manage building energy consumption by end use. For this, it is the best approach to collect direct end-use metering data for all buildings but in practically very difficult because of expense and long time. Moreover, it is not appropriate only the application of the building energy simulation based on model to derive energy consumption by end use due to error with energy consumption of actual building.

Therefore LBNL has been developed algorithm to estimate energy end use since 1980, the results are EnergyIQ based on web service. The final goal of this research is to develop algorithm to estimate energy end use with real state of Korea, so by selecting the reference buildings to meet the statistical significance level, it is necessary to collect on-site metered data.

In this study, the end-use sub-metering of office building in Seoul is ongoing hourly into cooling, heating, ventilation, domestic hot water, lighting, office equipment, elevator, miscellaneous since 1 March 2015. Weather conditions are not a crucial factor for lighting energy consumption in existing office building. So based on this sub-metering data, first we carried out an analysis of lighting energy use profile to utilize basic data in lighting energy consumption estimation.

Keywords: *Office building, Lighting energy use, End-use sub-metering, Estimation of energy end-use consumption*

1. Introduction

The South Korean government is managing the monthly energy consumption of electricity, city gas (LNG), and district heating system used by its existing buildings through the integrated building energy management system. This information about energy consumption by source of energy may be useful for the management of the national energy supply and demand policy, but there is not enough detailed information about energy consumption to lead occupants to participate in effective and practical energy saving activities. Therefore, the energy consumption of buildings needs to be controlled depending on end-use energy. For example, the energy consumption of residential buildings should be divided according to end-use such as heating, cooling, hot water supply, lighting, ventilation, electric appliances, cooking, etc., while the energy use of office buildings should be segmented into heating, cooling, hot water supply, lighting, ventilation(air movement), electric appliances, vertical transportation(elevators/escalators), city water supply, etc.

Here, the approach methods to acquire energy consumption by end-use can be divided into building simulation, direct end-use metering, and end-use disaggregation. Building simulation is a very common method, but its shortcoming is the lack of reality, given that there is a significant difference between the building assumption conditions and the actual building characteristics. The direct end-use metering method requires high costs and cannot draw general conclusions due to a limited number of sample buildings for measurement. The end-use disaggregation method provides disaggregated data about energy consumption of end-use by adjusting the building simulation based on the measurement data and collected information of a sample building, and it is worthwhile to apply the method to domestic buildings. In order to apply the end-use disaggregation method, it requires developing a disaggregation algorithm fit to a domestic condition. According to H. Akbari (1995), in order to develop a disaggregation algorithm, it requires selecting sample buildings for measuring and collecting measurement data by end-use energy, paying on-site surveys to gather information about equipment inventories,

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operation schedules, and the characteristics of buildings, and establishing a database of end-use energy after conducting an analysis of collected data, including regional climate characteristics. These databases are united through a statistical adjustment into a single database, based on which an end-use disaggregation algorithm will be developed.

We selected sample buildings for office building in Seoul and plans to install the measurement system to a total of 85 buildings to disaggregate end-use energy for a period of three years. The final purpose of this study is to develop disaggregation algorithm by identifying the characteristics of end-use through analysis of the above data for influential factors. This paper aimed to identify the characteristics of lighting energy use and to induce major influential factors through analysis of measurement data, which accounted for a relatively high-energy consumption ratio among non-HVAC energy in office buildings, and to use them as basic data in order to supplement and verify the end-use energy estimation equation.

2. Methodology

According to prEN 15193 (2006), the calculated method and the metered method are suggested as ways to determine the lighting energy use. The calculated method is once again classified into the comprehensive method and the quick method. The comprehensive method is to calculate an equation based on the actual building operation data (annual/monthly/hourly), and its shortcoming is that it cannot consider the energy consumption of some lighting control devices. In contrast, the quick method is to calculate an equation based on the standard data (annual), and although it can reduce the required time, it has its own limitation that it cannot consider the actual building conditions. The metered method is to measure energy consumption using electronic watt hour meters to the circuits in the low-voltage distribution panel, and provide the highest level of accuracy, but it is hard to be implemented due to cost and time.

Therefore, it is reasonable to develop an estimation equation of lighting energy use based on the monthly electricity bill data and the user input data. The basic input information to disaggregate lighting energy use from the total energy consumption through the estimation algorithm includes electricity bill information, building information, system information, operation information, and regional climate information (Fig. 1). To induce the required information, the influential factors in energy use need be taken into consideration by diving them into building factors, system factors, user factors, and weather factors. The building factors include the floor area (FLA), conditioned floor area (CFLA), number of floors (FLN), ceiling height (CLH), orientation (ORN), window-wall ratio (WWR), visible light transmittance (VLT), building age (BLAG), etc. The system factors include the type, power consumption and efficiency of lighting equipment(LTQ), lighting power density(LPD), interior illuminance(ILU), shading system(SHS), lighting control devices (manual, on-off, dimming, etc.)(LTCN). The user factors include operating time(OPHR), occupant density(OCD), behavioral patterns of occupants(OCS), and ownership(OWN), while the weather factors are the daylight factor(DAL), etc.(Fig. 2). The estimation equation of lighting energy based on these influential factors can be summarized as seen in Equation (1). This study will draw major influential factors through analysis of the measurement data of the sample buildings and will incrementally complement and verify the estimation equation.

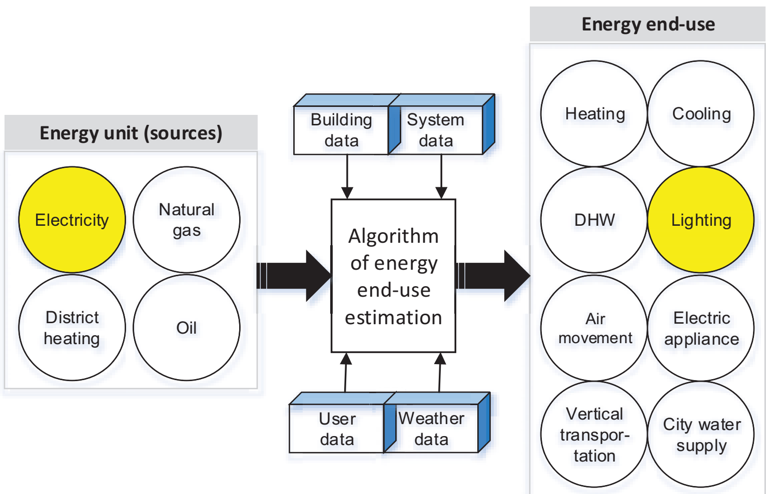

Fig. 1: diagram of the end-use energy disaggregation for office building

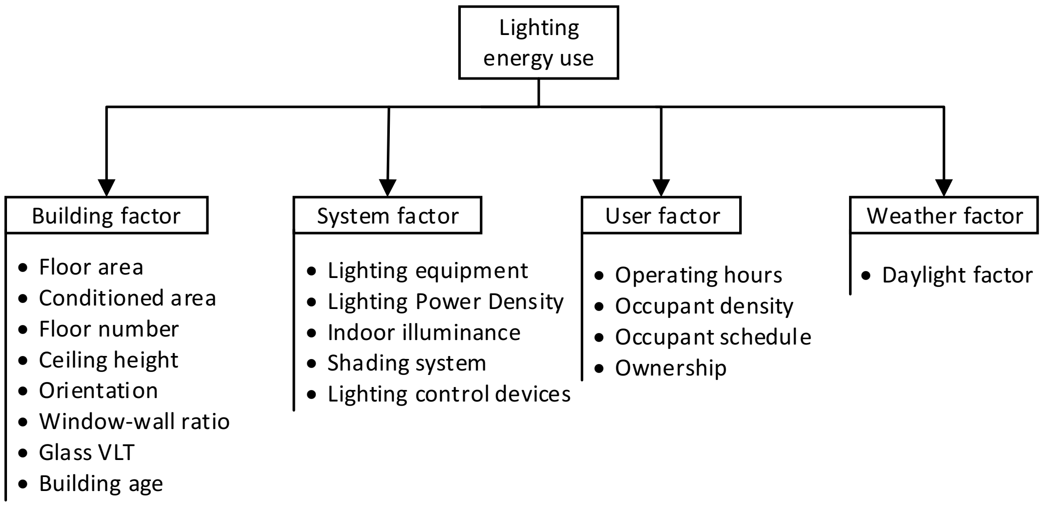

Fig. 2: Influential factors of building lighting energy use

$$E_{LT} = E_{LT0} + f_{LT}(BLD) + f_{LT}(SYS) + f_{LT}(USE) + f_{LT}(WEA) \quad \text{(eq. 1)}$$

$$f_{LT}(BLD) = \alpha_1 FLA + \alpha_2 CFLA + \alpha_3 FLN + \alpha_4 CLH + \alpha_5 ORN + \alpha_6 WWR + \alpha_7 VLT + \alpha_8 BLAG$$

$$f_{LT}(SYS) = \beta_1 LTG + \beta_2 LPD + \beta_3 ILU + \beta_4 SHS + \beta_5 LTCN$$

$$f_{LT}(USE) = \gamma_1 OPHR + \gamma_2 OCD + \gamma_3 OCS + \gamma_4 OWN$$

$$f_{LT}(WEA) = \delta_1 DAL$$

E_{LT}: *building lighting energy use*

E_{LT0}: *baseline lighting energy use*

$f_{LT}(BLD)$: *function of building factor*

$f_{LT}(SYS)$: *function of system factor*

$f_{LT}(USE)$: *function of user factor*

$f_{LT}(WEA)$: *function of weather factor*

$\alpha_n, \beta_n, \gamma_n, \delta_n$: *regression coefficients*

3. Case study

3.1 Description of the building

The target building for the measurement is summarized as seen in Tab. 1; it was located in the central district of Seoul(with a climate zone of the central region), and its construction was completed in 1990; it has total floor area of 1,265.1 ㎡ and has one underground floor and five ground floors. The use purpose, floor area, occupancy information, and lighting power density of each office floor can be seen in Tab. 2. The ceiling down-type fluorescent lights (FL) and electronic luminescence (EL) were used for office lighting, and the average indoor illuminance was 300lx; no lighting control systems were applied, while the indoor blinds were installed.

Tab. 1: Overview of case study building

Category	Contents
location	Seoul, Korea
building type	office & retail
building area(㎡)	198.5
gross floor area(㎡)	1,265.1
permitted/approved yr.	1989/ 1990
building size	B1F / 5F
 **whole view of the building**	 **indoor view of 3rd office floor**

Tab. 2: Overview of each floor

FL.	B1F	1F	2F	3F	4F	5F
Usage type	Parking lot, Storage	Retail	Office	Office	Office	Conference room
Af(㎡)	305.2	196.7	198.4	198.4	198.4	167.9
Ac(㎡)	0	73.6	166.4	166.4	166.4	136.0
No. occupants	0	2	7	18	16	0
Business hrs.	-	10:00~20:00	09:00~18:00	09:00~18:00	09:00~18:00	-
LPD(W/㎡)	5.7	15.9	8.9	9.7	9.7	9.6
Lighting equip. (office)	• FL32W×2ea×27set (1,728W)	• EL20W×52set (1,040W) • FL32W×2ea×4 set(256W) • total 1,168W	• EL20W×10set (200W) • FL32W×2ea×20set (1,280W) • total 1,480W	• EL20W×4set (80W) • FL32W×2ea×24set(1,536W) • total 1,616W	• EL20W×4set (80W) • FL32W×2ea×24set(1,536W) • total 1,616W	• EL20W×4set (80W) • FL32W×2ea× 18set(1,152W) • FL20W×2ea×2set (80W) • total 1,312W

The target office spaces for the measurement of lighting energy consumption were office spaces on the 2F-5F (Fig. 3) and the electronic watt hour meters mounted with the zigbee-type wireless transmission devices were installed to office lighting circuits in the distribution panel of each floor. The accumulated electricity consumption was measured by the hour starting from March 1, 2015 (Tab. 3) and the data measurement period for the analysis lasted until the end of July. After calculating the total electricity consumption of each floor, the lighting energy use was computed, which can be summarized and seen in the following Equation (2).

Fig. 3: office floor plan for sub-metering lighting energy use (L: 2~4F, R: 5F)

Tab. 3: Overview of sub-metering system

<table>
<tr><td>analysis period</td><td colspan="2">2015.03.01. 00:00 ~ 2015.07.31. 23:00</td></tr>
<tr><td>sub-metering method</td><td colspan="2">electronic watt hour meter on the lighting circuits in the low-voltage distribution panel per office floor
(three-phase four-wire system, zigbee)</td></tr>
<tr><td>
electronic watt hour meter</td><td>
communication gateway</td><td>
low-voltage distribution panel</td></tr>
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$$E_{LT} = \sum_{i=1}^{N} E_{LTi}$$ **(eq. 2)**

i: number of office floor

3.2 Results and discussion

3.2.1 Hourly lighting energy use

The monthly average of lighting energy use during the weekdays by month was recorded as 79.7Wh/㎡ in March, 80.8Wh/㎡ in April, 73.8Wh/㎡ in May, 74.5Wh/㎡ in June, and 73.3Wh/㎡ in July, while that during the weekends by month were estimated at 6.8Wh/㎡ in March, 5.1Wh/㎡ in April, 6.7Wh/㎡ in May, 5.4Wh/㎡ in June, and 15.2Wh/㎡ in July.(Fig 4) The highest hourly average of lighting energy consumption by month was recorded at 4.7kWh at 17 pm on March 12, 5.1kWh at 17 pm on April 23, 5.3kWh at 16 pm on May 8, 4.5kWh at 12 pm on June 8, and 5.0kWh at 10 am on July 15, and the morning hours showed a higher occurrence ratio of monthly average peaks of lighting energy consumption.

Fig. 4: average hourly lighting energy use

According to a study by Xin Zhou et al. (2015), the 24 hours of the weekdays can be divided into a total of 6 time zones: the morning communing hours, the morning working hours, the lunch hour, the afternoon working hours, the closing hours, and the night hours (Fig. 5), but the total period time can vary depending on time zones. The morning commuting hours (3 hrs.) ranging from 6 am to 9 am showed a sharp increase in lighting energy use, which remained at a constant level during the morning working hours (3 hrs.) spanning from 9 am to 12 pm. The lighting energy use during the lunch hour from 12 pm to 13 pm was reduced by 1.6-6.8% compared to the morning working hours. Although the light energy use during the afternoon working hours (4 hrs.) from 13 pm to 17 pm showed a relatively constant level but displayed a greater deviation compared to the morning working hours. The hourly lighting energy consumption declined over the lapse of the closing hours (4 hrs.) from 17 pm to 21 pm, which displayed a more steady incline than the morning working hours. The night hours zone from 21 pm to 6 am of the next day (9 hrs.) showed an almost flat incline, but displayed a much wider deviation depending on the presence and absence of overtime work. The weekends showed a similar deviation in lighting energy consumption like the night hours zone.

According to the monthly lighting energy consumption rate of each time zone, the afternoon working hours took up the highest percentage at 28.5%, followed by the morning working hours (21.5%), the closing hours (15.4%), the lunch hour (13.8%), the morning commuting hours (9.8%), and the night hours (7.6%), and the weekends & holidays (3.3%).(Fig. 6)

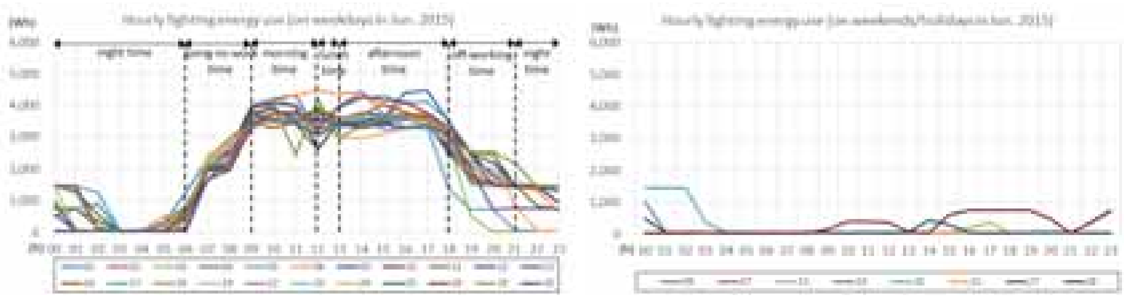

Fig. 5: hourly lighting energy use during 24 hours (L: weekday, R: weekend)

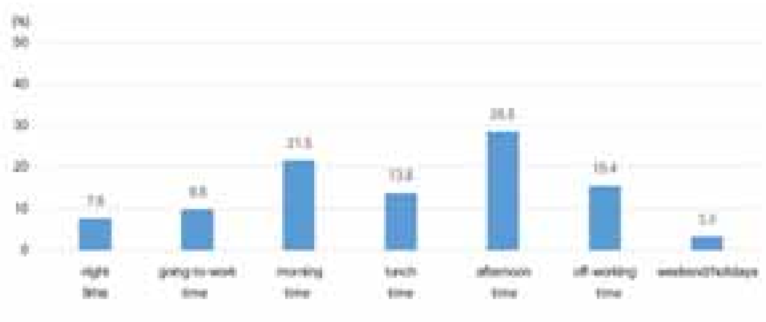

Fig. 6: The ratios of lighting consumption by time zone to lighting energy use per month

The hourly-based energy consumption of office lighting was recorded at 10Wh for the 3-5F offices, while that of the 2F office displayed a remarkably higher level of 20Wh. This was due to a high ratio of electronics lamps installed on the 2F office, almost 2 times that of the other office floors, as they were believed to consume more standby power than fluorescent lamps. (Tab. 4)

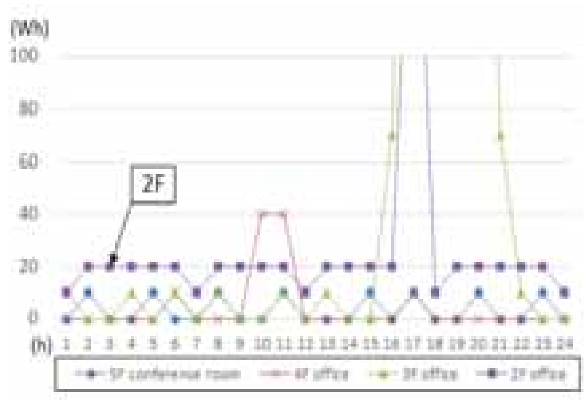

Fig. 7: base lighting energy use

Tab. 4: The ratios of electrics lamps power to total lamps power for office floor

Floor	2F office	3F office	4F office	5F conference room
EL power(W)	200	80	80	80
FL power(W)	1,280	1,536	1,536	1,232
total lamps power(W)	1,480	1,616	1,616	1,312
EL/total ratio(%)	13.5	5.0	5.0	6.1

EL: electrics lamps, FL: fluorescent lamps,

EL/total ratio: electrics lamps to total lamps power ratio

3.2.2 Daily lighting energy use

The ratios of the monthly average lighting energy consumption during the weekdays were recorded at 97.2% in March, 98.4% in April, 94.9% in May, 98.1% in June, and 95.1% in July, while those during the weekends 2.8% in March, 1.6% in April, 5.1% in May, 1.9% in June, and 4.9% in July. The average energy consumption ratio of the weekdays was estimated at 96.7%, while that of the weekends were at 3.3%.(Tab. 5)

Tab. 5: The ratios of monthly lighting energy use for weekday vs weekday/holiday

	Mar.2015	Apr. 2015	May 2015	Jun. 2015	Jul. 2015	avg.	SD
weekday(%)	97.2	98.4	94.9	98.1	95.1	96.7	1.7
weekend/holiday(%)	2.8	1.6	5.1	1.9	4.9	3.3	1.7

3.2.3 Monthly lighting energy use

The ratio of lighting energy use against the total energy consumption by month was recorded at 15.4% in March, 19.0% in April, 16.2% in May, 12.6% in June, and 10.1% in July. The monthly average lighting energy consumption was within 1,100~1,200kWh. The lighting energy consumption was relatively lower in May, as the working hours of the month were reduced by the increased number of holidays, which was 1.8 times more than the other months. As the air-conditioning operation started from June, the energy consumption surged, while the percentage of lighting energy use against the total energy consumption showed a declining tendency (Tab. 6).

Tab. 6: The ratios of energy use to whole building electricity consumption per month

	Mar.2015	Apr. 2015	May 2015	Jun. 2015	Jul. 2015
WHE(kWh)	7,632.3	6,367.7	5,498.2	8,749.0	11,281.5
LTE(kWh)	1,174.9	1,206.7	888.4	1,100.5	1,139.8

LTE/WHE ratio(%)	15.4	19.0	16.2	12.6	10.1
No. weekend/holiday	9	8	14	8	8
total operating hours (2F~5F)	1,505	1,788	1,290	1,544	1,586

WHE: whole building electricity consumption, LTE: lighting energy use

3.2.4 Correlation between lighting energy use and influential factors

As useful information was collected for the correlation analysis between lighting energy use of each office floor (2F~5F) of the case-study building and influential factors, the air-conditioned floor area was selected as a building factor, the lighting density and indoor illumination as system factors, and the number of occupants and use time as user factors can be seen in Tab. 7. According the results of the correlation analysis between the influential factors and light energy use, the correlation between the number of occupants and the use time revealed the highest coefficient of 0.95 in average, followed by the air-conditioned floor area, indoor illumination, and lighting density. The influential factors which belong to the user factors showed higher levels of correlation, but this was believed to be due to the design of the building to provide similar levels of lighting density to offices within the same building. Further studies need to be carried out in the future in order to conform the correlation between user factors and lighting energy use by comparing it with several different buildings.

Tab. 7: variable's values of correlation analysis

LTE(kWh)		2F Office	3F Office	4F Office	5F Conference room
Mar.2015		249.2	528.0	364.6	25.9
Apr. 2015		255.0	530.3	376.2	36.9
May 2015		207.8	394.9	261.3	18.9
Jun. 2015		255.3	528.7	298.0	13.5
Jul. 2015		252.5	557.9	308.8	15.0
FLA (㎡)		198.4	198.4	198.4	167.9
LPD (W/㎡)		8.9	9.7	9.7	9.6
ILU (lx)		269	309	289	286
OCD(person/㎡)		0.04	0.11	0.10	0.00
OPHR (avg. hrs.)	Mar.2015	424	441	335	192
	Apr. 2015	347	432	344	223
	May 2015	297	338	288	210
	Jun. 2015	333	495	321	196
	Jul. 2015	338	524	368	199

Tab. 8: Correlation coefficient of lighting energy use with influential factors

influential factor	BLD Factor	SYS factor		USE factor	
	CFLA	LPD	ILU	OCD	OPHR
Mar.2015	0.84	0.25	0.61	0.97	0.82
Apr. 2015	0.84	0.26	0.61	0.97	0.97
May 2015	0.86	0.17	0.57	0.95	0.97
Jun. 2015	0.86	0.17	0.57	0.95	0.97
Jul. 2015	0.80	0.20	0.63	0.92	1.00
avg.	0.84	0.21	0.60	0.95	0.95
ranking	3	5	4	1	1

4. Summary and Conclusions

In order to develop an estimation equation of lighting energy use of office building to be suitable to domestic situations, we analyzed the measurement data collected from the case-study building, identified the characteristics of lighting energy use, and drew major influential factors to be used as basic data to supplement and verify the estimation equation.

The major study results are as follows;

(1) For estimation of lighting energy use, this study examined the influential factors in energy consumption by classifying them into the building factors, system factors, user factors, and weather factors;

(2) The monthly average of lighting energy use of office building during the weekdays by month was recorded at 79.7Wh/㎡ in March, 80.8Wh/㎡ in April, 73.8Wh/㎡ in May, 74.5Wh/㎡ in June, and 73.3Wh/㎡ in July, while that during the weekends by month were estimated at 6.8Wh/㎡ in March, 5.1Wh/㎡ in April, 6.7Wh/㎡ in May, 5.4Wh/㎡ in June, and 15.2Wh/㎡ in July, and the morning hours showed a higher occurrence ratio of the monthly average peaks of lighting energy consumption;

(3) According to the monthly lighting energy consumption rate of each time zone, the afternoon working hours took up the highest percentage at 28.5%, followed by the morning working hours (21.5%), the closing hours (15.4%), the lunch hour (13.8%), the morning commuting hours (9.8%), and the night hours (7.6%), and the weekends & holidays (3.3%);

(4) This was due to a high ratio of electronic lamps installed on the 2F office, almost 2 times that of the other office floors, as they were believed to consume more standby power than fluorescent lamps;

(5) The ratios of the monthly average lighting energy consumption during the weekdays were recorded at 97.2% in March, 98.4% in April, 94.9% in May, 98.1% in June, and 95.1% in July, while those during the weekends 2.8% in March, 1.6% in April, 5.1% in May, 1.9% in June, and 4.9% in July. The average energy consumption ratio of the weekdays was estimated at 96.7%, while that of the weekends were at 3.3%;

(6) According the correlation between lighting energy consumption of each office floor within the case study target building and influential factors, the correlation with the number of occupants and use time showed the highest coefficients, followed by the conditioned floor area, indoor illumination, and lighting density.

Future studies need to conduct a comparative analysis by targeting numerous sample buildings in order to identi fy and confirm various possible correlations between lighting energy consumption and influential factors.

Acknowledgement

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