Influence of LED Lamps on Air-conditioning Load and Energy Consumption in Commercial Buildings

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Abstract

In commercial buildings, installation of LED lamps has been accelerated due to their low electricity consumptions. The air-conditioning load caused by lighting is closely related to electricity consumptions of lamps. Therefore, if fluorescent lamps are replaced by LED lamps, the air-conditioning load and resulting energy consumptions of air conditioners should be influenced. In this study, we calculated the air-conditioning load in an electronics retail store located in central Japan at every one hour through a year based on thermal characteristics of fluorescent and LED lamps. Then, by combining those air-conditioning loads of the store and the partial load performance of air conditioners, we calculated electricity consumptions of the air conditioners at every one hour through a year. By replacing the fluorescent lamps with LED, the annual cooling load decreased by 17% while the annual heating load increased by 30%, consequently the annual thermal load did not change so much with this lamp replacement. As a result, the annual cooling electricity consumption of air conditioners decreased by 7 - 11% whereas the annual heating electricity consumption increased by 9 - 20%. However, because the reduction of lighting electricity consumption with LED lamps was larger than the increase of the annual heating electricity consumption, the annual electricity consumed by lighting and air conditioning decreased by 21%.

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1. Introduction

In business-related buildings such as office buildings and mass merchandizing stores, energy used by air-conditioning and lighting amounts to more than 50% of their total energy consumptions [1]. Therefore, the reduction of their energy consumptions is an important issue for the energy-saving of those buildings. Recently, installation of LED lamps on these buildings has been accelerated due to their high energy-saving effect and long operating life. In our measurements in an electronics retail store, the air-conditioning load (cooling load) caused by heat emission from lighting amounts to about 30% of the total cooling load in the store even in midsummer, and this percentage increases in an intermediate season. In the heating season, on the other hand, the heat emission from lighting contributes to reduce the heating load in the building. Since the cooling load caused by

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the lighting system is almost proportional to the electricity consumptions of the lamps [2], the air-conditioning load in the building can be also influenced if conventional fluorescent lamps are replaced by LED lamps with smaller electricity consumptions. However, the influence of LED lamps on the air-conditioning load and energy consumption in a business-related building is not yet clarified quantitatively [3-5].

With these points as background, we have been investigating thermal and luminous characteristics of fluorescent and LED lamps experimentally, and calculating air-conditioning loads and energy consumptions in several model buildings. In this study, we at first calculated numerically the air-conditionings loads in an electronics retail store for several kinds of lighting systems with fluorescent lamps or LED lamps. We used the simulation software "BEST" [6] developed in Japan to calculate the air-conditioning load in the store at every one hour through a year. By integrating the hourly air-conditioning loads over a year, the influence of replacement of fluorescent lamps by LED lamps on the annual air-conditioning load in the store was examined quantitatively. Next, by combining the air-conditioning load in the store, meteorological data, and the partial load performance of an air conditioner installed in the store, we calculated the energy consumptions of the air conditioner at every one hour through a year. Then, we calculated the annual energy consumptions of the air conditioner and lighting, and evaluated quantitatively the total energy-saving effect LED lamps from viewpoints of both lighting and air conditioning.

2. Calculation of Air-conditioning Load in the Store

2.1. Mathematica model in BEST

We used "BEST" (Building Energy Simulation Tool) program to calculate the air-conditioning load of the store. This program is a whole building energy analysis and thermal load simulation software. It was developed by an industry-government-academia joint group in Japan consisting of general contractors, designers, manufacturers, universities and government in 2005 and has continuously been refined to date [6]. The model to calculate the air-conditioning load in a building is briefly explained here, but please refer the manual of BEST program [7] for the details of the numerical models and constants used in them.

In this program, the temporal change of the thermal load in one room in a building (defined as room *i* here) is calculated based on the heat balance in room *i* at the *n*th time step expressed by the following equation.

$$C_i\,(d\theta_i/dt)_{,\,n} = Q_{W,\,n} + Q_{IW,\,n} + Q_{F,\,n} + Q_{INF,\,n} + Q_{AIR,\,n} + Q_{IH,\,n} + Q_{AC,\,n} \quad (1)$$

C_i is the heat capacity of room *i* and θ_i is the air temperature in room *i*. Therefore, the term in the left-hand side shows the temporal change of the thermal load in room *i*. Each term in the right-hand side of Eq. (1) is expressed as follows.

$Q_{W,\,n}$ = thermal load entering through the outer walls and windows of room *i*

$$= \Sigma\,\{K_{Wo,\,k}\cdot\theta_{Oe,\,k,\,n} + K_{Wi,\,k}\cdot\theta_{i,\,n} + F_{W,\,k,\,n}\} \quad (2)$$

$K_{Wo,\,k}$: thermal conductance of the outer side of the *k*th outer wall of room *i*
$\theta_{Oe,\,k,\,n}$: sol-air temperature (SAT) for outer side of the *k*th outer wall of room *i* (known value)
$K_{Wi,\,k}$: thermal conductance of the inner side of the *k*th outer wall of room *i*
$\theta_{i,\,n}$: air temperature in room *i* (unknown value)
$F_{W,\,k,\,n}$: heat emitted from the *k*th outer wall of room *i* under unsteady condition

$Q_{IW,\,n}$ = thermal load entering through the inner walls between room *i* and neighboring rooms

$$= \Sigma\,\{K_{IWo,\,j}\cdot\theta_{j,\,n} + K_{IWi,\,j}\cdot\theta_{i,\,n} + F_{IW,\,j,\,n}\} \quad (3)$$

$K_{IWo,\,j}$: thermal conductance of the outer side of the inner wall between room *i* and neighboring room *j*
$\theta_{j,\,n}$: air temperature in room *j* (unknown value)
$K_{IWi,\,j}$: thermal conductance of the inner side of the inner wall between room *i* and room *j*
$F_{IW,\,j,\,n}$: heat emitted from the inner wall between room *i* and room *j* under unsteady condition

$Q_{F,\,n}$ = heat emitted from the furniture etc. equipped in room *i* under unsteady condition

$$= K_F\cdot\theta_{i,\,n} + F_{F,\,n} \quad (4)$$

K_F : thermal conductance of the outer wall of furniture etc. equipped in room *i*
$F_{F,\,n}$: heat emitted from furniture etc. under unsteady condition

$$Q_{INF,\,n} = \text{thermal load by drafts of outdoor air} = C_p\cdot\rho\cdot V_{INF,\,n}\,(\theta_{O,\,n} - \theta_{i,\,n}) \quad (5)$$

C_p : specific heat of air

ρ : density of air
$V_{INF, n}$: volume flow rate of drafts
$\theta_{O, n}$: temperature of outdoor air

$Q_{AIR, n}$ = thermal load by ventilation between neighboring rooms = $\Sigma\, C_p \cdot \rho \cdot V_{j, n}\, (\theta_{j, n} - \theta_{i, n})$ (6)
$V_{j,n}$: volume flow rate of ventilating air between neighboring rooms

$Q_{IH, n}$ = thermal load by heat generation of equipment in room i = $\Sigma\, Q_{IHl, n}$ (7)
$Q_{IHl, n}$: heat generation of each equipment l

$Q_{AC, n}$ = heat supplied by air conditioners in cooling and/or heating operations
$= C_p \cdot \rho \cdot V_{D, n}\, (\theta_{D, n} - \theta_{i, n})$ (8)
$V_{D, n}$: flow rate of air supplied by air conditioners
$\theta_{D, n}$: temperature of air supplied by air conditioners

The thermal load by lighting is included in the internal heat generation term Q_{IH} expressed by Eq. (7). In the case of the lighting system with LED lamps, the value of this term is set to be smaller than that of the fluorescent lamps. Details of the heat emission from the lighting system are explained later in this paper.

2.2. Specification of the model store

In this study, we calculated the hourly air-conditioning load in the building with several kinds of lighting systems through a year to examine the influence of LED lamps on the air-conditioning load. We selected an electronics retail store located in Nagoya city (central Japan) as a model building, in which we had measured the air-conditioning load through a year [8]. The measuring method is explained in the reference [9]. The meteorological condition of Nagoya is almost the same as that of Tokyo. Table 1 shows the detailed specifications of the model building set in BEST. Its floorage and structure are the same as those of the real electronics retail store in which we had made the field measurements in the preceding study. Heat emissions from displayed items and humans, amount of ventilation were determined referring the data obtained in the field measurements.

Table 1. Specifications of model building

Location	Nagoya (Central Japan)	
Category of building	Electronics retail store	
Total floorage	2,640 m^2	
Floor height / Ceiling height	5.0m / 4.5m	
Wall structure	Exterior	Plaster board 100mm Glass wool 100mm ALC panel 100mm
	Floor	Vinyl plastic 3mm Concrete 200mm
	Roof	Plaster board 10mm Glass wool 100mm Steel 5mm
Internal heat generation	Humans: 0.4 people/m^2, Instruments and displayed items: 10 W/m^2	
Air-conditioning time	10 o'clock - 21 o'clock	
Air-conditioning condition	Temperature	24 ºC (summer) 22 ºC (winter) 23 ºC (autumn, spring)
	Flow rate of outdoor air	4 m^3/h/m^2
Draft	0.2 times/hour	

Table 2. Specifications of lighting systems in the model building

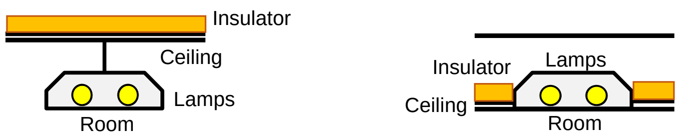
Lighting type	Light fixture	Type of lamp	Luminaire luminous flux (lx)	Number of lamps	Total electricity consumption (W)
A	Straight-tube type	Fluorescent lamp	14,924	288	49,824
	Straight-tube type	Fluorescent lamp	7,733	36	3,132
	Straight-tube type	Fluorescent lamp	4,383	4	180
B	Straight-tube type	LED lamp	13,040	288	35,712
	Straight-tube type	LED lamp	6,140	36	2,232
	Straight-tube type	LED lamp	3,100	4	128

Table 3. Calculation conditions of lighting systems

Case	Lighting type	Installation type	Lighting load (W/m^2)	Note
1	A (fluorescent)	ceiling-suspended	20.1	100% of electricity consumption
2	B (LED)	ceiling-suspended	14.4	100% of electricity consumption
3	A (fluorescent)	ceiling-embedded	10.5	52.4% of electricity consumption
4	B (LED)	ceiling-embedded	7.3	50.4% of electricity consumption

Table 2 shows the specifications of the lighting systems in the model building. The lighting system with straight-tube type light fixtures and fluorescent lamps was equipped in the real store, and its specification is shown in the upper part of Table 2. In this study, we assumed that the fluorescent lamps equipped in the real store were replaced by LED lamps with equivalent luminaire luminous fluxes (lower part of table). However, luminaire luminous fluxes of LED lamps are about 13% lower than those of fluorescent lamps, thus one may feel slightly darker with LED lamps in comparison with fluorescent lamps.

Table 3 shows the calculation conditions of the lighting systems. We examined two types of installations of light fixtures; one is the ceiling-suspended installation shown in Fig. 1(a) and the other is the ceiling-embedded



(a) Ceiling-suspended lighting installation (b) Ceiling-embedded lighting installation

Fig. 1 Installation methods of lighting systems

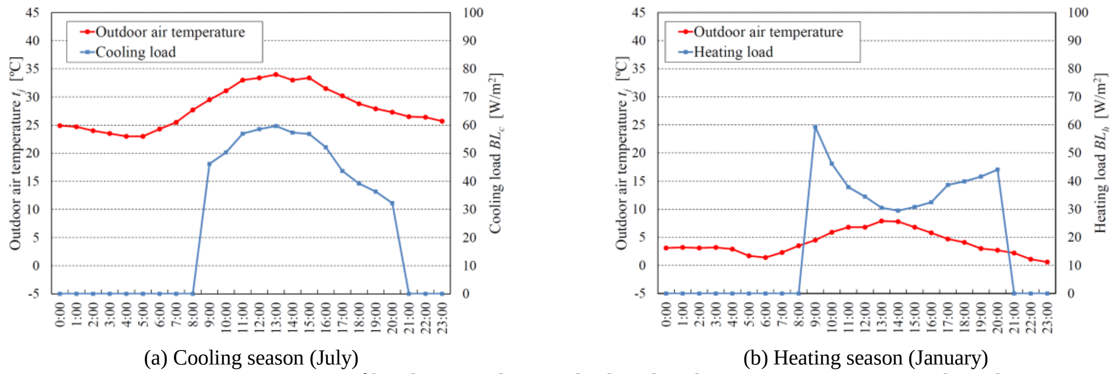
installation shown in Fig. 1(b). The former was used in the real store, and the thermal load by lighting was assumed to be equal to the electricity consumption of lamps. In the latter, the thermal load by lighting was calculated based on the downward heat emissions of lamps determined by the preceding experiments [10]; the fraction of the downward heat emission to the electricity consumption was 0.524 for the fluorescent lamps and 0.504 for LED lamps. In this study, fluorescent lamps and LED lamps were combined with these installation types and the air-conditioning loads were calculated for four cases (Case 1 – Case 4) listed in Table 3.

2.3. Results of Air-conditioning Load

Figures 2(a) and 2(b) show variations of hourly air-conditioning loads per unit floorage calculated for one day in July and January, respectively. We assumed that air conditioning was closed down completely during night. Outdoor air temperature averaged in every one hour t_j is also shown in figures. The cooling load in the store BL_c generally changes in accordance with the outdoor air temperature and it attains the maximum around 13:00. On the other hand, the maximum value of the heating load BL_h appears at 9:00 at which an operation of an air conditioner starts, because cold heat is accumulated in the walls and roof of the building in the night-time.

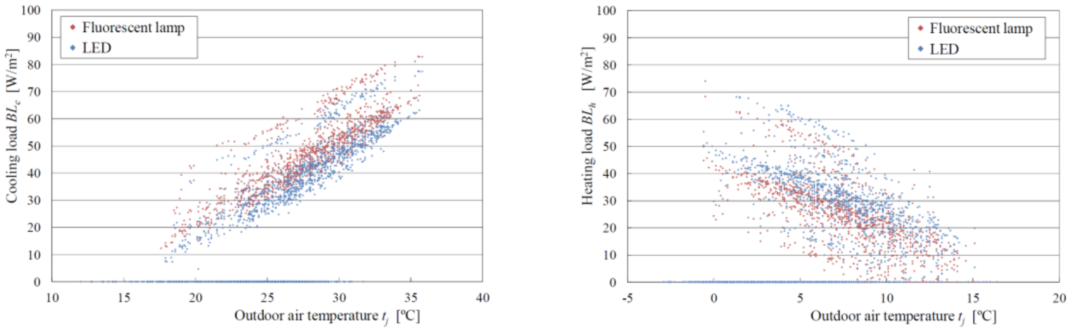
We arranged these hourly air-conditioning loads to the outdoor air temperature t_j. Figures 3(a) and 3(b) show the results of the cooling load and the heating load per unit floorage, respectively, obtained with the ceiling-suspended lighting installation. Red symbols show the result for fluorescent lamps (Case 1) and blue ones show those for LED lamps (Case 2). Data during night with no A/C operations, i.e., $BL_c = BL_h = 0$, are included in these figures. It is found that the air-conditioning loads change almost in proportional to the outdoor air temperature in both cooling and heating seasons. The cooling loads decrease by replacing the fluorescent lamps with LED lamps because heat emission from lamps decreases with LED. For the same reason, the heating loads increase with LED lamps.

By averaging these hourly air-conditioning loads in a year at every one degree of outdoor air temperature t_j, we rearranged the air-conditioning load in the store as a function t_j. Figure 4 shows the comparison of the temperature-mean air-conditioning load measured in the real electronics retail store and that calculated by BEST for Case 1 with the ceiling-suspended installation of fluorescent lamps, which is the same lighting system as that of the real store. The heating load is shown by negative values. As estimated from the results in



(a) Cooling season (July) (b) Heating season (January)

Fig. 2 Time-series variations of hourly air-conditioning loads and outdoor air temperature in typical one day



(a) Cooling load (b) Heating load

Fig. 3 Distributions of air-conditioning loads at every one hour in a year to outdoor air temperature

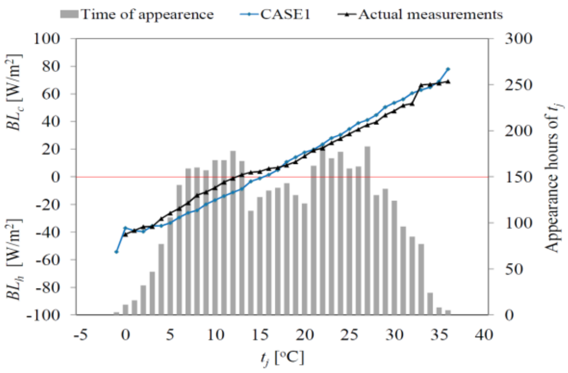


Fig. 4 Comparison of measured and calculated air-conditioning loads in a year for Case 1

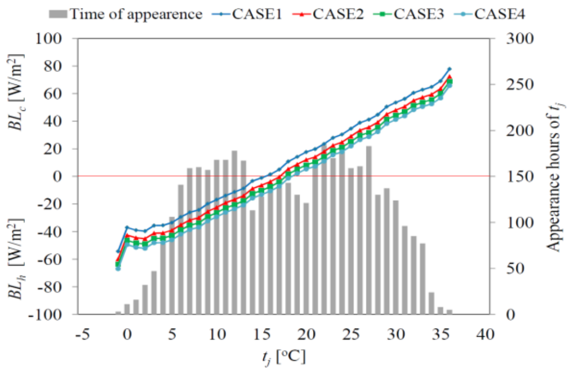


Fig. 5 Variations of temperature-mean air-conditioning loads to outdoor air temperature for Case 1 – Case 4

Figs. 3, the air-conditioning load changes linearly with respect to the outdoor air temperature t_j, and the cooling load switches to the heating load around 15 ºC. The predicted air-conditioning load agrees quantitatively with the measured result, and this supports the validity of the numerical results obtained by BEST.

The temperature-mean air-conditioning loads BL_c and BL_h obtained for Cases 1 – 4 in Table 3 are shown in Fig. 5 together with the appearance hours of outdoor air temperature t_j in a year. In all cases, air-conditioning loads change linearly with respect to t_j and dBL_c/dt_j and dBL_h/dt_j are almost constant irrespective of calculation conditions. The cooling loads switch to the heating loads around 15 - 18 °C. By changing the lighting from fluorescent lamps to LED, the outdoor air temperature at which the cooling load switches to the heating load becomes higher and the annual cooling loads decrease. The difference of this switching temperature is 2 ºC for the ceiling-suspended installation, but it decreases to 1 ºC for the ceiling-embedded installation.

By integrating the cooling and heating loads shown in Fig. 5 with appearance hours of t_j, we obtained the annual air-conditioning loads of this store. The results are summarized in Table 4. In Case 1, the annual cooling load is 2.3 times as large as the annual heating load. By replacing the fluorescence lamps with LED lamps (Case 2), the annual cooling load decreases by 17% while the heating load increases by 30%. In Case 4 with the ceiling-embedded installation of LED lamps, the annual heating load is 17% larger than the annual cooling load. This result means that, in using LED lamps with the ceiling-embedded installation, the maximum air-conditioning load may appear in the heating season even in a building with large internal heat generations. This suggests that the maximum electric power demand may arise in midwinter with LED lamps. The measured air-conditioning loads are smaller than the simulation results as shown in Table4. This difference between the measured and simulated thermal loads is mainly ascribed to the setting value of draft in BEST.

Table 4. Annual air-conditioning loads in the store

	Case 1	Case2	Case 3	Case 4	Measurement
Cooling load [MJ/m^2]	290	242	211	186	231
Heating load [MJ/m^2]	126	164	192	217	86
Annual load [MJ/m^2]	416	406	403	403	317

3. Calculation of Energy Consumptions

3.1. COP characteristics of air conditioner

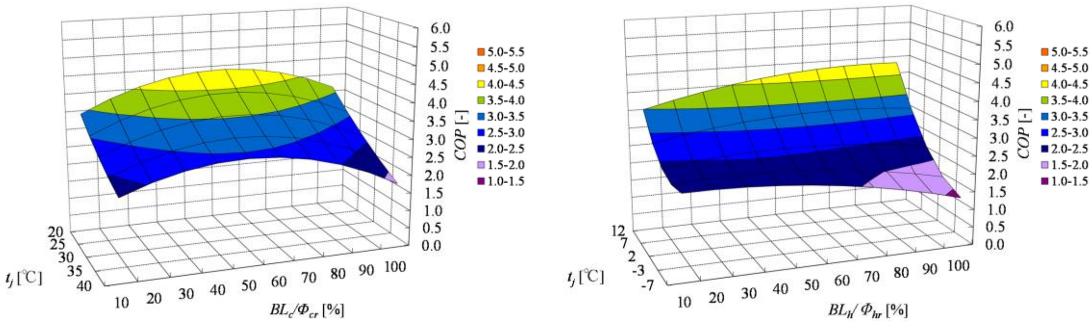
By combining the air-conditioning load described above, meteorological data, and COP characteristics of the air conditioner, we calculated the seasonal/annual energy consumptions of the air conditioner for Case 1 – Case 4. In the real electronics retail store, electric heat pump VRF systems of Japan make were installed. Thus, as the air conditioner used for the calculation of energy consumptions, we selected the electric heat pump VRF system that was manufactured by the same Japanese company as that installed in the real store. In order to make clear detailed COP characteristics of this VRF system, we made the partial load performance tests [11]. In the cooling performance test, outdoor air temperature t_j was changes from 20 °C to 45 °C at 5 °C intervals, and the indoor thermal load BL_c was changed from 12.5% to 100% of the rated cooling capacity of the air conditioner. Cooling COPs were measured at 36 test points. In the heating performance test, outdoor air temperature was changed from -7 °C to 12 °C and the indoor thermal load BL_h was changed from 12.5 % to 100 % of the rated heating capacity of the air conditioner. Heating COPs were measured at 31 test points.

Based on COP data obtained by the partial load performance tests, we can plot "COP surface" by expressing COPs as a function of outdoor air temperature t_j and the air-conditioning load ratio BL_c / Φ_{cr} or BL_h / Φ_{hr}, where Φ_{cr} and Φ_{hr} designate the rated cooling and heating capacities of the air conditioner, respectively [11]. Figure 6 shows the cooling and heating COP surfaces of the tested VRF system. The cooling COP shows high values in the intermediate cooling load region and increases as t_j becomes lower. The heating COP is generally lower than the cooling COP. The increase of COP in the intermediate load region such as observed in the cooling COP surface does not appear in the heating COP surface.

3.2. How to calculate electricity consumption of air conditioner

In this study, COP of the air conditioner was calculated at every one hour through a year by combining COP surfaces described above, the hourly outdoor air temperatures, and hourly air-conditioning loads such as shown in Fig. 2. Then, the hourly electricity consumptions of the air conditioner were calculated from COP and the air-conditioning load. By integrating them, we obtained the annual/seasonal electricity consumptions of the air conditioner. As described above, COP of an air conditioner is expressed as a function of the outdoor air temperature t_j and the air-conditioning load ratio BL_c / Φ_{cr} or BL_h / Φ_{hr}. In order to calculate the air-conditioning load ratio, the rated cooling and heating capacities of the air conditioner installed in the store Φ_{cr} and Φ_{hr} must be determined. In this study, they were determined in the following method.

We calculated the standard deviation of the hourly air-conditioning load (denoted as σ) in every one degree of t_j. Then, the value of "temperature-mean air-conditioning load BL_c or BL_h + 3σ" was calculated in every one degree of t_j. Since the purpose of this study is to examine the influence of replacement of fluorescent lamps by LED lamps on the air-conditioning energy consumption in the store, this calculation was made in Case 1 and Case 3 with fluorescent lamps. Moreover, considering that the maximum air-conditioning load usually occurs in summer in this type of building use, the maximum value of "$BL_c + 3\sigma$" was assumed to be equal to the rated cooling capacity of the air conditioner installed in the store Φ_{cr}. Figure 7 shows the results of BL_c and $BL_c + 3\sigma$



(a) Cooling COP (b) Heating COP

Fig. 6 COP surfaces of VRF system obtained by partial load performance tests

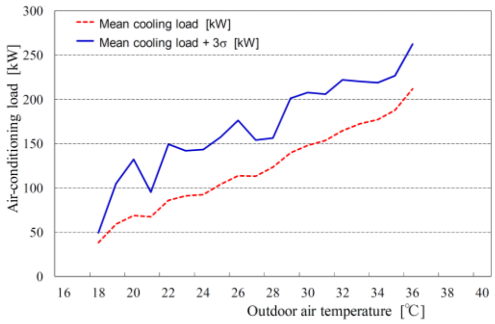


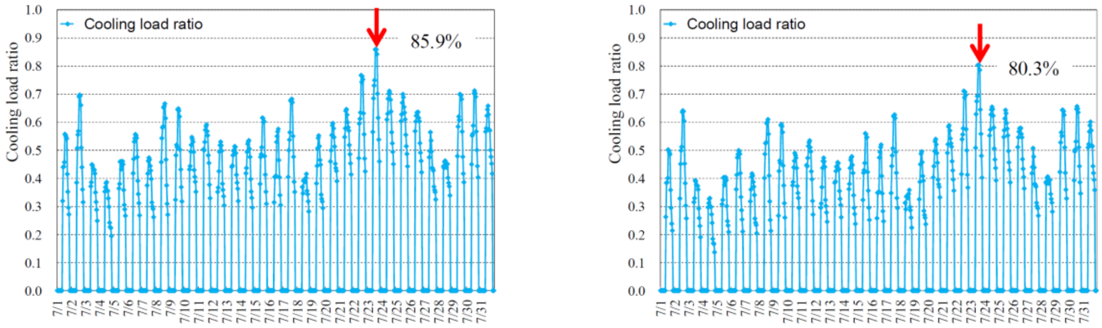
Fig. 7 Distributions of temperature-mean cooling load and “temperature-mean cooling load + 3σ” in Case 1

obtained for Case 1 with the ceiling-suspended lighting installation and fluorescent lamps. In this case, Φ_{cr} was assumed to be 262 kW. In Case 3 with the ceiling-embedded lighting installation and fluorescent lamps, the cooling load is smaller than that for Case 1 and Φ_{cr} = 238 kW. These values of Φ_{cr} mean the minimum required cooling capacities of the air conditioner installed in this electronics retail store. The rated heating capacity Φ_{hr} was assumed to be 1.1 times of Φ_{cr} considering the general specification of the VRF system.

3.3. Results of electricity consumptions in the cooling season

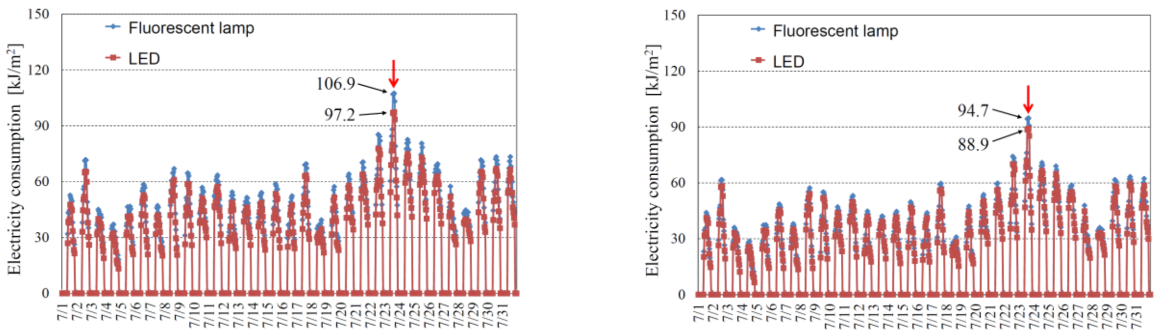
As examples of time-series variations of the cooling load ratios for the air conditioner in summer, BL_c/Φ_{cr} at every one hour in July obtained for Case 1 and Case 2 are shown in Fig. 8. The maximum cooling load ratios are observed at 13:00 – 14:00 on July 23rd (red arrows in figures) and, by replacing the fluorescent lamps (Case 1) with LED lamps (Case 2), the maximum BL_c/Φ_{cr} decreases from 85.9% to 80.3%. This reduction of the cooling load is caused by the lower heat emission from LED lamps.

Figure 9(a) shows the comparison of electricity consumptions of the air conditioner per unit floorage obtained at every one hour in July for Case 1 and Case 2 with the ceiling-suspended lighting installation. The maximum electricity consumption shown by red arrow is decreased by 9.5% by replacing the fluorescent lamps with LED lamps. This reduction of the maximum electricity consumption of the air conditioner contributes to suppress the demand power in midsummer. Figure 9(b) shows the results for Case 3 and Case 4 with the ceiling-embedded lighting installation. In these cases, the amount of heat emitted from lamps toward the indoor space is reduced to half of their electricity consumption as described before. Therefore, the cooling load and resulting electricity consumption of the air conditioner show generally smaller values that those for Case1 and Case 2 shown in Fig. 9(a). The air-conditioning electricity saving effect of LED lamps becomes relatively small, and the maximum electricity consumption of the air conditioner is decreased by 6.0% with LED lamps.



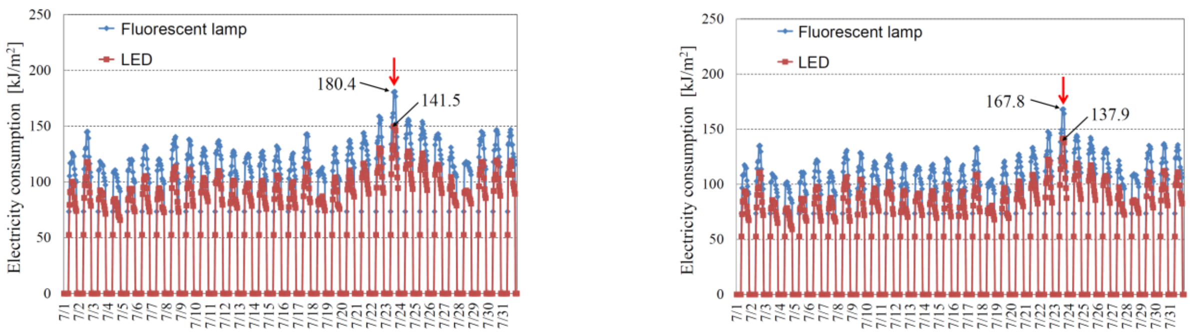
(a) Case 1 (fluorescent lamps) (b) Case 2 (LED lamps)

Fig. 8 Variations of cooling load ratios at every one hour in July



(a) Case 1 and Case 2 (ceiling-suspended installation) (b) Case 3 and Case 4 (ceiling-embedded installation)

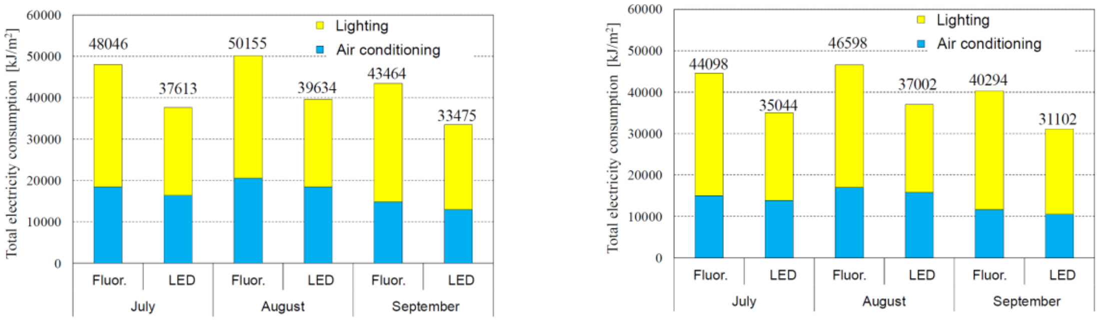
Fig. 9 Comparisons of electricity consumptions of air conditioner at every one hour in July



(a) Case 1 and Case 2 (ceiling-suspended installation) (b) Case 3 and Case 4 (ceiling-embedded installation)

Fig. 10 Comparisons of electricity consumptions of air conditioner and lighting at every one hour in July

Next, we calculated the sum of electricity consumed by lighting and air conditioner at every one hour in July. Figures 10(a) and 10(b) show the results for ceiling-suspended lighting installation (Cases 1 and 2) and ceiling-embedded lighting installation (Cases 3 and 4), respectively. By replacing the fluorescent lamps with LED lamps, the maximum electricity consumption can be decreased by 21.5% for the ceiling-suspended installation and by 17.8% for the ceiling-embedded installation. Based on these results, we calculated the sum of electricity consumed by lighting and air conditioner in three months in the cooling season (July, August and September) for Case 1 – Case 4. Figure 11 shows the results. In all cases assumed in this study, the electricity consumed by lighting is larger than that consumed by the air conditioner. The electricity consumed by lighting is decreased by 28.4% in three months with LED lamps, whereas the decrease ratios of the air- conditioning electricity are 11.1% and 6.6% for the ceiling-suspended lighting installation and ceiling-embedded installation,



(a) Case 1 and Case 2 (ceiling-suspended installation) (b) Case 3 and Case 4 (ceiling-embedded installation)

Fig. 11 Comparisons of electricity consumptions of air conditioner and lighting in the cooling season

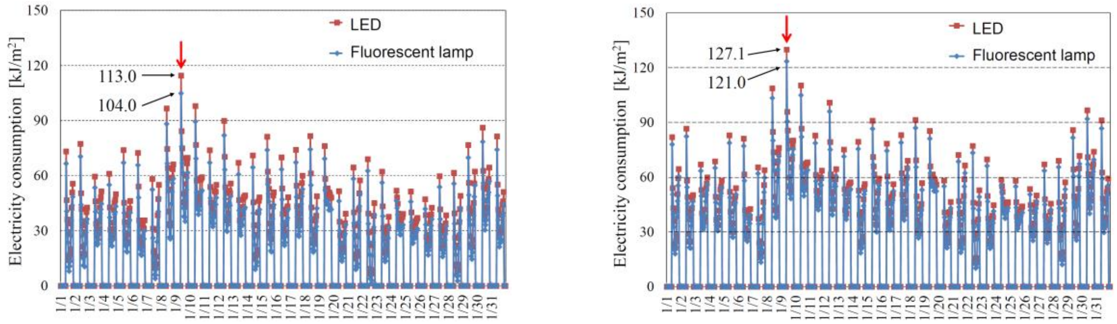
respectively. As a result, the total electricity consumptions of lighting and air conditioning are decreased by 21.8% and 21.3% with LED lamps for the ceiling-suspended and ceiling-embedded installations, respectively. It should be noted that the mean cooling COPs in these three months were about 3.4 in all cases, and the influence of lighting was not observed in the seasonal COPs.

3.4. Results of electricity consumptions in the heating season

In the heating season, the maximum heating load ratio appeared at 9:00 – 10:00 on January 9th and it increased from 63.8% (Case 1) to 69.1% (Case 2) by replacing the fluorescent lamps with LED lamps, because heat emission from lamps toward the indoor space decreased with LED lamps. Since the maximum cooling load ratio in the cooling season was larger than 80% in these cases as shown above, the maximum air-conditioning load appears in summer in case of the ceiling-suspended lighting installation. However, we found that the maximum value of BL_h / Φ_{cr} for Case 4 with the ceiling-embedded installation of LED lamps was 83.5%, and this value was larger than the maximum cooling load ratios for Case 4 (80.8%). This result suggests that, in the combination of the ceiling-embedded installation and LED lamps, the maximum air-conditioning load appears in winter even in the electronics retail store with large internal heat sources.

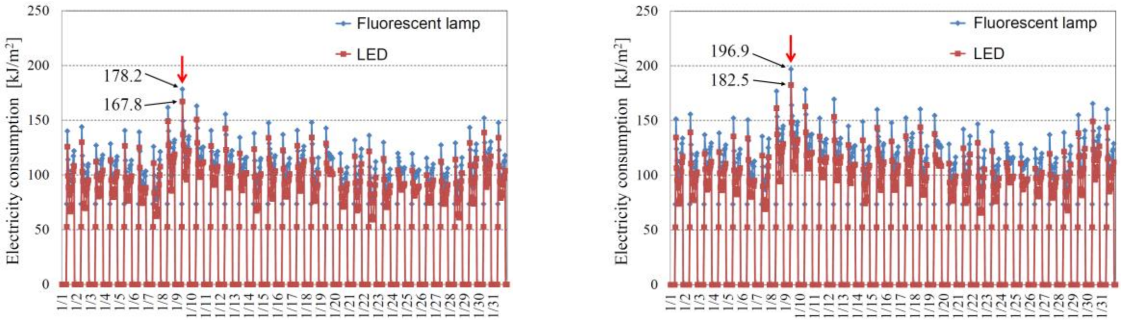
Figure 12(a) shows a comparison of electricity consumptions of the air conditioner per unit floorage obtained at every one hour in January for Case 1 and Case 2 with the ceiling-suspended lighting installation. The maximum electricity consumption of the air conditioner is increased by 8.7% by replacing the fluorescent lamps with LED lamps. In Case 3 and Case 4 shown in Fig. 12(b), the maximum electricity consumption of the air conditioner is increased by 5.0% with LED lamps.

Figure 13 shows the comparisons of electricity consumed by lighting and air conditioner at every one hour in January. In Case 2 and Case 4 with LED lamps, the increase of the electricity consumption of the air conditioner is cancelled by the decrease of the electricity consumption of lamps. As a result, the maximum electricity consumptions are decreased by 5.8% and 7.3% for Case 2 and Case 4, respectively. Figures 14(a) and 14(b) show the electricity consumptions of lighting and air conditioner in the heating season (December, January and February) obtained for the ceiling-suspended lighting installation and the ceiling-embedded installation, respectively. The electricity consumed by lighting in three months is decreased by 28.4% with LED lamps, whereas the air-conditioning electricity consumption is increased by 20.1% and 8.5% in Case 2 and Case 4, respectively. As a result, the total electricity consumptions of lighting and air conditioning are decreased by 15.4% and 16.3% with LED lamps for the ceiling-suspended and ceiling-embedded installations, respectively. The mean heating COPs in three months were 3.0 – 3.1 in all cases, and the influence of lighting was not observed clearly in them.



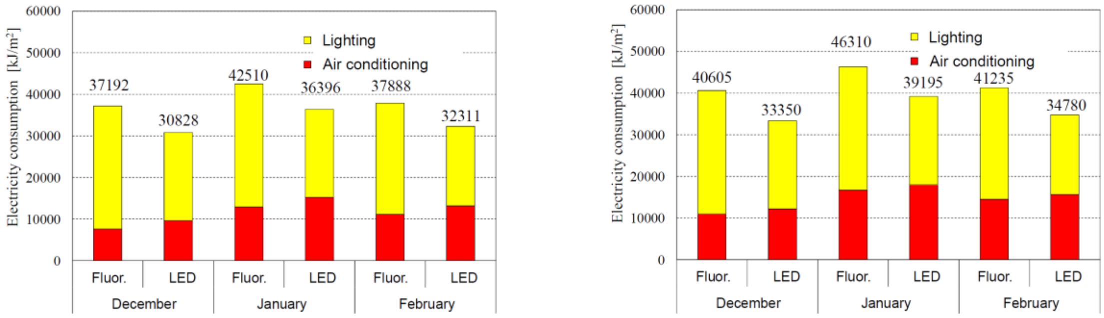
(a) Case 1 and Case 2 (ceiling-suspended installation) (b) Case 3 and Case 4 (ceiling-embedded installation)

Fig. 12 Comparison of electricity consumptions of air conditioner at every one hour in January



(a) Case 1 and Case 2 (ceiling-suspended installation) (b) Case 3 and Case 4 (ceiling-embedded installation)

Fig. 13 Comparisons of electricity consumptions of air conditioner and lighting at every one hour in January

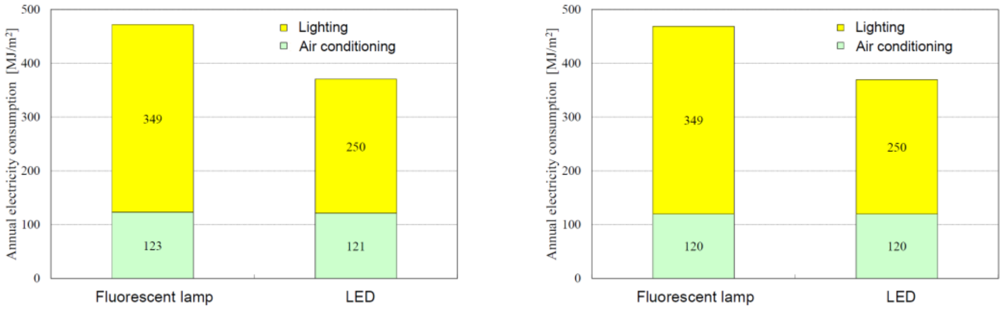


(a) Case 1 and Case 2 (ceiling-suspended installation) (b) Case 3 and Case 4 (ceiling-embedded installation)

Fig. 14 Comparisons of electricity consumptions of air conditioner and lighting in the heating season

3.5. Annual electricity consumptions of lighting and air conditioning

Figures 15(a) and 15(b) show the comparisons of annual electricity consumptions of lighting and air conditioner in the ceiling-suspended lighting installation and the ceiling-embedded lighting installation, respectively. There are not significant differences in electricity consumptions of the air conditioner for all cases, because the decrease of cooling electricity consumption of the air conditioner with LED lamps is cancelled by the increase of the heating electricity consumption. Therefore, it follows that the energy-saving effect of LED lamps is mainly brought about by the decrease of electricity consumed by themselves. Since the annual electricity consumption of lighting decreases 28% with LED lamps, the electricity consumed by lighting and air conditioning in a year can be decreased by 21% in both lighting installations.



(a) Case 1 and Case 2 (ceiling-suspended installation) (b) Case 3 and Case 4 (ceiling-embedded installation)

Fig. 15 Comparisons of annual electricity consumptions of air conditioner and lighting

4. Conclusions

In this study, by combining the air-conditioning loads in an electronics retail store obtained by numerical simulations and COP characteristics of an air conditioner installed in it measured by the partial load performance tests, we examined quantitatively the influence of LED lamps on the air-conditioning load and electricity consumption in the store. It was found that, by replacing the fluorescent lamps with LED lamps, the annual cooling load decreased by 17% while the annual heating load increased by 30% at most. As a result of those changes of air-conditioning loads, the annual cooling electricity consumption of air conditioners decreased by 7 - 11% whereas the annual heating electricity consumption increased by 9 - 20%. However, because the reduction of lighting electricity consumption with LED lamps was larger than the increase of the heating electricity consumption, the annual electricity consumption of whole store decreased by 21%.

References

[1] The Energy Conservation Center Japan, *Energy Conservation for Office Buildings*, 2010, http://www.asiaeeccol.eccj.or.jp/brochure/pdf/office_building.pdf

[2] The Society of Heating Air-Conditioning and Sanitary Engineers of Japan, *Practical knowledge of air conditioning system*, 1995, Ohmsha, (in Japanese)

[3] Qin, Y., Lin, D. and Hui, S.Y., A simple method for comparative study on the thermal performance of LEDs and fluorescent lamps, *IEEE Transactions on Power Electronics*, Vol. 24, 2009, pp. 1811-1818.

[4] Han, H. J., Jeon, Y. I., Lim, S. H., Kim, W. W. and Chen, K., New developments in illumination, heating and cooling technologies for energy-efficient buildings, *Energy*, Vol. 35, 2010, pp. 2647-2653.

[5] Ahn, B. L., Jang, C. Y., Leigh, S. B., Yoo, S. Y. and Jeong, H., Effect of LED lighting on the cooling and heating loads in office buildings, *Applied Energy*, Vol. 113, 2014, pp. 1484–1489.

[6] http://www.ibec.or.jp/best/english/index.html

[7] http://www.ibec.or.jp/best/program/pdf/manual/C_031_kenchiku_20161209.pdf

[8] Watanabe, C., Nakayama, H., Miyata, H., Miyaoka, Y., Mizutani, S. and Hirota, M., Measurements of Thermal Loads in Large Electric Home Appliance Retail Stores, *Proc. 2010 Annual Meeting of The Society of Heating Air-Conditioning and Sanitary Engineers of Japan*, 2010, pp. 573-576 (in Japanese)

[9] Hirota, M., Watanabe, C., Sakuraba, I., Miyaoaka, Y., Nakayama, H., Ohashi, E., Maruyama, N. and Nishimura A., Energy Saving of Air-conditioning in Mass Merchandisers by Operational Change of Air-conditioning System, *Proc. 10th IEA Heat Pump Conference*, 2011, 8.14, on CD-ROM

[10] Miyaoka, Y., Nakayama, H., Hirota, M., Onishi, M., Yoshizawa, N., Tadokoro, T., Effect of Energy-saving Lamps on Air-conditioning Load in Business-related Building, *Proceedings of the 24th IIR International Congress of Refrigeration*, 2015, paper no. 442.

[11] Miyaoka, Y., Iwata, Y., Nakayama, H., Hirota, M., Onishi, M., Evaluation of Annual Energy Consumption of Multi-split type EHP Air-conditioner for Buildings, *Proceedings of the 12th IEA Heap Pump Conference*, 2014, paper no. O.2.4.2.