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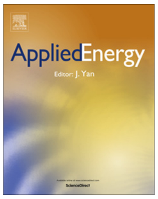

Effect of LED lighting on the cooling and heating loads in office buildings

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HIGHLIGHTS

- Application of heat control strategy reduces total energy consumption of LED lighting.
- Convective heat from LED lighting should be emitted outdoors during cooling period.
- Seasonal optimization of convective heat lowers total energy consumption.

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ABSTRACT

LED lighting has the potential to provide energy savings, and in many countries, there are policies to encourage its use owing to its higher efficiency and longer life in comparison to other lighting fixtures. However, since 75–85% of the light electric power in LED lights is still generated as heat, the sole use of LED lighting in a building could have a negative effect on the cooling load. In this paper, we study the heating properties of LED lighting and establish a management strategy to exploit these properties to reduce the energy used for heating and cooling of buildings. Using a simulation program, the energy consumption of the Green Building in Daejeon, Korea, and the virtual building provided by the U.S. Department of Energy (DOE) was computed according for different light fixtures. A control strategy is more applicable to LED lighting than to general fluorescent lighting, especially for the cooling of a building, because the use of a return-air duct and the heat sinks on the LED fixtures allow the heat to be better directed. Deployment of LED lights in combination with such a control strategy can help to increase the energy efficiency of a building.

1. Introduction

Increased energy consumption and CO_2 emissions in urban environments have made strategies to save energy and improve efficiency a priority in the energy policies of most countries [1]. Energy consumption for lighting in buildings, in particular, is a major contributor to CO_2 emissions, and has been estimated to account for 20–40% of the total energy consumption in buildings [2–4].

According to a recent review, investing in energy-efficient lighting is one of the most cost-effective ways to reduce CO_2 emissions, and other studies have shown that existing technology could reduce electricity use for lighting by 50% [5–7].

Of the existing technology, LEDs have particularly shown a rapidly increasing trend with regard to their light efficacy. This is demonstrated in the research conducted by Jenkins et al. in the UK, in which it was estimated that energy savings of 56–62% in a typical 6-storey office building could be achieved, resulting mainly from the change in the usage from fluorescent lights to LED lights (thus improving the lighting efficiency) and reduction in night-time usage [8]. Further, LED lights have 9–10 times longer lives than fluorescent lights. For these reasons, LED technology is being considered as the next generation of lighting [9].

Therefore, many countries have implemented national LED lighting projects. Through the 'Next Generation Lighting Initiative', the United States is aiming to develop LED technology with a luminous efficiency of 200 lm/W and to have a 50% share in the global lighting market by 2020. Japan, through the 'Light for the 21st Century project', has set a goal of a 20% reduction in lighting energy by widespread installation of white LED lighting and development of 120 lm/W LED technology [10,11]. According to the 2010 revised Japanese Energy Basic Plan, Japan plans to replace 100% of existing lights with highly efficient technologies (including LED and organic EL lighting) by 2020 [12]. The EU has issued the LED Quality Charter setting a high-quality voluntary standard to be used in Euro-

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pean utilities, industries, and other sectors that could benefit from LED lighting [13].

In Korea, the government plans to replace more than 30% of existing lighting fixtures in public institutions with LED lights by the end of 2012, and has established regulations specifying that from 2013, in new constructions and in the expansion and reconstruction of existing buildings, more than 30% LED products must be installed. Thus, the LED industry has been growing steadily in size and value owing to the support of governmental policies [14,15].

However, the current efficiency of LED lighting is similar to that of fluorescent lighting; cool white LED lights have an efficiency of 60–150 lm/W, which is comparable to 50–100 lm/W, the efficiency of linear fluorescent lights [3,16]. Furthermore, approximately 75∼85% of the light electric power in LED lights is still generated as heat, although heat generation and thermal management technologies are being developed [17,18]. The heat from the lighting is divided into visible light, convective, and radiant heat. Visible light accounts for approximately 8% of the incandescent light-emitting efficiency, and radiant heat and convective heat generation, which affect indoor heat, together account for 92% (Table 1). Fluorescent lighting and LED lighting emit 21% and 15–25% visible light, respectively, and fluorescent lighting emits 37% radiant heat and 42% convective heat, whereas LED lighting emits 75∼85% convective heat [19].

The thermal properties of a light source depend on the method of installation of the light fixture as shown in Fig. 1. Generally, incandescent lights are suspended from the ceiling, whereas fluorescent lights and LED lights are mounted on the ceiling in a recess. For suspended-type lighting, the light fixtures emit radiant heat into the room along with visible light, and this increases the indoor cooling load. For recessed-type fluorescent lighting, less radiant heat is emitted than from the suspended type, and the remaining heat stays in the ceiling as convective heat. However, for LED lighting, most of the heat generated stays in the ceiling as convective heat because no radiant heat is emitted from the light source and this increases the indoor cooling load.

Although the lighting policies of many countries have concentrated on the diffusion or replacement of LED light, as these lights emit radiant and convective heat more than visible light, it is necessary to recognize lighting energy as a heat source, not only a visible light source. In this paper, we establish the control strategy using the position change of the heat sink and evaluate the energy consumption of a building when LED lighting is installed. Then, we propose an optimized LED lighting control strategy to reduce the total building energy consumption.

2. Methods

2.1. Control strategy for LED lighting

LED light fixtures consist of an optical film, a printed circuit board (PCB), a heat sink, and a driver, as shown in Fig. 2 [20]. The PCB converts an input electrical signal to light, and the heat sink conducts heat that then stays in the vicinity of the LED light fixtures.

Table 1
Heating properties of light fixtures [19].

	Incandescent (%)	Fluorescent (%)	LED (%)
Visible light	8	21	15–25
Radiant heat	73	37	–
Convective heat	19	42	75–85

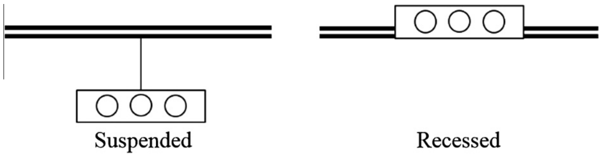

Fig. 1. General method for installation of lights on the ceiling.

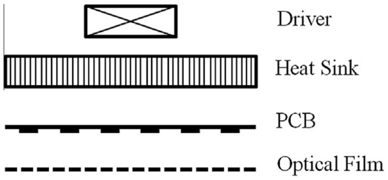

Fig. 2. Basic structure of LED light fixture in this study.

The thermal effect of LED lighting can be controlled because the heat sink is divided across the LED chip and can be used to reduce the heating and cooling load of buildings. Using these properties of LED lights, we established a control strategy to reduce indoor heat gains from light heat during cooling periods and to make full use of light heat during heating periods. As shown in Fig. 3, during a heating period, the Heat Sink 1 is attached to the PCB of LED light and heat from the heat sink should be exposed to the indoor area so that most of the convective heat, ranging from 75% to 85%, will be emitted indoors, thus acting as an internal heat source and reduce the heating load. During the cooling period, the Heat Sink 1 is separated from the PCB and the Heat Sink 2 is attached using a heat pipe and most of the convective heat will then be emitted outdoors through the existing return-air duct and exhaust fan, thus reducing the indoor heat gain and the cooling load.

In order to investigate the effect of the movable heat sink, we conducted an experiment using a small chamber with a LED light fixture and the results are shown in the Supplementary information.

2.2. Simulation of the Green Building

To analyze the impact of this control strategy for LED lighting on the heating, cooling, and lighting energy consumption of an actual building, we have applied it to the Green Building (GB), located in Daejeon, Korea, at the latitude of 36°N and the longitude of 127°E, using the simulation program, *EnergyPlus*.

The Green Building is shown in Fig. 4 and the physical characteristics of the building are listed in Table 2. The Heating, Ventilation and Air Conditioning (HVAC) system is a Variable Air Volume (VAV) system using ice thermal storage system in the cooling period and perimeter zone. The convector and the VAV system with Air Handling Unit (AHU) were used in the heating period. The lighting fixtures are double fluorescent lamps and the light density is 10.2 W/m^2. Air-conditioned zones are thermostat controlled with a zone set-point temperature of 28 °C for the cooling period (July–September) and 18 °C for the heating period (December–March).

The annual total end-use energy of the Green Building, which was actually measured, is EUI 189.28 kW h/m^2 yr including tenant electricity, of which lighting energy consumption accounts for 13.71 kW h/m^{2}yr (∼7.2%), heating energy consumption for 79.72 kW h/m^{2}yr (∼42.1%), and cooling energy consumption for 13.82 kW h/m^{2}yr (7.3%). The analysis was performed using the *EnergyPlus* simulation program, and the total energy was reproduced to within about 5%, as shown Fig. 5. Fig. 6 shows the zone plan for the simulation model, which consists of four parts: the