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Economic analysis of the daylight-linked lighting control system in office buildings

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Abstract

The objective of this study is to perform an economic analysis of the daylight-linked automatic on/off lighting control system installed for the purpose of energy savings in office buildings. For this, a building was chosen as a typical example, and the energy cost was calculated by using the daylight and building energy analysis simulation. When the lighting control was utilized, an economic analysis was performed using a payback period that was calculated by comparing the initial cost of installing the lighting control system with the annual energy cost which was reduced thanks to the application of the lighting control.

The results showed that the lighting energy consumption, when the lighting control was applied, was reduced by an average of 30.5% compared with the case that there was not lighting control applied. Also, the result for total energy consumption showed that, when lighting control was applied, this was reduced by 8.5% when the glazing ratio was 100%, 8.2% for 80%, and 7.6% for 60% when compared to non-application. The payback period was analyzed in terms of the number of floors in a building; 10 floors, 20 floors, 30 floors, and 40 floors. Hence, the building with 40 floors and glazing ratio 100% resulted in the shortest payback period of 8.8 years, the building with 10 floors and glazing ratio 60% resulted in the longest period of 12.7 years. In other words, the larger the glazing ratio and the number of building floors are, the shorter the payback period is.

Keywords: Daylight; Energy saving; Lighting control system; Lighting energy; Office building; Payback period

1. Introduction

Recently, intelligent building is rapidly increasing with the development of information-oriented technology and telecommunication environment. The lighting environment of the office has, therefore, also been responding to these changes and aims to improve the quality and creation of a comfortable lighting environment (Fontoynont, 2002). Also, the requirement of reducing energy consumption has become more important in Korea like the other countries because of a rise in the oil prices, a high dependence on foreign energy resources and a global warming problem due to using fossil energy. Moreover, heat gain due to electric lighting represents significant proportion of the total building cooling load (Li and Lam, 2001). In Korea, approximately 24% of the total energy is consumed in buildings, and approximately 35.8% of the building energy is consumed by lighting systems and electric outlet (Korea Energy Management Corporation). The detailed rate of energy consumption is shown in Fig. 1. Therefore, methods for reducing the energy consumption of the lighting systems in the buildings are highly required.

One of the methods is to exploit the daylight coming into indoor areas more effectively. If the lighting can be automatically turned off according to the level of daylight flowing indoors, the amount of electrical energy consumed for artificial lighting can be thereby reduced. And owing to

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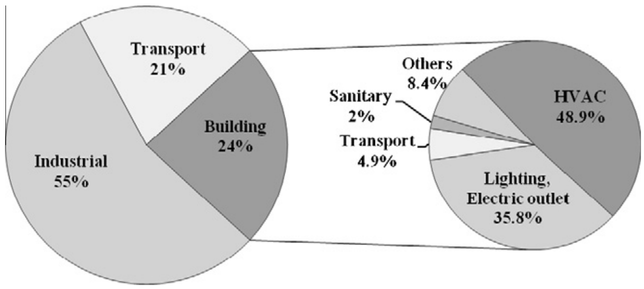

Fig. 1. The composition of energy consumption.

the decrease of heat gain caused by artificial lighting, cooling energy can be also reduced in office buildings (Aries and Newsham, 2008; Athienitis and Tzempelikos, 2002; Ihm, 2004; Li et al., 2006; Onaygil and Guler, 2003). In other words, the effect would be to reduce an annual total energy consumption through the application of lighting control system (Roison et al., 2008; Lah et al., 2006). This also helps the occupants to increase working efficiency, satisfaction and productivity (Park and Athienitis, 2003) by exploiting radiant energy and the color rendition that characterizes daylight (Song et al., 2003). Thus, the introduction of an electric lighting control system (Lawrence Berkeley National Laboratory (LBNL), 2000) is necessary because correct passive control, which uses natural daylight effectively, is not possible (Cho, 2007). Designers, however, need to make a decision as to whether it is feasible to introduce the electric lighting control system because this incurs additional initial costs.

In this study, in order to analyze the economics of such a lighting control system, an example building was selected, and the control range was determined by employing a daylight analysis simulation using 3Ds Max 8.0 Radiosity that was performed according to a grazing ratio that gives the most information regarding incoming daylight. Following this, when the artificial lights were turned off, the amount of reduction in electrical energy was calculated. In addition, the amount of cooling energy reduction based on the electric lighting control was calculated by using the building energy analysis simulation. Moreover, the initial cost of introducing the electric lighting control system was calculated according to the number of building floors. And, in order to analyze an economics of the electric lighting control systems, a payback period method was used. The payback period was calculated by comparing the initial cost of introducing the electric lighting control system with the cost of the annual energy reduction based on the above values. This economic evaluation was analyzed based on the office building in Korea. This paper will also present the reference data that designers can determine whether they choose the automatic on/off lighting control system, by presenting adequacy of introduction of electric lighting control system through quantitative analysis such as the payback period method. The flow chart for this study is illustrated in Fig. 2.

2. Indoor illumination analysis to determine the lighting rate

2.1. Outline of the simulation

In order to establish the lighting control range and evaluate the performance of indoor lighting environment that involves artificial lighting and daylight which changes according to various conditions, an example building was chosen as a simulation model at first stage. And it is a typical office building which is located near Seoul. An envelope of this model building is covered with glass, except for the core space which is located in north, and it is rectangular in shape. By considering a recent tendency that office buildings which are composed of an envelope covered with glass for designing effect are increasing, the office building which has all the envelopes covered with glass was selected.

Plan size of standard level of model building is 52.5 m in width, 19.95 m in depth, with a ceiling height of 2.7 m. And the location and the area of the core space were equally used with the model. A plan of the model building is shown in Fig. 3. To evaluate the indoor lighting performance of the model building, a daylight analysis simulation was carried out. The daylight analysis simulation was performed using 3Ds Max 8.0 program. This is a program that Radiosity was added to Lightscape which developed by Autodesk Company, and used for analysis of daylight through quantitative calculation of illumination as well as express of daylight. Also, this program can express the distribution of the illumination by various tools and the various images.

Input conditions of simulation to measure the illumination on indoor work plane of model building are shown in Table 1 (Kim et al., 1993; Yoo et al., 2005). The reflectance of the interior surface was set according to recommendations from the International Engineering Society of North America (IESNA). As the type of glass, colored multi-layer windows with a visible ray transmittance of 60%, and a reflectivity rate of 7% were used.

To reflect the recent trends of office planning, drawings and documents of fifteen domestic buildings built after the 1990s and five overseas buildings, they were examined. In most buildings, the use of high-efficiency fluorescent became widespread with the design illumination range from 500 to 600 lux (Yang et al., 2008).

The common Korean standard for the visual environment is the desired illumination level as specified in KS A 3011, this was then compared with foreign standards and the desired illumination levels of the case buildings. The results are shown in Table 2. In this study, the design illumination level was set to a minimum of 400 lux and an average of 500 lux in consideration of the recent upward tendency for preferred illumination levels.

In order to compare the variation of the daylight range coming into indoor areas, the grazing ratio of envelope was set at 100%, 80% and 60% (Ghisi and Tinker, 2005). The time at which the illumination was calculated was set from 09:00 to 18:00 at intervals of 1-h during the time of occupancy.