Heliostat based daylighting system for multi-floor office buildings

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Abstract

Many approaches have been demonstrated in the dayligting system to deliver light at the interior. There has been a requirement to capture high intensity of sunlight to illuminate the whole building. Therefore, we propose a cost-effective daylighting system to illuminate multi-floor office buildings. Sunlight is captured, guided, and distributed through heliostats of circular plane mirrors, mirror light pipe (MLP), and prismatic light guide, respectively. In order to increase the efficiency of the system, uniform illumination is achieved at the interior of each floor of the building. It guarantees to save electric lighting power consumption by delivering an average illuminance of more than 500 lx.

I. Introduction

Due to the increase in global warning, there has been high demand to produce more energy from renewable energy systems. In 2009, 43 percent of CO_2 emissions were produced from coal, 37 percent from oil, and 20 percent from Gas, and the emission approaches to 515.5 million tonnes of CO_2 in Korea [1]. Buildings are the main source of power consumption and greenhouse gas emission in the whole world. 46 and 71 percent of total energy is consumed in the buildings of Korea and U.S, respectively [2]. Solar energy is one of the main sources for electricity production, and it can be utilized for electricity generation from solar cells, thermal applications, and daylighting. Sunlight can be used to improve indoor environments, and it can also be utilized to treat skin disorders and other illnesses. Eyes and skin absorb non-visible ultraviolet wavelengths, which are needed to synthesize the production of vitamin D_3, and there is 60% increase of strokes and heart attacks due to low vitamin D [3]. Therefore, visible and non-visible spectrum of sunlight is required for the health of humans.

Electric lighting is one of the biggest end use of electricity. In the buildings, most of the area is illuminated by artificial light rather than daylight; however, different architectural designs for buildings have been introduced to illuminate the building by introducing windows and other open places in the building [4]. Daylight building is estimated to reduce lighting energy consumption by 50 to 80 percent [5]. Previously, daylighting systems were not discussed as a major topic. One of the reasons most of the solar concentrators were developed for photovoltaic power generation and thermal applications. There have been numerous demonstrations of various daylighting systems using light pipes [6]. Previously, the building was illuminated by installing daylighting system separately for each floor, which produces issue of high cost and complexity. The system can be expended by increasing the heliostats. Therefore, the model can be easily crated by knowing the required illumination to illuminate the building. It helps to reduce power consumption and greenhouse gas emissions, and it improves indoor environments for a healthy lifestyle.

II. Heliostats with mirror light pipe

Multi-floor office buildings are the major source of world energy consumption. It can be decreased by introducing daylighting systems. Here, we propose a cost-effective approach for daylighting system to achieve high intensity of light. Every component in the simulation is implemented and tested using LightTools™ as shown in Fig. 1. Heliostats are arranged in circular arcs (i.e., r_1= 1.5 m, r_2= 2.5 m, r_3= 3.5 m, and r_4= 4.5 m) around a MLP with a focusing mirror at the top. MLP can be mounted at one side of the building or at the center of the building to distribute light in two directions. Heliostats can be increased by introducing more circular arcs to increase the intensity of light. Each capturing mirror has two axis sun tracking device to track the sun all the daytime, and they direct the light towards the focusing mirror which inserts the light into MLP. The shape of the MPL is cylindrical to achieve uniform light by obeying the law of reflection. All the light from focusing mirror is directed into the MLP by

$$D_t = D_m \tag{1}$$

where D_t is the diameter of the MLP and D_m is the diameter of the focusing mirror, which makes an angle of 10.12 degree with the ground axis. The transmittance of the MLP can be approximated as [7]

$$T = R^{l\tan\theta/d_{eff}} \tag{2}$$

$$d_{eff} = \pi d/4 \tag{3}$$

where R is the reflectivity of the pipe, l is the length of the pipe, θ is the angle of incidence of the illuminating radiation with respect to the axis of the MLP, and d_{eff} is the effective diameter. Light at each floor is transmitted inside the light guide to illuminate the interior uniformly through directing mirror. Light guide is made using prismatic optical film with 99% transmittance and reflection [8] and multilayer optical film with 97% reflection [9] as shown in Fig. 3.

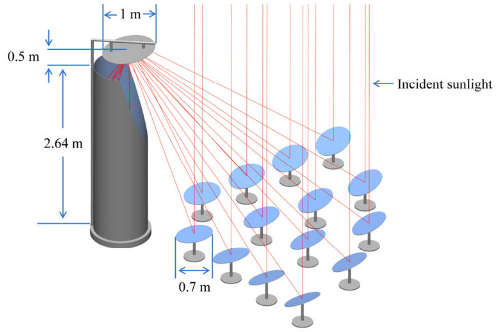


Fig. 1. Capturing and focusing sunlight into the mirror light pipe.

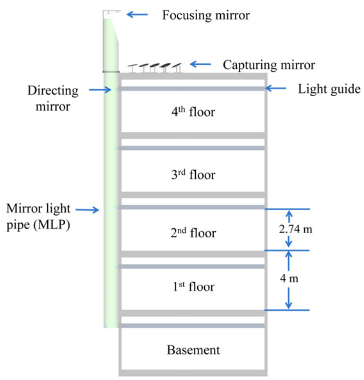


Fig. 2. Schematic design to illuminate Multi-floor building by sunlight.

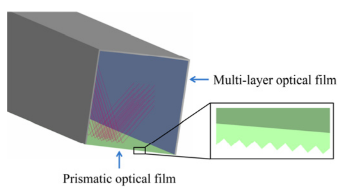


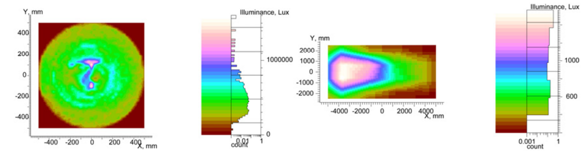
Fig. 3. Prismatic light guide to distribute sunlight at the interior.

III. Simulation and Results

In order to achieve uniform illumination at the indoor, MLP should be illuminated uniformly, which is attained by managing the reflection angles of heliostats. For daylight, lumens can be calculated to simulate the whole model for indoor, which is given by [10]

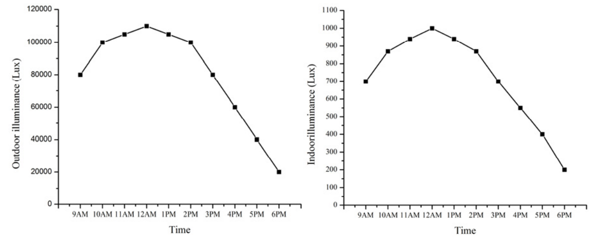
$$E = \frac{dF}{dS} \tag{4}$$

where E is the measured illuminance, dF is the input luminous flux in lumens, and dS is the area of the concentrator. Results have shown that uniform illumination is attained inside the MLP as mentioned in Fig. 4(a). The length of the light guide depends upon the building size and required illuminance. An average illuminance of 850 lx is achieved at the interior as shown in Fig. 4(b). Illuminance varies all the daytime at outdoor as mentioned in Fig. 5(a). Therefore, average indoor illuminance was measured by inserting different illuminance values as illustrated in Fig. 5(b). Our main target is to deliver an average illuminance of more than 500 lx inside the building for most of the daytime, which is the requirement for office building [11]. If the required range of illuminance decreases, LEDs will be turned on to fulfill the deficiency.



(a) (b)

Fig. 4. (a) Uniform illumination inside MLP (b) illuminance distribution at 4th floor.



(a) (b)

Fig. 5. Illuminance at different daytimes (a) outdoor (b) indoor.

IV. Conclusions

A cost-effective daylighting system has been demonstrated to save electric lighting energy consumed in the multi-floor office buildings. High intensity of light has been captured to illuminate the whole building. Uniform sunlight has been achieved inside the MLP and at the interior. The system can be expended by increasing heliostats in circular arcs to capture more sunlight. The research is in the early stages of development and implementation of the system. Photovoltaic cells can be integrated to produce electricity. In addition, more sunlight can be guided into light guide and transmitted at long distance by designing directing mirror in an efficient way.

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