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# NUMERICAL ANALYSIS FOR LIGHTING BY USING OPTICAL FIBER

Hiroki Gonome[*,§], Kazuya Watanabe[*], Takahiro Kono[*] and Jun Yamada[*]
[*]Dep. of Mech. Eng. SIT, Tokyo, Japan
[§]Correspondence author. Email: gonome@sic.shibaura-it.ac.jp

**ABSTRACT** Sunlight attracts attention as an illumination energy. An optical fiber can receive the illumination energy from the sunlight for indoor illuminations. However, it is difficult to supply necessary light as illumination throughout all the daytime because receivable angle of illumination energy is limited to narrow angle. Therefore, in this study, a new technique was proposed that is attaching a scattering medium at the edge of the optical fiber to expand the receivable angle. To calculate an effect of the technique, Monte Carlo method was used for radiation transfer in the scattering medium. As a result, the receivable angle of illumination energy became the 0-80°.

## INTRODUCTION

Electricity is essential for human being. Saving electrical energy is perennial problem for engineering. In electrical energy, light accounts for nearly a fifth of global electricity demand for end use. Therefore, it is important to develop lighting system without electricity.

As substitute for an old lighting system which needs electricity, a new lighting system which directly uses sunlight is considered as shown in Fig. 1. In the new system, sunlight is guided to a place where needs light. Many researchers [*e.g.,* Kischkoweit 2002 and Kim et al. 2010] have proposed new technologies utilising daylight in buildings and to assess their performance for the benefit of those

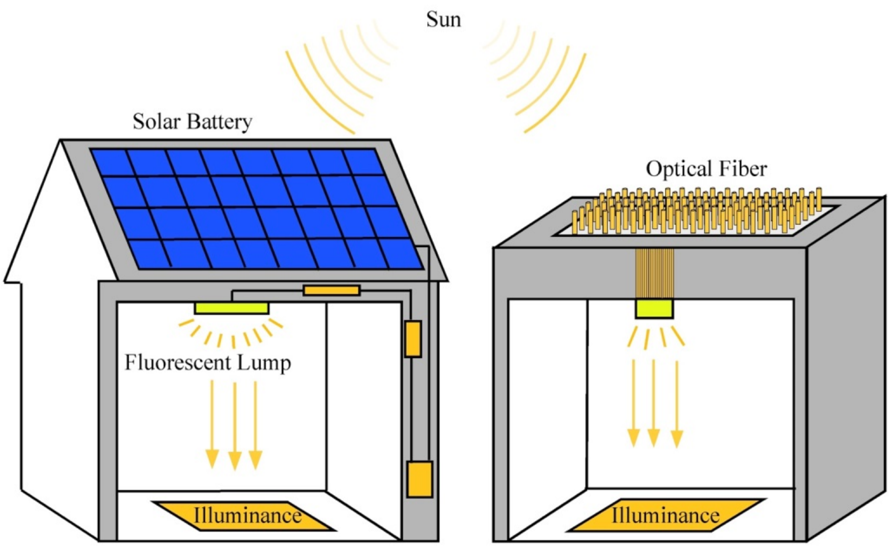


Figure 1. Schematic of indoor light guided from sunlight through optical fibers.

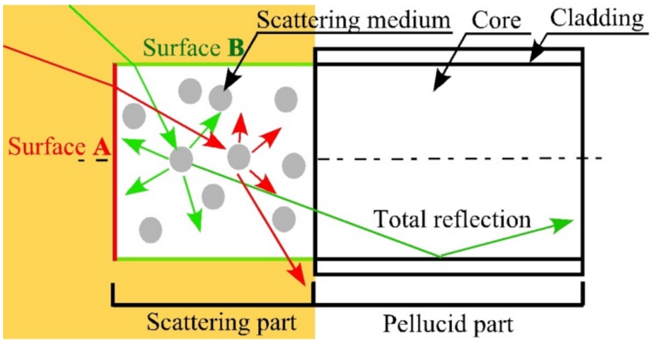


Figure 2. Schematic of optical fiber attached scattering medium at edge.

concerned with the building industry, particularly building design practitioners, lighting engineers, builders, product manufacturers, building owners and property managers. Sekine [2005] proposed that reflectional mirrors are set in a duct and guide sunlight to indoor. Wittkopf et al. [2010] presented a novel method to study how well non-imaging daylight collectors pipe diffuse daylight into long horizontal funnels for illuminating deep buildings. However, it is too expensive to use for family use and difficult to construct [Mayhoub and Carter 2011]. As substitute for the expensive tube light guidance system, optical fiber has attention. Xue et al. [2011] presented a novel sunlight concentrating and optical fibre guiding system for daylighting applications and its experimental investigation. They constructed a sunlight concentrator unit which includes a novel mirror image co-focus compound parabolic concentrator. Sapia [2013] and Han et al. [2013] used the optical fiber and a solar concentrator for a daylighting addressing system in buildings. In the system, a sun-tracking parabolic concentrator collected sunlight. As they have done, optical fiber needs concentrator to collect a lot of sunlight because of its narrow acceptance angle However, their concentrator is also too expensive to use for family use. To familiarize a new lighting system without electricity, the cost must be reduced.

In this study, a new lighting method without expensive sunlight concentrator is presented that is attaching a low-cost scattering medium at the edge of the optical fiber to expand the receivable angle. To estimate the performance of the lighting system, radiative transfer in the optical fiber was calculated by Monte Carlo method.

## METHOD

Optical fiber is constructed by central core and surrounding cladding. Refractive index of core $n_1$ is higher than the one of cladding $n_2$. Therefore, the light is transferred by total reflection in the range of acceptance angle $\theta_0$. To expand the receivable angle, a scattering medium is attached at the edge of the optical fiber. Figure 2 shows the schematic of optical fiber attached scattering medium at edge. Usual optical fiber has only top surface which can receive light. In this method, receivable surface is expanded from not only top surface A but also to side surface B by attaching scattering medium. Therefore, transferred light flux might increase because non-receivable light is guided in acceptable angle.

## NUMERICAL

To estimate the performance of the lighting system, radiative transfer in the optical fiber was calculated by Monte Carlo method. Radiative transfer in optical fiber is expressed by following equation:

$$\frac{1}{\alpha+\sigma_s}\frac{dI(s,\Omega)}{dS} = -I(s,\Omega) + \frac{\sigma_s}{4\pi(\alpha+\sigma_s)}\int_{4\pi} p(\Omega' \to \Omega)I(s,\Omega')d\Omega' .$$

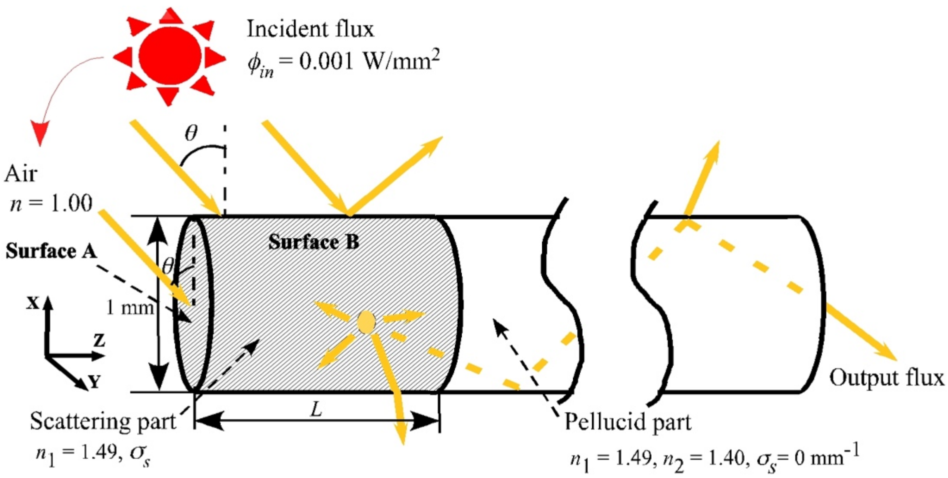


Figure 3. Numerical model of radiative transfer in optical fiber.

where $I$ [Wm$^{-2}$sr$^{-1}$] is the intensity of incident radiation, $s$ is directional vector, $\Omega$ [sr] is solid angle, $S$ [m] is the path length through an element, $\alpha$ [m$^{-1}$] is an absorption coefficient, $\sigma_s$ [m$^{-1}$] is a scattering coefficient, $p$ [-] is a scattering phase function. Figure 3 shows the numerical model of radiative transfer in optical fiber. Diameter of optical fiber is 1 mm. Surrounding media is air with $n$ = 1.00. Refractive index of core $n_1$ is 1.49 and the one of cladding $n_2$ is 1.40. Scattering coefficient of pellucid part is 0 mm$^{-1}$. Incident flux $\phi_{in}$ = 0.001 W/mm$^2$ irradiates from top surface A or side surface B at an angle of $\theta$. Scattering coefficient of scattering part $\sigma_s$, length of scattering part $L$, and incident angle of sunlight $\theta$ are variable. In this calculation, a scattering phase function assumed to be isotropic scattering and scattering part assumed to be non-absorbing media ($\alpha$ = 0 mm$^{-1}$). Incident photon is scattered in scattering part and transferred to pellucid part. Number of photon is 10,000. Acceptance angle is assumed to be 20.1˚, in other words, photon can be transferred to pellucid part if incident angle is lower than 20.1˚. Finally, output flux $\phi_{out}$ is calculated and lighting efficiency $\eta = \phi_{out} / \phi_{in}$ is derived.

## RESULT AND DISCUSSIONS

Figure 4 shows the effect of scattering coefficient on the lighting efficiency when the length of scattering media is 10 mm and the incident angle of sunlight is 55$^{o}$. The incident angle was simulated on equinox day in Japan. The lighting efficiency increased with scattering coefficient from 0.01 to 0.3 because the light guided from side surface B increased. The lighting efficiency became maximum when the scattering coefficient was 0.3. The lighting efficiency decreased with scattering coefficient from 0.3 to 9.0 because the light guided from top surface A decreased. When the scattering coefficient was over 9.0, the lighting efficiency made constant. These results showed that the control of scattering coefficient was important to achieve maximal performance. However, the maximum lighting efficiency was about 4.0%, quite low. In this calculation, it was simulated that the scattering part was made by spherical particle and fiber resin. Therefore, a scattering phase function assumed to be isotropic scattering. To improve the lighting efficiency, the directional control of light is so important that a nano rod or nano fiber should be considered. Additionally, the setting angle of optical fiber also should be considered. Finally, our calculation should be calibrated, then the experiment must be done in the future.

## CONCLUSION

In this study, a new lighting method without expensive sunlight concentrator was presented that is attaching a low-cost scattering medium at the edge of the optical fiber to expand the receivable angle. To estimate the performance of the lighting system, radiative transfer in the optical fiber was calculated

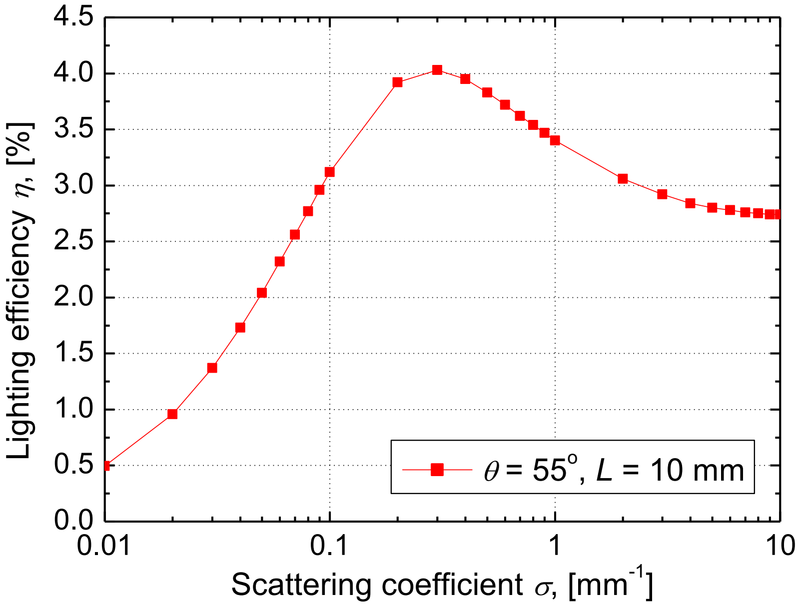


Figure 4. Effect of scattering coefficient on lighting efficiency when length of scattering media is 10 mm and incident angle of sunlight is $55^o$

by Monte Carlo method. The results can be concluded as follows:

1. The lighting efficiency increased with scattering coefficient from 0.01 to 0.3 because the light guided from side surface B increased.
2. The lighting efficiency decreased with scattering coefficient from 0.3 to 9.0 because the light guided from top surface A decreased.
3. The lighting efficiency became maximum when the scattering coefficient was 0.3. It showed that the control of scattering coefficient was important to achieve maximal performance.

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