Using Prismatic Structure and Brightness Enhancement Film to Design Cascadable Unit of Static Solar Concentrator in Natural Light Guiding System

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ABSTRACT

Due to the energy crisis, the principle of green energy gains popularity. This leads the increasing interest in renewable energy such as solar energy. How to collect sunlight for indoor illumination is our ultimate target. A Natural Light Guiding System includes collecting, transmitting, and lighting parts. To date, most studies of collecting part have delicate in dynamic concentrators which include sun tracking systems. They are powered by small electric motors and require some type of control module to follow sun path, so it requires maintenance and adds a good bit of complexity to the system. The application area of dynamic concentrator is limited. In order to create a low cost, easily set up, and applied on large area structure, we design a unit of static concentrator to collect sunlight for indoor illumination which is prismatic and cascadable. The unit is made up of prismatic structure and can collect the nature light, sunlight, for indoor illumination. For offer more saving energy and more stable illumination, we consider the total collected energy in the whole day and the relationship between the efficiency of the static concentrator and time. We change the size of prism to be different and add the BEF structure to improve the unit. According to the simulation, the prismatic structure with different right-angle prism could advance the total collected energy and the BEF could advance the stabilization of efficiency in the whole day.

Key words: Natural Light Guiding System, Static Concentrator, Cascadable Unit, Prismatic Structure, Total Internal Reflection (TIR), Brightness Enhancement Film (BEF), Parallel Beams, Indoor Illumination

1   INTRODUCTION

In response to the energy crisis, the principle of green energy gains popularity. This leads the increasing interest in renewable energy such as solar energy, wind energy, hydraulic power, ocean energy, geothermal energy, and biomass. In the research about renewable energy, one of the most important topics is how to use the energy with highest efficiency. In the renewable energies, solar energy has many advantages, abundant in nature and clean. Besides, it is a global energy, so we can utilize it anywhere in the world. In this paper, how to collect sunlight for indoor illumination is our ultimate target. A Natural Light Guiding System could be separated into collecting, transmitting, and lighting parts [1]. The system could use the solar energy without optical-electronic transformation. To date, most studies of collecting part have delicate in dynamic concentrators which include sun tracking systems [2-6]. They are powered by small electric motors and require some type of control module to follow sun path. It requires maintenance and adds a good bit of complexity to the system. Therefore, the application area of dynamic concentrator is limited. In order to create a low cost, easily set up, and applied on large area structure, we design a unit of static concentrator to collect sunlight for indoor illumination which is prismatic and cascadable.

2   NATURAL LIGHT GUIDING SYSTEM

Natural Light Guiding System includes collecting, transmitting, and lighting parts, as shown in fig. 1. In the structure of the system, the input is natural light that is daylight and includes diffuse light and direct light. The direct light is sunlight which stands for about 85 % of the available daylight in clear days. In the system, the collecting part could be separated into dynamic and static types. A dynamic concentrator will gather sunlight with sun tracking system for highest efficiency. The concentrator is powered by small electric motors and requires some type of control module to follow sun path. It requires maintenance and adds a good bit of complexity to the system. A static concentrator will collect daylight without any electric element. The advantages of the concentrator are simple, cheap, and easy to install and maintain, and the disadvantage is lower efficiency. The transmitting part could be a fiber or light guide whose important factor is low loss, and the lighting part could be a reflector or lens whose important factor is suitable distribution of intensity.
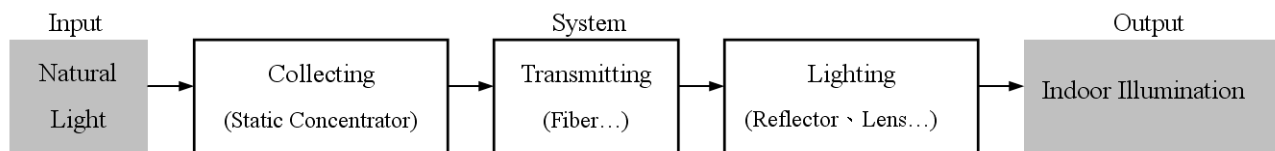
Input	System	Output
Natural Light	Collecting (Static Concentrator) → Transmitting (Fiber…) → Lighting (Reflector、Lens…)	Indoor Illumination

Fig. 1 The illustration of the Natural Light Guiding System

3   STATIC CONCENTRATOR

In order to create a low cost, easily set up, and applied on large area structure, we design a unit of static concentrator to collect sunlight for indoor illumination which is prismatic and cascadable. The unit is made up of prismatic structure and can be separated into two parts. The first part changes the plane beam, such as sunlight, into line beam. In the same way, the second part changes line source from the first part into point source which was good at light transmission.

3.1   Prismatic Structure

The static concentrator is shown in Fig. 2. The unit is made up of prismatic structure that includes two parts. The first part of the unit is made up of three right-angle prisms .This part changes the plane beam, such as sunlight, into line beam. It means the prismatic structure can reduce the dimension of beam. In the same way, the second part changes line source from the first part into point source which was good at light transmission. A point source is easier to be coupled with light pipe, compared with the plane and line light sources.
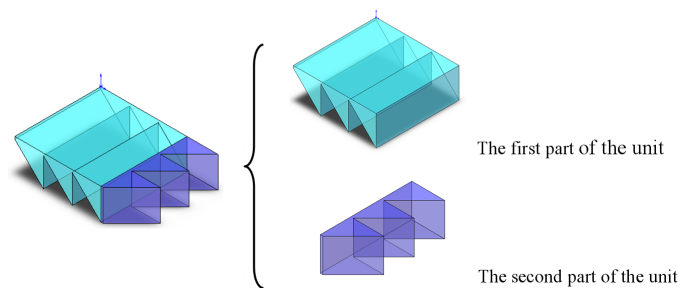

The first part of the unit

The second part of the unit

Fig. 2 The illustration of the cascadable unit which is prismatic structure

For collecting sunlight by static state, we use optical software, FRED, to simulate the efficiency of the concentrator with different incident angle. We adopt the information of sunlight data in July, 2006 in Taipei, from the Central Weather Bureau to analyze the static concentrator. First, we change the unit of the average irradiance energy from radiometric energy unit (MJ/m^2) into photometric power unit (lm/m^2) with the Spectral Luminous Efficiency. The Spectral Luminous Efficiency is the sensitivity of human eye from CIE. The distribution of the average illuminance is shown in Fig. 3. Second, we calculate the incident angle, θ_i, of sunlight from the elevation angle, θ, and azimuth angle, ψ, of sun, as shown in Tab. 1.
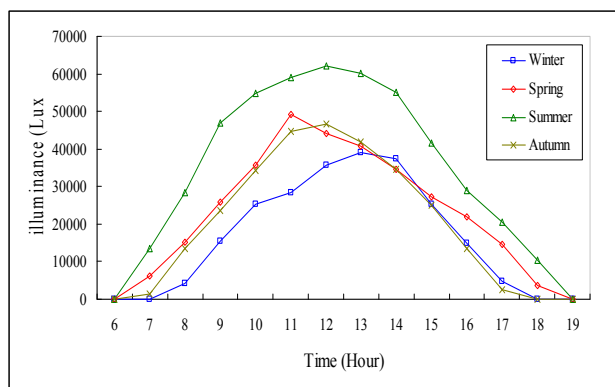
Fig. 3 The distribution of average illuminance of sunlight

Tab. 1 The incident angle of sunlight in different o'clock

Time	7	8	9	10	11	12
θ	24.10°	37.30°	50.70°	64.20°	77.80°	87.80°
ψ	74.10°	78.60°	82.90°	87.40°	94.40°	226.40°
θ_i	−65.06°	−52.15°	−39.08°	−25.78°	−12.17°	1.59°
Time	13	14	15	16	17	18
θ	24.10°	24.11°	24.12°	24.13°	24.14°	24.15°
ψ	24.11°	24.12°	24.13°	24.14°	24.15°	24.16°
θ_i	15.29°	28.85°	42.11°	55.17°	68.03°	80.94°

According to the Tab. 1, the efficiency of the unit with different incident angle is shown in Tab. 2. We use the information of the Tab. 2 to make Fig. 4 for easy reading. The static concentrator has maximum efficiency when the incident angle of sunlight is zero in which the value is about 60 %. Although more of the efficiency are lower than 50 % and the distribution of the efficiency vary with incident angle, the unit suits with our purpose, static, inexpensive, without using any electronic devices, and can be applied in large area.

Tab. 2 The efficiency of the unit

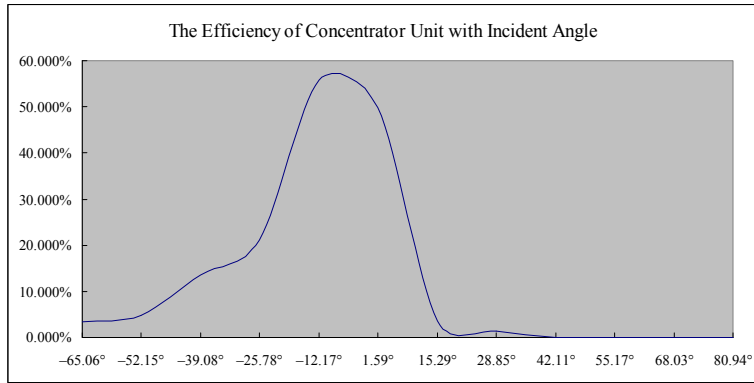| Time	7	8	9	10	11	12
θ_i	−65.06°	−52.15°	−39.08°	−25.78°	−12.17°	1.59°
Efficiency	3.354%	4.746%	13.525%	21.097%	55.841%	49.755%
Time	13	14	15	16	17	18
θ_i	15.29°	28.85°	42.11°	55.17°	68.03°	80.94°
Efficiency	3.613%	1.495%	0.000%	0.000%	0.000%	0.000%

Fig. 4 The efficiency of the unit

3.2 Different Size of Prismatic Structure

For indoor illumination, the efficiency of the static concentrator should be independent on the time and season. For saving energy, the total collected energy should be the most important factor on the collecting part. In order to fit the above conditions, we redesign the unit of the static concentrator and evaluate the unit with the total collected energy. As shown in Eq. 1, we evaluate the collected energy of the unit from 7 o'clock morning to the 6 o'clock afternoon.

$$
\begin{aligned}
&\sum_{i=7o'clock}^{18o'clock} (effciency)_i \\
&= \int_{7o'clock}^{18o'clock} (effciency)d(hour) \\
&= 1hour \times (effciency)_{7o'clock} + 1hour \times (effciency)_{8o'clock} + \ldots + 1hour \times (effciency)_{18o'clock}
\end{aligned}
\tag{1}
$$

In the redesigning, we use different right-angle prisms to make up the two part of the unit, as shown in Tab. 3.

Tab. 3 The illustration of the redesigned units

We use different ratios of the right-angle prisms in the two parts of the unit. The heights are 10.5-12.5-16.5 and 8.5-12.5-16.5 in the first part, and 12.5-12.5-12.5 and 10.5-12.5-14.5 in the second part. According to the structures on the Tab. 3, the efficiencies of the unit with different incident angle are shown in Tab. 4. The unit 4 has the most collected energy, 1.84348, that is more than the original unit, 1.53426. The total energy of the unit 4 raises 20.15%.

Tab. 4 The efficiency of the redesigned units

Time	7	8	9	10	11	12	13	14	15	16	17	18	Total
θi	−65.06°	−52.15°	−39.08°	−25.78°	−12.17°	1.59°	15.29°	28.85°	42.11°	55.17°	68.03°	80.94°	
Original Unit	3.354%	4.746%	13.525%	21.097%	55.841%	49.755%	3.613%	1.495%	0.000%	0.000%	0.000%	0.000%	1.53426
Unit1	3.872%	5.498%	14.589%	26.572%	63.734%	51.400%	3.336%	1.739%	0.000%	0.000%	0.000%	0.000%	1.70740
Unit2	4.434%	6.333%	16.927%	27.046%	63.790%	53.100%	4.176%	2.465%	0.000%	0.000%	0.000%	0.000%	1.78271
Unit3	4.217%	6.264%	15.529%	24.399%	58.168%	53.057%	3.339%	1.945%	0.000%	0.000%	0.000%	0.000%	1.66918
Unit4	4.610%	7.218%	18.107%	29.011%	64.556%	54.283%	3.869%	2.694%	0.000%	0.000%	0.000%	0.000%	1.84348

The compare of the original unit and unit 4 is shown in the Fig. 5. Although the total collected energy of the unit 4 is more than the original unit, the efficiency still depends on the incident angle of sunlight.
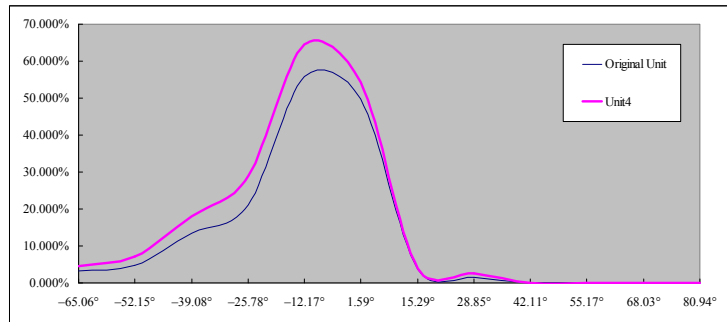

Fig. 5 The compare of the original unit and unit 4

3.3   Prismatic Structure with BEF

According to the characteristic of the prismatic structure, the angle of the exit light will become bigger. Because the incident light of the second part is from the first part, the efficiency of the second part is bad. For improving the efficiency, we use BEF, brightness enhancement film, in the first part of unit to reduce the angle of the exit light.
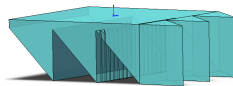

Fig. 6 The illustration of the original unit with BEF

As shown in the Fig. 6, we add the BEF on the exit surface of prisms. The right prism of the first part in the Fig. 6 will connect with the second part, so we add the BEF on the middle prism (named BEF_2), left prism (named BEF_1), and both prisms (named BEF_1&2) separately. According to the improvement, the efficiencies of the unit with different incident angle are shown in Tab. 5.

Tab. 5 The efficiency of the original unit with BEF

Time	7	8	9	10	11	12	13	14	15	16	17	18	Total
θ_i	−65.06°	−52.15°	−39.08°	−25.78°	−12.17°	1.59°	15.29°	28.85°	42.11°	55.17°	68.03°	80.94°	
Original Unit	3.354%	4.746%	13.525%	21.097%	55.841%	49.755%	3.613%	1.495%	0.000%	0.000%	0.000%	0.000%	1.53426
BEF_2	9.373%	13.364%	31.615%	31.748%	26.341%	26.707%	6.477%	10.964%	4.214%	0.676%	0.000%	0.000%	1.61479
BEF_1	4.827%	6.221%	25.420%	28.027%	39.482%	37.228%	1.970%	7.499%	2.809%	0.183%	0.000%	0.000%	1.53666
BEF_1&2	17.755%	14.332%	26.825%	25.928%	21.865%	21.184%	8.884%	12.848%	6.127%	1.298%	0.323%	0.125%	1.57494

The BEF_2 has the most collected energy, 1.61479, that is more than the original unit, 1.53426. The total energy of the BEF_2 raises 5.25%. The compare of the unit with and without BEF is shown in the Fig. 7. Although the improvement of the total collected energy is smaller than the unit 4, the efficiency distribution is more uniform that suits indoor illumination.
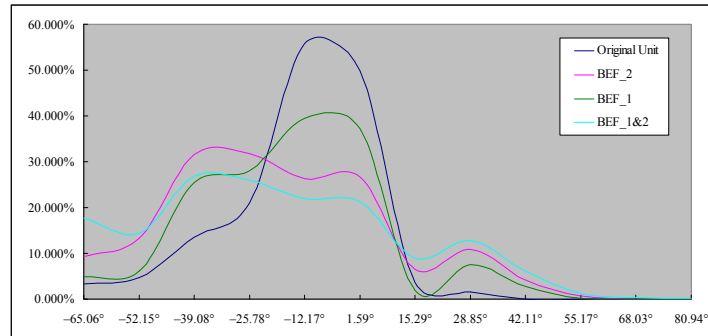

Fig. 7 The compare of the unit with and without BEF

4 RESULT

For indoor illumination and saving energy, we combine the improvements, different right-angle prisms and BEF. We add the BEF on the middle prism of the first part on the unit 4. The prismatic structure with different right-angle prisms could improve the total collected energy, and the BEF could improve the distribution of efficiency to be uniform. The efficiency of the unit with different incident angle is shown in Tab. 6.

Tab. 6 The efficiency of the original unit and the finally design

Time	7	8	9	10	11	12	13	14	15	16	17	18	Total
θi	−65.06°	−52.15°	−39.08°	−25.78°	−12.17°	1.59°	15.29°	28.85°	42.11°	55.17°	68.03°	80.94°	
Original Unit	3.354%	4.746%	13.525%	21.097%	55.841%	49.755%	3.613%	1.495%	0.000%	0.000%	0.000%	0.000%	1.53426
BEF_2 + Unit4	11.650%	16.616%	34.549%	35.588%	36.480%	32.620%	7.604%	13.809%	4.560%	1.880%	0.609%	0.462%	1.96427

The BEF_2 + unit 4 has the most collected energy, 1.96427, that higher than the original unit with 28.03 %. The compare is shown in the Fig. 8.
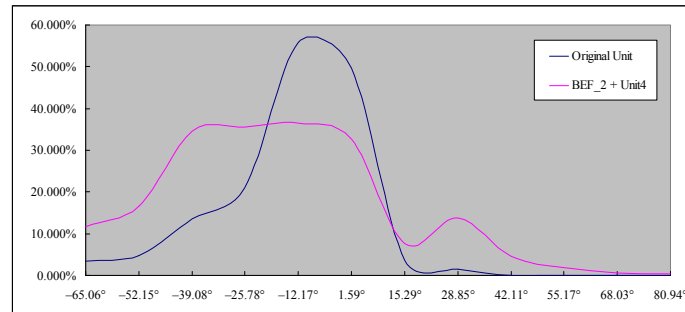

Fig. 8 The compare of the original unit and BEF_2 + unit 4

5   CONCLUSION

Natural Light Guiding System has collecting, transmitting, and lighting parts. We design a static concentrator for the collecting part whose advantages are low cost, easily set up, and applied on large area structure. The concentrator is made up of a prismatic unit. For indoor illumination and saving energy, we use different right-angle prism and BEF to improve the unit. The prismatic structure with different right-angle prism could advance the total collected energy. The BEF could advance the efficiency distribution to be uniform.

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