Performance Evaluation of a Solar Tracking Lighting System

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The California Lighting Technology Center recently partnered with the California Energy Commission, Sonoma Clean Power Authority and Frontier Energy Inc. to evaluate opportunities in emerging daylighting technologies. One such technology was a solar tracking lighting system with the promise to deliver both energy savings and daylight via optical fibers to the core of buildings that otherwise do not have access to daylight. Specifically, the research team evaluated the electrical and photometric performance of the Parans SP4-24.2 Fiber Optic Solar Tracking daylighting system (**Figure 1**).

The Parans SP4-24.2 is the second largest model in the Parans SP4 product family which ranges in size based on the number of discrete solar collectors. This system consists of 48 discrete solar collectors, a motorized base and an electronic control system. The electronic controller uses a global positioning system (GPS) and time data to enable the device to stay precisely aligned with the sun throughout the year. Each of the 48 solar collectors focus the incident solar radiation onto the end of a glass fiber. Each group of four fibers is then combined into a single fiber-optic cable bundle with a diameter of 1 millimeter and a maximum length of 300 ft,[1] resulting in 12 discrete light sources for this model. Parans offers a variety of unpowered luminaires that function as a transition between the fiber-optic cable and the traditional commercial interior. The luminaires are available in most common commercial form factors as well as more unique architectural designs. They can be coupled with one or more fiber bundles depending on the size and lighting requirements of the application. Parans also offers a hybrid luminaire which utilizes LEDs in addition to daylight from the fiber bundles. According to the manufacturer's documentation, each of the 12 fiber bundles can deliver up to 1,300 lumens (lm). The SP4 product family ranges from 16 to 80 solar collectors, which corresponds to four to 20 individual light sources.

Overall, the evaluation showed that the tested device is a highly efficacious lighting system suitable for select general lighting applications. The system load measured at 12.3 watts when in solar tracking mode and 8.3 watts when in standby mode, which resulted in the luminous efficacy of approximately 620 lumens per watt. This is nearly five times that of a typical LED luminaire's efficacy in today's market. With the ability to deliver light significantly farther into a building than other core daylighting technologies,[2] the Parans system is poised to offset significant electrical lighting loads in the existing building stock. Specifically, this system is best suited for spaces not bordering the building envelope within tall multistory buildings such as open offices, lobbies or restrooms. To ensure task-specific light levels are delivered throughout the year, integration with electric lighting may be needed.

The system can be roof- or wall-mounted and requires only one building penetration for all the light points. Furthermore, routing the fibers through a building is analogous to routing

electrical cabling, which can happen in conduit and requires no plenum or plenum space. In addition, the performance evaluation of the Parans SP4-24.2 determined it is an efficacious daylighting technology that can offset an estimated 3,780 GWh of electrical lighting load in today's U.S. commercial buildings each year.

CLTC evaluated the performance of the Parans system by conducting three tests:

1. CLTC measured light output throughout the day under different weather conditions. Using this data, CLTC analyzed the light output in terms of percent change for different time scales ranging from one second to 10 minutes.
2. CLTC measured spectral absorption of the collectors and fibers.
3. CLTC evaluated the electronic control system and the motor by measuring the power draw over time to validate the manufacturer's total energy-use claim.

Luminous Flux. To quantify the performance of the system over time, CLTC measured the illuminance of six[3] of the fiber bundles in custom calibrated test chambers equipped with Konica Minolta T-10 meters sampling every two seconds. With this data, CLTC calculated the luminous flux of the six fiber bundles from early May to mid-August 2020. Throughout the data collection period, the daily maximum luminous flux varied between 650 to 1,500 lumens, achieving a higher output than the manufacturer's claimed maximum output. However, the output of the Parans system was highly influenced by weather and cloud coverage. **Figure 2** shows data from May 13, 2020, which exemplifies how the luminous flux varies on a cloudy day. Every time a cloud passed in front of the sun, the system light output dropped significantly.

From 12 p.m. to 3:30 p.m. on this day, the system delivered minimal measurable luminous flux to the testing chambers. Additionally, there were over 900 instances where the total luminous flux of the fiber-optic system varied by 10% over the span of two-seconds on May 13, 2020. Fluctuations of this magnitude over such a short interval were perceivable to the research team and deemed to be undesirable. Additionally, there were 21 instances where the luminous flux varied by more than 90% over two-seconds. A

Figure 1. Parans SP4-24.2 Fiber Optic Solar Tracking system installed at California Lighting Technology Center for evaluation.

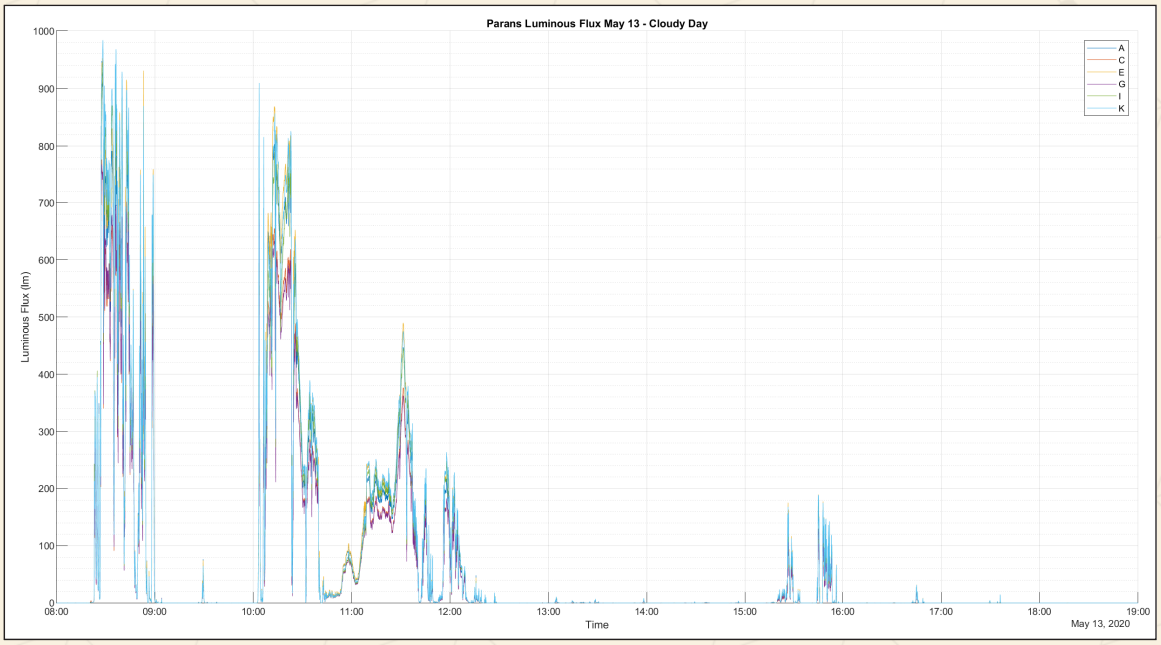

Figure 2. A cloudy day in May resulted in the lowest delivered luminous flux for most fiber bundles over the span of the data collection period.

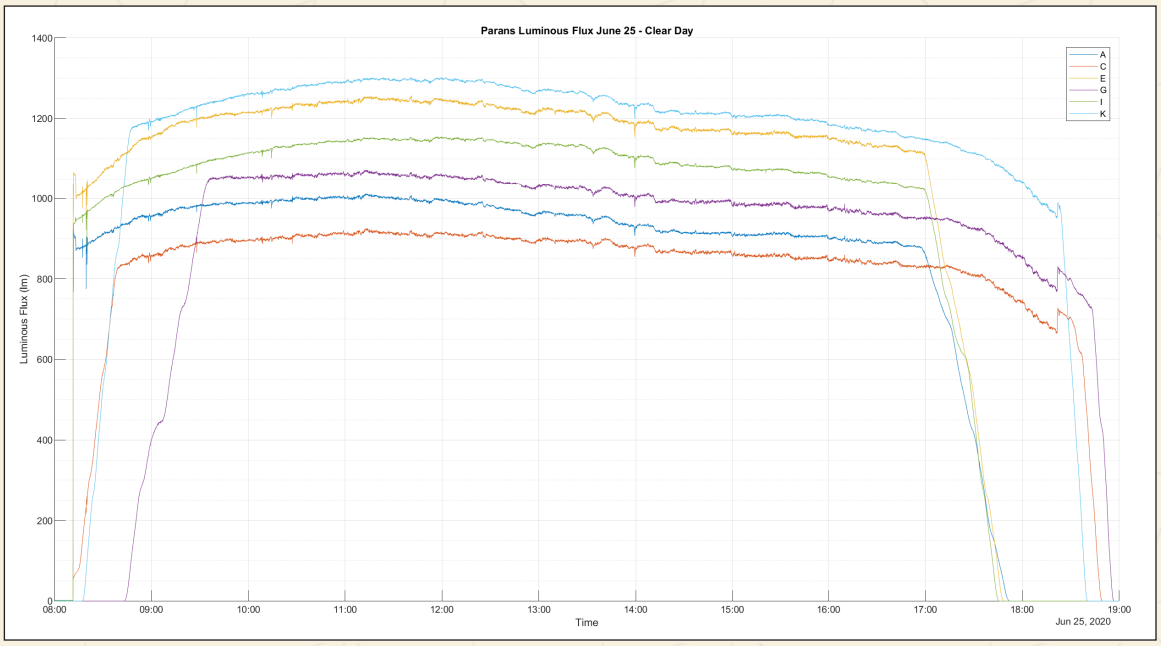

Figure 3. On a summer day with clear skies, the system delivered consistent light output for most of the day.

fluctuation of 90% over two-seconds is similar to turning a light on and off. Utilizing the Parans hybrid luminaires would supplement the sporadic daylight on these cloudy days to improve the consistency of delivered light levels at the cost of electrical energy use.

By contrast, on a clear day, such as June 25, 2020, the system delivered a very consistent light output throughout the day (**Figure 3**).

While the light output of each fiber did vary slightly throughout the day, there were few fluctuations that would be noticeable

and/or disturbing to occupants.

Overall, the Parans system was able to consistently deliver between 900 to 1,200 lumens per fiber with a maximum output of 1,600 lumens.[4] On a clear day, the system can deliver consistent light output for most daylight hours. On a cloudy day, the system output will fluctuate as the sun is obscured by clouds, potentially delivering no light at all.

Spectral Quality. While many consider daylight spectrum to be best-in-class, the spectral selectivity of the optical sub-systems may result in poor color rendering and undesirable chromaticity. CLTC measured the spectral power distribution for each of the 12 bundles using a 2-meter integrating sphere equipped with a CDS-3020 Spectrometer at solar noon on April 15, 2020 (**Figure 4**).

The average color rendering index (CRI) of the 12 bundles was 83.5 with an average Duv of 0.0222 and CCT of 5065K (**Table 1**). The resulting light is cool white with a green-ish hue in color appearance as compared to daylight.

Power Draw & Efficacy. To determine the energy savings potential of the system, CLTC measured the system's power draw over time. This unit has two separate electrical systems that require power, the control electronics and the motorized tracking system. CLTC metered

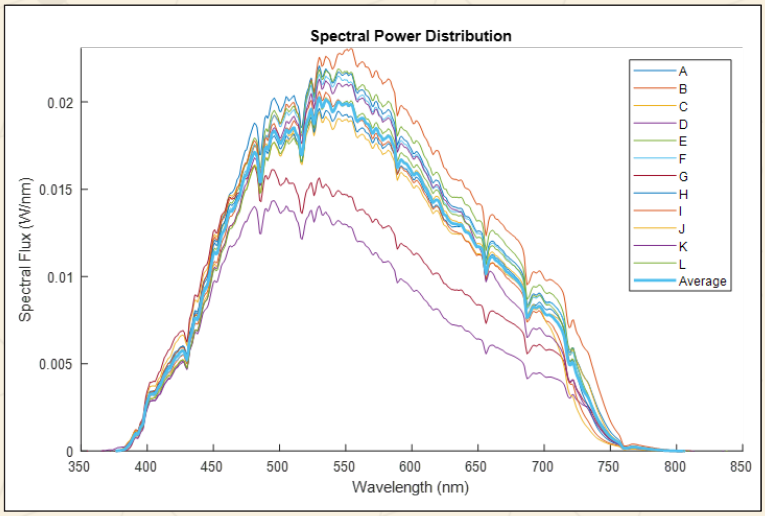

Figure 4. Spectral power distribution for each fiber bundle.

Fiber	Light Output (lm)	CCT (K)	Duv	CRI
A	1,533	5080	0.0232	83
B	1,603	4668	0.0217	82
C	1,363	5295	0.0203	85
D	932	6179	0.0258	82
E	1,540	4899	0.0220	83
F	1,498	4978	0.0235	82
G	1,083	6135	0.0192	87
H	1,380	5126	0.0207	85
I	1,413	5255	0.0232	83
J	1,406	4934	0.0228	83
K	1,473	4886	0.0241	81
L	1,414	4839	0.0218	83
Mean	**1,412**	**5065**	**0.0222**	**83.5**

Table 1. Color quality and light output for each of the 12 fiber bundles under daylight at solar noon on April 15, 2020.

	Control Unit	Solar Tracker Motor	Combined
Tracking (W)	5.3	7.0	12.3
Stand-By (W)	4.8	3.6	8.3
Average Daily Energy Use (Whr/day)	121.2	131.3	252.5

Table 2. Power draw and daily energy-use for the control unit and tracking unit for tracking and standby modes.

With sensors, the hybrid luminaire could modulate the LED output to compensate for periods of reduced daylight

each electrical system and collected power data from May 14 to June 26, 2020. The system has two operating states: tracking and standby. When the system is in tracking mode the power draw for the combined system measured 12.3 watts (**Table 2**).

When in standby mode, the system measured 8.3 watts. Over the course of a day, the entire system consumed an average of 252.5 Whr/day. Based on the average luminous flux for each day, a mean efficacy of 620 lumens per watt was calculated for the duration of the testing period. For comparison, a high efficiency LED luminaire's efficacy is approximately 120 lumens per watt in today's market, making this system approximately five times as efficacious as today's LED solutions when daylight is available.

With the ability to deliver daylight up to 300 ft into a building, the SP4-24.2 is well suited to deliver natural light to the lower floors of multistory buildings where traditional core daylighting technologies are unable to reach. According to the Commercial Building Energy Consumption Survey, there are approximately 13,000 commercial buildings that are over 10 stories in height in the U.S. With a maximum building penetration depth of 100 ft (approximately seven stories), traditional core daylighting systems are unable to provide daylight to approximately 1,260 million sq ft of commercial building space. Assuming a conservative lighting power density allowance of 1 watt per sq ft and an annual use time of 3,000 hours, the system is poised to offset up to 3,780 GWh of annual electricity use nationally.

While the SP4-24.2 is a highly efficacious daylighting system, at its current stage of development it may not be suitable for all lighting applications due to the chromaticity and the weather-driven fluctuations of the delivered light. Currently, the manufacturer offers a "hybrid" luminaire which combines LEDs with one or more fiber-optic bundles. While this hybrid approach increases the reliability and color quality of the delivered light, there is additional electrical energy use by the LEDs.

To further improve the performance of the Parans system, the research team recommends incorporating real-time light level and color sensing to the hybrid luminaire product offering. With these sensors, the hybrid luminaire could accurately modulate the output of the LEDs to compensate for periods of reduced daylight due to weather or smoke events. Additionally, the use of tunable multi-channel colored LEDs could improve the color quality of the combined artificial light and daylight. With these improvements, the Parans system would be suitable for additional applications further increasing the overall energy savings potential of the system. ◎

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End Notes

1. 300 ft is the maximum suggested fiber length by the manufacturer.
2. An assessment of commercially available tubular daylighting devices showed a maximum manufacturer recommended tube length of 20 to 100 ft, depending on manufacturer and product category.
3. Only six of the 12 fiber bundles were sampled due to a limitation in the quantity of metering equipment.
4. Maximum luminous flux of 1,603 was measured on clear day April 15th, 2020, at 12 p.m. using a two-meter integrating sphere.