LOW-POWER MICROSCALE TRACKING FOR LOW-PROFILE DAYLIGHTING

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PROJECT TITLE: Self-Tracking Concentrator Photovoltaics
PROGRAM: OPEN 2012
AWARD: $3,404,028
PROJECT TEAM: Glint Photonics
PROJECT TERM: April 2013 – March 2017
PRINCIPAL INVESTIGATOR (PI): Dr. Peter Kozodoy

TECHNICAL CHALLENGE

Artificial lighting accounted for about 10% of total U.S. energy consumption in 2015 (about 9.7 quads). A significant portion of this energy consumption occurs when sunlight is shining directly on the building. Daylighting can offset artificial lighting energy consumption while delivering higher quality, full-spectrum sunlight into interior spaces, but typical daylighting options such as windows and skylights can only address areas near the building skin. Tubular skylights and daylight concentrators have been explored to deliver light deeper into buildings. However, it is difficult to provide a steady source of lighting due to the sun's changing position in the sky. Daylight concentrators that require complex mechanical trackers to keep the system pointed at the sun have been expensive and have not achieved significant market penetration. Nearly all currently available daylighting systems require major building modifications to route light pipes, impacting the integrity and aesthetics of the building, as well as driving up installation cost. The introduction of a low cost, low profile, stationary and aesthetically pleasing daylighting system could result in significant reduction in artificial lighting energy use during daylight hours.

TECHNICAL OPPORTUNITY

Approaches for daylighting concentrator systems have been limited by two major factors. The first is the quality, durability, and cost of the optics and the second is the requirement for a mechanical tracking platform to keep the optics pointed at the sun. Recently, advances in achieving high precision, low cost molded optics have enabled consideration of new optical designs. High clarity, durable, injection molded plastic optics, such as lens arrays, can now substitute for expensive and heavy glass components in many situations. These components are amenable to high volume manufacturing, thereby lowering cost and facilitating the adoption of low-profile optical systems to allow a more aesthetically pleasing appearance. New optical designs allow the external tracking requirements to be shifted to the interior of the panel, allowing for stationary, fixed tilt installation.

INNOVATION DEMONSTRATION

Glint Photonics' (Glint) goal was to improve sunlight capture through a low-profile tracking system using a novel optical design. Furthermore, Glint sought to improve light transfer into the building using a low-cost design that easily integrates into building structures. Glint's original capture design featured a single lens array and a fluidic optical system. However, Glint's modeling and

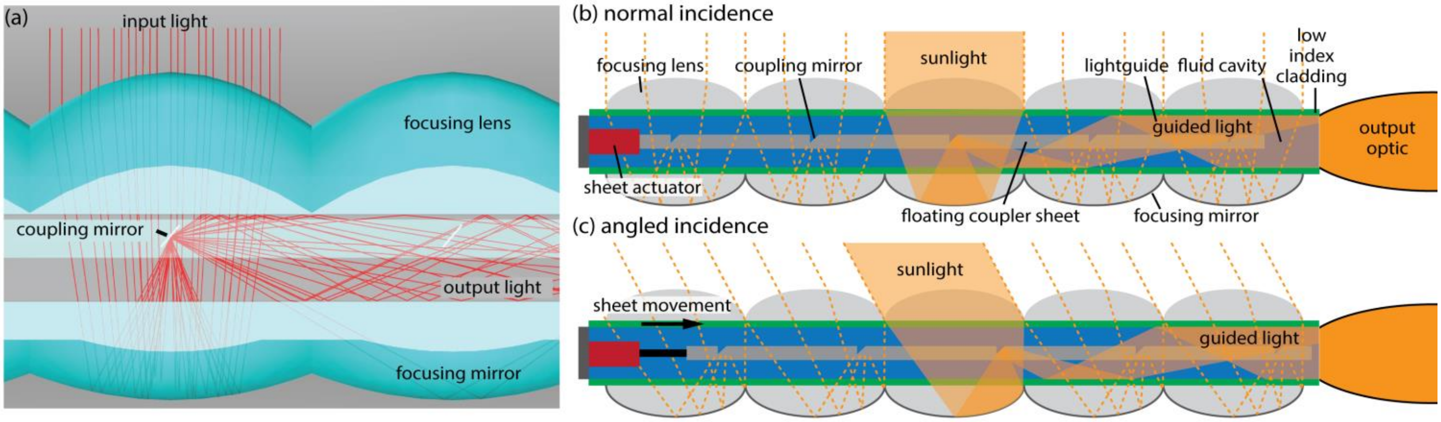

Figure 1: Illustration showing a cross section of the Glint catadioptric optical system. Ray trace shown in (a), tracking action shown in (b). Incoming light is focused onto a light coupling mirror, which passes the light into the lightguide.

experimental work revealed fundamental limitations in the fluidic optical design. Therefore, Glint redesigned the tracker and settled on a catadioptric optical system (Figure 1) that uses both reflective and refractive optics to access a large range of incident angles up to about 60 degrees off axis.

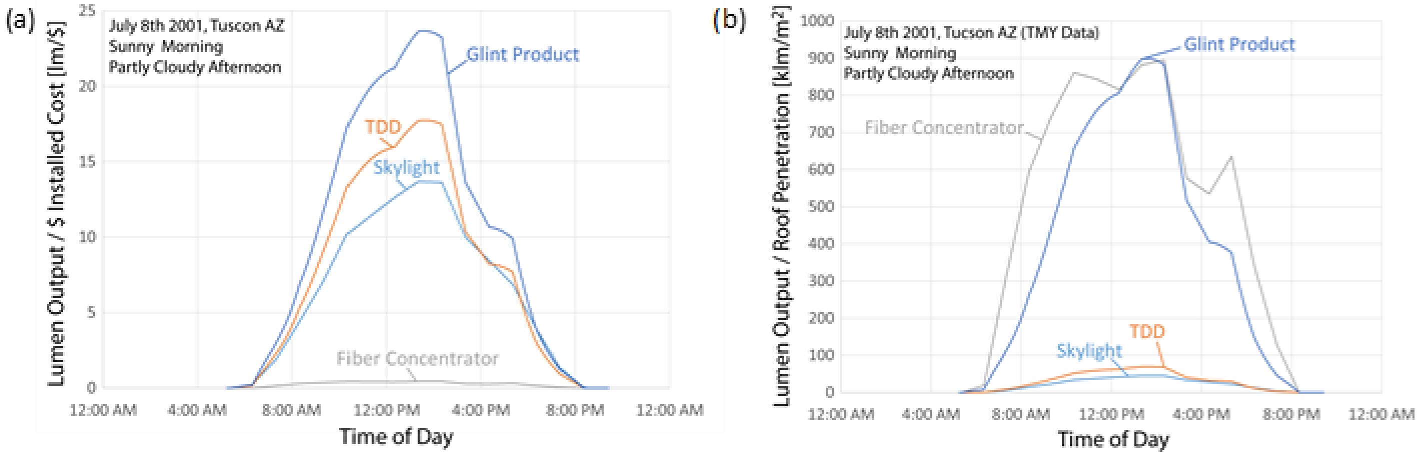

Figure 2: Daylighting system output during a representative day in Tucson, AZ (based upon TMY data). Data is shown per installed capital cost (a) and per unit area of roof penetration (b). TDD = Tubular Daylighting Device

The catadioptric system uses an active microscale tracking scheme that adjusts the position of an array of reflective optics (the light couplers) at the foci of the reflective back lenses. A closed-loop control system actively adjusts the position of the coupler array throughout the day to follow the sun's movement. Actuation of the coupler sheet is accomplished via magnetic transmission, allowing the actuators themselves to be located outside the panel optics. Glint has demonstrated tracking concentrator prototypes at the 4-inch scale (7x6 lens elements) with optical efficiencies[1] between 30-45% (depending on the angle of incidence) using the company's first generation optical design. The prototype components have been subjected to temperature cycling and UV exposure tests with no appreciable degradation observed (<0.5%/yr degradation in transmission projected). Glint is now developing the next generation panel, which will be 170 in^2 in size with 14x26 lens elements. The new panel is designed to have an output of >18,700 lumens/m^2, based on improved optics, boosting the optical efficiency to near 50%. The performance and cost effectiveness of the Glint system is expected to surpass that of comparable tubular daylighting devices (TDDs) or fiber based daylighting systems (Figure 2), both in terms of lumens per dollar and light delivered per area of roof penetration.

Glint has also worked on light transmission and delivery methods compatible with low cost, attractive installations (Figure 3). Glint tested several configurations for optimal light transmission and found hollow reflective light pipes to be the most advantageous as they do not attenuate the transmitted spectrum, have high optical efficiency, and are designed to fit within architectural wall spaces. Its design includes a reflective film applied to inexpensive sheet metal ductwork and can accommodate turns and bends within the wall spaces. Unique among daylighting technologies, the Glint panels can also be façade-mounted as awnings or light shelves (see Figure 3), with output optics that project captured light deep into a building interior at high efficiency.

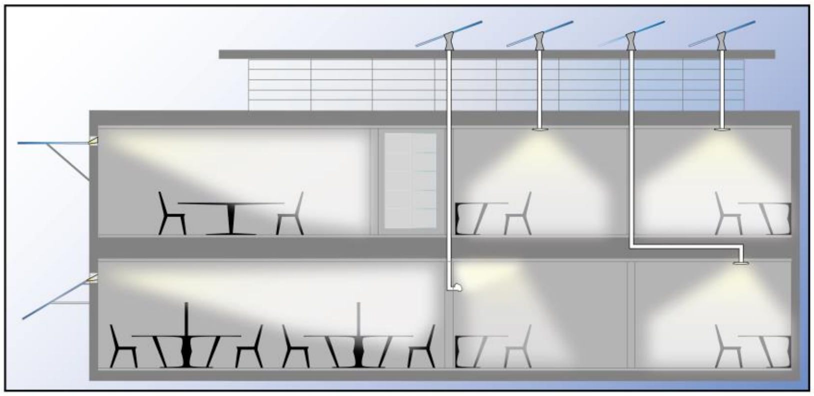

Figure 3: Diagram of rooftop concentrator and façade-mounted panels providing daylight to building interior.

To date, this ongoing project has demonstrated the feasibility of the daylighting system at the component level. The company's innovation was made possible through the coupling of newly available, inexpensive precision molded optics with Glint's novel optical design. The current technoeconomic analysis for the new generation design estimates an installed cost of \$177/ft^2 of concentrator

[1] Optical efficiency is defined as the ratio of the luminous emittance (lumens per unit area) from the concentrating panel (exiting the waveguide) to the luminous energy incident on the aperture of the concentrating panel (illuminance).

for a typical roof-mount situation. This is comparable to tubular daylighting devices and an order of magnitude less expensive than existing commercial products with trackers.

PATHWAY TO ECONOMIC IMPACT

Glint has developed a light delivery strategy based on discussions with lighting industry experts who have helped refine and vet the company's design to minimize cost and ensure potential customer concerns would be addressed. The progress made during the ARPA-E award led to a $1.08M follow-on award from the Building Technologies Office within the Department of Energy's Office of Energy Efficiency and Renewable Energy (EERE) in 2016, under which Glint will continue to advance its technology towards a commercial-ready product, fully integrating all components of the light collection and delivery system and optimizing performance. Furthermore, they will be enhancing the durability/reliability of the whole product and validating the performance and installation procedures through active test deployments on buildings. Product introduction to the market will be facilitated by partnering with several contract manufacturing firms in the United States to fabricate and assemble the daylighting system domestically.

LONG-TERM IMPACTS

Through its work on this project, Glint has pioneered the design and engineering of planar solar tracking systems for low-profile solar capture and concentration. The technical knowledge gained in the project has the potential to facilitate tracked solar light capture for both daylighting and solar energy applications. The potential impact of large-scale daylighting adoption would reduce lighting energy by as much as 70% for high solar irradiance locations in the United States (e.g. California and Arizona), and provide 40%-50% savings across the whole country. The global market for daylighting products is projected to be $6B in 2017, and currently 93% of the market is in skylights for commercial and institutional buildings.[2] The global market for electric lighting is around $89B, and the segments most easily addressed by Glint's daylighting technology (office, shop, hospitality, and industrial) comprise $37B of this market.[3] Glint's concentrator has a competitive advantage over alternative systems due to its aesthetically appealing low profile and comparably small required building penetration area. The concentrator is also adaptable for other optics applications, such as concentrated solar power. For example, in solar PV, low profile and less complex concentration and tracking schemes would enable lower cost concentrated photovoltaic (CPV) modules.

INTELLECTUAL PROPERTY

As of January 2017, the Glint project has generated two invention disclosures to ARPA-E and two U.S. Patent and Trademark Office (PTO) patent applications.

[2] Lux Research, "Nearly-Zero Energy Building Materials Market to Grow to $16.5 Billion in 2017," 2013. http://blog.luxresearchinc.com/blog/2013/06/nearly-zero-energy-buildings-will-deliver-strong-growth-for-materials-manufacturers-but-geographic-segmentation-must-drive-strategy/

[3] McKinsey and Company, "Lighting the Way," 2013. https://www.mckinsey.de/files/Lighting_the_way_Perspectives_on_global_lighting_market_2012.pdf