Value of Utilizing Tubular Daylighting Devices in CSU, Channel Islands' Gateway Hall

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Daylighting is becoming an increasingly more important aspect of building design as our planet's natural resources deplete and the cost savings for daylighting systems grow. California State University, Channel Islands (CSUCI) values the use of daylighting and aims to incorporate it into its upcoming project, Gateway Hall. One option of daylighting that the campus is considering for this project is tubular daylighting devices (TDD). This paper will study the use of tubular daylighting devices and the potential cost savings that they could have on Gateway Hall. The company leading the way in TDD technology is Solatube, whose products are among the most efficient and advanced in the industry. To understand the cost benefits of TDDs, this paper estimates the cost of using Solatube's SolaMaster series throughout the building. Then, CSUCIs yearly sunshine hours show us how many hours in a year that the TDDs could replace the use highly efficient LEDs, which are typical at CSUCI. The findings showed that TDDs were able to cut energy needs for lighting by nearly 75%, but due to the relatively low cost of lighting the building with LEDs and high initial cost of TDDs, the return on investment is low. Though large scale use of TDDs in place of LED lighting doesn't bring high savings to the campus, they are a means of providing comfortable lighting and reducing the campus's energy requirements.

Key Words: Tubular Daylighting Device, Daylighting, Solar Lighting, Energy Savings

Introduction

Daylighting is one of the oldest concepts when it comes to building design. Previous to the discovery of electricity and the introduction of artificial light, the sun was the best way to illuminate indoor environments. Buildings from homes to churches incorporated windows and skylights in order to achieve a well-lit indoor space. The introduction of artificial light came in and changed the way buildings are designed. With access to fossil fuels and misunderstanding of their limited supply and environmental effects, thick walled buildings with their own separate ecosystem, isolated from the outside world, were the standard. This type of construction required less specialization, less windows, and devalued natural light reaching working spaces. Stabilized utility prices, and disregard for daylighting's benefits to human productivity, led to a lack of effort in utilization of natural light. But in today's world, solar-energy systems have been given another look, and the benefits of these systems have been given new value. California State University, Channel Islands (CSUCI) located in Camarillo, CA is one such example of an institution that values daylighting systems and its savings. The campus, opened in 2001, consists of new construction alongside existing remodeled buildings and abandoned unused buildings. Prior to becoming a CSU, the campus served as the Camarillo State Mental Hospital from 1932 until it was closed and abandoned in 1997. CSUCI has been tasked for the last two decades with remodeling the campus to serve as a center for learning and growth. The campus still has future spaces to remodel and new buildings to build, meaning a lot of opportunity for daylighting. The CSUCI campus invests in sustainability and considers it a priority. CSUCI Department of Facilities Services wrote that it "has pursued campus energy conservation since Sustainability efforts were made a priority at the beginning of the 2008/09 academic year" (CSUCI Department of Facilities Services, 2017). The campus is constantly trying to reduce its energy needs to help have less of an impact on our world's finite resources. The Gateway Hall project shows potential for daylighting systems to be incorporated into design, for it is currently in its feasibility stage. The project has been scoped and the design has been conceptualized. CSUCI wants to consider the use of using tubular daylighting devices (TDD) as a means of daylighting the building. This paper will study the value of using TDDs in this upcoming CSUCI project.

Background

Daylighting is the integration of widows and openings into a design in order to achieve optimal indoor lighting and thermal environment and reduce the need for artificial systems to maintain said environment. When defining daylighting, it is important to understand the distinction between daylight and sunlight. Daylight is distributed light that is cool in temperature and creates a comfortable, properly illuminated building space. While sunlight is the direct and uninterrupted light from the sun which has negative effects on building environment that daylighting attempts to eliminate through the use of shading and glazing systems (Garris, 2001). Allowing direct sunlight into buildings can lead to glare, over-heating and overall discomfort of the space. There are two basic strategies of daylighting. Toplighting, which is introducing daylight through the ceiling from above and sidelighting, which is bringing daylight in through the side of the building, usually through the use of windows. Utilizing daylight while integrating efficient artificial lighting to supplement for building needs can be a complicated process, but allows us the opportunity the create the most satisfying building environment we can.

The importance of daylighting buildings is growing. Winsor explains that there are three main arguments for daylighting (Winsor, 2001). These include energy efficiency, life-cycle cost paybacks and occupant satisfaction and health. The first argument for using daylight over lighting that is reliant on electrical utilities, is the energy savings. Today's buildings strive to save on energy needs and become more sustainable. There is a precedence for the United States to analyze the benefits of using daylighting tactics to reduce building energy requirements. According to the 2012 Commercial Building Energy Consumption Survey (U.S Energy Information and Administration, 2016), in 2012, lighting was responsible for 10% of total electricity use in the commercial building sector. Which is actually down 11 percentage points from the previous Commercial Building Energy Consumption Survey, which was in 2003. This drop in energy use for lighting is credited to the widespread change to fluorescent and LED lighting over less efficient incandescent bulbs. Daylighting may provide the means to lower commercial building's energy needs for lighting even more.

With nonrenewable energy resources on the decline and the cost of these resources on the rise, buildings are turning to daylighting as a renewable resource to help create a smaller impact on our environment. This is accompanied with life-cycle cost paybacks, which are the cost benefits received over the life cycle of the building. Owners take on an added cost when utilizing a daylighting system, but this initial cost can be can provide savings on energy needs that make this initial investment worth it over the building's life.

Cost benefits aside, a huge push for daylighting is occupant comfort and health. Natural lighting creates a connection to the outside world and data has shown that workers are more productive in day lit environments as compared to those that are artificially lit. In a 1999 study titled, Daylighting in Schools, student performance was compared in classrooms with more daylight vs those with less. They found "students in classrooms with the most daylighting were found to have 7% to 18% higher scores than those in rooms with the least" (Heschong, 1999). This study used data from three different school districts in three different states, California, Washington, and Colorado, to support their claim that there is a predictable performance benefit to daylighting. Not only is there a productivity improvement, but also an overall benefit to the happiness and comfort of occupants and in more day lit spaces. Daylight can provide a space with a natural spectrum of light that allows occupants to feel more comfortable and this can make the space more aesthetically pleasing.

Tubular Daylighting Devices

A major disadvantage of some methods of daylighting is glare and overheating. And this can actually cause the building's HVAC system to have to work harder to rid the building of this added heat, causing the buildings energy needs to increase. There are methods of daylighting that attempt to successfully diffuse light in order to reduce glare and provide comfortable lighting. One such method is the use of tubular daylighting devices (TDD), which are also referred to as solar tubes or sun tubes. TDDs are a toplighting strategy that harnesses direct sunlight and are able to properly diffuse light and provide appropriate lighting to building spaces. TDDs allow buildings to utilize solar light in interior spaces that normally would require artificial light. These devices effectively replace the need for skylights in the goal of achieving natural light.

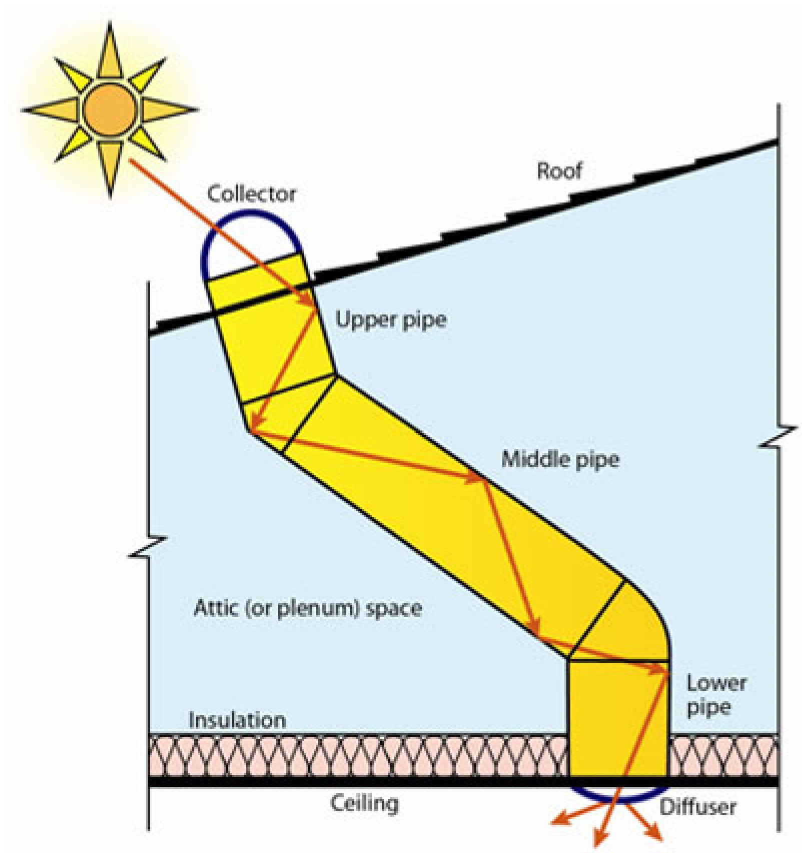

Figure 1: TDD diagram

TDDs give a building the opportunity to seamlessly rely on the sun as a means of lighting. TDDs are recessed fixtures that may seem to be an ordinary light, but the light requires no electrical energy to give it power. Instead the fixture has a tube that is highly reflective, which is connected to a dome that is installed above the roof in order to absorb sunlight from any direction. This makes it a highly versatile form of daylighting. No matter the orientation of the building, the dome will be able to use the sunlight. The light that passes through the reflective tubing, then the diffuser within the fixture provides sufficient lighting, eliminating the need for artificial light during sunlight hours. A leading competitor in the TDD industry is Solatube. Solatube has been in the daylighting industry for 25 years and provides effective TDDs which are the most innovative in the industry. Solatube carries a long line of products for different TDD needs. The line of products that is best suited for typical commercial buildings is the SolaMaster Series. This series of TDDs are designed to serve office spaces, corridors, classrooms, retail & restaurants and other commercial spaces with high versatility (Solatube, 2014 C). They can be used in spaces with ceiling heights of 8' – 30' and due to Solatubes highly reflective tubing, which they call the Spectralight Infinity Tubing, they can deliver effective lighting to lower levels. Solatube claims its product "is made of the world's most reflective material, allowing it to achieve a Specular Reflectance of over 99.7% for visible wavelengths of light" (Solatube, 2014 B). There are other TDD manufacturers, such as Velux, who provide efficient daylighting. But these companies use reflective silver tunnels that can't match the performance of Solatube. Velux claims that its TDDs provide 98% reflectivity (Velux, 2017). Figure 2, taken from Solatube's daylighting fact sheet, gives the effectiveness of the TDD at different tubing lengths based on tubing material (Solatube, 2014 B). The Solatube TDD only loses about 6% of potential lighting at 20' which would be an approximate length of the tube to serve the first floor of a two story building (see Figure 2). Other materials have a large drop off in reflectivity at these depths. With this kind of technology, the opportunity for daylighting a building is high. This system can accommodate bends and turns, making installation a more seamless process due to its versatility. Because of their high performance, this case study will base its analysis off of Solatubes TDDs.

Tubing Material	Specular Reflectivity	Light Efficiency for 10' Tube Length	Light Efficiency for 20' Tube Length	Light Efficiency for 30' Tube Length	Light Efficiency for 40' Tube Length
Spectralight® Infinity	99.7%	97%	94%	92%	89%
Enhanced Silver	97%	74%	54%	41%	31%
Enhanced Aluminum	95%	60%	36%	23%	14%
Corrugated/ Flexible	84%	18%	3%	1%	0.1%
Approx. Number of Bounces based on Tube Length		10	20	29	38

Figure 2: Light Output of Various Tubing Materials

SolaMaster series comes in two models. The model that claims to maximize sunlight at any time of the day and is recommended for office space and corridors, which are pertinent to the CSUCI project space, is the Solatube 330 DS. This model uses a "LightTracker Reflector" which is a reflector that is made out of Solatubes' tubing material that is used to increase light output (Solatube, 2014 C). As well the tubes use a cool tube technology that is a proprietary material that "filters out heat-infused infrared rays to minimize solar heat gain" (Solatube, 2014 C). Once reflected light has made its way down the tubing, it is distributed through the space by a diffuser, which is able to control the lighting and offer diffused light that can properly illuminate indoor spaces. An added accessory that is optional is a daylight dimmer, with a dimmer switch. This allows occupants to reduce lighting if needed, in the case of presentations or any scenario where lighting is unwanted. This gives occupants the power to adjust lighting levels to suit their needs. TDDs are especially appealing to renovation projects, such as the CSUCI Gateway Hall, because of their ease of installation. The tubing is maneuverable without risking insufficient light. And Sather wrote that TDDs are "the easiest daylighting solution for retrofit applications because they typically don't require structural modifications" (Sather, 2014).

Methodology

This case study aims to calculate the feasibility of retrofitting TDDs as a means of daylighting the CSUCIs Gateway Hall project. I will estimate yearly cost savings of lighting the building with TDDs and without them. Then, based on construction cost, what the break-even point and return on investment (ROI) would be. This will provide CSUCI with a conceptual cost analysis for using TDDs in this project. This case study will also provide the industry with how effective TDDs are in a system that uses high efficiency LED lighting, which is a growing lighting solution. My hypothesis is that lighting the building entirely with TDDs during sunlight hours will have large energy savings and significant cost benefits.

Case Study

Project Details

CSUCI has been tasked with renovating outdated spaces to accommodate students and faculty in a healthy environment. The next major project that the campus plans to pursue is Gateway Hall. Gateway Hall is currently an abandoned part of campus. The CSUCI Gateway Hall Program and Feasibility Study Report laid out the parameters and goals of the future project (Co Architects, 2017). The current structures use 142,000 square feet in the Northern end of campus. The Gateway Hall is the first building that incomers arrive at when entering campus through the main entrance. The goal of this project is to "energize the north end of campus as well as defining the arrival point for those entering the campus from the north" (CO Architects, 2017). This project is broken up into two phases. Phase 1 being demolition and renovation and phase 2 being new construction. For the sake of this case study, I will be analyzing the phase 1 renovation for the utilization of TDDs. Phase 1 will consist of enrollment services, faculty offices, academic advising, and student business services. Meaning this building will be a high energy and focused work environment. The building's gross square feet is 69,930. The feasibility report uses a 2.5 grossing factor to suggest that the entire Phase 1 renovation will consist of 26,920 assignable square feet (ASF). The building has a floor-to-floor height of 11' and consists of 2 floors. A list of ways to be more energy efficient is given in the report and CSUCI plans consider all of them. One consideration that the report lists is, "consider the use of skylights and / or sun tubes." TDDs have been used on this campus in previous renovations, typically on a small scale. One such example is the Arroyo Hall, where TDDs were used along with artificial lighting to reach its lighting requirements. The feasibility report also states that the project will consist primarily of high efficiency LED lighting (Co Architects, 2017).

Analysis

My first step in my calculations is to establish the initial cost of adding TDDs into the building renovation. For this, I will use typical pricing model for unit cost and installation cost based on researched information and provided Solatube pricing criteria. I must first establish the amount of TDDs the building space will need to be properly illuminated. Solatube has specific criteria for spacing commercial TDDs for optimal use. Figure 3 was pulled from their spacing criterial reference sheet (Solatube, 2014 A). Using the criteria below, (see Figure 3) Solatube claims that for an 11' ceiling height, the TDDs should be placed between 11' and 14.3'. Assuming each light will be spaced at 14'x14' to maximize efficiency, the TDD can cover a floor space of 196 square feet (sf). Total assignable space for the building is 26,920 square feet, meaning it will need a minimum of 138 TDDs for sufficient illumination at 196 sf per TDD. Meaning 138 total SolaMaster units for the entirety of the project. I was provided unit pricing by a Solatube representative at roughly $600 per unit for the office/classroom spaces. And based off of Fixr's cost estimate for installation, I will assume roughly $400 per unit for installation, giving me a total cost per unit of $1,000 per unit (Fixr, 2017). CSUCI's Associate Director of Planning, Design and Construction, James Walsh, stated that based on previous jobs on campus, this was a reasonable estimate (Walsh, 2017). This gives me a total construction cost of $138,000 to install TDDs for the building.

Space Type and Spacing Criteria		
Spacing	**Enclosed Spaces[1]**	**Open Plan Spaces[2]**
From Walls	Spacing ≥ 0.5 x MH (1.0 x MH = Maximum)	Spacing ≥ 0.5 x MH (1.0 x MH = Maximum)
Between Units	1.0xMH < Spacing < 1.3xMH (Maximum Spacing = 1.5xMH)	1.0xMH < Spacing < 1.3xMH (Maximum Spacing = 1.5xMH)
Tips	Using a single unit to light more than a 5m x 5m space may cause shadowing of wall surfaces and unacceptable uniformity of work surface illumination.	Using a single unit to light more than a 48 m^2. partitioned space may cause unacceptable shadowing of desk surfaces.

Figure 3: Solatube TDD Spacing Criteria

In order to understand the cost benefits on using TDDs in the lighting system on this building, I need to calculate what the building would otherwise have spent if the TDDs were not included in the lighting system. I need to make a few assumptions in my calculations. One assumption is the buildings use of LED lighting as its source of artificial lights, which was stated earlier in Project Details. So for the sake of this project, I will assume the use of a high efficiency LED fixture that is comparable in performance to other LED lights on the market. I will use the Deco Lighting BLLT-LED. This fixture is a 40Watt/4062 Lumen fixture, giving it a 101.5 Lumen/Wattage rating (Deco Lighting, 2016). I will assume the buildings lux requirements, which is suggested as 500 lux for normal office work based on the Engineering Toolbox (Engineering Toolbox, 2017). Lux is the number of lumens per meter squared for a building. This means my calculation will include a .093 square meter (sm) per square foot (sf) conversion factor. Based on this required number of lumens for the building and the LED's lumen per watt rating, I will calculate the necessary wattage for the building. And based on 40 watts per unit, I will estimate the number of BLLT-LEDs required.

500 lux x (26,920sf x .093sm/sf) = 1,251,780 lumens
1,251,780 lumens / 101.5 lumens/watt = 12,332.8 watts
12,332.8 watts / 40 watts/fixture = 309 BLLT-LED

Based on these calculations, this entire space will need 309 high efficiency light fixtures. Now, in order to calculate how much having TDDs will reduce the cost of lighting the building, I need to have an estimate of how many hours in a given year the building will have optimal sunlight in order to properly illuminate the building without the assistance of artificial light. Because my take off provides enough TDDs to properly illuminate the space on its own during optimal sunlight hours, I will need to calculate a realistic number of hours that Camarillo gets adequate sunlight. There is currently a lack of sunshine duration information for Camarillo. Sunshine duration is the number of total hours that a given place has sunshine. I will estimate sunshine duration based on total sunny days. Sperling's Best Places' climate overview of Camarillo states the city gets 273 sunny days a year (Sperling's Best Places, 2017). I will base the amount of sunny days off of a 355 day calendar, subtracting 10 days for holidays, which adjusts to 265 days of sunlight in Camarillo in a year. And based on an average day length of 12 hours, this gives us 3180 hours of sunshine a year. I will also assume $0.12 per kilowatt hour (kWh), which is the average cost per kWh in the U.S.

3180 hours/year x 40 watt/fixture = 127.2 kWh/fixture per year
127.2 kWh/fixture per year x $.12/kWh = $15.26 per year, per fixture
$15.26 per year, per fixture x 309 fixtures = $4,716.58 per year

This number provides us with how much energy and money that the TDDs are saving in a given year. But in order to compare with lighting costs without TDDs, I must also calculate the cost of lighting the building entirely with LED lighting, based off a 355 day year and 12 hours of lighting per day.

4,260 hours per year x 40 watt/fixture = 170.4 kWh/fixture per year
170.4 kWh/fixture per year x $.12/kWh = $20.45 per year, per fixture
$20.45 per year, per fixture x 309 fixtures = $6,318.43 per year

Financial Analysis

If the building was to be lit with LED lighting alone, assuming 12 hour per day of LED lighting for 355 days per year, would cost $6,318.43 per year. And with TDDs, the cost would be reduced by $4,716.58 per year. Meaning that TDDs would cut energy needs for lighting by 74.6%. And the annual cost for lighting the building with TDDs and LEDs would come to $1,601.85. Based off of the $138,000 initial cost, our return on investment is 3.4% and payback period is 29.3 years. Figure 4 below shows the cumulative cash flow based on ten year increments. Figure 5 displays the annual cost of lighting for the building would be with and without TDDs in the lighting system

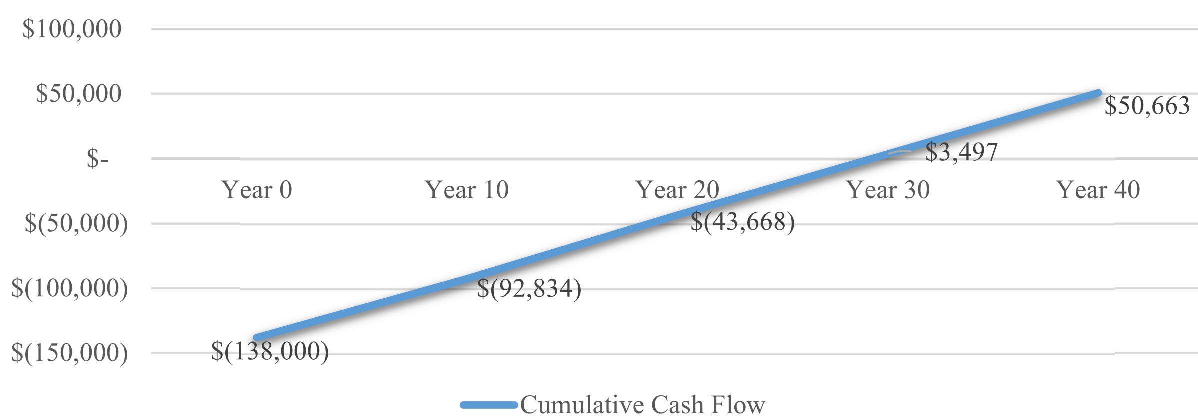

Figure 4: Cumulative Cash flow

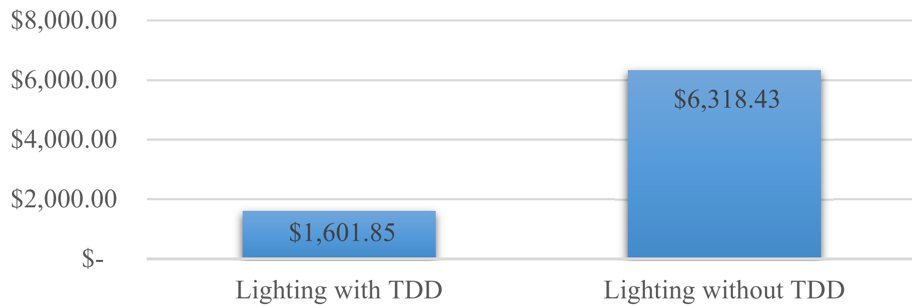

Figure 5: Annual Lighting Cost

Advantages

The campus would be able to cut a significant percentage of its annual energy needs for lighting. Due to its location at the entrance of campus, CSUCI would be able to display this new system to visitors. Both faculty and students would be able to occupy this space under natural lighting, which provides benefits to both occupant productivity and comfort. And because this is diffused natural light, the building doesn't face problems with daylighting causing indoor furnishings to fade over time. Other daylighting strategies also face unwanted glare and even heat. TDD's effectively avoid these issues. Also, this will have a low impact to schedule and not affect structural members of the building, due to TDD's versatility. And though the payback period is relatively long, there would be savings further down the road. Daylighting and sustainability not only improves the space itself, but it also proves the point that the campus is making efforts to reduce its footprint, which makes the campus more appealing to the public.

Disadvantages

With a return on investment of 3.4%, cost savings are not a significant factor in pursuing this system, as it would take nearly 30 years to break even. Also, because the campus has had limited use of tubular daylighting devices in the past, there is a level of risk that the campus is inheriting when using them on such a large scale project such as this one, due to inexperience. Another disadvantage is the roof aesthetics. This is typically not of huge concern, but the campus' Spanish style roofs are very important to the theme of the campus. And TDDs domes add a significant number of roof top fixtures.

Conclusion

My findings show the potential savings of using TDDs as a means of daylighting the renovated portion of the Gateway Hall project. My hypothesis showed to be partially correct. While the TDDs had a significant effect in reducing energy needs, it wasn't able to provide significant savings to the building. But the use of daylighting would provide other benefits to the campus. The reason that these TDDs didn't provide large savings was the effectiveness of LED lighting. High efficiency LEDs are able to keep lighting cost very low to begin with and even large cuts in lighting requirements doesn't provide large savings. A recommendation would be to utilize TDDs as a small scale daylighting strategy. This could bring some of the benefits to TDDs into the building without making as big of a financial investment. Though, this case study's findings show small savings of TDDs when used with high efficiency LED lighting, the future of TDDs is a complete lighting integration. Solatube currently has a product, the Solatube Smart LED, which is a TDD that has LED lighting built inside that turns on when its daylight sensor detects that the sun is not providing enough light. Currently, this system is designed for small spaces, typically in the residential sector. The LED lights do not provide enough lighting to use in commercial spaces. But as manufacturers, like Solatube, are able to create more advanced TDD-LED integrated systems, savings for TDDs could become much more significant. With these systems, commercial buildings could effectively replace the use of standalone lighting fixtures and energy needs for lighting could be reduced all across the world. In a world of diminishing natural resources, these smart systems could be the means of reducing the world's lighting energy needs in a cost efficient, effective way.

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