Energy Saving Potential of SunCooler Off-Grid Solar Powered Ventilator/Destratifier

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1. Introduction and Technology Description

High-bay facilities are generally not cooled by mechanical vapor compressors but rely on either passive or powered ventilation to maintain temperature. In the winter time, high-bay spaces that are heated can develop large thermal gradients between the floor (cold) and ceiling (hot) level. This increases energy consumption and decreases occupant comfort. Some facilities may use grid-powered ceiling fans to mix the interior air, but often nothing effective is done to destratify the building.

Given these challenges, Northwest Renewable Energy Corporation (NWREC) has developed a solar powered technology, named the "SunCooler" (example shown in Figure 1) that can provide destratification during the winter, and ventilation (exhaust or induction) in the summer time. The SunCooler unit mounts on top of a roof-mounted curb. With level or pitched curbs, the SunCooler can be installed on any roof angle. The current product line covers air handling from 1000 CFM, 2500 CFM and 15,000 CFM. Photovoltaic panels ranging from 130 W, 275 W and three 320 W (960 W combined) modules are mounted on angle on top of the unit housing. The PV modules power the proprietary onboard controls and energy storage system. SunCooler units operate in 24vdc, 36vdc and 48vdc with axial propeller diameter sizes of 12", 16" and 36". The PV module provides sufficient electrical power to simultaneously operate the following unit's functional components: wireless control system, interior/indoor T/H/CO_2 sensors, outdoor T/H sensors for environmentally sensing operational run time parameters, charging of batteries housed within the unit which allow the ventilator to operate at night, motorized sealed dampers used for air flow directional control and to prevent heating or cooling loss when not operating and other operational controlling scenarios.

Figure 1: SunCooler solar powered ventilator/destratifier

The SunCooler can be operated in multiple modes, as shown in Figure 2. During induction, fresh air is brought from the outside and moved

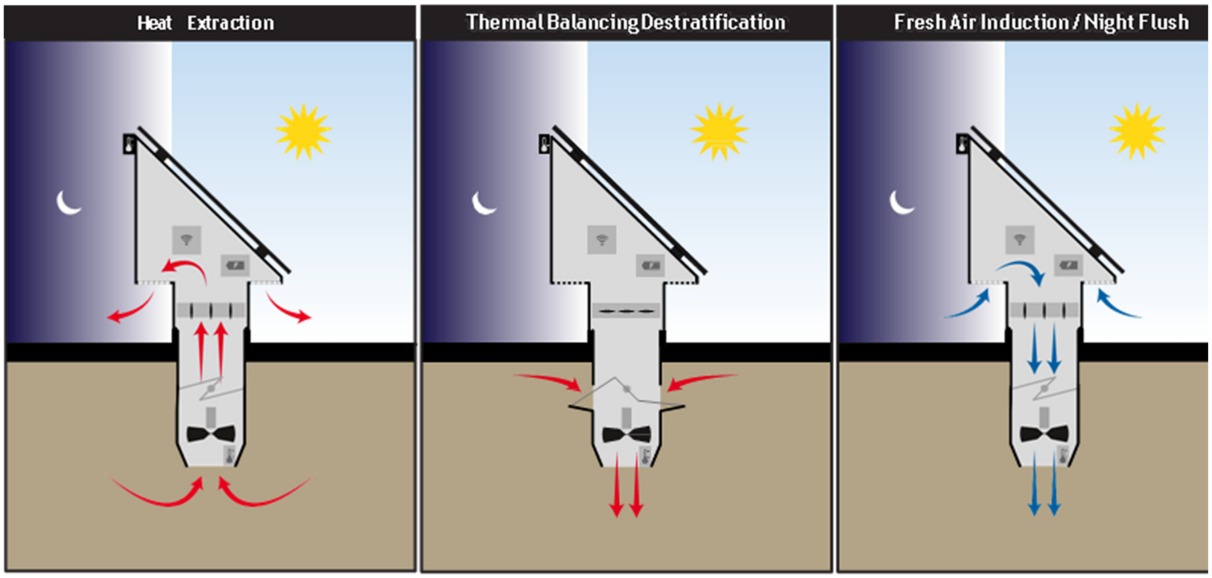

Figure 2: Fan operation modes, (NWREC, 2017)

into the conditioned space, providing cooling. Cooling would typically be done during the night (e.g., "night flush") on battery power when the outdoor temperature is lower than the indoor and humidity levels are below some threshold value. It also provides air replacement which can have an impact on CO_2 levels. The exhaust mode is when the fan unit is open to external air, but the fan direction is reversed, pulling air from the indoor environment. This can aid with cooling in daytime operation by removing the heated air that collects at ceiling level via stratification in warmer seasons as well as the removal of CO_2, or other containments within the space. The final mode, destratification, occurs when dampers are closed to the external air and internal baffles are opened to gain access to ceiling height air for mixing.

2. Description of Field Trial

From September 2016 to December 2017, researchers at Oregon State University conducted a field trial of the SunCooler technology installed in a large distribution center and a small school-room, both located in the Albany/Corvallis, OR region. The purpose of the study was to evaluate the performance, reliability, and energy saving potential of the device in a real-world application using a combined experimental and computational approach. Seven SunCooler units were installed in a portion of a 1.5 million square foot warehouse and operated continuously in destratification or induction mode for a period of 16 months. In parallel with experiments, a detailed computational fluid dynamics (CFD) simulation of the destratification performance of the device was developed and parametric evaluation of destratification for different warehouse

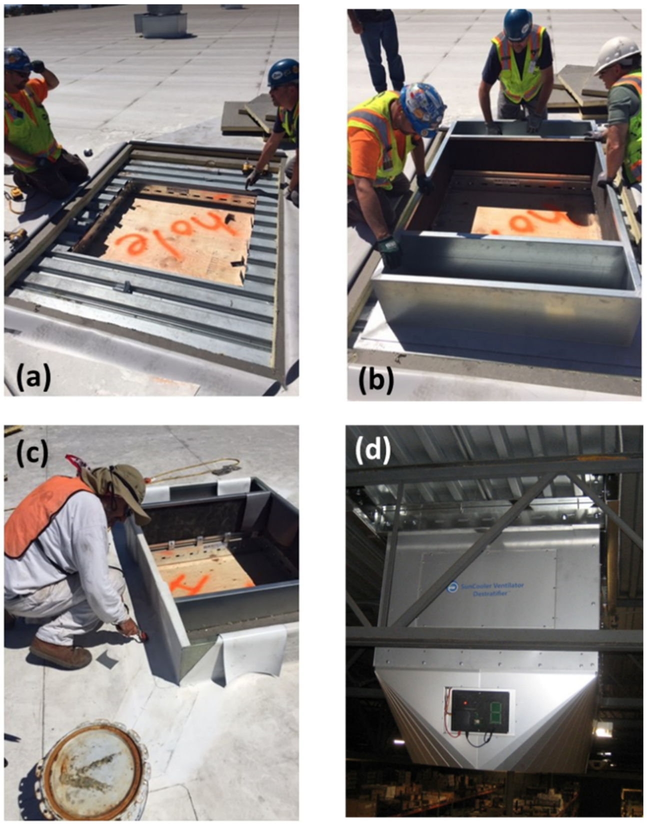

Figure 3: Photograph of installation process showing (a) covered roof pentration, (b) roof curb installation (c) water proofing and installation and (d) interior view of installed SunCooler

configurations and operational conditions. Details of the model development and validation can be found in freely available sources[1,2], for the interested reader.

Approximately 1/3 of a 1.5 million square foot warehouse was utilized for the field trial. The warehouse operates in two modes, summer and winter. Wall and roof mounted exhaust fans are enabled during summer mode, and roof mounted heaters are enabled during winter mode. Within the experimental space there were 4 zones which each contain multiple 10 HP wall and roof exhaust fans which can either exhaust or induce air. In total there are 8 wall exhaust fans, and 2 roof exhaust fans. These fans are utilized to cool the building via night flush, inducing external air during the night. The heaters utilized are Direct Gas-Fired Make-Up Air (MAU) units. There are 7 heater units, which are rated for 12,045 CFM and utilize 1.3 million BTU/hour. During winter mode, these heaters are set to activate when reading 63 °F at the Northern wall, or 62 °F at the Southern wall, both thermostats at floor level. Seven SC15000 model SunCooler units were installed at the warehouse in a North/South oriented column at a 90 ft spacing. The units were installed evenly between North to South running girder trusses, with photographs from the installation shown in Figure 3. A key advantage of the SunCooler technology for retrofit applications is that no grid power is required, decreasing installation cost and permitting requirements.

Inside the warehouse, wireless temperature sensors were installed as shown in Figure 4 at heights ranging from 7 ft to 32 ft from the ground. This allowed the temperature profiles throughout the warehouse to be measured and the local effects of the SunCooler to be observed.

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[1] Polander, M. D., Harder, E. D., Junker, J. F., Fronk, B. M. (2018). Numerical Analysis of Time Required for Destratification in Warehouses, 5th International High Performance Buildings Conference at Purdue, West Lafayette, IN, July 9-12.

[2] Polander, M. D. (2018). *Investigation of Destratification in Warehouses* (Master's Thesis). Oregon State University, Corvallis, Oregon. Available from: http://ir.library.oregonstate.edu/concern/graduate_thesis_or_dissertations/8g84mr920

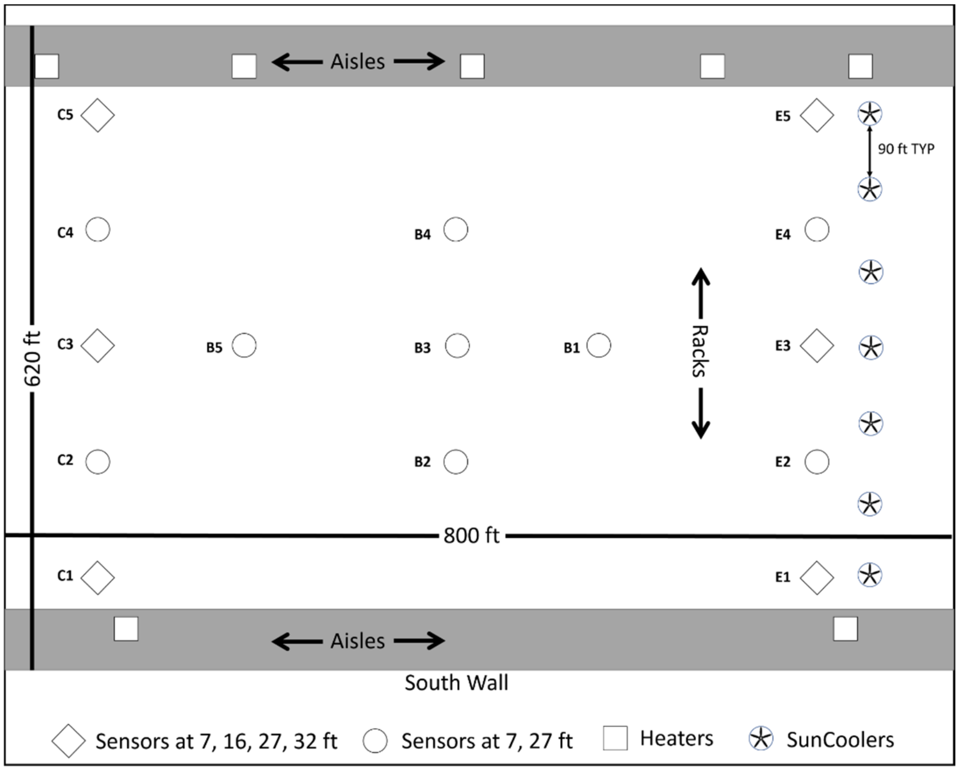

Figure 4: Schematic of warehouse sensor layout

In addition, sensors were installed to determine heater on/off operations and exhaust fan on/off operation, enabling and estimate of energy savings potential.

3. Energy Saving Potential and Payback

Potential warehouse energy savings using the SunCooler have been found. It should be noted that the Albany, OR climate is very mild, and heating and cooling costs are much lower than in other areas of the country. Alternate payback periods are also explored.

3.1 Cooling Season Energy Savings Potential

During the summer months, the SunCoolers were set to operate in induction mode at nighttime using stored solar energy. The existing grid-powered wall and roof mounted exhaust fans in the vicinity of the SunCooler units were disabled during the study. Existing fans in other parts of the warehouse were run as normal. Figure 5a shows the average ceiling temperature for the control and experimental (SunCooler zone), demonstrating minimal difference between experimental and control zone in summer months. Figure 5b shows the local ceiling temperature change in the vicinity of a SunCooler, illustrating the potential to provide cooling via induction cooling. Despite disabling the grid-powered fans in the experimental zone, the facility thermal environment was maintained, suggesting that SunCooler could be used to replace existing grid-powered equipment when it reaches end of life, installed as a retrofit in facilities that don't have any powered ventilation, or installed in new construction to provide cooling.

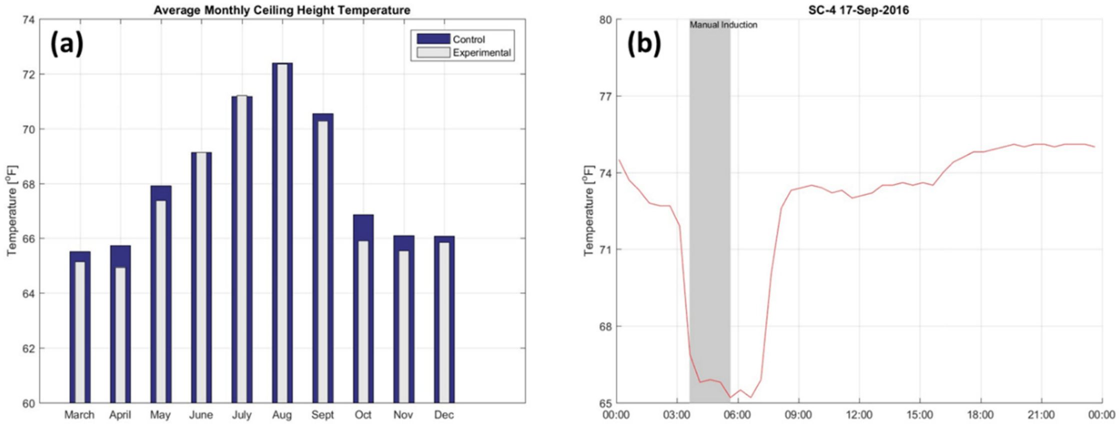

Figure 5: (a) Average ceiling height temperature for control and experimental zone and (b) local ceiling height temperature during a manual induction event

To estimate energy savings, the total operational hours of all the existing grid-powered fans was determined using the on/off sensors, shown in Figure 6. June 2017 shows an unexpectedly low fan operation time. The exact cause of this is unknown. Thus, two cost savings were estimated from the available data. One set with the recorded run times, and one set with the June 2017 operation time assumed as an average of the May 2017 and July 2017 operation times.

To determine the cost of operation the fan motor wattage (assuming fully loaded motor) was multiplied by the hours of operation, 19,574 hours (measured), and the commercial cost of electricity per kilowatt hour in Albany, Oregon, 0.0843 cents per kWh, as of the time of publication of this paper. This resulted in an estimated annual savings of $12,309 by using the SunCoolers instead of grid-powered fans. Using a "corrected" hours of operation of 25,200 where the June hours were assumed to be an average of May and July, the estimated operational savings by using SunCoolers was $15,847 per year.

3.2 Heating Season Energy Savings Potential

During the heating season, the SunCoolers can be run in destratification mode, where no outside air is introduced. Destratification during heating season is believed to save energy primarily through a reduced ceiling temperature[3]. At a given ambient temperature, heat loss through the roof will increase with an increase in temperature at the ceiling height. With destratification, the temperature at the ceiling will decrease as the air is mixed to a more uniform temperature. This increases occupant comfort by increasing air temperature near the floor. In the field trial, it was found that the warehouse was actually under heated. The MAU units ran nearly continuously during the winter months, and the stratification profiles observed were consistent with those for unheated space (Figure 6a). Thus, this particular warehouse would not see significant energy savings for destratification. However, the SunCoolers were able to provide local destratification (Figure 6b), and operate reliably during the winter months, where the solar resource is very

[3] Aynsley, R. (2005). Saving Heating Costs in Warehouses. *ASHRAE Journal*, *47*(2), 46-51.

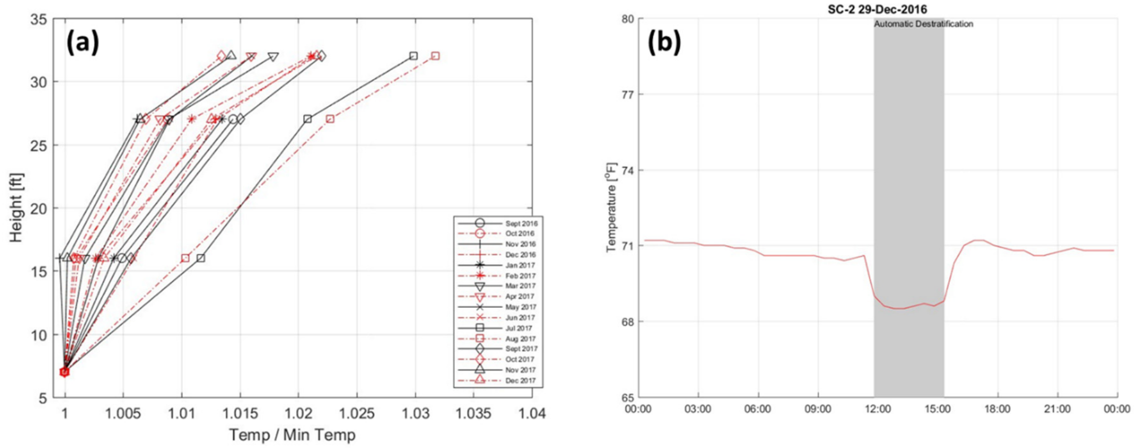

Figure 6: (a) Average stratification profile for each month and (b) local ceiling height temperature during a destratification event

limited in Oregon. To estimate energy savings potential, the model of Aynsley[4] (Eqs. 1 and 2) was applied to the warehouse for different scenarios, assuming it was sufficiently heated.

$$\dot{Q} = UA \cdot \Delta T \tag{1}$$

$$FS = Hrs \frac{\dot{Q}_{bd} - \dot{Q}_{ad}}{HHV \cdot \eta} \tag{2}$$

Here, $\dot{Q}$ is the rate of heat loss through the roof before destratification (bd) and after destratification (ad). U is the average overall heat transfer coefficient for the roof. U is approximated as 0.13 $BTU/ft\ °F$ as in the work Aynsley (2005). A is the area of the roof for area in which the experiment was performed, 500,000 ft^2. ΔT is the temperature difference between the exterior and interior surfaces. The interior temperature will be hypothetical for this study, as the warehouse was under heated and destratification is not beneficial under this condition. However, destratification savings are related to the ratio between before and after destratification ceiling temperatures. Which means the savings are driven by the number of degrees the ceiling temperature is able to be reduced, not the actual ceiling temperature. For the exterior temperature, weather data was collected from the National Oceanic and Atmospheric Administration, shown in Table 1.

Table 1: Average temperature data – Albany, Oregon °F

	January	February	March	April	May	June	July	August	September	October	November	December
High	46	51	56	60	67	73	82	82	77	65	53	46
Low	34	35	37	39	44	49	52	51	48	42	38	34

4 Aynsley, R. (2005). Saving Heating Costs in Warehouses. *ASHRAE Journal*, *47*(2), 46-51.

Averaging the high and low temperatures for January through April, November, and December yields an average exterior temperature of 44.08 °F, which corresponded to the months in which the distribution center operated in winter mode. FS is the fuel saved for a given number of hours. Hrs is the hours in which destratification is being performed. Using the months in which winter mode was activated, this results in 4,344 hours of operation. HHV is the higher heating value, or caloric value of the fuel being used. The MAU heaters utilize natural gas, which has an HHV of 1,000,000 BTU/dekatherm. Finally, η is the efficiency of the heaters, which is reported to be 92% from MAU specification sheet provided by the vendor.

To calculate the savings from destratification, all values in Eq. 1 are held constant with the exception of the interior temperature. The interior ceiling temperature is estimated to be 86.5 °F. The value is assumed based on the warehouse set points of 62 °F and 63 °F and the 24 °F initial temperature difference found in the analysis performed by Aynsley (2005). Then, to see a range of possible savings, the reduction in temperature by destratification is set to 1, 3, 5, and 7 °F, with the results are shown in Table 2. Here, the price of natural was assumed to be $8.53/dekatherm.

3.3 Estimated Simple Payback

Given the energy savings potential, the simple payback is an important parameter when making a decision of investing in a new technology. Two cases will be considered, one in which SunCoolers are purchased only to provide night flush cooling, replacing grid-powered fans, and one in which SunCoolers are installed to provide both induction cooling and destratification

Table 2: Energy savings potential for various destratification temperature reduction scenarios

	$\Delta T = 1$ °F	$\Delta T = 3$ °F	$\Delta T = 5$ °F	$\Delta T = 7$ °F
Reduction in Rate of Heat Loss from Baseline	65,000 BTU/hr	195,000 BTU/hr	325,000 BTU/hr	455,000 BTU/hr
Potential Avoided Gas Consumption	307 dekatherms	921 dekatherms	1535 dekatherms	2148 dekatherms
Potential Annual Savings	$ 2,617	$ 7,853	$ 10,471	$ 18,325

In the first case, thirty-five 15,000 CFM SunCoolers are required to service the 500,000 ft^2 warehouse section based on a 1:1 replacement of grid-powered fan CFM. At the time of publication, the estimated cost of a 15,000 CFM SunCooler that provides only induction is $4,500. Thus, the total equipment investment is $157,500, resulting in a simple payback of 9.9 years based on an annual energy savings of $15,847. This payback is for replacing grid-powered fans in the relatively mild climate of Albany, OR. For climates such as Phoenix, more hours of operation in induction or exhaust mode would be expected, and thus, greater savings. Figure 7 shows payback for replacing grid fans under different annual hours of operation and electricity cost scenarios. The plot assumes that it requires 3 SC15000 SunCoolers to replace a single, fully

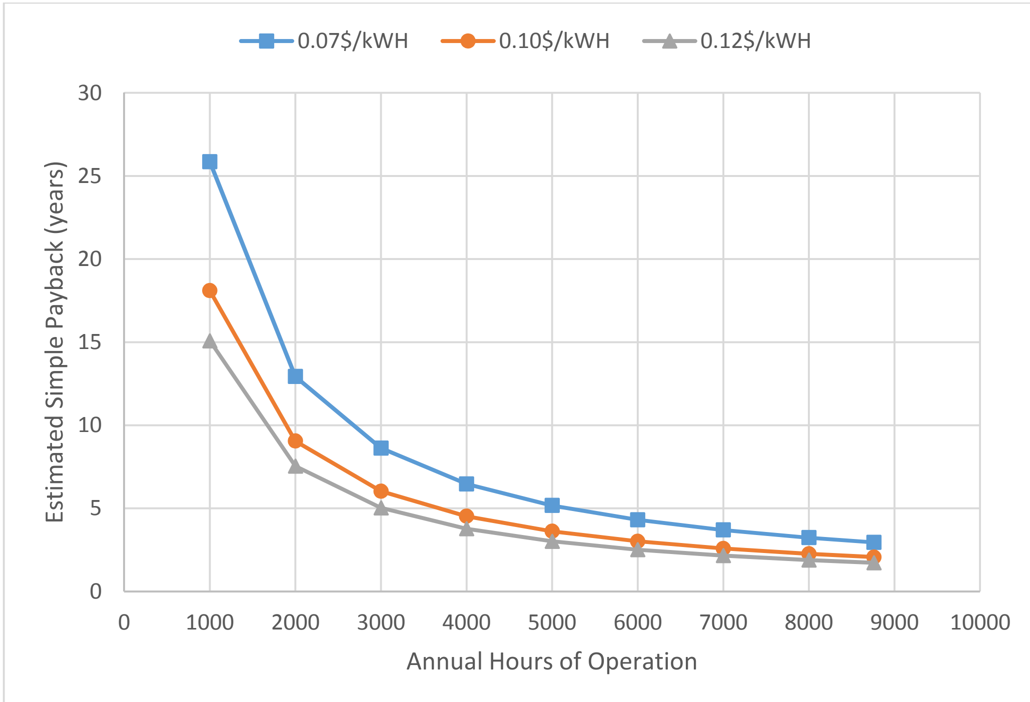

Figure 7: Estimated simple payback for varying hours of operation and power cost

loaded 10 HP, grid powered fan. The hours of annual fan operation range from 1000 hours to 8760 hours, the latter of which would be continuous annual operation. The three lines are for different power costs, ranging from 7 cents per kilowatt hour to 12 cents per kilowatt hour.

In the second case, SunCoolers were assumed to be used to provide both induction cooling in the summer and destratification in the summer. At the time of publication, the estimated cost of a 15,000 CFM SunCooler that provides induction and destratification is $5,500. Assuming a warehouse of 500,000 ft^2 and an area of coverage of a single SunCooler of 8,100 (based on modeling results), 62 SunCoolers would be required for destratification, representing an equipment cost of $341,000. The simple payback for different ceiling height temperature reductions is shown in Table 3.

4. Conclusions

An experimental and computational study of the performance of SunCooler solar powered ventilator/destratification units was conducted. Experiments were conducted for more than 16 months in a large warehouse, and a smaller experiment in a single school room. In the warehouse, the SunCoolers operated reliably for the entire project period. SunCoolers were able to operate at night and during short, cloudy winter days without operational issues. During the cooling season, the SunCoolers were shown to function adequately during night-flush cooling operations. The area of influence of the SunCooler were maintained at comparable temperatures to the rest of the warehouse. For this particular warehouse section, replacing the grid powered exhaust fans with SunCooler units (matching the rated CFM) would result in an estimated annual electrical cost savings of between $12,309 and $15,847. Assuming that 35 SunCoolers are required at an estimated unit cost of $4,500 to match the rated CFM, the simple payback period is 9.9 to 12.8 years for replacing the grid-powered fans only. In reality, it may be possible to utilize fewer SunCoolers to achieve the same cooling effect. Thus, this estimate is conservative. Furthermore, as the number of operation hours increases, the payback period drops quickly. Thus, the SunCooler system may be more economical in warmer climates.

Table 3: Estimated simple payback for different destratification scenarios

Scenario	Years
No Destratifier	9.9
$\Delta T = 1$ °F	18.4
$\Delta T = 3$ °F	14.3
$\Delta T = 5$ °F	11.7
$\Delta T = 7$ °F	9.9

During the heating season, the SunCoolers were run in destratification mode. The SunCoolers showed a local effect, decreasing the ceiling temperature several degrees Fahrenheit. However, a more significant observable impact on the building environment was limited by (1) the large square footage compared to destratification effect, and (2) the fact that the warehouse was under heated, preventing the formation of a significant thermal stratification profile. Thus, a separate smaller experiment was conducted and detailed computational model was developed to understand destratification behavior, including the required time to destratify a given environment. The results indicated that for the warehouse under investigation, SunCoolers should be arranged in a grid pattern with units separated by approximately 90' to produce a meaningful destratification effect. Using destratification energy savings models from the literature, it was estimated that the warehouse could reduce heating costs by between \$2,617 to \$18,325 for a ceiling temperature reduction from 1°F to 7°F, respectively, assuming the warehouse was sufficiently heated. For a 90' spacing in the 500,000 square foot section of the warehouse, this suggests 62 SunCoolers at a cost of \$5,500 are required to achieve the desired destratification effect. At a cost of \$5,500 per unit, the simple payback (inclusive of cooling season savings) ranged from 9 to 13 years for ceiling temperature reductions from 3°F to 7°F. For colder climates, the energy savings from destratification are expected to be greater than those in Oregon, reducing the payback time.

In sum, the SunCooler technology represents an alternative to grid-powered ventilation and ceiling fans to provide energy savings in summer and winter. The technology would be particularly attractive for retrofit applications in which installing grid-power would be too costly or impossible, as well as for off-grid applications. For applications in which a grid-powered technology is already installed, replacing it with a solar powered unit may be economically justified for sufficient hours of operation or for scenarios where fuel costs increase.