

Accelerating PV Cost Effectiveness Through Systems Design, Engineering, and Quality Assurance

Subcontract Report
NREL/SR-520-40335
July 2006

Phase I Annual Technical Report
4 November 2004 — 3 November 2005

J. Botkin
PowerLight Corporation
Berkeley, California

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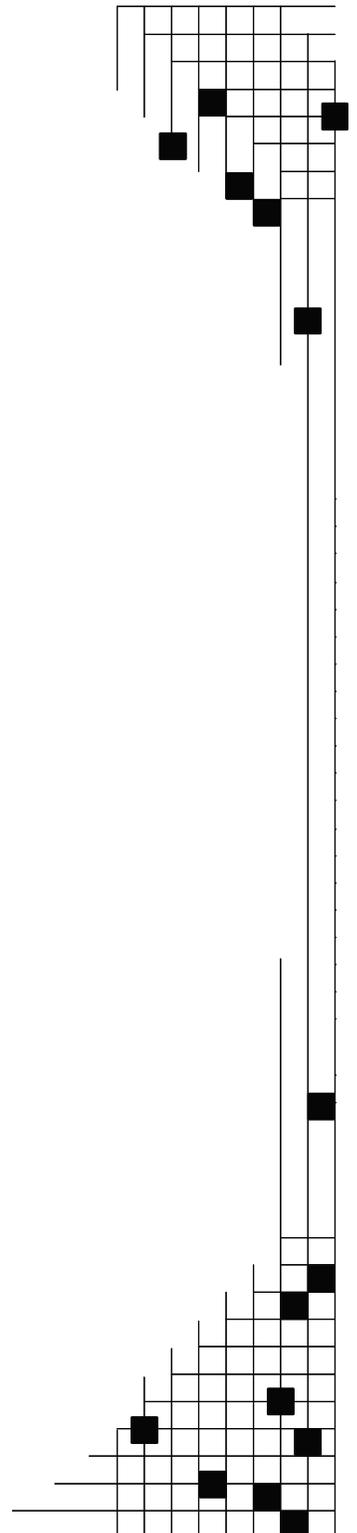
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Abstract

During Phase I of this PV Manufacturing R&D subcontract, PowerLight^{®1} Corporation has made significant progress toward the reduction of installed costs for commercial-scale, rooftop PV systems. PowerLight has worked to reduce operating costs by improving long-term reliability and performance through the development of more sophisticated tools used in system design and monitoring. Additionally, PowerLight has implemented design improvements with the goal of reducing cost while maintaining and/or improving product quality. As part of this effort, PowerLight also modified manufacturing and shipping processes to accommodate these design changes, streamline material flow, reduce cost, and decrease waste streams. During Phase II of this project, PowerLight plans to continue this work with the goal of reducing system cost and improving system performance.

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Executive Summary

PowerLight[®] Corporation provides the products and services required to install large-scale solar electric generation at any suitable site. PowerLight designs and installs complete systems, ensuring reliability, efficiency, and cost-effectiveness.

In 2004, PowerLight initiated the PV Manufacturing R&D subcontract, “Accelerating PV Cost Effectiveness through Systems Design, Engineering, and Quality Assurance.” This work effort focuses on cost reductions for PowerLight’s commercial rooftop product offerings: PowerGuard[®] Roof System; PowerLight Fixed Tilt Roof System (RFT10), and PowerLight Metal Roof System (RMR).

As part of this effort, PowerLight focused on developing improved tools for system design and monitoring in order to optimize system performance and minimize downtime under Task 1. PowerLight selected a laser-based site audit tool to facilitate the design process. In addition, PowerLight tested alternative hardware for data acquisition and reference sensors. Coupled with the more sophisticated alert algorithms under development, these devices provide PowerLight with better monitoring and diagnostic tools that will improve system performance and availability. Overall, these improvements will lead to better layout design, fewer design-related delays during installation, and maximized system output.

Prior to the start of this subcontract, PowerLight had completed design work on the first version of a mounting system with sloped PV, RFT10. Like PowerGuard tiles, this system was design for installation on flat roofs without penetrations, but it does not have the foam insulation of the PowerGuard tiles. Under Task 2, PowerLight prototyped a modified design based on updated wind load requirements, resulting in a more versatile product for a wider range of applications. PowerLight advanced this new design to full commercial deployment. Additionally, PowerLight developed design guidelines for installations on tall buildings and initiated efforts to develop guidelines for accommodating mechanically attached membranes. PowerLight also realized significant cost reductions by reducing raw material use in the production of PowerGuard tiles. Other work on PowerGuard enabled PowerLight to adjust to changes in PV backing materials.

PowerLight evaluated product improvements through comprehensive testing in order to verify that product quality is maintained throughout the design process. This reliability evaluation included wind studies; structural evaluation; seismic modeling; thermal monitoring; and electrical testing. Additional testing will be carried out in Phase II of this project. In addition to testing, PowerLight initiated pursuit of ICC certification; this effort has been suspended due to the limited potential benefits to the inspection process.

Under Task 4, PowerLight worked with suppliers to establish supplier quality standards with the goal of achieving a 99% first time acceptance of select products. By ensuring that suppliers have adequate quality systems in place, PowerLight avoids costly field repairs and delays. This also ensures that PowerLight’s systems perform at their maximum output, satisfying customers’ expectations

By continuing to implement lean-manufacturing techniques, PowerLight achieved a 99.96% yield for PowerGuard tile production, outstripping the Phase I goal of 99.7%. This yield is the result of improvements in manufacturing equipment and inputs from factory workers.

To address ES&H concerns, PowerLight evaluated means of decreasing site waste by 20%. Initially, PowerLight planned to develop reusable containers for shipment. However, due to prohibitive cost and space requirements of this option, PowerLight instead modified shipping practices and succeeded in increasing packing density, thereby reducing shipping costs by 20%.

The design improvements implemented during Phase I were evaluated through commercial demonstration projects. PowerLight reduced backerboard cost for a PowerGuard tile by 17.8% through a reduction in raw materials and labor, as well as optimized shipping density. Following implementation of improved monitoring capabilities, PowerLight found test systems performing at higher operating levels with increased availability, as compared to control sites in similar locations.

1 Introduction

1.1 Objective

The overall objective of this subcontract is the reduction of installed system costs for PV systems utilizing PowerLight Corporation's rooftop products.

1.2 Background

PowerLight manufactures its flagship product, the PowerGuard tile, in a facility in Berkeley, California. PowerGuard building-integrated photovoltaic roofing tiles generate electricity from solar energy. A PowerGuard tile consists of a flat plate photovoltaic (PV) laminate mounted onto a flat, rigid, extruded polystyrene (XPS) board. The XPS board is covered with a cementitious coating. Two edges of the XPS board are routed into a tongue profile, while the other two edges are given a groove profile. This design allows PowerGuard tiles to be assembled adjacent to each other in an interlocking fashion, as shown in Figure 1 below.



Figure 1: PowerGuard tiles showing interlocking tongue and groove profile.

PowerGuard tiles provide benefits in addition to the electricity produced in the form of added insulation and protection of the roof membrane from ultraviolet light. PowerGuard systems can reduce the heat transfer into a building and reduce operating costs.

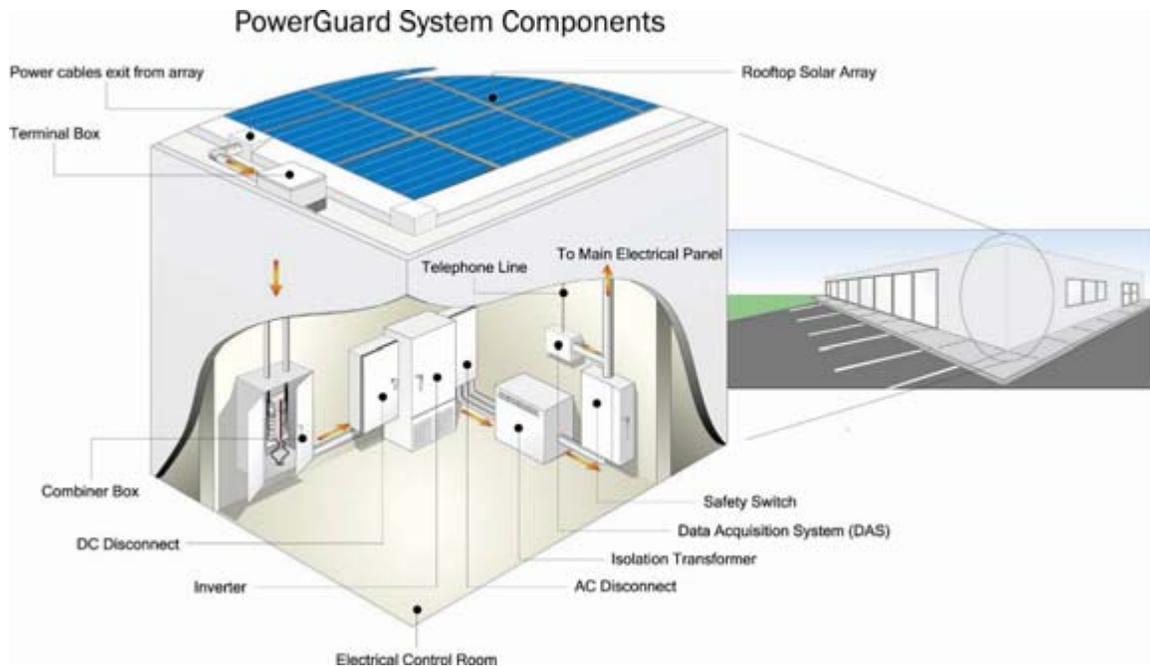


Figure 2: Building cross-section showing PowerGuard System Components

Adjacent tiles are tied together electrically through connectors supplied on each PV module, thus creating an electrical string of PV modules. One or more strings are then electrically connected in parallel at a remote location creating a solar electric array. The resulting DC current from the array is passed through a DC/AC inverter and isolation transformer before being tied into the building's electric distribution panel. Figure 2 depicts the system components for a PowerGuard array.

PowerLight also manufactures a PV mounting system for metal roofs called PowerLight Metal Roof System (RMR), using custom clips, shown in Figure 3, and a 10-degree sloped PV mounting system for flat roofs, RFT10, shown in Figure 4.

PowerLight is in the process of implementing design improvements to all three products to expand market applications, reduce cost, and improve quality and reliability. This report outlines the activities completed in Phase I of this subcontract.



Figure 3: RMR System



Figure 4: RFT10 Array

2 Results & Recommendations

2.1 Task 1: Design & Performance Reliability Improvements

The objective of this task is to improve the tools used to design and monitor PV arrays in order to optimize performance and minimize downtime. As part of this effort, PowerLight initiated development of an array-design tool with improved quality of data transfer from the roof to the system designer. In addition, PowerLight began development of an improved monitoring and diagnostic system to optimize system performance.

2.1.1 Site Audit Tool

Background

An accurate site audit is an important step in the design of a PV system. If the site audit does not capture all potential obstacles or shading issues, installation costs can increase, and system performance can suffer. The current methods used to measure rooftops involve the use of distance measuring wheels and tape measures, generally measuring from the closest edge of the roof to the point or object being measured. This method results in points being defined from numerous reference points, and, occasionally, disorganized information and missing critical dimensions.

PowerLight is developing an improved procedure and improved tools for measuring the available space on flat rooftops for installation of solar panel arrays. These will provide increased accuracy of distances measured, as well as a reduction in errors caused by omission of critical dimensions.

Approach

PowerLight reviewed available tools that would help an auditor create an accurate and complete site plan without undue expense. Two tools were evaluated. A laser-based tool allows one person to complete a site audit using a stationary target. The other tool is a global positioning satellite (GPS) auditing system made by Tectonics Corporation.

PowerLight performed a cost-benefit analysis of the two tools and conducted a field trial with the laser tool. The field trial consisted of verifying distance measurements and developing a procedure to yield the most accurate site audit from a minimum number of measurements. PowerLight also designed a prototype stationary target that enables the audit to be performed by a single operator.

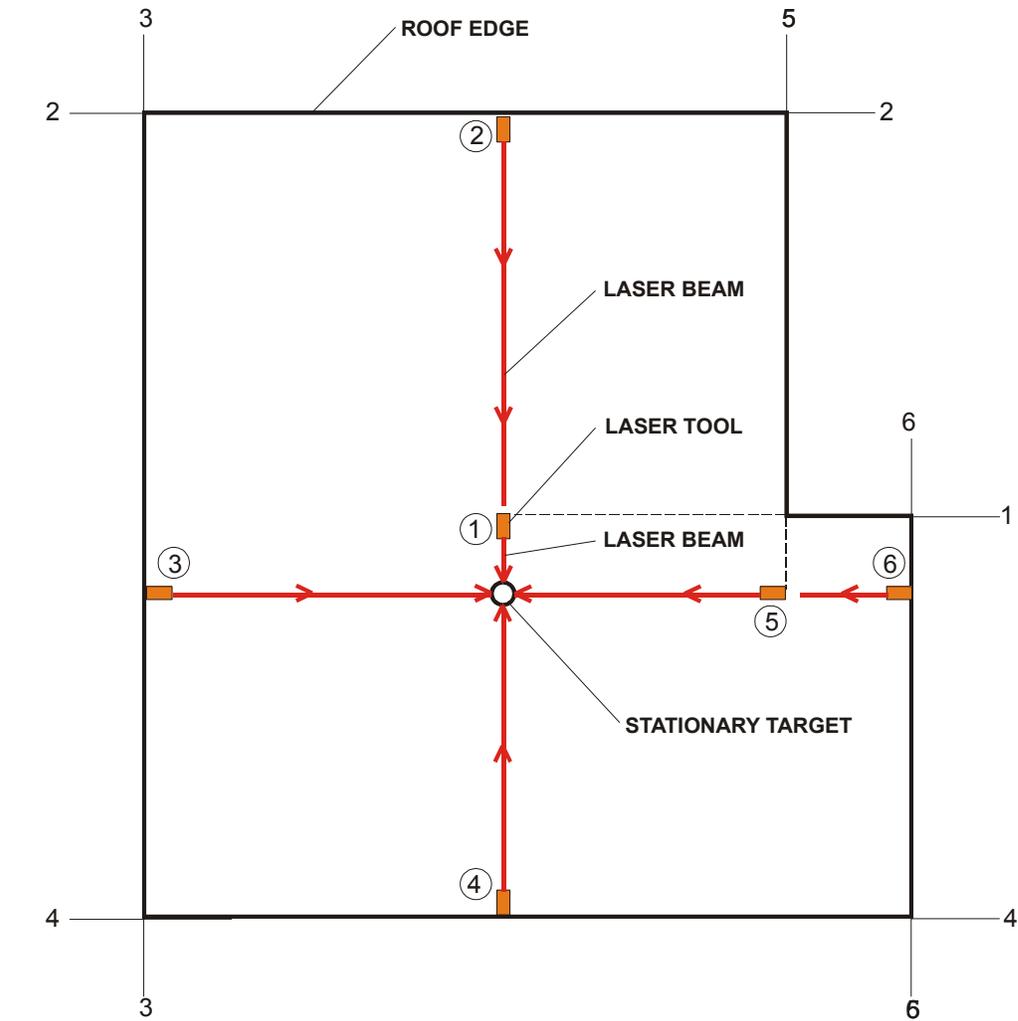
Results

PowerLight has concluded that the laser approach is preferable to the GPS system primarily because it guarantees a consistent level of accuracy from site to site. The concern with GPS-based systems is that the accuracy and availability of data will differ from site to site. The laser tool approach lends itself to a more organized and more easily tracked set of dimensions. Missing dimensions will be caught quickly as the operator moves through the process of identifying all the features of the rooftop. It also reduces the overall number of measurements necessary, as each point is defined by only two dimensions.

Figure 5 illustrates how the laser-tool is used on a simple rooftop example. The stationary target is placed at a convenient central location on the roof. Six

measurements are made from key locations determined by the roof's shape and perimeter lines. These locations are identified by the numbered circles in the figure.

SAMPLE ROOFTOP



① INDIVIDUAL MEASUREMENT I.D. NUMBER, STORED IN LASER TOOL MEMORY

4 TWO MEASUREMENT I.D. NUMBERS REQUIRED TO DEFINE EACH CORNER OF ROOF EDGE, (THESE NUMBERS BECOME "USER INPUT" FOR VBA SOFTWARE TO DEFINE X AND Y COORDINATES IN CAD)

SIX MEASUREMENTS PROVIDE ALL X AND Y COORDINATES NECESSARY TO DEFINE THE ENTIRE OUTLINE OF THIS ROOF.

Figure 5: Example of rooftop dimensioning process using laser tool

This “ordinate” style of dimensioning lends itself to transfer from the rooftop into a computer aided design (CAD) system. The laser tool can store the distances measured, which can then be downloaded to an ASCII text file on the CAD station.

PowerLight is developing Visual Basic (VBA) software to read the distances from this text file and draw lines from point to point to create an accurate layout of the rooftop. The software flow chart is illustrated in Figure 6. The VBA software queries the CAD operator to input two ID numbers to define the first point of the drawing. These ID numbers are then found in the text file, and the corresponding distance is passed to the VBA software variables to be used as X and Y coordinates of the point in CAD.

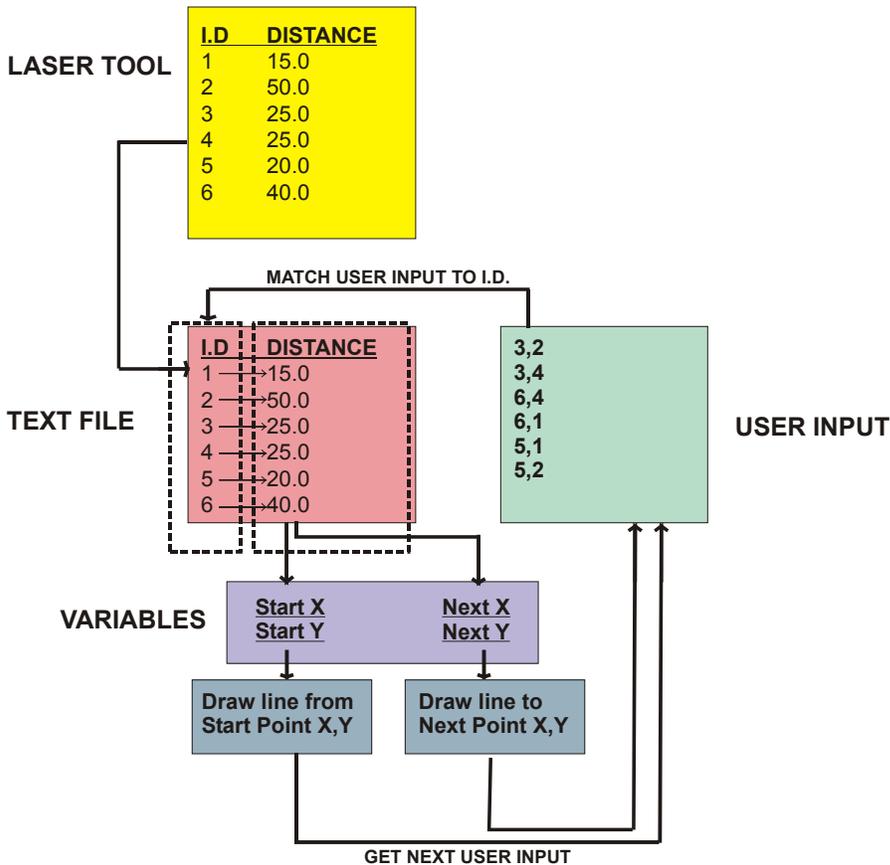


Figure 6: Basic flow-chart for processing audit data in CAD tool

The VBA software then queries the CAD Operator for the next two ID numbers, redefining the variables and drawing the line to the new X and Y coordinates in CAD. This process is repeated until the CAD Operator selects the “end” button on the query dialog box.

Conclusion

PowerLight has made significant progress in the implementation of new array design tools. These improvements will lead to greatly enhanced accuracy of site audits, resulting in improved system design and efficiency. Overall, the direct labor associated with system design will be reduced, and the risk of costly delays for installation projects will be greatly diminished.

2.1.2 Monitoring & Diagnostics

Background

PowerLight actively monitors over 40 MW of installed PV systems. Monitoring includes daily alerts on system availability and performance, as well as weekly trend analyses. With such a large number of systems, implementing a sophisticated diagnostic system results in streamlined customer support and optimized system performance.

Approach

PowerLight is pursuing a two-pronged approach to meet the objective of improved system availability and performance through more sophisticated diagnostic capabilities. As part of this effort, we procured, tested, and fielded advanced monitoring system hardware with the goal of improving access to system performance information – both in terms of the level of information available and the timeliness of its reporting to customer service staff. Concurrently, we worked to improve the analytical system used to evaluate system performance data and send alerts and alarms to customer service staff. This analytical approach will result in faster recognition of more subtle performance problems and reduce instances of nuisance alerts and alarms. The combination of advanced hardware and improved analytical tools will lead to an improvement in overall system reliability and performance.

Advanced hardware monitoring systems reviewed for this project include stand-alone data acquisition systems (DAS) and data collection modules embedded in system inverter (power conditioning) units. PowerLight tested two types of hardware monitoring systems, installed in five test systems. The performance of these test systems was compared to that of a group of control systems. The various test and control sites are identified in Table 6 in section 2.7.1.

As a first step toward improved monitoring capabilities, PowerLight looked for alternative data loggers with better real-time data and alarm functionality than those used currently. PowerLight focused on data loggers that have embedded web servers and firewalls and that can post data to the web in XML format. These features are desirable for many corporate clients concerned with network security issues.

PowerLight purchased and evaluated four new data loggers: Campbell CR 1000, Omni DataWeb 4008, Omega Omp-MODL, and Meteocontrol Weblog device. Each of the data loggers have real time alarm capabilities and advanced network security options.

PowerLight also evaluated the use of the embedded data monitoring and alarming capabilities of the Xantrex S series inverters as one advanced hardware monitoring option. In October, PowerLight completed the commissioning of the communications module of the 100 kW S-Series inverter located at Site 24. We began monitoring the site with this communications module once the site host completed the installation of the necessary local network cables and security access.

The real-time Xantrex Graphical User Interface (GUI) will improve our ability to monitor the site and increase system availability in two ways. Information will be available in real time, giving instant notification of inverter status, including specific fault information when the inverter is in a faulted condition. In addition, the GUI will enable some remote inverter control, allowing PowerLight staff to reset many faults and restart the inverter from our offices in Berkeley, eliminating the lag time between fault notification and on-site reset. Figure 7 shows the installed inverter at Site 24. The communications module of the inverter is mounted on the left hand side of the inverter (not visible in photo).

PowerLight's standard data acquisition system is in the middle background of the photo (circled) behind the glass jar-style energy meter.



Figure 7: Xantrex S-Series inverter installation with PowerLight DAS

The second approach to improving system performance and reliability is through improved analysis of the performance data collected from each system. Currently, PowerLight receives performance index alerts for systems when the performance index (PI) drops below a user-defined threshold for the site. Performance index is determined by dividing the actual energy produced by a site during the day by the amount of expected energy for the day. Expected energy for the day is calculated using basic system parameters and meteorological data recorded at the site, including irradiance from a LICOR pyranometer, ambient temperature, and wind speed. While adequate, PowerLight worked to improve the following aspects of this monitoring approach:

- 1) Current performance index alert thresholds are set to ensure that we are aware of performance problems while minimizing the number of nuisance alarms from expected influences like soiling. With a more sophisticated alert algorithm, PowerLight could be more sensitive to performance problems that occur between the threshold and the 100% performance index level. Currently, we do not receive alerts for potential performance problems that do not cause the PI to dip below the user-defined threshold.
- 2) Calculating expected energy for the day using pyranometer data sometimes results in inaccurate PI values because the spectral response of the pyranometer is different from that of the PV array. This effect is particularly pronounced on cloudy days and in winter.

To address these limitations, PowerLight conducted two studies. In the first study, PowerLight devised and tested several sophisticated alert algorithms for performance index. We have developed and tested six different algorithms using between five and seven months of recorded data for nine different systems. To date, PowerLight has developed algorithms to compare sites in similar regions and to evaluate trends in long-

term system performance. These algorithms provide better reference points for expected system performance, resulting in fewer nuisance alarms and more alarms for non-outage-related problems. Overall, these algorithms are expected yield improved performance alerting once implemented. PowerLight will continue to develop and validate these and other algorithms in the second phase of the project.

The second study involved the difference between PIs as calculated using different irradiance sensors, namely pyranometers and reference cells. As mentioned above, the spectral response of the pyranometers is different from that of a reference cell, with the response of the reference cell being closer to that of the array. Because of this, PIs calculated with reference cell data should be steadier and produce fewer nuisance alarms and inaccurate PI values than PIs calculated using pyranometers.

Results

PowerLight has reached the following conclusions based on the testing of the various data loggers:

- The CR1000 offered the most functionality and ease of use.
- The Omni also offered the same functionality as Campbell's data logger and was relatively easy to use.
- The Omega was the most difficult to set-up, and tech support has so far been poor. The system also did not integrate well with some of the weather sensors currently used by PowerLight.
- The Weblog device, produced by a German company called Meteocontrol, has proven to be effective in European systems and is of interest for U.S. applications. However, there are some preliminary problems that prevent its commercial use at the moment. For example, the modem is not compatible with U.S. telecommunications, and error codes are in German.

Based on these conclusions, PowerLight installed a Campbell CR1000 logger, shown in Figure 8, at a major customer site in Oakland for further evaluation. The installation occurred without any problems and to date the unit is performing very well.



Figure 8: Campbell CR1000 Data Logger

To determine whether replacing pyranometers with reference cells will improve PI evaluation, we monitored five sites with both types of sensors at each location. The data from the reference cell produced a steadier calculation of PI for all sites. Figure 9 shows the comparison between PI as calculated using pyranometer data and PI as calculated using reference cell data for a sample site. The circled regions highlight the steadier nature of the PI calculated with reference cell irradiance data.

Sample System PI as Calculated from Reference Cell and Pyranometer Data Charted Against Energy Produced and Insolation Measured by these Instruments

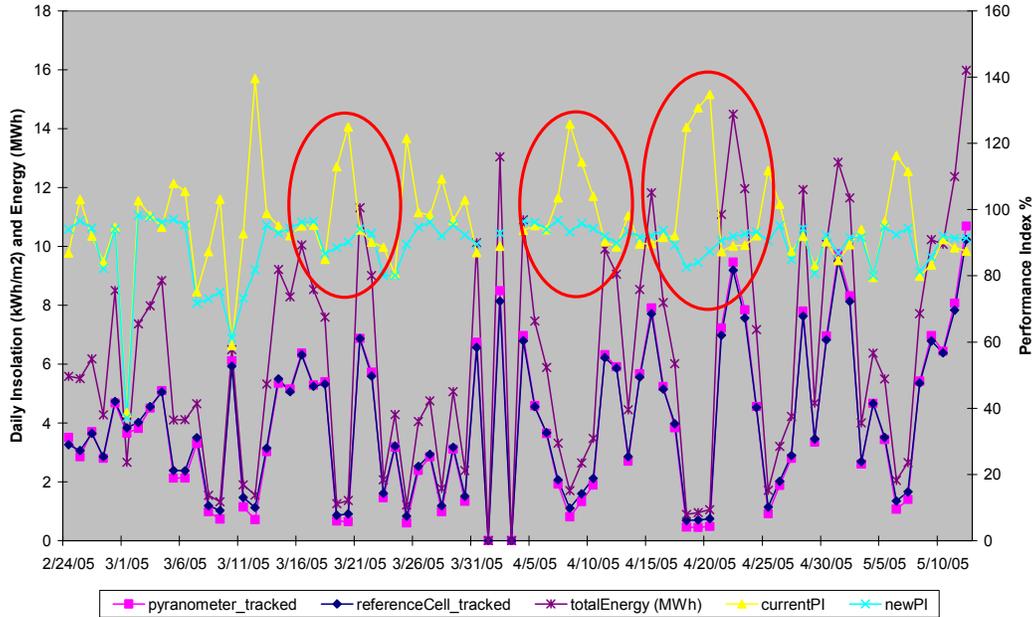


Figure 9: Comparison of site performance index using a reference cell and pyranometer.

In addition, PowerLight tested the six performance alert algorithms from the first study on the two sets of performance indices (pyranometer-based and reference cell-based) and concluded that PIs calculated with reference cells result in 37% fewer nuisance alarms. Further work on this study will include the investigation of PIs for a larger pool of systems.

Conclusion

To optimize system performance, PowerLight is improving the tools used to design and monitor PV arrays. As part of this effort, PowerLight is investigating the use of alternative hardware for data acquisition and reference sensors. In field tests to date, the CR1000 data logger has performed reliably, following a straightforward installation. The use of a reference cell, in place of a pyranometer, provides in more consistent performance tracking and is estimated to result in 37% fewer nuisance alarms. PowerLight has also made significant progress in the development of sophisticated performance diagnostics. Continued validation work on these algorithms is required prior to implementation.

2.2 Task 2: High Reliability Cost Reductions

The objective of this task is to lower balance-of-system costs by making improvements to the design of PowerLight systems in an effort to broaden the market for its rooftop products.

2.2.1 PowerLight Fixed Tilt Roof System – RFT10

As part of this effort, PowerLight is developing a foamless tile design targeted for customers without added-insulation needs. The new product is called RFT10. It features a 10° sloped PV module and an aluminum and stainless steel support structure.

Prototype Design

Background

The thermal insulation benefit of PowerGuard tiles is valued by many customers, but not by all. Customers who want to install a PV system on the roof of a building in which temperature is not controlled may not place a high value on increasing the insulation value of the roof. For those customers, a lower cost option that does not include thermal insulation would be attractive. For this reason, PowerLight has developed an alternate tile design without the XPS insulation.

Approach

At the start of this subcontract, PowerLight had completed design work on the first version of the foamless tile. A small system was installed in December 2004 based on this initial design. Since the start of this subcontract, the foamless design has been modified to accommodate a larger PV module with higher output. Several features were redesigned based on lessons learned during this installation and also to improve function or reduce cost of the parts.

Like the PowerGuard tile, the new foamless product is designed to install on a flat roof without penetrations through the roof membrane. The foamless product was designed with the PV module at a fixed slope of 10°. In order to ensure the safety of this design, it was necessary to understand the behavior of the tiles in the range of wind conditions to which installed arrays would be subjected. An extensive series of wind tests were initiated to quantify the wind performance of the product. These tests were a combination of computational fluid dynamics (CFD) modeling and wind tunnel testing. CFD modeling is a useful tool for comparing the performance of various designs without the cost of testing in a wind tunnel. Once a design has been optimized using CFD, it can be tested in the wind tunnel to verify the model predictions.

The wind performance of the foamless product is related to the specific weight of the array (the weight per unit area). One of the results of the wind testing was the calculation of the specific weight required to withstand various wind conditions. For areas that do not experience high velocity winds, a low array weight can be used. In higher wind zones, the array weight must be increased to ensure that the array stays in place. Each module has a wind deflector on the north side. As part of this effort, the design of the wind deflector was modified so that it could hold concrete pavers. The number of pavers inserted into each deflector is determined by the specific weight required.

The improvements described above are all incorporated into the new production version of the foamless product. The installation of a large-scale system was initiated in late July and is expected to be completed soon. This installation will help to verify the efficacy of the improvements and provide more information on the ease of installation of the design.

Results

The finished design of the foamless product is shown in Figure 10 through Figure 12. Figure 10 shows the wind deflector, which now can accommodate concrete pavers to adjust the specific weight of the array.

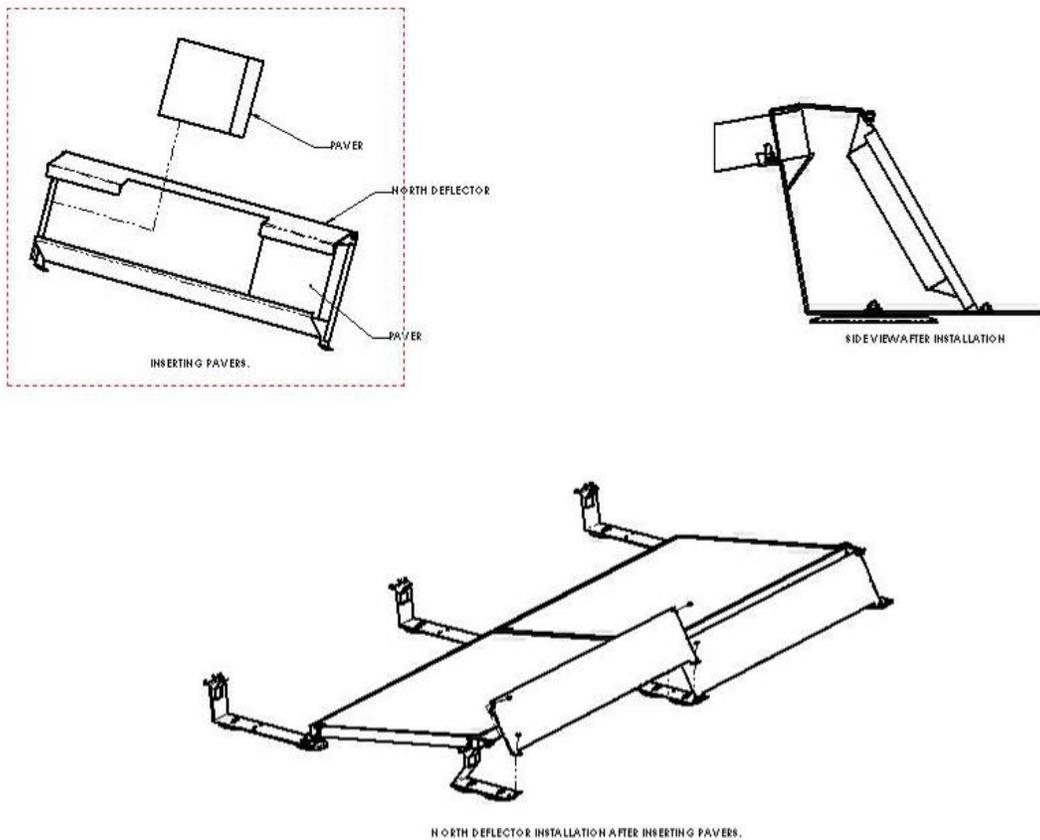


Figure 10: Deflector designed to hold pavers

Figure 11 shows a rendering of an array of foamless tiles. Wind deflectors are installed on the east and west end of each row. The northwest corner of the array is shown in Figure 12 with the wind deflectors removed from one tile.

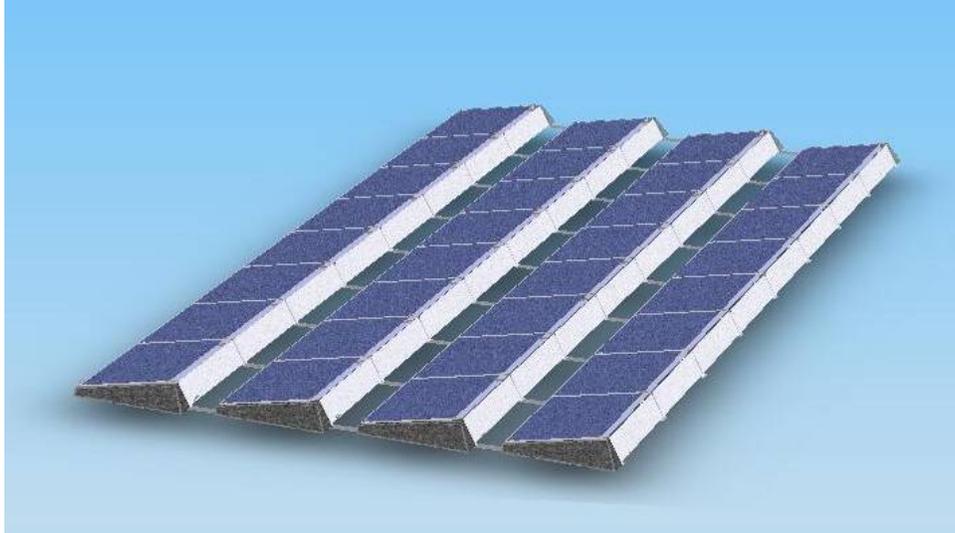


Figure 11: Rendering of array of foamless tiles

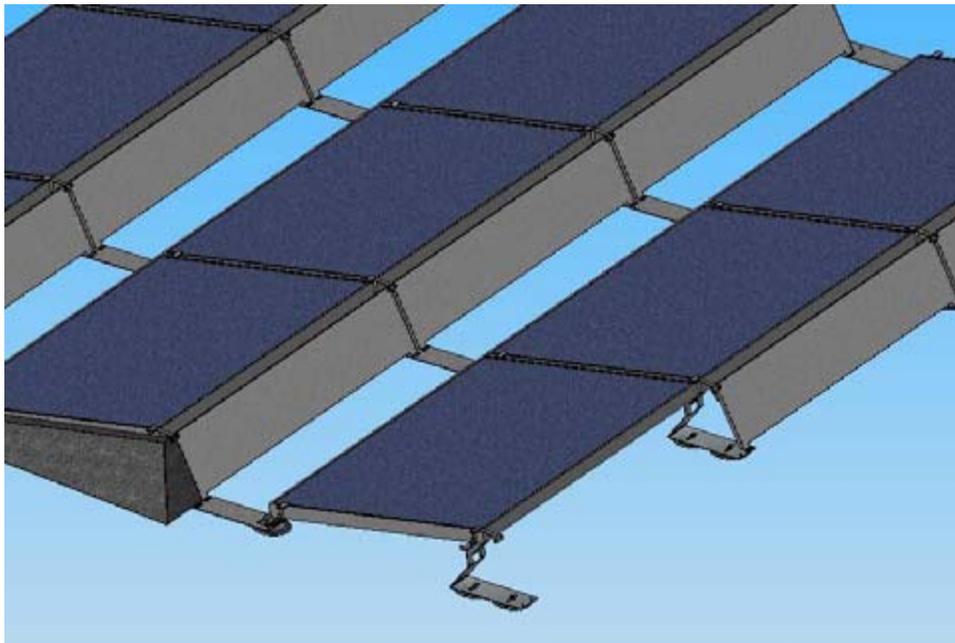


Figure 12: Detail of array showing northeast corner

Figure 13 through Figure 15 show photographs of the current design of the foamless product.



Figure 13: Foamless Product



Figure 14: Foamless Product - with west wind deflector installed



Figure 15: Foamless Product – showing north and west wind deflectors

Array Securement Design

Background

For most applications, RFT10 can be installed without being fastened to the building roof. In sites that have severe wind loads, however, positive securement of the array may be required. In most cases, the weight of the system is adjusted with concrete pavers to meet the wind loads of each building site. If the wind loads are high enough that the minimum array weight required by the wind loads exceeds the number of pavers that can be accommodated, then the array requires positive securement to the roof.

When positive securement is required, the array must be able to transmit lateral load across the array to the anchor points. Additionally, some method of attaching the array to the anchor points must be provided. In order to incorporate these features into the design of the RFT10 product, PowerLight calculated the magnitude of the lateral loads under varying wind conditions. Using the results of wind tunnel tests and computational fluid dynamic modeling carried out under Task 3 of this project, PowerLight analyzed the loads to which the array is subjected and created a design for the securement.

Approach

Once the basic design was completed, as discussed in the previous section, PowerLight began working on additional features that would allow the system to be installed in sites at which the array needed to be positively secured.

Wind tunnel testing was carried out under Task 3 of this project to determine the magnitude of the lateral loads that the wind applied to the array. With an array in the middle zone of a roof in the wind tunnel, the failure velocity was measured with gradually increasing array weights. The friction coefficient between the array and the roof was measured, and the results were used to determine how much force was applied laterally by the wind. This was extrapolated to the point at which the array was prevented from moving by securing it to the roof. This load was used in creating the design for the additional features that allow the array to be secured to the roof.

Once the loads were understood, the first step was to create a design that allowed lateral transfer of loads from one module to another. The basic design consists of a PV module, supports, and a wind deflector, as shown in Figure 13. These form the top two legs of a triangle. The roof forms the bottom leg of the triangle. However, when a large load is applied laterally, the supports slide on the roof, as the triangle becomes stretched across the roof. To prevent this, PowerLight added a wire rope that connects each support to the next one, preventing them from sliding apart and creating a strong triangular structure.

Once the array was capable of transferring lateral loads, PowerLight developed a design for attachment points to connect the array to an anchor on the roof. The loads on this anchor depend on the number of rows within the array. PowerLight created design guidelines to calculate the load that must be supported by the anchors.

Results

The changes to the RFT10 design are shown below. A wire rope was incorporated into the design to allow the array to transfer lateral loads, as discussed above. The wire rope is shown in Figure 16. At each end of the wire rope, a swaged-on ball engages a keyhole slot that is stamped into each end of each support piece. Figure 17 and Figure 18 show the engagement of the ball with the keyhole slot in the supports.

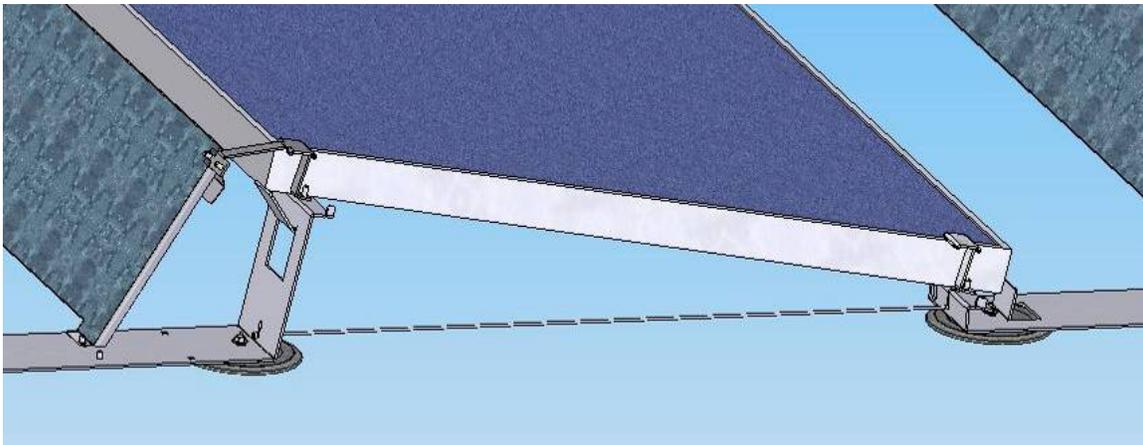


Figure 16: Wire rope connecting supports

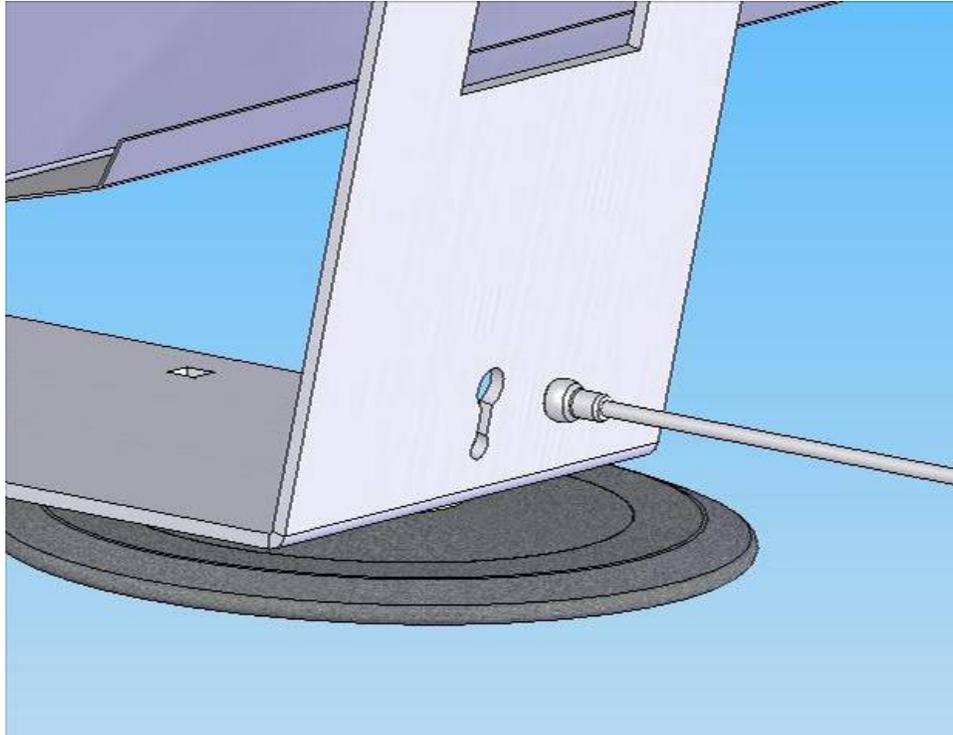


Figure 17: Ball on wire rope engaging keyhole slot in south end of support

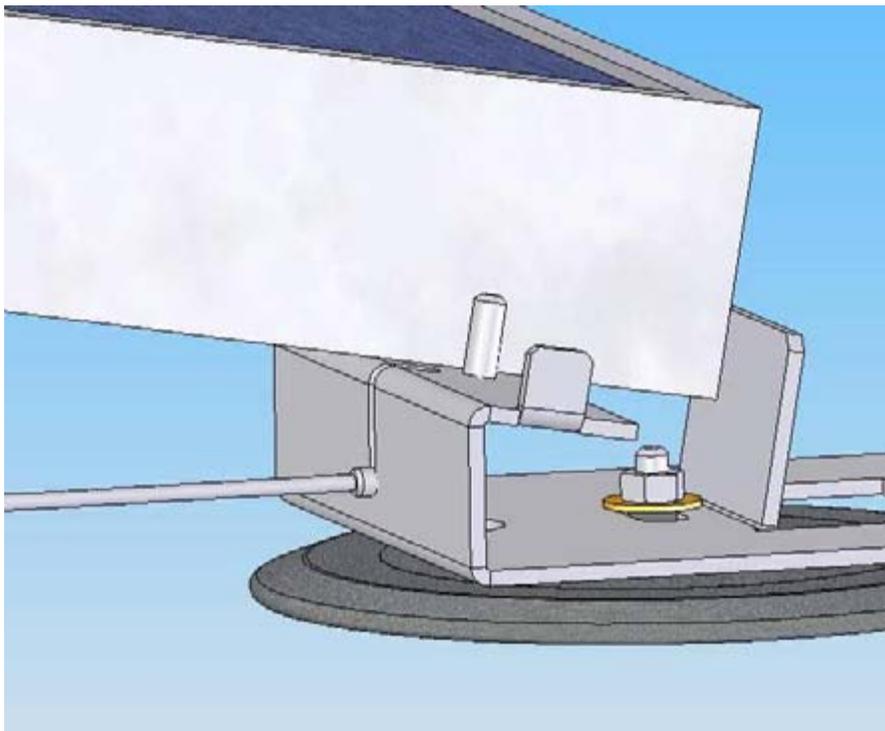


Figure 18: Wire rope and keyhole slot in north end of support

PowerLight added features to the support pieces that provide attachment points to anchors on the roof. At the southern edge of the array, these features consist of

extended tabs and square holes that support an aluminum spreader bar. The square holes fit carriage bolts that connect the supports to the spreader bar. The spreader bar allows up to four supports to be connected to one anchor point. The attachment of the spreader bar to the southern supports is shown in Figure 19. At the northern edge of the array, similar square holes were added to the support, but in this case, the spreader bar could be installed beneath the wind deflectors, as shown in Figure 20. Figure 21 shows how the spreader bar can span up to four supports.

Once the array is assembled on the roof and the anchor points are located, one or more holes are drilled in the spreader bar to attach it to the anchor(s).

The design improvements shown in these pictures have been incorporated into the production parts. Figure 22 and Figure 23 show the first prototype parts made with these improvements.

Conclusion

These improvements to RFT10 expand the range of sites where this product can be installed. The improved design can now be installed on most flat-roof buildings in wind zones up to 120 mph.² This is an important step in the development of this product, as this low-cost mounting system can now be installed at almost any potential site.

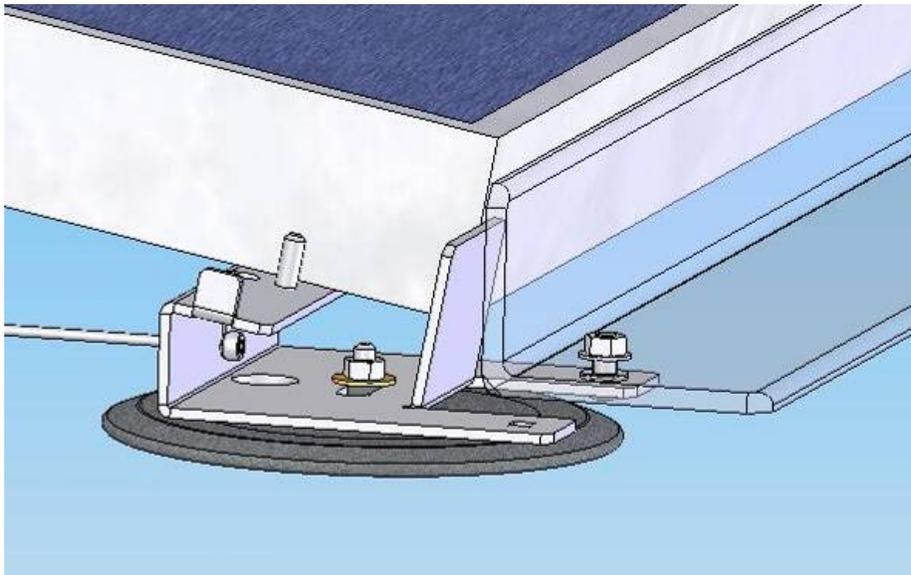


Figure 19: Attachment points for spreader bar on southern support

² As defined by ASCE Standard 7-05

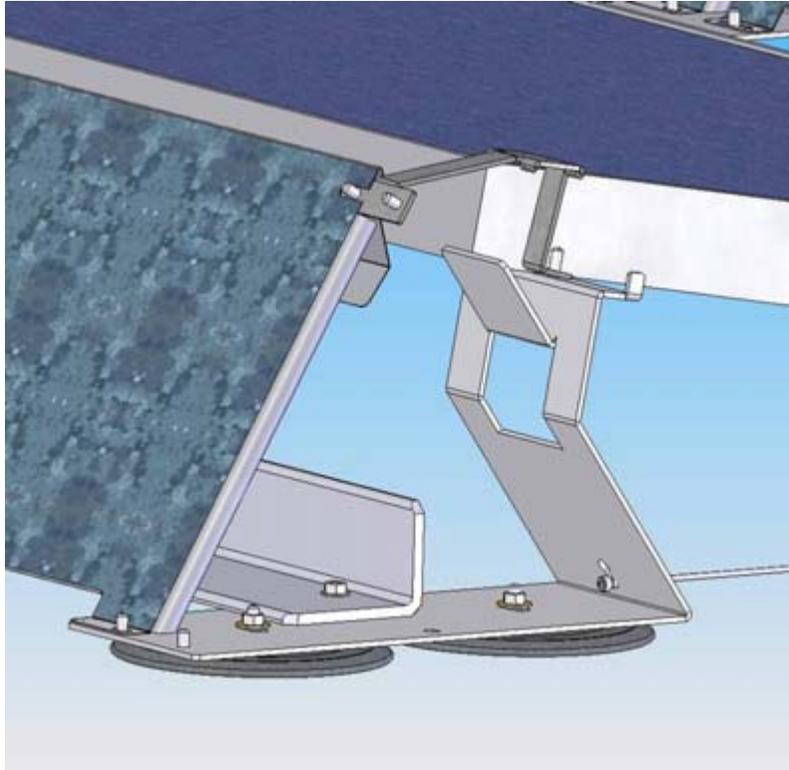


Figure 20: Attachment of spreader bar to northern support

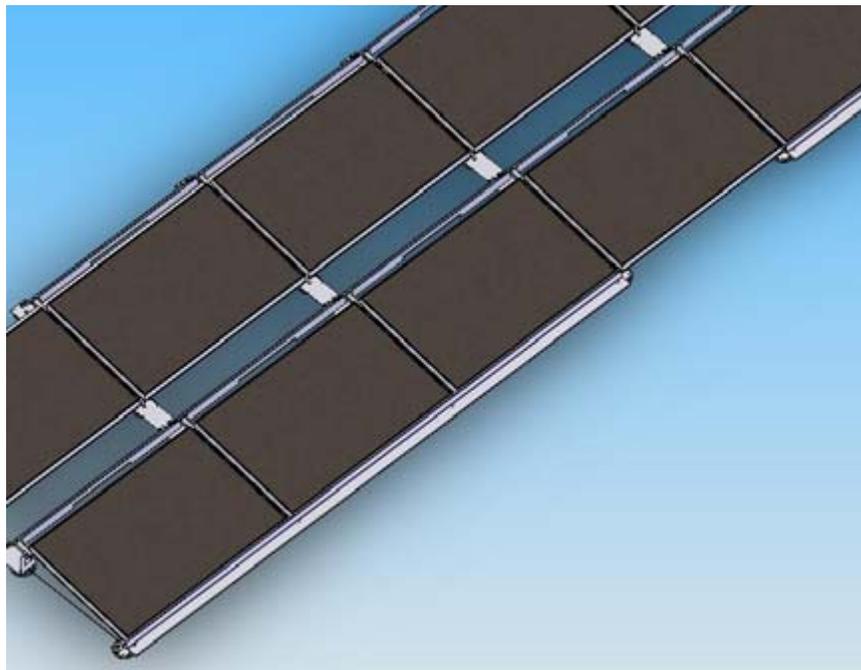


Figure 21: Spreader bar spanning four supports



Figure 22: Prototype parts with securement features



Figure 23: Southern support with keyhole slot and spreader bar attachment points

2.2.2 Tall Buildings and Mechanically Attached Roof Membranes

Objective

The objective of this subtask was to develop design guidelines for PowerGuard systems installed on tall buildings and buildings with mechanically attached roof membranes.

Background

PowerGuard is a ballasted, lightweight PV roofing system. Depending on the array geometry, a PowerGuard system may weigh 4-9 lb/ft². The array weight is far less than typical wind uplift pressures on most buildings, which can range from 20 lb/ft² to over 100 lb/ft². PowerGuard remains stable when subjected to high wind uplift pressures due to the permeability of the system, which equalizes pressures on the top and bottom surface of the tiles. While this phenomenon is well documented in the wind and roofing industries, wind tunnel testing in accordance with the American Society of Civil Engineers (ASCE) Practice No. 67 is the only recommended approach for quantifying the wind performance of a permeable roofing system.

PowerLight has conducted extensive wind tunnel testing in compliance with the ASCE standard. Prior testing was conducted on buildings with heights up to 50 ft. Due to limitations on the size of the wind tunnel selected and the ability to fabricate accurate scale models of PowerGuard systems, it is not possible to model wind loads on a PowerGuard system installed on a building taller than 55 ft. When PowerGuard systems were installed buildings taller than 50 ft, wind tunnel data had to be extrapolated to the taller building heights. While preferable to interpolate between test data points, this method was considered acceptable for buildings up to 80 ft in height, but undesirable when extrapolating to buildings that were several hundred feet in height.

PowerGuard can be accurately modeled at a scale as low as 1:32. At this scale, a 55' tall building creates the maximum allowable blockage in the wind tunnel. When the maximum allowable blockage is exceeded, the atmospheric boundary layer will not be simulated properly, which would result in an inaccurate modeling of the flow over the wind tunnel models. Wind tunnel experts suggested that pressure measurements be taken for a model of a tall building at a smaller scale. The results could then be compared to those for low-rise buildings for which PowerGuard failure data had been collected during prior tests. One could then identify the pressure conditions on rooftops that are likely to induce a failure in PowerGuard systems on a building of any height. This approach eliminated the need to include a model of a PowerGuard system on top of a tall building.

Mechanically attached roof membranes also present a design challenge for ballasted PV roofing systems. In certain wind conditions, these membranes may billow because the membranes are secured only along the edges. Prior testing showed that if billowing occurs, the membrane may lift over 12" in height, which is substantial enough to dislodge a lightweight, ballasted roofing system. However, there is disagreement among industry experts regarding the conditions that would cause membrane billowing and the appropriate method for assessing the billowing potential of a given site. There is clear agreement that billowing potential is dependent on the following parameters: wind speed; wind gust duration; width of the membrane between fasteners; quality of the roof seal around the perimeter of the building; permeability of the building walls; geometry of openings in the building walls, such as windows and doors; permeability and geometry of the building's HVAC system; geometry of partitions within the building; and permeability of the roof deck.

If all of the above parameters could be easily quantified, a test program could be carried out over a range of parameters and applied to specific buildings. At the beginning of this project, PowerLight expected to define a test program with a consultant and launch into the testing of the various parameters, leading to the creation of design guidelines for PV systems on mechanically attached membranes. The creation of the test program has been a much greater challenge than anticipated. Many of the parameters are impractical, if not impossible, to quantify on specific buildings. It is especially challenging to determine the permeability of the HVAC system, building walls and roof decks without incurring a significant expense, as well as inconveniencing the building occupants. It is possible that these parameters could be studied for a broad range of building types and then applied to specific buildings.

Despite the above challenges, PowerLight has made some important progress on this task as discussed in the following sections.

Wind Tunnel Pressure Measurements on Tall Buildings

Pressure measurements were measured on buildings with heights of 30', 60', 120', and 240'. Parapet heights varied from 0' to 4'.

Mean uplift pressures on the rooftop were calculated and compared to code predictions. We found that the code under-predicts uplift pressures on the rooftops of buildings over 60'. It is believed that the test results are accurate and that the code is in error. The testing used in the code data was done with older technology and was extrapolated from data measured on shorter buildings. The error in the code has apparently not resulted in failures in the field. Roof deck failures may have not occurred because the roof decks of tall buildings are designed to not only withstand wind uplift but also provide reinforcement to the building against wind drag and wind-induced oscillation. However, the error in the code could have negative consequences for roof cladding systems, such as PowerGuard.

The data collected in this study was used to calculate a correction factor so that PowerGuard failure data collected on low-rise buildings could be extrapolated to taller buildings and account for the high uplift pressures on tall buildings. This correction factor was then used to finalize wind design guidelines for PowerGuard systems on buildings up to 240' in height.

Mechanically Attached Roof Membrane Wind Securement

At the beginning of this task, PowerLight had the following questions with respect to mechanically attached roof membranes:

1. Is it possible to inspect a building and engineering drawings of a building to determine if membrane billowing is a potential risk?
2. If testing is needed to assess the potential for membrane billowing, how would the testing be done?
 - a) What is the range of typical permeabilities of commercial walls and roof decks?
 - b) What is the range of typical permeabilities of typical HVAC systems?
 - c) Once test data is collected, how can it be applied to existing buildings?

To determine the answer to the first question, PowerLight consulted with wind and roofing experts. All wind and roofing experts consulted agree that with the data currently available, it is not possible to determine whether or not membrane billowing can occur through inspections. Manufacturers of mechanically attached roof membrane systems design the securement of these systems under the assumption that some billowing could occur.

Based on this assessment, PowerLight contacted several wind testing experts, including three at wind tunnel facilities, to determine the best method of evaluating the billowing potential of commercial buildings with mechanically attached roof membranes. Most experts could not think of a straightforward way to investigate this problem because of the difficulty in modeling the movement of the roof membranes and the porosity of building materials. However, one test facility with strong expertise in building and roof aerodynamics conceived of a unique wind tunnel testing program. However, the test program had some gaps, as it did not clearly address items 2(a) through 2(c) above. It was clear that this needed to be determined before investing in the test program.

An extensive search was conducted to quantify these parameters. Initially, we believed that the energy efficiency industry would be a good source of data. However, it turned out that most of the available data is for residential buildings only, while the commercial sector is the focus of this study. Finally, we identified an infiltration expert, who is knowledgeable in both commercial and residential buildings. This expert believes he could fill in the gaps in the proposed wind-testing program by accessing existing, unpublished infiltration data for commercial buildings, as well as conducting measurements on actual buildings.

The result of this research is that a clear test program has been developed to investigate the billowing potential of mechanically attached roofs. The first step in this program is to quantify the permeabilities of walls, roofs, and HVAC systems of typical commercial buildings. Once significant progress has been made in this subtask, PowerLight will investigate the feasibility of quantifying these parameters in existing buildings. If it is believed that this method is feasible, the program will move into the second stage of this effort.

This stage consists of wind tunnel testing on buildings with the range of permeabilities identified. The wind testing will identify which building features would likely induce membrane billowing, when subjected to various wind flows, and what sections of the roof would be affected.

Conclusions

Wind tunnel testing on tall buildings has been completed and results have been incorporated into PowerGuard design guidelines.

The development of design guidelines for wind securement on mechanically attached roof membranes requires further research and testing. A path for a test program has been set and will be carried out during Phase II of this subcontract. The result of the test program will be design guidelines for securing ballasted PV systems when installed on mechanically attached roof membranes.

2.2.3 Alternative PV Backing Material

Background

Historically, PV vendors have used Tedlar^{®1}, a fluoropolymer manufactured by Dupont, as a backing material. Recently, some vendors have been switching their backing material from Tedlar to PET (polyethylene terephthalate, a plastic resin and form of polyester). The structural integrity of the PowerGuard tile depends in part on the adhesive bond between the XPS standoffs and the PV backing material. Extensive testing was conducted on the bond between XPS and Tedlar to ensure a reliable bond would be maintained over the design life of the product. This testing had to be repeated in order to ensure an adequate bond to the PET backing material.

Approach

In order to accommodate this change, PowerLight had to look for different adhesives to use in the assembly process of PowerGuard tiles. An adhesive had been identified, and in November, the first full scale production occurred using this new adhesive. Despite good results in test conditions, initial results in the factory did not yield the required bond strength. A variety of tests showed that the surface energy of the PET needed to be increased through the application of a corona discharge treatment. Once a procedure was implemented to apply this treatment, the bond reached the required strength and production resumed.

Results

The initial approach to find a new adhesive did not yield acceptable results. The second approach, using a modified process, yielded excellent results and also provided a lower-cost solution than the first approach would have. Once the details were worked out, a new PV preparation line was designed and implemented as part of Task 5.

2.2.4 PowerGuard Cost Reduction

Background

Excluding the PV module, the mortar coating is the most expensive component of the PowerGuard tile. In an effort to reduce product cost, PowerLight focused on reducing direct material cost for the backerboard.

Approach

PowerLight identified the following three options to reduce the cost of the mortar coating:

1. Reduce the amount of latex in the mortar - The latex in the PowerGuard coating increases flexibility, compressive strength, freeze-thaw resistance, workability of the wet mix in the production line, and the bond strength of the mortar to the extruded polystyrene (XPS) foam. PowerLight's initial estimate was that a reduction in the latex content of the mortar could save \$40,000 per year at current production levels.
2. Reduce the thickness of the mortar - The standard thickness of the PowerGuard mortar is 0.24". However, the UL listing and fire rating for PowerGuard is applicable to a mortar thickness as low as 0.125". A reduction in the thickness of the mortar would also result in a substantial savings, as stated above. Possible negative affects of a reduction in thickness include reduced resistance to impact;

difficulties in maintaining a thinner coating in the production line; and reduced bond strength to the XPS spacers if insufficient mortar is between the spacer and XPS backer board.

3. Evaluate alternate latex and potential latex suppliers - At the beginning of this project, PowerLight had received quotes from a latex supplier that could replace the current supplier at significant cost savings.

In order to evaluate the feasibility of these approaches, PowerLight carried out a comprehensive testing program, as discussed in Section 2.3.1.

Results

Based on the results of the reliability evaluation, PowerLight implemented process changes to adopt the reduced mortar thickness. Efforts to change the mortar composition did not yield satisfactory results. However, PowerLight was able to negotiate a lower price on the latex with the current supplier. These changes have resulted in significant cost savings.

2.3 Task 3: Reliability Evaluation

2.3.1 PowerGuard System Testing

Objective

PowerLight identified ten possible product improvements that would result in increased markets for PowerGuard, reduced cost, and/or improved reliability and quality. To take advantage of these benefits, the proposed product improvements need to be researched, validated, and implemented when results are favorable.

The ten product improvements are summarized in Table 1. The product improvements and thermal monitoring project are then described in more detail in the following sections.

Table 1. PowerGuard Product Improvements

Item	Product Improvement	Benefit
1	Create design guidelines for mechanically attached, single-ply membrane roofs	Increase the range of approved roofing types for PowerGuard systems.
2	Update product design guidelines to address wind performance of PowerGuard when air gaps are present under the perimeter curb.	Large air gaps under the PowerGuard perimeter curb may affect wind performance. The result of this research will improve the reliability of PowerGuard systems while also ensuring that the systems are not over-designed.

Item	Product Improvement	Benefit
3	Update product design guidelines to address wind performance of PowerGuard when installed on top of gravel-ballasted roofs.	Significant cost savings could be achieved if gravel can be left in place underneath PowerGuard systems.
4	Finalize design guidelines for a light-weight curb.	A lighter-weight curb would expand the market for PowerGuard to include roofs with a low dead-loading capacity. In addition, a lighter weight curb would save money by reducing the amount of roofing pavers used to ballast the system.
5	Reduce latex-content of the PowerGuard mortar coating	The latex is the most expensive component in the PowerGuard mortar coating. Reducing the amount of latex in the mortar would result in a significant savings.
6	Reduce mortar thickness	Reducing direct material consumption results in reduced cost of for the PowerGuard tile assembly.
7	Alternative latex	Identifying alternative latex would allow PowerLight to negotiate lower pricing with vendors.
8	Shipping Cost Reduction	Reducing system cost and site waste
9	Alternative PV Backing Material Validation	Allowing the use of PET-backed modules reduces the environmental impact of producing PowerGuard tiles.
10	Validation of in-line PV attachment manufacturing process	Converting the production of PowerGuard tiles into a single continuous process will reduce cost by eliminating labor between steps.

Wind Research on Mechanically Attached Membrane Roofs

Background

Mechanically attached membrane roofs are a common roofing system on flat, commercial buildings. Because these systems offer an inexpensive way of installing white, reflective roofs without the use of adhesives that contain volatile organic compounds, mechanically attached membrane roofs are becoming increasingly more common.

Under some wind conditions and on certain types of buildings, the mechanically attached roof membrane can billow, which could compromise the structural integrity of a ballasted PV system. Design guidelines for ensuring the structural integrity of a PowerGuard system on this type of roofing system have not yet been available due to the following challenges:

1. It has been difficult to identify situations where membrane billowing could occur, since it depends greatly on a building's wall and roof deck permeability, the quality of the roofing system design and installation, the permeability of the HVAC system, and the wind conditions at the site. With the exception of wind

conditions at the site, most of these parameters are unknown for a particular site without a costly and time-consuming research program.

2. PowerLight has not yet found a cost-effective mitigation strategy to ensure that the structural integrity of a ballasted PowerGuard system is maintained on sites that have a risk of membrane billowing.

A significant increase in approved roofing types for PowerGuard systems could be obtained by resolving these technical challenges. Over the past five years, PowerLight has researched this problem extensively with world-renowned experts in mechanically attached membrane roofs and wind testing. Roof membrane manufacturers, scientists, and engineers specialized in the testing of these roofing systems, aerodynamics experts, and roofing consultants were consulted to develop a strategy that would bring clarity to the problem. This past research resulted in the following conclusions:

1. Roof membrane billowing can occur on these types of roofs to the extent that light-weight ballasted PV systems could dislodge. However, it is also believed that some buildings, especially those in low wind zones and with small wall openings, never have a billowing problem.
2. In most cases, billowing occurs along the outer edges of the roof (with 25' of the edge on most buildings); however, in some cases, it could also occur in the middle of the roof.
3. Within some limits, roof membrane manufacturers, roofing consultants, and building owners are not concerned if the roof membrane billows. If the membrane is not structurally damaged, remains water tight, and does not make noise within the building, the roofing industry accepts that light to moderate billowing may occur, and the mechanical fastening of the roofing system is designed accordingly.
4. No one in the roofing, HVAC, or energy efficiency industry has identified a simple and inexpensive way of quantifying building-wall and roof deck permeabilities. Further, although abundant data for these parameters is available for residential buildings, very little published data beyond expected ranges of permeabilities is available for commercial buildings.
5. No one in the roofing industry has developed a method for determining the likelihood that membrane billowing could occur beyond "engineering estimates."
6. Buildings with large openings, such as roll-up doors, or buildings that could develop large openings during a wind storm, such as broken windows during a hurricane, are highly susceptible to membrane billowing. In some cases, membranes can be completely torn off the roof.
7. Wind tunnel experts did not believe that this problem could be simulated in a wind tunnel in a way that would yield useful data.
8. PowerLight tested numerous methods of mitigating a billowing roof membrane; however, the only successful strategy was to add securement to the membrane between the secured seams, which are typically 6' on center. This concept costs between \$10,000 - \$40,000 to install on a 100 kW system. In addition, this method requires many roof penetrations, almost defeating the purpose of a lightweight, ballasted PV system. This approach does not address whether or not extra securement is required for a specific application. As such, the added cost may be incurred unnecessarily.

After five years of research, this research program had appeared to reach a dead end. However, work during this phase has resulted in a new approach that was developed with the help of an aerodynamics expert and an expert in building infiltration, which PowerLight is considering.

Approach

A new approach has been developed that would identify the wind conditions and building types that could cause a membrane to billow. To the extent possible without revealing confidential information, this plan is summarized as follows:

1. A wind tunnel model would be fabricated with various wall porosities that span expected extremes.
2. Pressures on the building walls, ceiling and roof would be measured at a reference wind speed.
3. The pressures measured could be used analytically to determine whether the pressures across a roof membrane are substantial enough to lift the membrane in various regions of the roof.
4. It is hoped that in many cases, a building's HVAC system may provide sufficient pressure relief to prevent the membrane from lifting. If this is the case over a wide range of building surface porosities, then it would not be necessary to quantify the actual porosity of surfaces in specific buildings.
5. If we find that the typical HVAC system is not permeable enough to prevent billowing, and that billowing is highly dependent on wall and roof deck porosity, an expert in the area of building infiltration will be consulted to develop a field test protocol or analytical approach to estimating a specific building's porosity. This will allow the wind tunnel results to be applied to specific buildings.
6. If cases are identified where billowing is expected, some new mitigation strategies will be modeled analytically or in the wind tunnel.

Results

The creation of the test program has been a much greater challenge than anticipated. Many of the parameters are impractical, if not impossible, to quantify on specific buildings. It is especially challenging to determine the permeability of the HVAC system, building walls and roof decks without incurring a significant expense, as well as inconveniencing the building occupants. It is possible that these parameters could be studied on a broad range of building types and then applied to specific buildings. However, there is a concern that it would be expensive and/or inaccurate to quantify the necessary parameters on specific buildings. The result of the test program would be guidelines for determining if billowing could occur on specific buildings, and, if it is expected, suggested for reducing the risk of membrane billowing.

Wind Research – Gaps Under the PowerGuard Perimeter Curb, Gravel Under PowerGuard Systems, and Light-weight Perimeter Curb

Background

Several questions have arisen regarding the wind performance of PowerGuard:

1. Current wind design guidelines are based on wind tunnel testing where the scale-model perimeter curb was placed on a model roof with a very flat surface so that little to no air could penetrate beneath the curb. On some buildings, the roof is not perfectly flat due to the presence of overlapping roof seams and the normal development of low and high areas on the roof surface over time. *When the curb is placed on a non-flat surface, allowing air to penetrate beneath the curb, is wind performance affected?*
2. Prior research in the wind testing industry has shown that air gaps under an array of roofing pavers reduce wind performance. On gravel-ballasted membrane roofs, a significant amount of air is trapped within the voids in the gravel. Although the effect of trapped air under the system has not been quantified for PowerGuard, gravel is typically removed from gravel-ballasted roofing systems before installing PowerGuard to ensure structural integrity in high winds. *Despite a possible reduction in wind performance, can gravel be left in place on some buildings in low wind zones and still exceed design wind conditions?*
3. The weighted PowerGuard curb sometimes exceeds the roof loading capacity of some buildings, while also necessitating the shipping and handling of large quantities of heavy roofing pavers on each project. *Is it possible to reduce the weight of the curb for some projects?*

PowerLight developed one test program to address these questions, as described below.

Approach

Wind tunnel testing was conducted on scale models of PowerGuard arrays in various configurations. First, tests were conducted on some control configurations to compare to prior results. A good match was obtained, and new configurations were tested. These configurations included: (i) the presence of gaps underneath the curb to simulate a non-flat roofing surface; (ii) the introduction of gaps underneath the entire array to simulate the presence of gravel; and (iii) a lightweight curb.

Results

Results for the curb with gaps, simulating a non-flat roofing surface, showed that the wind performance is highly sensitive to the presence of gaps. Test results showed that when gaps are present under the curb, performance may be reduced or increased depending on whether a proprietary edge treatment is installed around the curb. This edge treatment was developed during these tests and increased the performance of the array beyond that of a PowerGuard system installed on a perfectly flat roof. These results show that gaps under the curb can help or hinder wind performance depending on the curb design. PowerLight is pursuing the development of a full-scale curb that incorporates the edge treatment. The cost of the curb is not expected to increase due to this design modification.

Results of the testing on an array installed over gravel showed that in many cases, gravel will need to be removed from underneath the array, but on buildings under 30' in a wind zone of 85 mph, gravel may be left in place.

The lightweight curb results showed that a reduced-weight curb can be used on many projects in low wind zones, provided that a perimeter treatment is used when curb gaps are present.

The wind tunnel results described above are currently being incorporated into PowerGuard design guidelines.

Mortar Research – Reduced Latex Content, Reduced Mortar Thickness, and Alternative Latex

Background

As part of the cost reduction effort described in Section 2.2.4, PowerLight produced prototype backerboards with reduced latex in the mortar and reduced mortar thickness. In addition, efforts were underway to evaluate the possibility of using an alternate latex to reduce cost. PowerLight implemented a research and testing program to evaluate the feasibility of these potential changes to the PowerGuard production process.

Approach

To evaluate the reduction in latex content and the reduction in coating thickness, PowerLight performed the following tests on three types of samples: control samples with a standard thickness and latex content; samples with reduced latex; and samples with reduced mortar thickness:

1. Resistance to freeze-thaw cycling (based on ASTM C666)
2. Tensile bond strength of mortar to foam before and after freeze-thaw cycling
3. Shear bond strength before and after freeze-thaw cycling
4. Resistance to impact
5. Reinforcement strength of groove (control and reduced thickness only)
6. Compressive strength before and after freeze-thaw cycling (control and reduced latex only)
7. Full-scale uplift test (reduced thickness only)

Freeze-thaw resistance is a critical parameter for any concrete product installed in a freezing climate. The water-to-cement ratio and latex content are the key parameters affecting freeze-thaw resistance of the mortar.

ASTM C666 is the standard test to evaluate the freeze-thaw resistance of concrete. Samples are placed in a container with water, and the containers are placed in a temperature-cycling chamber where temperatures oscillate between -18°C and 5°C for 300 cycles.

Tensile bond strength of the mortar to the XPS spacers and backerboard is important because this bond is what holds the PV module in place when handled or when under a tensile load, such as during a windstorm. Two types of tests are used to evaluate the strength of this bond., To test the bond of the mortar to the XPS backerboard, wooden blocks are adhered to the mortar surface and pulled off the backerboard using an actuator connected to a load cell. To test the bond of the XPS spacers to the mortar, a

wooden block is adhered to the top of each spacer, and this block is in turn connected to the actuator and load cell. Figure 24 shows this test set-up.

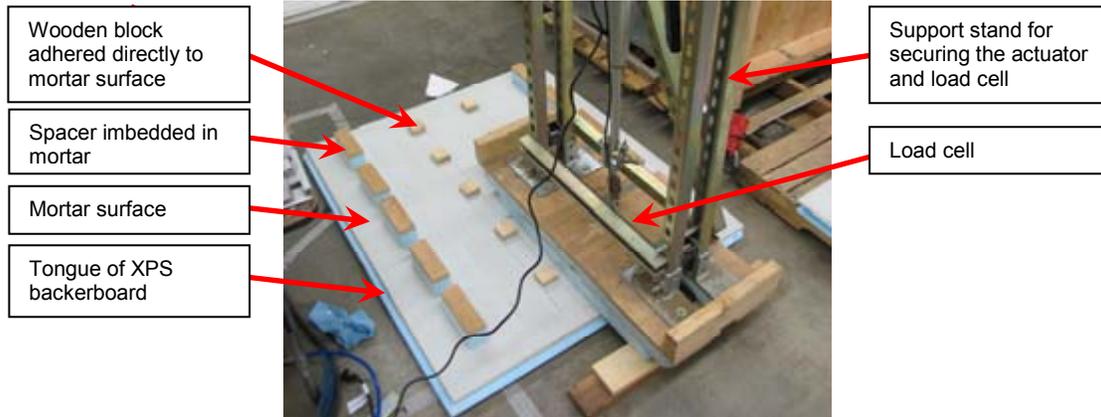


Figure 24: Two methods of measuring the tensile bond strength of the mortar to the XPS.

Although it is not expected that PowerGuard tiles will experience large shear loads, experience on our production line has shown that a poor bond between the XPS spacer and mortar may be more easily identified by a shear test than by a tensile test. PowerLight performed shear tests on three types of sample tiles: standard mortar formula and thickness; reduced latex formula; and reduced mortar thickness. The first type of samples served as the control group against which the results of the other two were compared. A photo of the test set up is shown in Figure 25.



Figure 25: Shear test on XPS spacer bonded to mortar.

Impact resistance is another important property of the mortar. During shipping and installation, PowerGuard tiles may experience impact loads against the sides of the tiles. The mortar reinforces the fragile edges of the XPS foam to protect it from chipping and deformation. Damage on the order of a few inches along the perimeter of the tile is considered to be acceptable; however, more substantial damage could compromise the structural integrity of the tongue-and-groove interconnection between tiles. To ensure

that a reduction in latex content or mortar thickness would not result in unsatisfactory impact resistance, PowerLight devised an impact test. The test consisted of a pendulum with a mass attached to the end. The pendulum was elevated at various heights to determine the energy required to cause impact damage to the edge of the tiles. A photo of the test is shown in Figure 26.



Figure 26: Impact test on mortar.

As discussed above, the mortar reinforces the XPS foam edges against horizontal impact loads. Similarly, the mortar also reinforces the top of the foam along the routed groove edges to resist uplift loads more effectively. PowerGuard wind design guidelines are based on wind tunnel tests in which the wind velocity that initiates tile uplift is used as the failure velocity. In a worst-case wind event, PowerGuard tiles may experience small vertical oscillations. The mortar along the groove edges adds considerable strength to the foam, so that foam breakage above the groove will not be a mode of failure. Reduced latex content or reduced mortar thickness may reduce the strength of this reinforcement. Therefore, PowerLight devised a test to measure the strength of the groove reinforcement. Small sections of the tile perimeter were cut and mounted in a tensile tester. A wooden fixture with the form of the XPS tongue was inserted into the groove edge of the test sample. The wooden fixture was lifted while the test sample was held in place. The load that caused failure was recorded for control samples and samples with reduced latex and reduced mortar thickness. A photo of the test set up is shown in Figure 27.



Figure 27: Strength of groove test.

PowerGuard tiles are not subjected to large compressive loads, so in a sense the compressive strength of the mortar is not part of the design criteria. However, it is well known in the concrete industry that the compressive strength of concrete is an indicator of concrete quality and freeze-thaw resistance. In addition, the test is very easy to perform and requires minimal material for the test. The compressive strength test on the mortar is based on the ASTM test C597. In this test, 1" diameter x 1" height samples of mortar are fabricated and allowed to cure. The samples are then compressed until failure occurs, and the load causing failure is recorded. This test was conducted on samples with the standard amount of latex and with a reduced amount of latex. Freeze/thaw testing was planned to be done following a series of tests on unconditioned samples. A photo of the test set up is shown in Figure 28. The minimum compressive strength is 3500 psi.



Figure 28: Compressive strength test.

Full-scale testing was also conducted on samples with reduced latex and reduced mortar thickness. In this test, a 3x3 array of tiles was assembled on the shop floor. A perimeter curb was installed around the array of tiles. The center tile was connected to a load cell and cable and winch assembly. The center tile was lifted until failure occurred. A photo of this test set up is shown in Figure 29.



Figure 29: Tile uplift test.

PowerLight contacted a manufacturer of alternative latex to obtain pricing for their product. The pricing was significantly less than that of the current vendor. Initially, this made the new latex an attractive replacement, but the supplier of the standard latex reduced their price to match the new one. This change in pricing eliminated the incentive to devote testing time to the new latex, and this effort was abandoned.

Results

Error! Reference source not found. shows the results of the mortar testing. The impact and compressive strength of the samples with reduced latex content were determined to be unsatisfactory. However, the performance of the reduced mortar thickness samples in all tests was found to be adequate. The cost savings afforded by this design change are substantial, so this improvement was immediately incorporated into the production line.

Table 2: Mortar testing results

Item	Test	Reduced Latex	Reduced Mortar Thickness
1	Freeze-thaw resistance	N/A*	Pass
2	Tensile strength	Pass	Pass
3	Shear strength	Pass	Pass
4	Impact resistance	Fail	Pass
5	Reinforcement strength of XPS groove	Pass	Pass
6	Compressive strength	Fail	N/A
7	Full scale tile uplift	N/A*	Pass

*These test were not completed due to failure of impact resistance and tile uplift tests.

Shipping Cost Reduction

Background

As part of Task 6 of this contract, PowerLight had the goal of reducing shipping costs and site waste by at least 20%. In order to accomplish this, PowerLight changed the height of the stacks of PowerGuard tiles from 12 tiles to 15. The details of this effort are discussed under Section 2.6.2 “Waste Stream Reduction.”

This change in stack height increases the loads applied to the tiles at the bottom of the stack during shipping. Prior to implementing this change in production, we wanted to make sure that it would neither decrease product reliability nor increase shipping damage. To evaluate this, we implemented a shipping test with the increased stack height.

Approach

In the shipping tests, control pallets with a standard number of tiles were shipped alongside pallets with an increased number of tiles. Standard shipping practices were followed. A datalogger capable of measuring shock was placed in a pallet to record accelerations in three directions. Tiles were inspected before and after shipping. The acceleration data was analyzed to determine the loads to which the tiles were subjected.

Once the change was implemented in production, PowerLight planned to inspect the pallets of tiles as they were unloaded at job sites during the first months after the process change. This approach would provide feedback from a much larger sample size.

Results

No damage was found during the first round of shipping tests, so the change was put into production. There were six reported instances of damage reported during the first few shipments. PowerLight engineers conducted a second round of testing with accelerometers and found that the loads applied to the tile could be greater during handling with a forklift than those measured during shipment by truck. Field crews were instructed to avoid sudden bumps with the taller stacks. At the same time, PowerLight had been working on reducing the thickness of the mortar coating on the PowerGuard backerboards. This change was implemented while these initial shipments were taking place. The change in mortar thickness results in a lighter tile. When the lighter weight tiles were put into production, no more shipping damage was observed. PowerLight continues to inspect shipments periodically to ensure that no damage is occurring, but many thousands of tiles have been shipped with the increased stack height without any problems.

Alternative PV Backing Material Validation

Background

As discussed in Section 2.2.3, PowerLight modified the manufacturing process for PowerGuard tiles to accommodate new backing material being used on PV modules by some suppliers. An extensive validation program was implemented to verify structural integrity of the PowerGuard tiles made with this new process.

Approach

Much of this testing was done in conjunction with a search for new adhesives and process changes that would provide an adequate bond to the PET. Initial tests were carried out on a variety of samples, and when a promising material was found, it was subjected to a full range of tests.

In this test, samples consisting of PET-backed modules adhered to XPS standoffs were fabricated. Unconditioned samples were used as controls, and some samples will be conditioned in a temperature cycling test, humidity-freeze test, and water-immersion test. All conditioning tests are based on UL 1703 and IEC 61215 tests.

Results

PowerLight completed testing on small-scale samples with chosen adhesive. Once the testing was completed on small-scale samples, full-scale tiles were made with the new adhesive. In this case, the small scale testing had to be done twice. Initial tests showed good results using a reactive hot-melt adhesive, but when it was implemented on full-scale tiles, the results were not acceptable. Modifications were then made to the adhesive process wherein the PET material was treated with a corona-discharge probe prior to being adhered to the spacers of the PowerGuard backerboard. The addition of this process allowed the use of a lower-cost adhesive. Once this change was made, we had good results both in the lab and in the factory.

Because of this change to the adhesion process, the testing plan had to be expanded to include some testing of the PV modules to ensure that the corona-treatment process did not damage the backskin in any way. PowerLight conducted testing of the electrical resistance of the backskin of several modules before and after corona treatment. The resistance was within specifications before and after treatment.

Validation of In-Line PV Attachment Manufacturing Process

Background

As part of the ongoing effort to remove any non-value added activity from the manufacturing process for PowerGuard, PowerLight is investigating combining the two parts of PowerGuard production into one continuous operation. Currently, the backerboards are made and then stacked for curing of the cementitious coating. Once the coating is cured, the PowerGuard tiles are assembled with the PV laminates and packaged for shipment. The next goal in improving the manufacturing process is to add the PV laminates during the coating process so that once the coating is cured; the tiles are ready to be packaged for shipment. This will eliminate the labor involved with stacking and unstacking the tiles between operations. It will also reduce the floor space required for the manufacturing process and reduce opportunities for damaging work-in-process.

To ensure that this change does not negatively affect the bond between the XPS spacer and mortar, testing was conducted on tiles made in a batch process and compared to tiles made during pilot runs of the inline PV attachment process.

Approach

Testing consisted of a destructive tensile test on the tiles to ensure the tiles can meet an uplift requirement of 50 lbs. per square foot (psf). The test setup is shown in Figure 30.



Figure 30: Tensile test of PowerGuard tile made with continuous process

Results

PowerLight conducted a series of pilot runs to determine the feasibility of the continuous manufacturing process. Samples were taken from these pilot runs and tested in PowerLight's testing facility. The initial results showed a slight decrease in bond strength. However, the results also indicated that the load may have been applied unevenly during the testing. The test apparatus will be improved for the next round of developmental tests. Based on the results, the manufacturing engineers began looking into alternate methods of handling the tiles during the continuous process so that there would be no disturbance of the bond. Another pilot run is planned for early 2006.

Thermal Monitoring

Background

PowerGuard tiles are the most lightweight and wind resistant ballasted PV product on the market. PowerGuard tiles are installed directly on the roof surface and have horizontal PV orientation, both design features that improve wind performance. However, these aspects can result in higher PV temperatures when compared to sloped PV modules that are elevated off the roof surface. The purpose of this effort was to document that PowerGuard systems in hot climates operate within an acceptable temperature range. PowerLight continues to work with industry experts to ensure that established PV test standards, such as UL1703 and IEC 61215, are predictive of PowerGuard's long-term reliability.

Approach

Four PowerGuard systems in hot climates were instrumented with thermocouples and monitored remotely via a data acquisition system (DAS). Three thermocouples were placed on two PV modules in each system.

Results

Peak PV temperatures were within the expected range. PowerLight is in the process of reviewing the data with Sandia National Labs, to ensure that established industry standards for PV testing would predict PowerGuard's long-term durability.

2.3.2 PowerLight Metal Roof System

Objective

The PowerLight Metal Roof System (RMR) is a PV mounting system for metal roofs that does not require penetrations through the roofing. Two engineering requirements must be met with this design: (1) the structural components must withstand all environmental forces such as wind, seismic, and gravity; and (2) all accessible conductive parts of the array must be grounded according to the National Electric Code (NEC) requirements.

The objective of this task was to ensure that RMR designs, which vary to accommodate different PV frames, meet these engineering requirements. The approach used to investigate these issues and the results of work performed during this phase are summarized below.

Background

Each PV module manufacturer has a unique PV frame design. The frames can be categorized into two types: external flange frame (EFF) and internal flange frame (IFF). Photos of these two frame types are shown in Figure 31 and Figure 32.



Figure 31: Examples of external flange frames

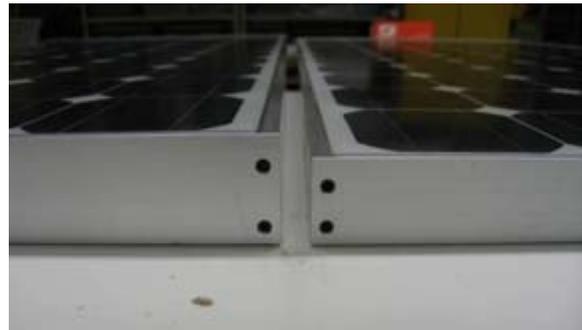


Figure 32: Examples of internal flange frames

Standing seam and corrugated metal roofs can be used as a mounting structure for PV modules. PowerLight has developed standardized mounting clips to mount EFF and IFF PV frames to structural components, such as S5 clamps or Unistrut. These structural components are then attached to the metal roofing using standard industry practices. A photo of an S5 clamp is shown in Figure 33.

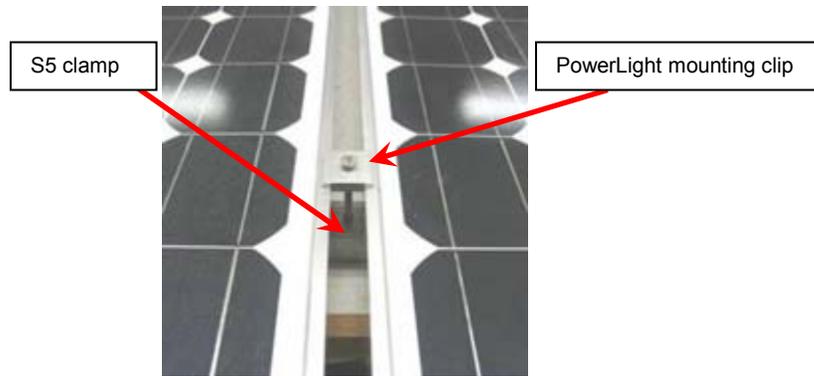


Figure 33: S5 clamp and PV mounting clip to secure two PV modules.

The complete assembly – the PV mounting clip, PV frame, and structural components – must meet certain design requirements. The design must meet UL and IEC standards, which dictate wind loading and grounding requirements. To ensure that the clip designs meet these criteria, the assemblies were tested to these standards, as described below.

Approach

Grounding Tests

UL 1703 specifies that the resistance between accessible conductive components in a PV system cannot exceed 0.1 Ohms. PowerLight evaluated the IFF and EFF clip assemblies to ensure that the resistance was below this value. In this test, leads of a highly sensitive milli-ohmmeter are connected to two adjacent PV frames in order to measure the resistance across the clip assembly, as shown in Figure 34.

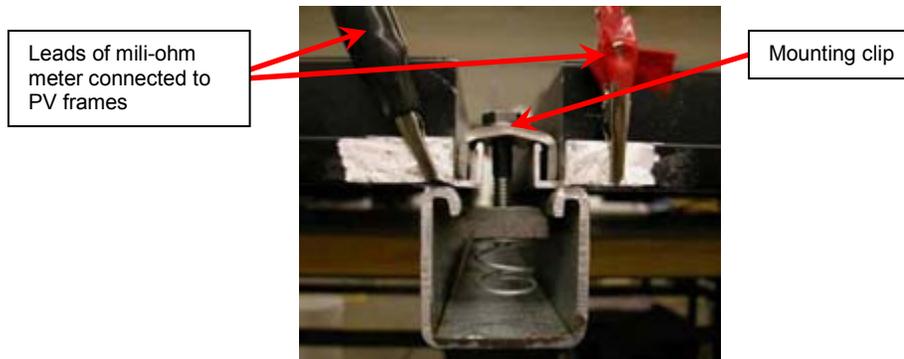


Figure 34: Ground testing of mounting clip and frames.

Uplift Resistance Tests

UL requires that PV modules pass a loading test where 45 psf is applied to the module surface. Permeable PV roofing systems typically have excellent pressure equalization, resulting in lower wind loads on the module. PowerLight tested the IFF and EFF clips in a tensile test, as shown in Figure 35. A vertical load was slowly applied until failure occurred, and the load causing failure was recorded and compared to the UL requirement.

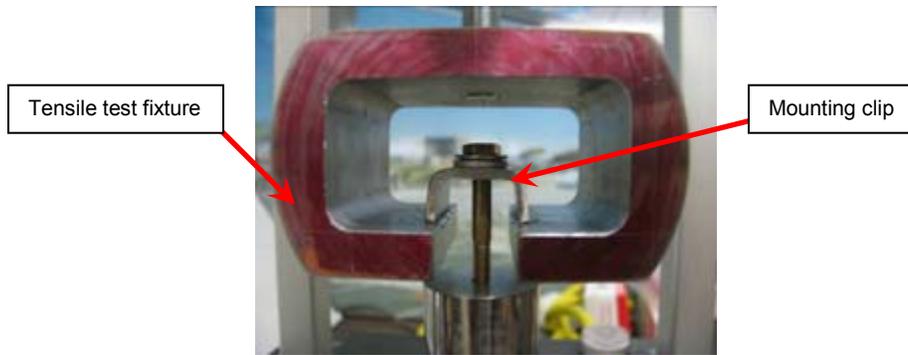


Figure 35: Mounting clip uplift test.

Lateral Load Testing

For most PV systems on a metal roof, wind and gravity loads create a negligible lateral load on the mounting system. However, the design must be able to withstand seismic loads.

PowerLight used International Building Code (IBC) guidelines to calculate expected lateral loads on the PV array in a severe seismic event. Then a lateral loading test was conducted to determine if the assembly could withstand the predicted load. A photo of the test setup is shown in Figure 36.

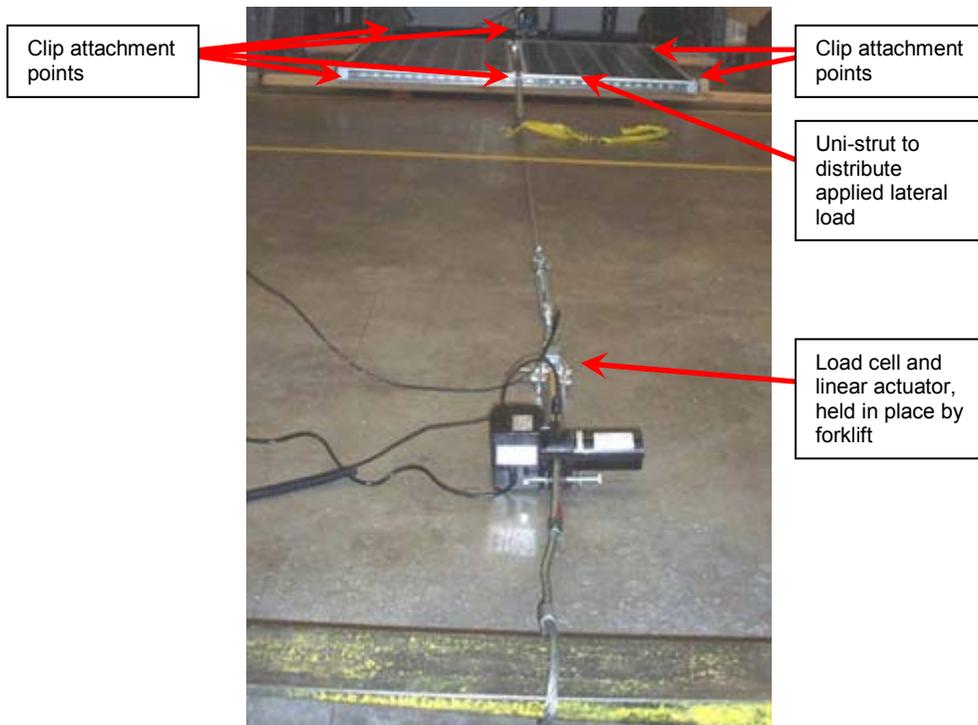


Figure 36: Lateral load test on RMR mounting clip.

Results

The IFF and EFF clip assemblies passed the grounding, uplift, and lateral load tests. PowerLight obtained UL listing for these assemblies following evaluation.

2.3.3 PowerLight Fixed Tilt Roof System

Objective

The purpose of this task was to:

- Conduct wind tunnel testing to evaluate the sensitivity of the RFT10 product to building height, parapet height, and array orientation,
- Create wind design tools to be used to determine the securement requirements for various wind conditions,
- Conduct full-scale load testing on the RFT10 product to ensure that expected wind loads will not cause structural damage to components,
- Conduct ground testing to ensure that all accessible conductive parts are adequately bonded to a common earth ground, and
- Conduct seismic testing and analyses to verify that the RFT10 assembly can withstand typical seismic events.

Background

Prior to the start of this contract, preliminary wind tunnel testing on RFT10 had been completed for a limited set of conditions. The test results showed the behavior of RFT10 in these conditions, but further testing was required to quantify the wind performance in the whole range of site conditions in which RFT10 is likely to be installed. In particular, the effect of tall buildings, varying parapet height, and high wind zones needed to be determined.

Wind tunnel testing was conducted on 1:32 scale models of RFT10 tiles. At this scale, the rigidity of the interconnect joints may deviate from the full-scale product. The RFT10 interconnects have some flexibility in the vertical and horizontal directions. Preliminary wind testing showed that the mode of failure for RFT10 arrays is usually by array sliding and, in some cases, by lifting in the edge and corner regions of the roof. To address these issues, testing on full-scale tiles in the laboratory was conducted to evaluate the structural integrity of the array during simulated sliding and uplift wind failure conditions.

RFT10 systems have accessible conductive components throughout the field of the array. Each conductive component must be bonded to a common earth ground according to NEC. During this phase, grounding tests were conducted internally to ensure an adequate ground was achieved. Additionally, PowerLight obtained UL listing for the grounding clips for two types of PV modules (EFF and IFF), following evaluation.

Experience with PowerGuard projects has shown that for sites in moderate to severe seismic zones, sufficient documentation is needed to convince building officials that ballasted PV roofing systems with no mechanical fastening to the building structure will remain safe during and after a seismic event. PowerLight hired a seismic modeling consultant to predict the behavior of an array of RFT10 during a severe seismic event. The goal of the testing and analysis was first to document the ability for the RFT10 interconnects to withstand seismic forces, and second to analytically study the array's response to various seismic events and building types.

The approach used for the testing on RFT10 is described below, followed by a discussion of the results.

Approach

Wind Testing and Wind Design Tools

A scale model of the RFT10 array was fabricated. For these tests the following parameters were varied: building height, parapet heights, array position, and array weight. The friction coefficient between the model array and model building was adjusted to represent worst-case field conditions such as a slippery single-ply roof membrane.

For each test configuration, the array was set up on the model building, and the wind speed in the tunnel was slowly increased until failure occurred. In some cases, failure occurred due to tile lifting around the edges of the array, and, in others, the entire model array slid on the roof surface. Figure 37 shows a typical test configuration.



Figure 37: Wind tunnel model for an RFT10 array installed on the edge of a building.

Wind tunnel data was used to create design charts for RFT10 systems. The charts show the type of securement needed for various building heights, local design wind speeds, and type of surrounding terrain.

Structural Testing

Four types of structural loading tests were done RFT10 assemblies. First, a lateral compressive load in the north-south direction was applied to a RFT10, as shown in Figure 38. The force was applied at the north end of the tile, while the south end was restrained. The purpose of the test was to simulate a strong wind hitting the north end of the array, causing the first row of tiles to be pushed into the interior sections of array. The force was increased until some part of the structure yielded. The force and displacement were then measured.



Figure 38: Lateral load test on RFT10 assembly. A compressive load is applied to the north side of the tile.

In a second test, a lateral compressive load was applied to the east side of a tile with the west side restrained. This configuration simulated a wind load hitting the outer eastern edge of the array. As before, the force was increased until some part of the structure yielded. The force and displacement were measured. A photo of the test set up is shown in Figure 39.



Figure 39: Lateral load test on an RFT10 assembly. A tensile load is applied to the east side of the assembly.

The third test simulated wind uplift failure. The purpose of this test was to ensure that the retaining clips were sufficiently strong to keep the PV module from being pulled loose under the most severe uplift loads that might be encountered. A photo of the test set up is shown in Figure 40.



Figure 40: Uplift test on an array of RFT10 tiles. A vertical force is applied to the center tile.

The strength of the PV mounting clips in the RFT10 assembly was evaluated in a loading test based on UL1703 and IEC 61215. In this test, 50 psf was applied to the module and clips. A photo of this test is shown in Figure 41.



Figure 41: Loading test on a PV module supported with RFT10 mounting clips.

Grounding Test

The RFT10 assembly has many accessible conductive components that must all be electrically connected together to create a reliable bond to earth ground. A test was conducted to verify that the resistance across the assembly was below an industry-established maximum of 0.1 Ohms. A photo of the test set up is shown in Figure 42.



Figure 42: Grounding test on an RFT10 assembly.

Seismic Testing

The goal of the testing and analysis was first to document the ability for the RFT10 interconnects to withstand seismic forces, and second to analytically study the array's response to various seismic events and building types.

First, friction coefficients between the assembly and various roofing surfaces were measured. A horizontal load was applied evenly to the sides of three tiles until motion occurred. The load causing motion was automatically captured by the data collection system and used to calculate the friction coefficient on a membrane roof. A photo of the test set up is shown in Figure 43. A typical low value was chosen for further evaluation of system performance in a seismic event.



Figure 43: Friction test on an RFT10 assembly.

Once the friction coefficient had been measured, the seismic modeling consultant began the analysis to determine the loads that would be applied to the RFT10 product during a

seismic event. This analysis takes into account: (i) the friction coefficient between the PV system and the roof; (ii) variations in building flexibility and local soil conditions; and (iii) several types of earthquakes.

In Phase 2 of this contract, structural tests will be conducted to ensure that the RFT10 assembly will remain in a safe condition after a seismic event. The tests will be similar to the structural tests that were performed to simulate wind loads, as shown in Figure 38 and Figure 39. The seismic tests differ in that the loads are applied to the assembly by the roof surface. A modified test set up will be created to simulate this type of loading.

Results

Wind Testing and Wind Design Tools

The wind tunnel test results provided a failure velocity and failure mode for each configuration that was tested. A safety factor was applied to all failure velocities. PowerLight reviewed the results extensively to identify worst-case conditions and to identify the dominant trends in the data. The results were then incorporated into a series of charts to be used as guidelines for array design.

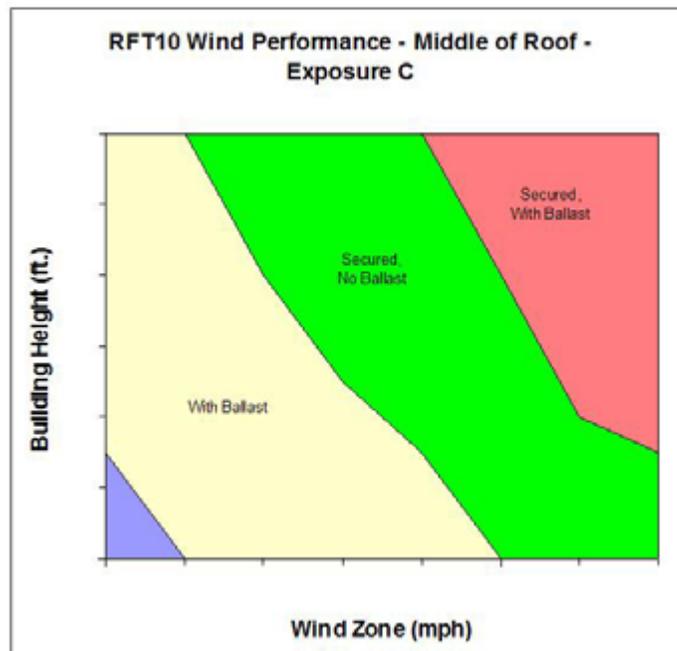


Figure 44: Wind design chart for RFT10 arrays in the middle of the roof in Exposure C.

A sample chart for the middle roof position, Exposure C terrain is shown in Figure 44. To use this chart, the designer first determines the building height, the location of the array on the roof (edge, corner or middle), type of surrounding terrain (Exposure A, B, C, or D), and the 3-second gust design wind speed for the location as defined by ASCE. The designer can then determine which type of securement is needed for the particular system. The securement types are defined as follows:

1. No ballast: the system may be installed with any additional ballast or securement.
2. With ballast: additional weight needs to be installed.
3. No ballast, with securement: perimeter penetrations need to be installed.

4. With ballast and securement: additional weight and perimeter penetrations need to be installed.

Structural Testing

The wind tunnel test results discussed above show that for sites in high wind zones, the array must be secured to the building. In these cases, anchor points will be placed around the perimeter of the array. The lateral load testing showed that under these conditions, the structure of the array must be augmented so that lateral loads can be transmitted through the array without deforming the individual structural elements. This additional structure is needed only for the north-south direction. In the east-west direction, the standard structure is sufficiently strong to transmit the loads. PowerLight designed a connector that will tie each support piece to the adjacent north and south support. This will be used only in sites where positive securement of the array is required.

Ground Testing

Results of the grounding tests indicated that the RFT10 assembly meets all safety requirements. A UL listing for the RFT10 clips was obtained, as stated above.

Seismic Testing

The friction test results were provided to the seismic modeling consultants, who used the data to complete their model of RFT10 behavior. The model predicts the maximum displacement of the array in a severe seismic event. The model showed that the maximum displacement of the array in a severe event was less than the standard offset from the array to the edge of the roof. Thus, with the standard offset, we know that no section of the array will become dislodged during seismic activity. This ensures that the array does not pose any threat to public safety.

2.3.4 ICC Certification

Background

At the inception of this project, PowerLight planned to obtain an Evaluation Report (ER) from the International Code Council (ICC), with the goal of streamlining the permitting process.

An ICC-ER for PowerLight's ballasted PV roofing products would demonstrate that the products comply with the International Building Code (IBC), including sections pertaining to fire safety, structural integrity, long-term durability, and wind safety. These concerns are among the most commonly raised questions from building inspectors.

Approach

PowerLight completed an extensive test program for all roof products, as discussed above, and initiated communications with ICC. An application package was submitted with engineering drawings, installation guidelines, and a sample Evaluation Report as requested by ICC.

PowerLight's expectation was that ICC would respond with a list of documentation and testing requirements, and that the test requirements could be easily met.

Results

On further evaluation, PowerLight determined that pursuing ICC certification would provide little additional value to the end customer. The expected benefit of having an ICC-ER is to facilitate permitting and PowerLight has found that this is no longer needed. Recently, questions from building officials during the permitting stage have decreased drastically. There are two reasons for this change: (1) the quality and comprehensiveness of PowerLight's submittals to building departments have improved significantly through continuous improvements based on feedback received from building inspectors; and (2) PowerLight's portfolio of successfully completed projects has increased to a point that brings a new level of assurance to building officials. In many cases, the building departments have worked on prior PowerLight projects, and therefore they are more familiar with the technology.

In addition, ICC responded with a list of testing and documentation requirements, including documentation of wind resistance. Initially, this did not appear to present a challenge. However, more in-depth discussions with ICC revealed that because the wind testing of PowerLight's products were not performed in an ICC accredited laboratory, the wind testing would need to be repeated under the supervision of ICC staff. PowerLight estimated that this would cost about \$100,000 for the ICC wind requirement alone. This additional cost combined with the lack of need to facilitate permitting has led PowerLight to decide not to pursue an ICC certification.

Conclusion

PowerLight chose to suspend its pursuit of an ICC-ER, as the UL listings, IEC certifications, and ASCE-compliant wind tunnel testing satisfy the requirements and expectations of building inspectors and end users. Should an ICC-ER be required due to changing market conditions, PowerLight will resume ICC evaluation efforts.

2.4 Task 4: Quality System Improvements

The objective of this task is to implement a supplier quality assurance program with the goal of achieving a 99% first-time acceptance of select supplied products and/or services.

Background

For PowerGuard, all tile components pass through PowerLight's factory. PowerLight has the opportunity to inspect all incoming material. However, such inspections are clearly non-value added activities. It is far more efficient to establish quality systems at PowerLight's suppliers to make sure that non-conforming material never leaves the supplier.

For products other than PowerGuard, all materials are shipped directly to the job site. For these products, it is vital that PowerLight's suppliers maintain adequate quality assurance systems to ensure that non-conforming material is not sent to the job site. Defects in the field result in much higher costs than those found in the PowerLight factory or during fabrication. As such, PowerLight's supply chain department creates partnerships with suppliers to establish quality systems that will be effective in minimizing and detecting non-conforming material before it is shipped. To accomplish this, a supplier quality standard is needed.

2.4.1 Supply Chain Management Procedures

Approach

PowerLight's goal has been to bring supplier's quality systems up to a level at which no inspection of incoming material is required. Additionally, PowerLight was to address field-quality issues by expanding documentation procedures and the existing closed-loop corrective/preventative action process to include site quality.

PowerLight expected to host a series of supplier quality seminars that would introduce PowerLight's suppliers to our quality standards and requirements. As this effort has progressed, it has required a different approach than originally anticipated. PowerLight has created a quality standard that is primarily focused on PV suppliers as quality issues with PV have the greatest impact on installation costs and system performance. This standard is discussed below.

For suppliers of other parts, primarily fabricated metal components, PowerLight's supplier base has changed over the course of the last year. As PowerLight's volume has increased, we have switched to some larger volume suppliers of metal parts. Most of these suppliers already have robust quality programs that conform to PowerLight's requirements. PowerLight has undertaken to audit the quality programs of suppliers using an ISO 9000 standard based procedure. Suppliers were trained if there was not an adequate QA system. The training sessions are followed with another audit. These audits are performed by either PowerLight or a third party inspector.

Results

PV Specification Package – PowerLight has set up long-term supply agreements with key PV suppliers. These agreements detail product expectations beyond what is typically called out in manufacturing cut sheets and specifications. These agreements include specific detail on delivered power requirements. Powerlight insists that the average power output of the modules in a given shipment are at or above the nameplate rating of the modules. This avoids the uncertainty associated with the manufacturing tolerance on output power. Warranty, certification, packaging, and inspection requirements are also included in these supply agreements. Further quality assurance protocol has been established to ensure that modules are adequately characterized to ensure accurate performance modeling and maximized system performance. This is described in Deliverable 1.4.2.

Manufacturing Facility Audits/Visits – PowerLight visits all the manufacturing facilities from which we order PV prior to placing our first order. During this initial visit we review the overall production process and quality protocols. Most facilities are ISO 9000 registered which covers most concerns regarding material traceability. We also check for general conformance to industry standard practices. At this time, our audit form is based on ISO 9000 quality standards. This form is filled out, and any areas on non-compliance are reported back to the supplier. These items are usually negotiated with each manufacturer depending on their relative importance to the products we are ordering. As stated above, PowerLight has also trained suppliers whose quality systems have been found to be inadequate.

Source Inspections – PowerLight contracts with local inspection companies to conduct periodic source inspection of outgoing material from the manufacturing facilities. This approach allows us to discontinue incoming material inspections. In so doing, we can ship PV directly to the installation site without warehousing the material.

Conclusion

The accomplishments described above are vital to the continued reduction of installed system cost. By ensuring that suppliers have adequate quality systems in place, PowerLight avoids costly field repairs and delays. This also ensures that PowerLight's systems perform at their maximum output, satisfying customers' expectations.

2.4.2 Supply Chain Quality Standard

PowerLight was to develop a supplier quality standard, defining the required quality of the supplier's products and services as well as performance metrics.

Approach

Historically, PowerLight's most costly quality issues have been related to PV modules. Therefore, PowerLight concentrated quality efforts for the most part on the PV suppliers. PowerLight worked with PV suppliers and independent testing facilities to establish meaningful and quantifiable quality metrics for PV modules. This appeared to be a straightforward undertaking at the outset. However, it quickly became much more complex. For example, discrepancies exist in test results from one test lab to another, further complicating this effort. In conjunction with work being done under Task 1 to improve system performance, PowerLight embarked on a program to quantify the variations in testing results and to create a consistent method for quantifying PV output.

PowerLight became aware of the magnitude of testing discrepancies when comparing the output of suppliers' flash testers with that of independent third-party testing labs. A group of PV modules were tested by a supplier and then sent to an independent testing lab where they were fully characterized. The flash test results provided an indication of the variation in calibration between the different testers but did not establish a benchmark.

Next PowerLight established a quality standard that defined an initial qualification technique to be used with each supplier. In conjunction with the independent testing lab, PowerLight created a testing protocol that benchmarks module performance in a way that provides an accurate prediction of system performance. Each manufacturer will send representative samples to this lab for this benchmark testing along with their flash test results. This method will provide a comparison between that manufacturer's flash test data and predicted system performance.

For ongoing quality control, each supplier is required to supply flash test data from each module. These data are adjusted based on the stored comparison between the manufacturer's flash tester and the benchmark test. The results can then be used to ensure that the supplier's modules meet PowerLight's specification and that the installed systems will perform as expected.

Results

PowerLight has established a quality standard for PV modules as discussed above. During Phase II, we will work with each module manufacturer and the independent test lab to collect the benchmark test data.

We now get all flash test data for every PV shipment sent to us in electronic format prior to release of shipment. Depending on specific shipping terms negotiated with the supplier, we sometimes receive this data while the modules are en route but reserve the right to refuse the shipment if we find the data to be out of agreed specification.

PowerLight catalogs these flash test data and is working on improved access for the catalogued data. In Phase II, we will be developing a system that will allow us to query this data by purchase order number or job number. This system will give us efficient access to information on exactly which modules are at which installations and what their measured outputs are. Additionally, we will be able to track PV serial numbers by project number so that we can track the PV output of a given system and compare this to its theoretical output at STC based on manufacturing flash test data.

This system will allow us to track module performance over time and update our simulation assumptions accordingly.

Conclusions

PowerLight's quality standard for PV modules is currently the most advanced in use by the PV industry. This will benefit PowerLight by ensuring that our installed systems perform at maximum output and satisfy our customers' expectations. Additionally, this standard will provide an example for the industry to follow, benefiting all PV manufacturers, installers, and customers, and leading to improved system performance throughout the industry.

2.5 Task 5: Manufacturing Improvements

The objective of this task is to implement lean-manufacturing techniques in order to maximize yield, improve cost, reduce labor, and reduce inventory levels. The targeted goals of this task include the development of manufacturing tools capable of reducing the labor required to manufacture PowerGuard tiles by 30%, increasing manufacturing yield to 99.7%, and increasing inventory turns to at least eight per year.

2.5.1 Manufacturing Yield Improvement

Background

Over the past several years, PowerLight has been implementing lean manufacturing concepts in the production of PowerGuard. This process is being continued under the current subcontract.

One of the main goals of lean manufacturing is the elimination of waste. Processes for which the customer is not willing to pay are identified as non-value added (NVA) processes. Inspection of parts is an example of one NVA process. Pull manufacturing is another key concept in lean manufacturing. Upstream stations in a manufacturing process only make product when the next station downstream requires them. This method minimizes the amount of work-in-process, which helps to keep costs low and minimizes the risk of damaging parts between stations. Excess handling is eliminated in the ideal setup, and all inspection is replaced by error-proofing where parts are made so that they can only be assembled the correct way. Waste can also be eliminated through the application of the 5-S principles, as follows:

- *Seiri* (Organization) or Sort- eliminate unnecessary items
- *Seiton* (Order) or Set in order- storage system & layout, provide for easy access
- *Seiso* (Cleanliness) or Shine
- *Seiketsu* (Neatness) or Standardize- continue the first three S's all the time
- *Shitsuke* (Discipline) or Sustain – develop these into a constant habit – this is the most important

Many of these lean concepts are implemented through *kaizen* events. During a *kaizen* event, the workers are asked to create a solution to a particular manufacturing challenge. The challenge can be organization of tools, layout of the workspace, layout of the workflow, improvements in ergonomics, or anything else that affects worker productivity, product quality, product cost, or safety. By involving the workers in the process of continuous improvement, they can have a sense of ownership for the product and the process, and they can be a source of good ideas since they are involved in the manufacturing process every day.

Approach

Improvements in yield were pursued primarily in two areas. The final assembly process has been labor intensive and prone to variable results. By automating portions of this section of the manufacturing line, labor costs could be reduced, yield could be improved, and manufacturing capacity could be increased. The first areas to be automated were the cleaning of the PV modules and the application of a surface treatment process for PET-backed modules prior to assembly into PowerGuard tiles. While the previous process did not produce a large number of rejects, there was no mechanism in place to ensure that these two steps are being carried out properly or to detect rejects. Machinery was specified that would produce consistent, adequate results for these steps.

The second area where yield improvement was pursued was in the mixing of the ingredients for the cementitious coating. Different liquids are mixed together, and then this mixture is combined with dry ingredients to create the coating. The process of mixing the liquids together is controlled by a programmable logic controller and is essentially error-proofed. The mixing of the liquids with the dry ingredients, however, was less precise and had no safeguard. The implementation of a new liquid pumping system was undertaken to deliver a preset flow rate to match the flow rate of the dry ingredients. This modification was expected to improve the quality of the coating, as well as reduce the labor requirement by decreasing the amount of monitoring required to operate the coating process.

In addition to the improvements listed above, two *kaizen* events were planned during Phase I of this project as part of Task 6. These provided an opportunity for the workers to be involved in the improvement process. The *kaizen* events focused on improving quality control and process efficiency, as discussed below.

Other improvements to the manufacturing process were planned. Product yield must be maintained or improved, as these improvements are implemented. Experiments were carried out to reduce the cost of the coating materials. Testing was done to ensure that product quality is not compromised by these changes. The stack height of PowerGuard pallets was increased to improve shipping density and lower cost. Testing ensured that the increased stack height would not cause tiles on the bottom of each stack to be damaged during shipping.

Floor space restrictions and scheduling issues have resulted in a large number of PowerGuard tiles being sent to a temporary storage warehouse. This has added cost and created many opportunities for product to be damaged during shipping and handling. PowerLight continues to work on ways to minimize this transfer of materials by improving the scheduling process. This will result in lower cost and fewer rejects.

Results

The greatest impact on the measured yield of PowerGuard tiles was achieved through the implementation of the error-proofed mixing system for the liquid and dry ingredients of the coating. This new pumping station was combined with an improved data monitoring system. Two parameters are monitored as primary indicators of coating quality: the polymer-to-cement ratio and the water-to-cement ratio. The new monitoring system collects data on material flow and calculates these parameters in real time. A plot of these parameters is then stored for each day of production, providing traceable information for each lot of PowerGuard backerboards made. Figure 45 shows a typical plot from one production run. A solid line is displayed above and below each parameter plot showing the acceptable range for that parameter. The system is programmed to start collecting data when the flow rate exceeds a threshold level. This produces the slight scatter of outlying points each time the system starts and stops.

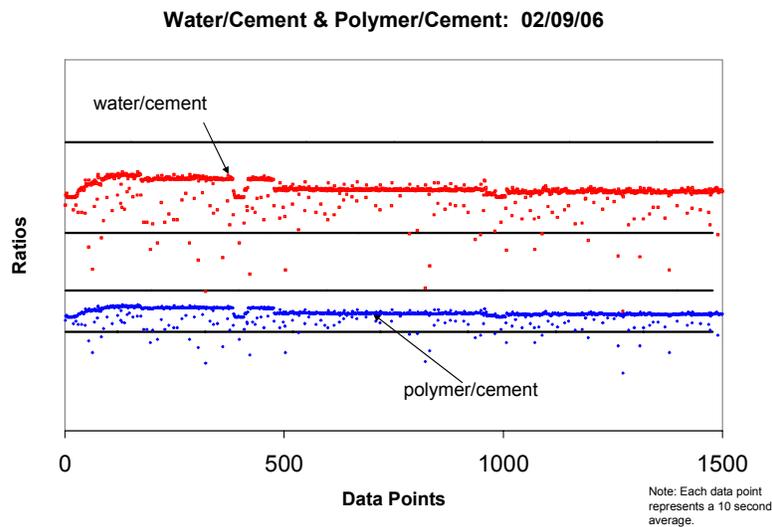


Figure 45: Typical plot from coating monitoring station

The implementation of the new pumping station improved the control of the mixing process and reduced labor required at the same time. Prior to the implementation of this new station, the mixture was controlled by an operator based on an analog flow meter. The mixture could vary widely depending on the skill and attentiveness of the operator. Figure 45 shows that the two critical parameters are now being maintained very tightly. An operator checks the function of the mixing system at the start of the coating run; after this initial check, it requires no attention. Figure 46 and Figure 47 show the new pumping station.



Figure 46: New pumping station for mixed liquids



Figure 47: Control panel for pumping station

The implementation of the new PV preparation line has improved PowerLight's quality control in this area, though it is difficult to quantify the improvement since there was no way to measure the quality previously. The new equipment provides consistent and effective cleaning and surface treatment for the PV modules prior to the final assembly process for PowerGuard tiles. The surface treatment function is used only for modules that have a polyethylene terephthalate (PET) backing material. While the PV modules are being processed, the system also scans and stores the serial numbers so that each

module can be tracked to its final installation site. These improvements help ensure that product performance and reliability will be maximized throughout the life of the product. Figure 48 and Figure 49 show the new PV preparation line.



Figure 48: PV prep line



Figure 49: PV prep line

Conclusion

The goal of this task was to improve yield to above 99.7% (reject rate of less than 0.3%). The yield statistics for PowerGuard production show an average yield of 99.96% (reject rate of 0.04%). This is compared to an average yield of 99.5% from the previous year. The improvements in the manufacturing equipment were vital to achieving this yield. The involvement of the workers in the improvement process through *kaizen* events was

also an important part of the process, as discussed in Task 6: Environment, Safety & Health.

2.5.2 Optimization of Inventory Levels

To facilitate reductions in inventory levels, PowerLight formed an interdepartmental team to coordinate manufacturing and installation processes in order to remove unforeseen delays, which result in the storage of finished goods. The continuing goal of this team is to find ways to increase inventory turns to at least eight per year.

By forming an interdepartmental team to study these schedule issues and to look for ways to avoid them, much of the wasted activity involved with storage and extra handling of material could be eliminated. In addition, by increasing inventory turns, the cost of inventory on hand will be reduced.

Approach

PowerLight has created a team to coordinate manufacturing and installation processes in order to remove unforeseen delays. This team had its first meeting in June 2005. The team consists of representatives from the following departments:

Projects – responsible for installing product at the job sites

Production – responsible for manufacturing PowerGuard tiles

Logistics – responsible for delivering goods to the job sites

Purchasing – responsible for supplying materials to Production and Projects

Production planning – responsible for scheduling material shipments and production.

Findings

The main issues discussed include:

1. Eliminating transfer of work-in-process from the PowerLight factory to warehouse storage
2. Planning production to accommodate smaller production runs to eliminate floor space constraints and to provide a consistent daily list of activities in the factory
3. Working with PV suppliers to improve the delivery schedule
4. Modify the PowerLight factory to accommodate more finished goods.

2.5.3 Labor Reduction

In order to decrease labor costs, PowerLight was to design new tools for material handling in the PowerGuard manufacturing process. The goal was to design equipment that would enable a worker to move components that are currently too awkward for single-person handling through the factory without assistance from other workers. The expected results of this task included the development of manufacturing tools capable of reducing the labor required to manufacture PowerGuard tiles by 30%.

A portion of these efforts focused on reducing labor costs, improving the consistency of processes, and reducing the amount of material handling during the process of preparing PV modules for assembly into PowerGuard tiles.

Approach

PowerLight has completed the design of a new portion of the assembly line that will change several parts of the PV module preparation process from a series of inconsistent, labor-intensive steps to a controlled, repeatable, and automated continuous process.

PV modules must be cleaned and tested prior to being assembled into PowerGuard tiles. The serial numbers must also be scanned. A surface treatment process is required on modules with PET backsheets, and a PowerGuard label must be printed and adhered. The cleaning and surface treatment processes are difficult to control and labor intensive. In order to ensure the quality of the process and to reduce labor costs, a new conveyor line was designed to perform all of these functions.

The first step in designing the new line was to create a comprehensive specification that could then be given to potential contractors who would design and build the equipment. Once a contractor was selected to design and build the equipment, the details of the process were discussed in order to define how each part of the process would be carried out. Input was solicited from engineers and factory workers within PowerLight. A single contractor was hired to design and construct the line. Other contractors were hired to provide design of subcomponents and a control system.

Results

We developed the specification below to define the new system.

SPECIFICATION

I. Overview

- A. This document describes the specification for the automated photovoltaic preparation line (PVPL). The current PVPL is a manual process. The module is first manually moved to the cleaning station where the module is manually cleaned using isopropyl alcohol. The module is then corona treated on sections where the spacers will be adhered. This is followed by scanning the serial number, and testing the PV module using the Dark I-V machine. Also, the Dark IV machine prints a label for all the tested modules. Currently the operations are performed in independent stations, hence the modules are manually moved from one station to another.
- B. The proposed line will move PV modules automatically from one station to another. The automatic material transfer will be achieved using a PLC controlled conveyor system. The Dark IV machine will be used to test the modules, scan serial numbers, and print labels. The modules will be cleaned using a piece of equipment manufactured by Wandres Corp. The system will also incorporate corona treating equipment, which will corona treat the sections on the modules backing where spacers will be adhered.

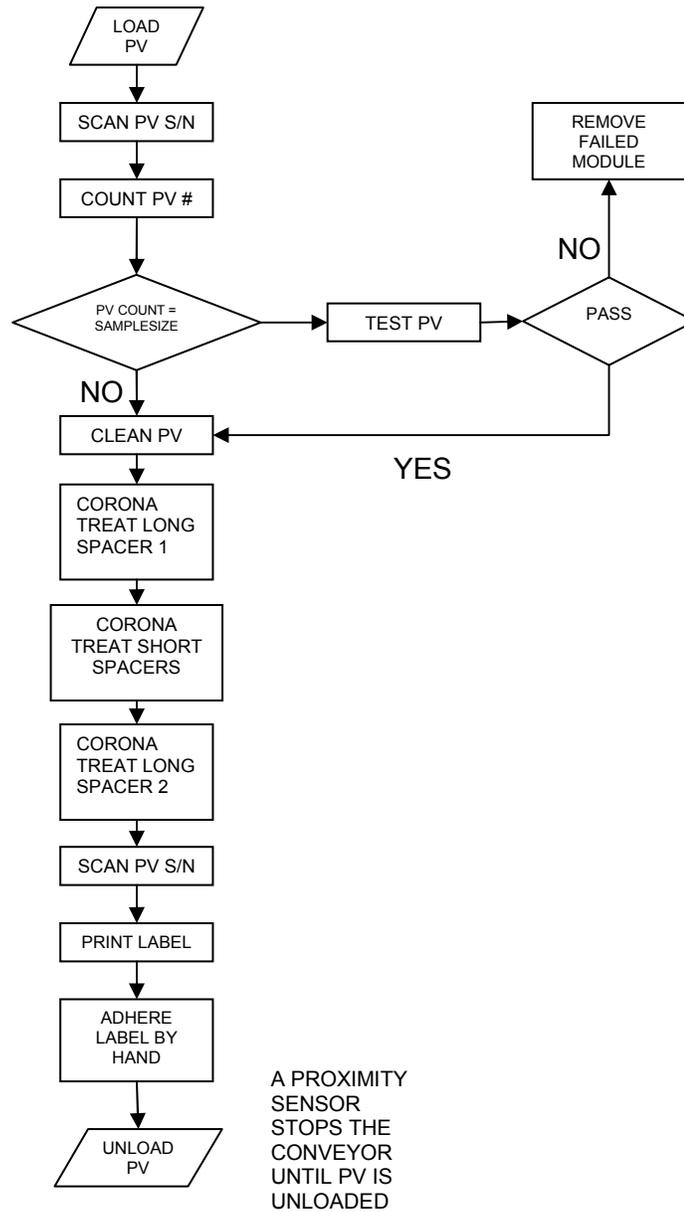
II. Safety

- A. The equipment must comply with all applicable OSHA safety requirements. Emergency stops shall be located on each side of the conveyor line and on the corona treatment machine. An additional emergency stop will be located on the cleaning machine and will be supplied by Wandres Corp. as part of that equipment. All of these emergency stops will be connected so that the entire system shuts down if any of them are triggered.

III. Requirements Summary:

- A. Throughput: minimum: 2 Modules per minute.
- B. The equipment shall be configurable for different module sizes.
 - 1) PV module size: Length: 45" to 65"; Width: 20" to 40"
 - 2) Module Weight: 15lbs – 50lbs
- C. PV module backing material: Poly-Ethylene Therephthalate (PET) or Tedlar
- D. Available utility hookup:
 - 1) Electric power: 120-208 VAC or 460 VAC 3-phase
 - 2) Air: 100 psi
- E. The PVPL manufacturer shall integrate the Dark IV testing equipment, PV cleaning equipment, and the Corona treatment equipment.

IV. Process Flow:



V. Other Requirements:

- A. The quote for the PVPL shall include integration and implementation costs.
- B. The quote shall be itemized
- C. The subcontractor shall provide detailed documentation on the construction, operation and maintenance of the equipment
- D. The subcontractor shall provide an extensive list of spare parts that will be needed for this system
- E. The quote shall include critical spare parts to be delivered with the system
- F. The subcontractor shall provide a document describing the warranty on the system

DESIGN

The equipment was designed concurrently with the control system. A series of meetings took place at PowerLight with all of the contractors working on the various components to ensure that everyone was aware of any changes in the plan and to discuss any technical issues that were encountered. As much as possible, standard components were used. A panel-cleaning machine was specified to automate the cleaning of the PV modules. The scanning of the serial numbers has been accomplished by PowerLight for some time with a custom-designed machine that also tests the modules and prints labels. The components of this machine were modified and rearranged to incorporate them into the new line.

Table 3: Summary of New Design

Current Process	Proposed Process
1. Labor Intensive – Seven Employees used currently	1. Semi-automated – Will require only two employees for loading and testing PV
2. Process – Poor repeatability, unreliable, no process controls	2. Process – PLC Controlled
3. Corona Treatment – Equipment not dependable, requiring regular maintenance, tool life 2 – 3 months, labor intensive	3. Corona Treatment – Dependable, industrial grade, minimal maintenance, automated
4. Cleaning – Labor intensive, inconsistent process	4. Cleaning – Automated, consistent and repeatable

Figure 50 shows the layout of the existing process. The layout and some components of the new design are shown in Figure 51.

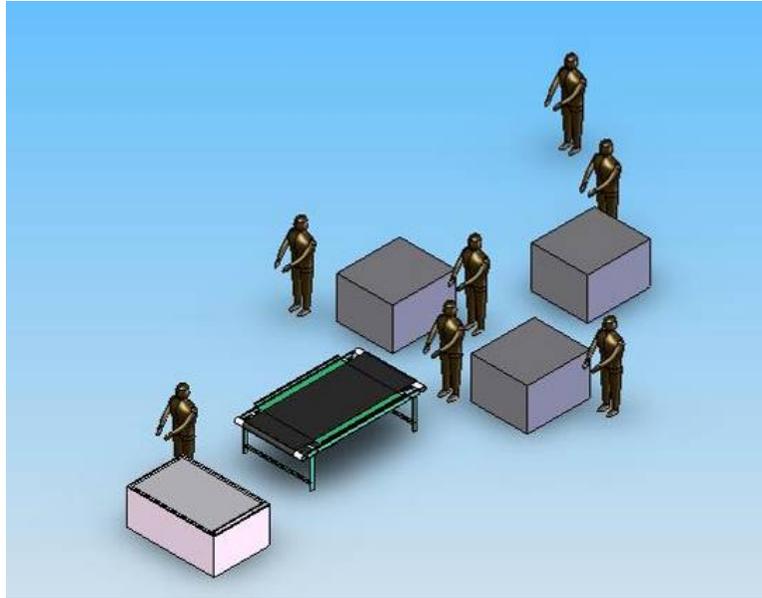
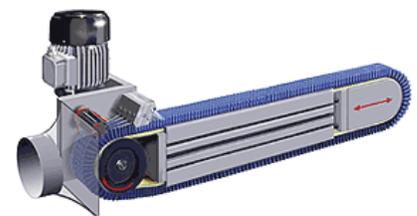
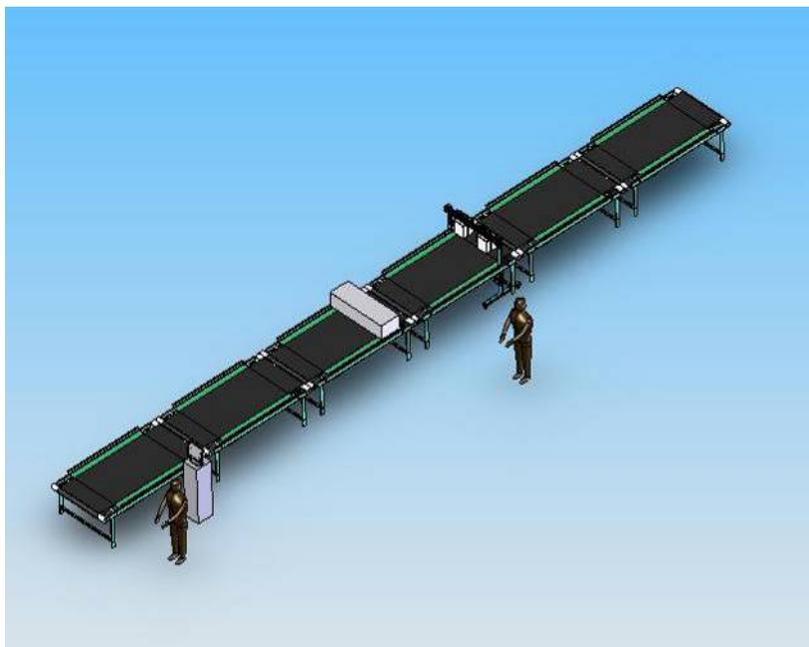


Figure 50: Existing Process



Panel Cleaning Machine



Surface Treatment Machine

Figure 51: New Equipment Layout

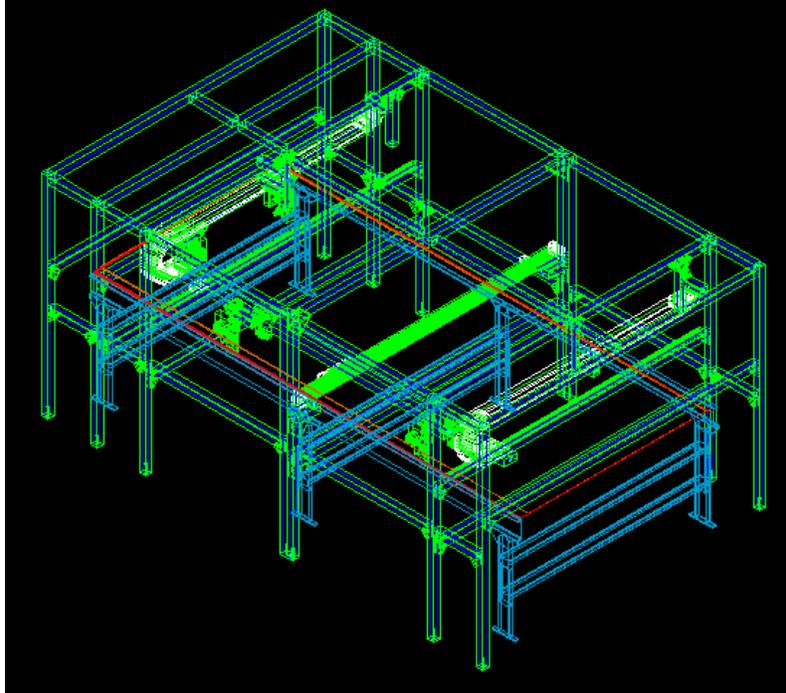


Figure 52. Layout of the Surface Treatment Section of the Equipment

2.6 Task 6: Environment, Safety & Health

The objective of this task is to reduce waste streams from both manufacturing and installation processes while working to improve the efficiency, ergonomics, and general safety of the workspace.

2.6.1 Kaizen Events

One of the goals of this task is the implementation of employee-suggested changes that result in improved efficiency, ergonomics, or general safety of the work environment. The tool used to implement these changes is called a *kaizen* event. *Kaizen* events will be discussed further in the Background section below.

Background

Currently, the PowerGuard manufacturing process is not continuous, as batch processing is employed. Once the backerboards are made, the coating must cure before the PV laminate can be adhered. A second curing step is required for the adhesive that is used to attach the PV laminate to the backerboard. When PowerLight first opened the Berkeley factory, the PV laminates were attached to the backerboards during the coating process. At that time, however, the coating process was not sufficiently well controlled to provide a consistent quality in the finished PowerGuard tiles; as such, the processes were separated. The coating process and final assembly process were improved significantly over the course of the next few years. The coating process is now tightly controlled, and the quality of the finished product is consistently very good. In light of this, it seems appropriate to combine the steps again to create one continuous process. This will have the benefit of reduced labor in material handling and improved use of factory floor space, allowing higher weekly production volume.

In order to set up a continuous, combined process, various changes needed to be made to the equipment layout and to details of the process. Hereafter, this process will be called the inline PV attach process.

In order to define and test these changes, PowerLight held a *kaizen* event with the factory workers to evaluate the feasibility of attaching PV modules to the wet backerboards.

Kaizen is a Japanese term that means continuous improvement. During a *kaizen* event, the workers are asked to create a solution to a particular manufacturing challenge. The challenge can be organization of tools, layout of the workspace, layout of the workflow, improvements in ergonomics, or anything else that affects worker productivity, product quality, product cost, or safety. The factory workers are a source of good ideas since they are involved in the manufacturing process every day. By involving the workers in the process of continuous improvement, they can have a sense of ownership for the product and the process.

Approach

The focus of the first *kaizen* event was to address issues concerning the shift to a continuous manufacturing process. The event started with a meeting to discuss the issues and come up with suggestions for improvements. The permanent manufacturing employees, the production supervisors, and engineers participated in the event. The following issues were identified at the meeting:

1. Layout of the process: The various pieces of equipment had to be rearranged so that the material could flow continuously. The normal setup had the coating process and the final tile assembly process separated by a large amount of space where the coated backerboards were stacked while the initial curing took place. The workers came up with their preferred layout of the equipment.
2. Spillage of the wet mortar on the conveyor: When the viscosity of the mortar varies, it can fall off the edges of the backerboards and get on the conveyor rollers. During the current process, the mortar is cured by the time that the PV laminates are attached. Any mortar on the bottom of the backerboards can be cleaned off. Even if it is missed, it will not stick to the top of the PV laminates when the tiles are stacked. With a combined, continuous process, the wet coating can get on the bottom of the backerboards and be transferred almost immediately to the top of the PV laminates. Better control of the viscosity will reduce this risk.
3. Contamination of the PV alignment fixture: The current alignment fixture registers the backerboard by contacting the edges of the coating. With the coating uncured, the alignment fences would quickly become contaminated with coating.
4. Spacers can lose contact with the backerboard when the tiles are lifted for stacking: When long spacers are adhered to the PV laminate, the spacers tend to pull away from the backerboard when the tile is lifted, disrupting the bond between the spacer and the coating.

The following were observed during the run:

1. The new layout proved to be effective for the pilot run. The coating edges must be trimmed after the coating process because they slump a bit during the insertion of the spacers and handling of the backerboards. If the coating edges

are trimmed too early, the coating will slump again, requiring the trimming to be repeated. If the trimming happens too late, the coating is too stiff and can break off at corners. The decision was made to trim the coating before the final assembly process. This worked well, though the PV alignment fixture was contaminated with coating as discussed below.

2. One difficulty that was encountered during the pilot run was the fluctuation of the liquid flow during the mixing of the coating. This had to be monitored very precisely in order to ensure that the viscosity of the coating was just right. More care than usual was taken to ensure that there was no spillage of the coating for the reasons discussed above. PowerLight subsequently installed a precise metering pump that controls the viscosity much more consistently, as discussed in Section 2.5.1.
3. As expected, the PV alignment fixture was contaminated with coating during the run. To compensate for this, the PV attach fixture was cleaned regularly during the pilot run. Based on the observations from this run, changes were discussed that would prevent this contamination. If the fences that are used to align the backerboard are moved so that they register against a lower portion of the tongue and groove profile, then the wet coating will not contaminate them.
4. As expected, once the PV laminate was adhered to the spacers, the backerboard was prone to sagging away from the spacers. When this happens, the spacers lose contact with the coating, disrupting the bond. If the coating is very fresh, then the spacer will adhere again when it is pushed back into the coating. However, it would be best to avoid this disruption altogether. Based on these observations, the spacer layouts of PowerGuard tiles are being evaluated to see if they can all be changed to use more short spacers rather than fewer long spacers. This will eliminate the disruption of the bond with the coating.

The focus of the second *kaizen* event was to design a new layout for the final assembly stations for PowerGuard tiles. The event started with a meeting to discuss the issues and come up with suggestions for the layout. The permanent manufacturing employees, the production supervisors, and engineers once again participated in the event. Several possible layouts were examined, and it was decided to experiment with a few. The assembly stations and associated equipment are easily moved around, so it was not difficult to rearrange them and try more than one layout.

Results

The first *kaizen* event was very successful. The ideas contributed by the employees were implemented for the layout of the pilot run, and their observations are being used to modify the equipment and some aspects of the tile design to improve the manufacturing process. These improvements will yield lower labor costs, lower space requirements, and lower cost for the PowerGuard manufacturing process. A continuous process will drastically reduce excess material handling, while reducing opportunities for damage to the product. The floor space required will be reduced as well. Once the tiles are completed during a continuous process, they can be packed in tightly for curing and then moved only when they are ready to be packaged and shipped.

The second *kaizen* event was also successful. After trying out several layouts, the workers agreed that one of them worked better than the other option. Once the equipment layout was decided on, the associated electric and pneumatic connections were moved to provide power for the new setup. The final layout is shown in Figure 53.

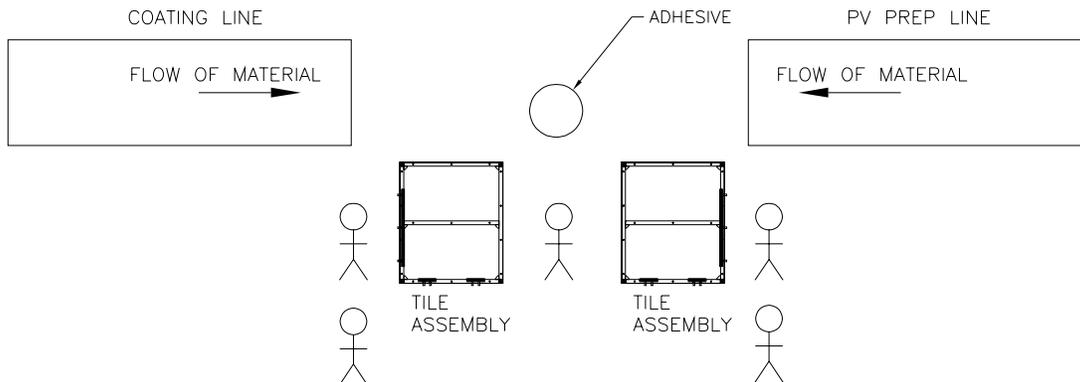


Figure 53: Tile Assembly Layout after Kaizen Event

The *kaizen* event was also important in giving the workers an opportunity to take part in improving their work environment. This gives them a sense of ownership that can help improve product quality and generate many good ideas.

2.6.2 Waste Stream Reduction

One of the expected results of this task is the development of an improved shipping method for PowerGuard tiles that would reduce shipping costs and site waste by at least 20%. At the start of this project, PowerLight expected to achieve this goal through the implementation of reusable shipping containers that maximize shipping density to the installation site and collapse for return shipment. In addition, PowerLight planned to investigate means of incorporating recycled materials into the design, when developing these reusable containers.

Background

Throughout its history, PowerLight has demonstrated a dedication to environmental protection and the health and safety of its workers. In 2003, PowerLight was awarded Green Business status by the county of Alameda, California demonstrating the commitment of the company to these concerns. PowerLight continues to look for new ways to mitigate environmental impact.

Site waste continues to be an opportunity for decreased waste streams and reduced cost. Removing packaging waste from the job site adds cost in the form of labor and disposal charges. It is also very important to PowerLight's corporate goals to create minimal environmental impact in the installation of PV arrays. For all of these reasons, it is important to reduce site waste.

Approach

PowerLight has looked for ways to reuse shipping containers in the past, but the cost has always been prohibitive due to the transportation cost associated with returning the containers to the factory. Prior to the start of this project, new analysis had shown that the cost of the return shipment could be offset by maximizing shipping density to the installation site. For example, by building containers that double shipping density and

then collapse for return shipment, the total number of trips to or from the site would be reduced.

The first step in this process was to evaluate the cost of different types of shipping containers. The preferred solution would be containers that are completely reusable. However, if that was not feasible, PowerLight wanted to investigate alternatives that would reduce site waste and environmental impact by increased shipping density and the use of recycled material.

PowerLight looked into a variety of materials for both reusable and single-use packaging, including recycled plastic and recycled cardboard. The cost analysis for reusable containers is shown in Table 4 below.

Table 4: Cost analysis of different packaging strategies for 750-kW installations

	Base case	Reusable containers	Increased stack height	Double stack
Job size (kW)	750	750	750	750
Module (W)	200	200	200	200
No. of modules required	3750	3750	3750	3750
Tiles per pallet	12	20	15	10
Pallets per truck	22	22	22	44
Cost per truck	\$3,000	\$3,000	\$3,000	\$3,000
No. of trucks required	15	9	12	9
Shipping cost to site	\$45,000	\$27,000	\$36,000	\$27,000
Cost per pallet	\$6	\$20	\$6	\$7
No. of pallets	313	188	250	375
Cost of pallets	\$1,878	\$3,760	\$1,500	\$2,625
Total cost to site	\$46,878	\$30,760	\$37,500	\$29,625
Return				
Capacity of truck for empty pallets	1056	1056	1056	1056
No. of trucks required	1	1	1	1
Return cost	\$ -	\$3,000	\$ -	\$ -
Total cost including return	\$46,878	\$33,760	\$37,500	\$29,625
Packaging/Transportation Savings		28%	20%	12%

Table 5: Cost analysis of different packaging strategies for 250-kW installations

	Base case	Reusable containers	Increased stack height	Double stack
Job size (kW)	250	250	250	250
Module (W)	200	200	200	200
No. of modules required	1250	1250	1250	1250
Tiles per pallet	12	20	15	10
Pallets per truck	22	22	22	44
Cost per truck	\$3,000	\$3,000	\$ 3,000	\$3,000
No. of trucks required	5	3	4	3
Shipping cost to site	\$15,000	\$9,000	\$ 12,000	\$ 9,000
Cost per pallet	\$6	\$ 20	\$ 6	\$7
No. of pallets	105	63	84	125
Cost of pallets	\$630	\$1,260	\$ 504	\$875
Total cost to site	\$15,630	\$10,260	\$12,504	\$9,875
Return				
Capacity of truck for empty pallets	1056	1056	1056	1056
No. of trucks required	1	1	1	1
Return cost	\$ -	\$3,000	\$ -	\$ -
Total cost including return	\$15,630	\$13,260	\$ 12,504	\$9,875
Packaging/Transportation Savings		15%	20%	26%

As demonstrated in Table 4, if a reusable container has a life of five trips and costs \$100, it will provide a 28% savings in packaging/transportation costs for large installations. As system size goes down, the benefit is reduced, as shown in Table 5 for a 250 kW system. For a 200-kW system, no cost savings is realized. A primary obstacle to implementation of reusable containers was the variety of sizes of PowerGuard tiles. PowerGuard tiles are sized to conform to the size of the PV module being used, and it is an advantage to be able to use the standard sizes offered by a variety of manufacturers. Even with a small number of sizes (three or four), the number of reusable containers that would need to be on hand at any one time would be prohibitively large, especially in the context of additional storage costs.

Another issue that has hampered this effort is the recent volatility in the PV supply. Delays in PV supply have forced PowerLight to store material for a portion of a job while waiting for PV to be delivered to finish production. This also increases the number of shipping containers that would need to be on hand. The cost of these shipping containers and the cost of storing them have proven to be prohibitive, though at some point in the future, changing conditions may make this viable.

Since reusable containers proved infeasible at this time, PowerLight looked for ways to increase shipping density and, thereby, achieve the site-waste and cost reduction goals. PowerGuard tiles were generally stacked 12 high on each pallet. This was primarily

done to allow workers to stack the tiles easily in the factory and to unstack them easily at the job site. A stack of twelve PowerGuard tiles is approximately 60 inches high. Most trucks have an interior height between 98” and 110”. If we could change the stack to close to 100”, then we would use much more of the available volume of the truck bed, reducing the number of trips required to bring material to a job site, thereby, reducing transportation costs. Unstacking a pallet that is eight feet tall, however, becomes nontrivial. This was seen as a potential liability. We then investigated the possibility of taking two pallets with stacks of PowerGuard tiles and placing one on top of the other for shipping. When the stacks were unloaded from the truck, the two pallets could be separated either prior to lifting to the roof or after they had been lifted to the roof. This would maintain an ergonomic unstacking height for the workers. PowerLight investigated the use of corner supports that were strong enough to support the second stack on top of the first one. Corner supports were found that were made from recycled plastic bags and were easily strong enough to provide the needed support. Figure 54 shows an initial test of these supports.



Figure 54: Test of corner supports in double stacked pallets

Unfortunately, this approach also ran into problems. To offset the cost of the second pallet and the stronger corner supports, each stack would need to be at least 20 tiles, or 10 tiles per pallet, to achieve significant savings, as shown in Table 4 and Table 5. While truck beds are available that can accommodate a 102” stack, these are not as common as trucks with lower ceilings, making the taller trucks more costly. This

required the stack height to be reduced to 18, and at this level, the benefit was reduced to almost nothing for the majority of system sizes.

The final approach was to increase the stack height as much as possible without adding a second pallet. With some experimentation, we found that the workers were able to stack and unstack up to 15 tiles. Table 4 and Table 5 show that this reduces shipping costs, as well as the associated site waste by up to 20%. The main issue with this approach was the compressive strength of the spacers of the bottom tiles. Shipping tests were carried out with accelerometers mounted on the top and bottom of stacks of various heights; the results of these tests are discussed below in the next section.

Results

The improvement that has proven to be successful is the increase in stack height from 12 to 15 tiles. This solution reduces the amount of packaging by 20% as well as reducing the number of truck trips required by 20%. The shipping tests showed that the accelerations experienced by the stacks during shipping do not cause compressive failures of the spacers. There was some indication, however, that rough handling of the stacks during loading and unloading of a truck could cause stresses that were potentially harmful. It was unclear, however, how big a risk this was. PowerLight engineers decided to implement the change in stack height and then monitor the installations that followed to determine the frequency and cost of any damage incurred. It is reasonable to accept a certain amount of damage if the cost of dealing with this damage is far less than the amount of money saved by the increase in shipping density. It was decided that any damaged tiles would be replaced so that there would be no risk to the structural integrity of any part of the system.

At the time of this report, PowerLight has shipped over 10,000 tiles with the new stack height, and there have been only 12 tiles damaged. The majority of this damage occurred during the first few shipments. Once the project managers became accustomed to dealing with the higher stacks, they were able to avoid damage to the tiles.

Conclusion

While the initial approach to decreasing site waste and packaging costs has not proven feasible, PowerLight has succeeded in accomplishing the goals of this portion of the task by reducing shipping costs by 20%. As conditions change, PowerLight will continue to look for ways to reduce costs and environmental impact.

2.7 Task 7: Commercial Demonstration

The objective of this task is to use commercial demonstration projects to assess the efficacy of the implemented modifications from the preceding Phase I task activities. A total of 2000 to 4000 PowerGuard tiles, totaling at least 500 kW_p, was to be used at commercial demonstration sites for this assessment. The performance of these commercial demonstration projects was to be monitored to quantify improvements in system performance, and the costs were to be collected to evaluate the results of cost reduction efforts in Phase I.

As discussed in Section 2.2.1, PowerLight has been developing a foamless tile design, called RFT10, targeted for customers without added-insulation needs. Like the standard PowerGuard tiles, RFT10 is designed to mount on flat roofs without the need for penetrations in most sites.

PowerLight has been working to reduce the cost of energy from rooftop PV systems by improving system performance and reducing installed system cost. The best way to gauge the effectiveness of these efforts is to monitor the performance and cost of actual installed systems.

2.7.1 System Performance

Approach

Improvements in system performance and reliability are being measured by comparing new systems, which have improved monitoring and diagnostic equipment with historical data from a range of existing systems. The “control” sites, listed in Table 6, were existing sites that we are using for comparison with the new sites.

Table 7 lists the “test” sites that were installed during the course of this project with new monitoring and diagnostic equipment.

Table 6: Existing Systems for Comparing System Performance

System ID	Site Type	Location	Inception Date	Rated Power (kWp)	Performance Index	System Availability
System 1	Control	Los Angeles, CA	4/30/2003	115.1	98%	100%
System 2	Control	Hayward, CA	1/8/2004	261.0	95%	100%
System 3	Control	Hayward, CA	2/14/2004	101.8	95%	100%
System 4	Control	Hayward, CA	3/24/2004	114.0	101%	98%
System 5	Control	Hayward, CA	1/5/2004	243.3	106%	100%
System 6	Control	Hayward, CA	1/5/2004	279.7	105%	95%
System 7	Control	San Francisco, CA	10/18/2003	234.5	97%	99%
System 8	Control	San Francisco, CA	10/18/2003	234.5	99%	100%
System 9	Control	San Francisco, CA	2/27/2004	207.0	102%	99%
System 10	Control	Walnut Creek, CA	1/30/2003	93.6	108%	100%
System 11	Control	Healdsburg, CA	6/18/2004	258.3	96%	99%
System 12	Control	Healdsburg, CA	6/18/2004	199.1	106%	100%
System 13	Control	San Mateo, CA	1/27/2003	233.7	94%	96%
System 14	Control	Sacramento, CA	2/3/2004	201.4	96%	94%
System 15	Control	Sacramento, CA	2/3/2004	201.4	95%	93%
System 16	Control	Rohnert Park, CA	1/29/2003	96.0	95%	100%
System 17	Control	Torrance, CA	2/6/2003	37.1	98%	96%
System 18	Control	Torrance, CA	2/5/2003	124.7	105%	100%
System 19	Control	Torrance, CA	2/5/2003	124.7	100%	100%
System 20	Control	Torrance, CA	2/5/2003	124.7	101%	100%
System 21	Control	Torrance, CA	2/5/2003	124.7	97%	100%
System 22	Control	Vallejo, CA	3/14/2003	107.8	89%	100%
System 23	Control	Vallejo, CA	3/14/2003	224.0	95%	98%
				Average	98.8%	98.6%

Table 7: Test Systems for Comparing System Performance

System ID	Site Type	Location	Inception Date	Rated Power (kWp)	Performance Index	System Availability
System 24	Test	Oakland, CA	6/9/2005	100	N/A	N/A
System 25	Test	Oakland, CA	7/28/2005	265	N/A	N/A
System 26	Test	Oakland, CA	7/28/2005	265	N/A	N/A
System 27	Test	Oakland, CA	7/28/2005	252	N/A	N/A
System 28	Test	Oakland, CA	7/28/2005	121.8	N/A	N/A

Results

Performance Index and Availability figures are shown in Table 8 for the control group of sites for two periods: September 1, 2004 - August 31, 2005 and February 1, 2005 - January 31, 2006. This data is shown for the test group for the periods from February 1, 2005 - January 31, 2006 only; data for Test System 24 are available from June 2005 and figures for Test Sites 25 through 28 include data from September 2005. Data for Systems 25 through 28 prior to September 2005 were excluded because of manual shutdowns associated with the project installation. Energy from these systems was tracked via the data acquisition system, but measures of availability and performance index for the site are slightly skewed by the frequency and duration of shut-downs related to breaker installations and other site work. During the period February 1, 2005 - January 31, 2006, twenty of the twenty-four control sites were off at some point during the year for planned maintenance or because of an unplanned outage (utility outage or inverter failure). None of the test sites suffered inverter outages during this period, and none were shut down for planned maintenance.

Table 8: Results of system performance monitoring

					Performance Metrics for 09/01/04 – 08/31/05		Performance Metrics for 02/01/05 – 01/31/06	
System ID	Site Type	Location	Inception Date	Rated Power (kWp)	Performance Index	System Availability	Performance Index	System Availability
System 1	Control	Los Angeles, CA	4/30/2003	115.1	98%	100%	95%	98%
System 2	Control	Hayward, CA	1/8/2004	261	95%	100%	91%	100%
System 3	Control	Hayward, CA	2/14/2004	101.8	95%	100%	95%	100%
System 4	Control	Hayward, CA	3/24/2004	114	101%	98%	98%	99%
System 5	Control	Hayward, CA	1/5/2004	243.3	106%	100%	101%	98%
System 6	Control	Hayward, CA	1/5/2004	279.7	105%	95%	102%	94%
System 7	Control	San Francisco, CA	10/18/2003	234.5	97%	99%	95%	100%
System 8	Control	San Francisco, CA	10/18/2003	234.5	99%	100%	95%	100%
System 9	Control	San Francisco, CA	2/27/2004	207	102%	99%	100%	100%
System 10	Control	Walnut Creek, CA	1/30/2003	93.6	108%	100%	106%	100%
System 11	Control	Healdsburg, CA	6/18/2004	258.3	96%	99%	102%	99%
System 12	Control	Healdsburg, CA	6/18/2004	199.1	106%	100%	108%	99%
System 13	Control	San Mateo, CA	1/27/2003	233.7	94%	96%	92%	94%
System 14	Control	Sacramento, CA	2/3/2004	201.4	96%	94%	93%	94%

					Performance Metrics for 09/01/04 – 08/31/05		Performance Metrics for 02/01/05 – 01/31/06	
System ID	Site Type	Location	Inception Date	Rated Power (kWp)	Performance Index	System Availability	Performance Index	System Availability
System 15	Control	Sacramento, CA	2/3/2004	201.4	95%	93%	93%	95%
System 16	Control	Rohnert Park, CA	1/29/2003	96	95%	100%	92%	100%
System 17	Control	Torrance, CA	2/6/2003	37.1	98%	96%	96%	96%
System 18	Control	Torrance, CA	2/5/2003	124.7	105%	100%	104%	100%
System 19	Control	Torrance, CA	2/5/2003	124.7	100%	100%	98%	100%
System 20	Control	Torrance, CA	2/5/2003	124.7	101%	100%	99%	100%
System 21	Control	Torrance, CA	2/5/2003	124.7	97%	100%	102%	100%
System 22	Control	Vallejo, CA	3/14/2003	107.8	89%	100%	87%	100%
System 23	Control	Vallejo, CA	3/14/2003	224	95%	98%	92%	97%
				Average	98.8%	98.6%	97.2%	98.4%
System ID	Site Type	Location	Inception Date	Rated Power (kWp)	Performance Index	System Availability	Performance Index	System Availability
System 24	Test	Oakland, CA	6/9/2005	100	N/A	N/A	106%	100%
System 25	Test	Oakland, CA	7/28/2005	265	N/A	N/A	106%	100%
System 26	Test	Oakland, CA	7/28/2005	265	N/A	N/A	111%	100%
System 27	Test	Oakland, CA	7/28/2005	252	N/A	N/A	97%	100%
System 28	Test	Oakland, CA	7/28/2005	121.8	N/A	N/A	103%	100%
				Average	N/A	N/A	104.5%	100.0%

Both the performance index and availability for the test sites are higher than for the control sites. This is due in part to the implementation of more advanced monitoring systems at these sites. However, these data are not sufficient to fully validate the more advanced monitoring. Availability and performance index are impacted by many factors, only one of which is the rapidity of PowerLight's response to a problem. For instance, the availability of System 6 is quite low because of an extended inverter outage at this system. Although PowerLight responded to the outage within 24 hours using our existing monitoring system, the inverter manufacturer was unable to diagnose the problem and fully repair the unit in a timely fashion; the inverter was down and/or running at half power for over two weeks. If such an outage had struck one of the test sites, availability would have been impacted similarly; although more advanced monitoring will help PowerLight respond to problems more quickly, it cannot change the amount of time that a system is off once a problem is discovered.

We can conclude from this data that the test sites are operating at higher levels of performance index and availability than the control sites, but a longer measurement period will be necessary to give us confidence in the role that our advance monitoring systems have played in this improvement. We will continue to monitor these sites during the second phase of this contract.

2.7.2 Cost Reduction

Approach

The cost reduction activities have involved modifications to standard PowerGuard tiles as well as improvements to PowerLight's newly introduced sloped product, RFT10. The sites that were used for these assessments are shown in Table 9.

Table 9: Sites for Cost Reduction Assessment

Site ID	Location	Product	Inception Date	Current Rated Power (kWp)
Site 1	Oakland, CA	PowerGuard	August 2005	262
Site 2	St. Helena, CA	PowerGuard RFT10	August 2005	229
Site 3	Napa, CA	PowerGuard RFT10	September 2005	195

Results

In August 2005, PowerGuard tiles with reduced coating thickness were installed at a demonstration site in Oakland, California. This was PowerLight's first opportunity to observe the quality of a large number of production tiles made with the new coating thickness, a cost-saving improvement implemented under Task 2: High Reliability Cost Reductions. It was also the first opportunity to install these tiles and confirm that the durability was not compromised. The array was constructed with 500 tiles that had the reduced coating thickness and approximately 1,300 tiles that had been made with the standard coating thickness. This allowed for a side-by-side comparison.

The workers appreciated the lower weight of the new tiles, which made them easier to handle. PowerLight engineers were on hand during the installation to look for any damage and to discuss the new tiles with the installers. Out of 500 tiles, 12 were found with various amounts of damage. In some cases, this was due to handling in the factory or shipping. Approximately eight of these tiles had been damaged on-site. Most of the damage was aesthetic only and did not compromise the structural integrity, so the tiles were still usable. PowerLight engineers discussed the damage with workers at the site and in the factory to find ways to eliminate damage. Future installations will be monitored to ensure that damage is minimized. Figure 55 shows the array with the reduced coating thickness during installation. Figure 56 shows a close-up of the difference in coating thickness between a standard PowerGuard backerboard and the new backerboard.



Figure 55: Demonstration array with reduced coating thickness during installation



Figure 56: PowerGuard tile with reduced coating thickness (on right)

The reduction in coating thickness, increased stacking height, and reductions in labor resulted in a reduction in backerboard cost of 17.8%.

In September 2005, PowerLight completed the installation of the first large-scale arrays of RFT10. The installation went smoothly with only a few exceptions. The most common problem encountered was galling and stripping of the threads of the studs that were pressed into the aluminum PV supports. PowerLight worked with the suppliers of the sheet metal parts and the studs to determine the cause of the stripping. Eventually,

the problem was linked to the temperature of the studs. The problem was duplicated reliably in the shop by using an oven to heat a plate with many studs pressed into it. The demonstration arrays were installed in August and September in the vicinity of Napa, California, where temperatures were routinely between 95°F and 100°F. A later installation done in New Jersey in the winter experienced no problems with stripping threads. PowerLight is looking into an appropriate lubricant that can be used to prevent the threads from being damaged during hot weather.

Another problem encountered was the amount of labor required to install the North-South wiring. These systems used an off-the-shelf wire gutter running between modules, shown in Figure 57. This system was difficult to keep aligned, and it did not accommodate variations in the roof contour easily. Based on this feedback, PowerLight subsequently redesigned the North-South wiring method so that it is much easier to implement, more flexible, and less expensive.



Figure 57: Wiring gutter during installation (designed changed after this installation)

The installation of these systems took less labor than was anticipated, with the exception of the North-South wiring. After the crews had one or two days' of experience, they were able to assemble the array pieces very quickly. It took some experimentation to learn that the array alignment was easier to maintain if the modules were installed in North-South columns rather than working from East to West in rows. Figure 58 shows an array during installation. Figure 59 and Figure 60 show a completed array.

As part of the ongoing monitoring of this system, PowerLight personnel inspected the array after a storm in December 2005 to make sure that the system was unaffected by the high winds. The system was found to be in perfect order. No changes were observed after a careful inspection.



Figure 58: RFT10 system during installation



Figure 59: Completed array from Southeast



Figure 60: Completed array from East

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