PHOTOVOLTAICS: THEORY TO REALITY AT THE BOWDOIN-GENEVA COMMUNITY CENTER IN DORCHESTER, MASSACHUSETTS

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INTRODUCTION

In today's fuel-conscious economy, most developers and facility managers are searching for real ways of reducing energy and operational costs. At the same time, our fossil-fuel-dependent country is witnessing the design community working with numerous experts in the renewable energy fields, such as solar energy systems, to solve the need for real reductions in fuel consumption and environmental pollution. These two forces are not only "greening" the construction industry, they have changed the way projects are envisioned, undertaken, and financed. The theories behind these Renewable Energy systems have always sounded like such wonderful ideas, but were normally the first systems dropped from a project for reasons of initial installation costs, unfamiliarity in the construction industry, or risk considerations from facility and maintenance professions concerned about investing in unproven systems.

Photovoltaic solar panel arrays have become one renewable energy system that has been tried and proven in Europe for years and is now becoming a common reality in the U.S. marketplace. With more and more projects obtaining financial assistance through funding grants, the payback analysis has become more palatable as a cost-possible solution; and the cost of the systems are reducing as the supply and demand has changed. As more photovoltaic product innovations come onto the market and more manufacturers and suppliers come into the market, the initial installation costs are also becoming more competitive. Project owners, or stakeholders, are also taking the time to analyze the real savings to their long-term operational budgets and their environment. In addition to saving costs, and the environment, photovoltaic arrays provide simple, low-maintenance solutions that can be as "visible" or "invisible" to the surrounding neighborhood and community. Gone are the inflexible large solar panel systems that need *to sit high above roofs at south-facing angles to best harvest the sun's energy. Today's products and systems can be installed in numerous ways, such as low-slope exterior window shading devices, or low slope flat roof installations, or integrated into the glass panes of a building's window system. These installation and system options give designers more site planning flexibility for optimal orientation to the sun, make more of the building's exterior surface areas available to the photovoltaic cells, and lend design solutions the flexibility for unique aesthetics and imagery or subtle integration into traditional or historic preservation designs.*

PROJECT BACKGROUND

The proposed Bowdoin Geneva Community Center is a new 45,000 square foot building sited on the corner of Bowdoin Street and Topliff Street in the Dorchester neighborhood of Boston, Massachusetts. The community center is a private development owned by a non-profit organizational partnership working closely with the City of Boston's department of neighborhood development to serve adult education and after-school youth programs. When completed the building will house the following programs:

Education Center: The Log School will provide adult education, after school and summer programs for school-age children, and a 40-children day care program with a secured outdoor playground.

Community Center: The center will provide after school and summer programs for teens and

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MATCH School in Boston MA by HMFH Architects, Inc. 20 kW flat laid roof-mounted photovoltaic array providing 14% of school's annual electricity consumption. 2003 NESEA Solar Electric Award.

pre-teens, computer rooms, and recreational programs. Bird Street, a non-profit organization well established in the neighborhood, will operate the center which expects to serve approximately 200 members of the community each day.

Food Pantry: A food pantry serving 250 families per week will be housed in this building and operated by the Federated Dorchester Neighborhood House (FDNH), a non-profit organization well established in the neighborhood, currently operating the pantry from the basement of an older building across the street from the site.

Community Fitness Center: A gymnasium with an NCAA regulation basketball court, weight and exercise facility, and associated locker rooms will be part of the community center operated by both Bird Street and FDNH.

Community Room: A community room will be available to the community at large for facilitating various community functions.

Retail: 1,000 square feet of street level retail space will be designed and will be leased by the partnership.

In the case of the Bowdoin-Geneva Community Center, the Dorchester Bay Economic Development Corporation[1] selected its architect, HMFH Architects, Inc., based on their award-winning green building designs, as well as their success in applying for and obtaining renewable energy funding grants. HMFH's first Green project was a passive solar home designed in 1978. Years later HMFH designed the first USGBC LEED®-registered public school in the Northeastern US; and has received more than $2,000,000.00 in renewable energy grants for its clients, from sources such as the Massachusetts Technology Collaborative.

The proposed Green project is to be developed on an inner-City brownfield site that is home to an abandoned gas station and an abandoned automotive repair shop. HMFH proposed following the US Green Building Council's Leadership in Energy and Environmental Design® process.[2] Using the LEED® process brings a level of "Green" validity to the project for its owners, users, and community in that the project is recognized as a Green building through the independent audit and certification of the U.S. Green Building Council. In this proposal, the architect also suggested that the developer consider pursuing a renewable energy grant from the Massachusetts Technology Collaborative[3] for the use of photovoltaics as a renewable energy source.

CONSIDERING THE USE OF PHOTOVOLTAICS

The theory of free electricity sounds great, but if the long-term feasibility or initial costs do not support the effort, most projects will not pursue the proposal. To start, the site attributes and the orientation of the building are partnered with the best solar cell products and systems. At Bowdoin-Geneva, the site slopes down hill from north to south. The building is located at the top of the hill, adjacent to 3-family, 3-storey residential properties. These givens matched well with the three-storey design and the proposed use of both low-slope photovoltaic (PV) roof mounted arrays and low-slope south facing arrays applied to the building facade as sunshades for the south facing windows. Feasibility studies and post-construction cost studies show that maximizing the size of the photovoltaic (PV) array and minimizing the use of supplemental support structure produces the best investment and payback conditions. The investment analysis needs to prove that the initial installation costs will be more than offset by the savings from the reduced energy costs, within a reasonable amount of time, and before the photovoltaic (PV) arrays need to be reconditioned. Grant funding is currently the wild card in this analysis. Being able to install a system for approximately 50% of the initial installation cost, thanks to renewable energy grants, gives the best payback time and enlarges the PV system to gain the necessary savings. Utility companies are also participating with the initial costs by offering utility rebates for implementing energy-saving products and systems. Lastly, philanthropic donations from established community members are common to projects determined to "green" their environment by using renewable energy systems on buildings designed for community use, such as neighborhood schools and community centers.

REALITY OF PHOTOVOLTAICS FOR BOWDOIN-GENEVA

Bowdoin-Geneva planned to benefit from all of the above, which required being awarded a grant if the photovoltaics were to become a reality for the proposed community center. If a grant could make the renewable energy system financially possible, then the project would pursue a Silver-certification under the LEED® program. Given the fixed budget, and the fact that LEED® Silver green buildings have proven to cost 2% to 5% more than basic LEED® certified green projects[4], it became crucial to balance the photovoltaic system size, the building's assumed energy savings via its high performance systems, and the funding sources. The project team of owner, architect, consultants, operators, and users needed to consider the project as a whole in order to avoid having the photovoltaic system consume too much of the limited financial resources and find itself on the cutting room floor.

30 kW low slope flat roof photovoltaic array. 2003 NESEA Green Building Award. Capuono Early Education Center, Somerville, MA, HMFH Architects, Inc. Awarded $630,000.00 in Grant Funds from the Massachusetts Technology Collaborative.

For several years HMFH Architects, Inc. has been working with Solar Design Associates, Inc. to apply for renewable energy grants, design renewable energy systems, and administer the installation of photovoltaic systems—mostly on projects with very delicate budgets, such as new public schools, existing building renovations, and in the case of Bowdoin Geneva, a non-profit inner-city community center.

The grant application included an experienced team, led by HMFH Architects and Solar Design Associates, who has successfully implemented other MTC renewable energy grants and photovoltaic systems.

In early 2006, Bowdoin-Geneva was awarded a $414,000.00 MTC renewable energy grant for designing and implementing a $685,133.00 photovoltaic (PV) system. With the inclusion of the renewable energy system, the project will register for a LEED® Silver certification from the USGBC.

The architect prepared the MTC Grant application for its client using system descriptions and analysis authored by the solar design consultant. The following information under the heading (SDA) is part of the MTC Grant and describes the Bowdoin-Geneva proposed system as authored by Solar Design Associates, Inc.

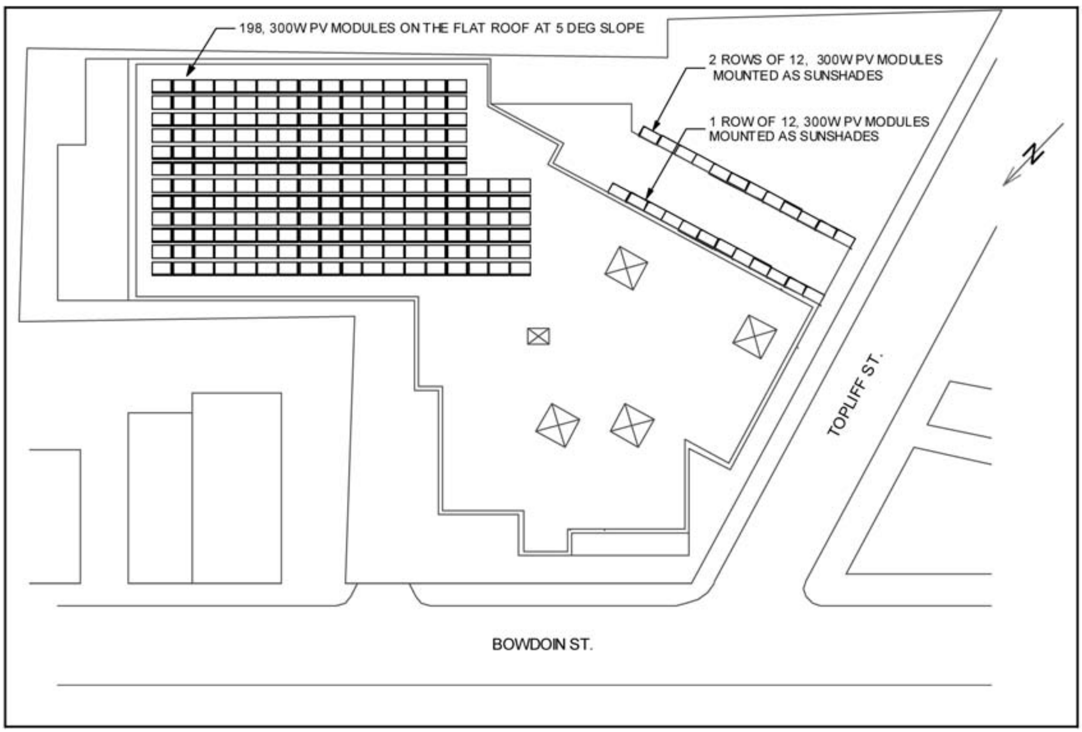
GRANT FUNDING (SDA)

The proposed project includes a low-slope photovoltaic (PV) system of approximately 59.4 kilowatts (kW) that will be installed on the building's flat roof, and a smaller PV system of approximately 10.8kW that will be installed as sunshades over the south facing windows. These systems will produce, on average, approximately 67,450 kilowatt-hours (kWhac) of electricity each year, which is expected to be over 19% of the building's annual electrical load. The estimated total installed cost of the systems is approximately $685,133.00, with an estimated payback of just about 20 years with funding assistance from the Massachusetts Technology Collaborative (MTC).

Solar Design Associates, Inc. (SDA) of Harvard, Massachusetts will develop recommendations, perform preliminary performance modeling, and generate cost estimates for the deployment of the PV systems on the building. This will be a landmark project for the area, and the installation of solar arrays will be a very appropriate addition to the architect's progressive design approach for the energy-saving mechanical and electrical systems within the building.

Two types of PV arrays are presented as viable applications of PV technology for the building that has been designed. The first is a rooftop array consisting of large-area modules held in place by ballasted roof racks. The second is an array of PV sunshades, where the PV modules will replace traditional sunshade elements and will mitigate unwanted solar gain while at the same time producing useful electricity. The end result will be an installation of renewable energy

FIGURE 1. BGCC building plan showing proposed PV system locations.



technology that both produces a significant portion of the building's power while also placing portions of it in a highly visible location. The proposed PV system locations are shown on the outline of the building in Figure 1 below.

The PV modules proposed for use in both of the systems in this project are high efficiency, large area crystalline modules with a power capacity of 300Wdc each. These modules currently have the highest power rating of the available modules on the market today. Given their size (approx. 4' x 6') and high power, these modules offer the advantage of requiring fewer installed pieces in order to achieve the desired power rating. Within the industry it is now standard that modules come with a 20-year production warranty that guarantees that after 20 years the modules will still produce 80% of their originally rated power output. The modules that were used to determine the system sizes and estimated annual renewable energy production for this study are locally manufactured in Billerica, MA and so if used in the project will have a relatively low shipping cost. The module manufacturer also offers a low-slope (5 degree tilt) rooftop mounting system for the module, similar to the one shown in Figure 2 below, and this type of system is seen as the best fit for installation on the roof of the gymnasium of the center as shown in Figure 1.

LOW-SLOPE FLAT ROOF PV SYSTEM (SDA)

This low-slope flat roof PV system offers several advantages over higher sloped roof mounted systems. First is the advantage of installation ease and low hardware cost. The system is typically simply ballasted by the weight of the modules and support components with some additional easily deployed perimeter ballast material. It is designed to sit directly on top of the roofing membrane and in most applications requires no roof penetrations or structural interface to secure the array. In order to withstand the typical wind loads, a higher-sloped system would require either heavy ballasts or roof penetrations to secure the array to the building structure, both of which would increase the installation cost.

A second advantage of the low-slope system is that it will produce more energy during the summer, and this is typically the time of year when the utilities experience their peak energy demand. PV systems produce more energy in the summer season because the sun is higher above the horizon than at any other time of the year. During this time, the low-sloped system will more directly face the sun, producing more energy per square foot than an equivalent high-sloped system.

The actual energy production of the low slope PV system will ultimately depend on a number of fac-

FIGURE 2. Flat roof low-slope PV mounting system.

tors, including the module technology that is selected and the orientation of the installed array. An array in Boston, MA is at optimal efficiency at a slope of 35 degrees and a due south orientation, so that the array is facing the sun throughout the majority of the year. The low slope rooftop system that was used as a model for this report has a slope of 5 degrees, which produces about 8% less energy than an array at the optimum slope. The rooftop system fits best if it is laid out parallel with the roof as shown in Figure 1. Since the slope is at such a low angle, changes in southerly orientation have little effect on energy production. If the low slope system were positioned due south, the increase in production would be less than 0.5%.

The rooftop systems on the market today utilize components that are supported by the roof and lie directly on the roof membrane, typically without being mechanically attached to the roof. If a wholesale modification or replacement of the roof is required, the system can be easily removed. One of the less obvious benefits of rooftop PV systems is that they shade the roof surface from the sun's harmful UV rays, potentially reducing damage and repair costs to the roofing membrane.

The inverters that have been considered during this study require module source circuits that are in multiples of 6 modules each, but new inverter offerings are constantly being offered, so it is expected that more options will be available at the time of installation should any changes be required. Some modules may be removed from the conceptual layout during the design process after the inverters have been selected and the optimal module multiple and system size have been determined. It is preferred that the equipment on the roofs where PV is planned be limited to what is necessary for roof drains.

In general, installation of the flat-roof PV system has not been seen to affect the roof manufacturer's standard warranty. As mentioned, a benefit of the rooftop PV system is that it can actually help to protect the finished roof surface from weathering. Typically, when the PV system installation is part of the original bid package, roofing manufacturers have minimal issues with the effect of the PV system on the finished roof surface. However, extra care should be taken during installation to protect the roofing material from damage.

Due to the large system size, it is recommended that the crates containing the modules, the modules' support system, and other required hardware be lifted onto the roof with a crane. It is important to consider the staging areas for the rooftop equipment and also confirm that the roof can handle the loading caused by the concentrated load from the crates of PV equipment.

There are several manufacturers that produce products like the one described in this report. These companies include (but are not limited to): Schott Solar (www.us.schott.com), Evergreen Solar (www.evergreensolar.com), PowerLight Corporation (www.powerlight.com), and Direct Power & Water (www.directpower.com). During the bid process, competitive bids from all of these manufacturers should be encouraged. It must be verified that the weight of the selected flat roof PV system does not exceed the design load of the roof structure. Most flat roof PV systems weigh approximately 5 pounds per square foot and typically have some concentrated loads around the perimeter where the system ballast is placed.

PHOTOVOLTAIC SUNSHADES (SDA)

Another location that has been selected for a PV array is the south facing windows as indicated in Figure 1. Sunshade modules help to mitigate solar heat gain and glare within the building while generating clean, renewable energy. Figure 3 demonstrates a BIPV sunshade system utilizing large crystalline PV modules similar to those selected for the Bowdoin-Geneva sunshade system. It is also possible to use amorphous silicone modules for an appearance similar to tinted glass. Sunshade BIPV systems should not be located over pedestrian areas as they may shed snow and ice during winter months. Figure 3 shows a similar installation of PV modules as sunshade elements on a building located in southern California.

The slope of the sunshade system modeled in this study has been selected to be at the optimum tilt mentioned above. The actual production will again depend on the actual orientation that the system is installed at, as well as the module technology that is used during the installation. Due to the Boston, MA weather file used in the modeling, this sunshade system actually performs slightly better at the slight easterly position that it is at (about 15deg east of

FIGURE 3. Example of PV sunshades.

south), than it does facing due south, but the difference again is less than 0.5%.

The sunshade support structure will be designed specifically to accommodate the photovoltaic modules during the design phase of the project.

The low-slope flat roof system and the sunshade array are the only PV system designs that were developed in detail in this study. There are other options for BIPV systems but they have not been considered in the preliminary building design. Custom insulated glass PV laminates could be installed in the southwest- and south-facing glazing of the building, but it is expected that material and installation costs would be at least double that of the flat roof system. In addition, the building architecture and planned use of the occupied space is more suitable for the sunshade system.

The low-slope array will not be visible from ground-level near the buildings, since the array lies relatively flat on the roof and the buildings are about 40 feet tall. The array would be visible from an elevated position some distance away. However, the sunshade-mounted array would be visible from the street, making the integration of PV on this building highly visible.

METHODOLOGIES—PV SYSTEM PERFORMANCE ESTIMATES (SDA)

All of the power ratings for the PV arrays in this report are presented in direct current kilowatts (kWdc) at Standard Test Conditions (STC). These test conditions are defined as 1000 W/m^2 irradiance, 25°C cell temperature, and spectral distribution at Air Mass 1.5. It is important to note that these conditions are produced in the laboratory solely for the purpose of rating the modules. The test conditions are not something that modules experience once installed, and any measured output needs to be normalized to the test conditions. The array sizes that have been proposed in this report have been derived from CAD files provided by the project architect. Estimated electrical energy harvest amounts are calculated with Solar Design Associates' software and represent the net expected AC kilowatt hours (kWh) output of the system after overall power conversion efficiency and local weather data is taken into account. The software utilizes 30 years (1961–1990) of weather observations for Boston to estimate the annual production of the PV system. These weather files are analyzed, and the system performance is determined, based on a typical year's weather conditions. It should be noted that an actual year may vary from this "Typical Meteorological Year" (TMY) data by as much as 25%. For the rooftop system the output for the months of January and February were removed from the total estimated production. This is to account for those periods when the array has enough snow coverage to reduce its output to zero. This is a reduction of about 11% of the annual estimated output of the rooftop array.

The overall conversion efficiency of DC power to AC power has been assumed to be 75%, which is representative of measured field values from similar systems. This includes wiring losses, inverter and transformer losses, module mismatch losses, and other miscellaneous system inefficiencies. The performance of the proposed arrays will likely vary on an annual basis from the performance estimates presented in this report, due to variations in the weather conditions from year to year. However, it is expected that over the life of the system they should be close to the averages that are described herein.

The inverters included in the cost estimates have been selected to best match the output of each array, and may change depending on the electrical characteristics of the final system. The goal of the array sizes selected was to implement the sunshade array over as much south facing window area as available and add additional capacity on the roof to bring the total capacity as close to 60kWac as possible, without going over. The 60kWac limit was chosen as it is currently the largest permissible capacity of distributed generation that is eligible for net metering.

The estimated average annual energy production that is used in the financial analysis takes into account an annual expected decrease in power production of the array. This is a normal occurrence and is in line with the manufacturer's production guarantee. For the technology chosen in this study an annual degradation factor of 0.25% was used. The annual energy production presented for the arrays in this report is the average annual production of the system over a 25-year period.

RESULTS—PV SYSTEM PERFORMANCE ESTIMATES (SDA)

The energy production studies run by SDA indicate that the 59.4kWdc rooftop PV system installed at Bowdoin-Geneva will produce an average of about 55,137 kWh each year over a twenty-five year period. The 10.8kWdc system is estimated to produce an average of 12,315 kWh each year. Figure 4 summarizes the system sizes and estimated output for the two PV systems considered for this particular building.

PV BALANCE OF SYSTEM COMPONENTS (SDA)

Solar electric systems generate direct-current (DC) electricity and require additional equipment beyond the PV array to interface with the building's electrical distribution system. This equipment is often referred to as the "balance of system" (BOS) equipment and is described below for the proposed arrays. Suitable space must be allowed for this equipment when designing a building with photovoltaic elements. The equipment is capable of being located either indoors or outdoors. In general, equipment that is located indoors is better protected from the elements and easier to service.

DC-to-AC inverters will be used to convert the direct current output from the PV arrays to alternating current compatible with that supplied by the utility. There are generally two types of inverters that can be used to convert the DC output of the array into utility grade AC power. Smaller inverters (less than 10kW) are typically single-phase "string" inverters designed to handle the electrical output of one or two source circuits or "strings" of PV modules. Combining panelboards are used to group the multiple inverters' outputs into a single output. Several string inverters along with their associated disconnects and panelboard are shown in Figure 5. It is anticipated that two 4.5kWac string inverters will be used for the sunshade system. More and more of the string inverters are coming with integral DC and AC disconnects.

Larger PV arrays with strings that share the same physical orientation typically utilize larger three-phase "central" inverters to maximize economy and minimize space. Figure 6 shows a central inverter and other BOS components. The inverter needs to be supplied with both a DC and AC disconnecting means on its input and output, but some inverters are now manufactured with integrated DC and AC disconnects.

The inverter strategy for this project will include a mix of large central inverters for the rooftop and string inverters for the sunshade. Specific inverters models will be selected in the design phase of the project. The "string" inverters: inverters are approximately 20" W × 30" H × 10" D, at 50 pounds each. The larger "central" inverters were selected; these are approximately 40" W × 30" H × 15" D, at 400 pounds each. The inverters and their associated transformers will release heat, and the area where they are located should be vented to the outside.

As there will be two separate PV systems it is expected that the MTC will want to track the output of the two systems separately. Therefore, in the preliminary schematic that was developed for this proj-

FIGURE 4. Proposed PV systems description.

PV system	Peak array power capacity at STC (kWdc)	Selected inverter capacity (kWac)	Ratio of annual energy production to installed capacity (kWhac/Wdc)	Estimated average annual electrical harvest (kWhac)
Rooftop	59.4	48.0	0.93	55,137
PV sunshades	10.8	9.0	1.14	12,315

FIGURE 5. String inverters and BOS components.

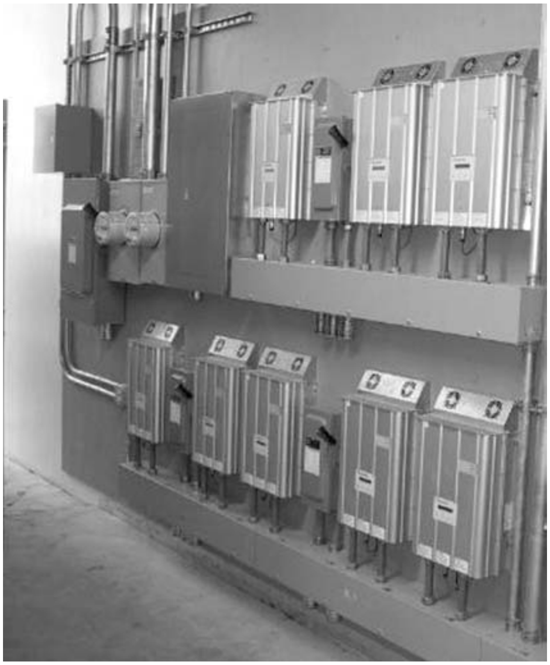


FIGURE 6. 30kW central inverter and BOS components.

ect, the inverters for each system are brought to an AC panelboard that combines the inverters' output (approx. 20" W × 40" H × 8" D) before they are fed to their respective production tracking meters. After being separately metered the two systems will then be combined before connection to the building's power distribution system.

The combined AC output of the systems typically back feeds a circuit breaker inside a power distribution panelboard, as a means for interfacing with the building's power distribution system. Consideration must be given to the de-rating requirements specified by the National Electric Code (NEC) when utilizing this method of interconnection. Regardless of the interconnection method, a lockable disconnect that is accessible to utility personnel is typically required between the output of the inverter and the point of interconnection, as described in the section on Electrical Interconnection.

Space in the building will also be set aside for the data acquisition system (DAS), which typically requires a small desk area to support the computer used to run the displays described. The DAS would need to be connected to the electric meter, and it could be located either in the main electric room or in a closet elsewhere in the complex. This DAS will also need to be connected to the Internet for the Massachusetts Technology Collaborative's (MTC) required automatic reporting to MTC's Production Tracking System (PTS).

The final electrical design will comply with the NEC code requirements for additional power sources in a power distribution system. Devices that are back fed or that are fed from two sources must meet special rating and labeling requirements. All code requirements will be met to the extent possible during the design phase to avoid additional expenditures during the construction process.

ELECTRICAL INTERCONNECTION (SDA)

The National Electric Code, in Article 690.64, outlines two methods for interconnecting a PV system—either on the supply side of the service disconnecting means or on the load side. The interconnection details will be determined as more details of the building's electrical design become available. Regardless of how exactly it is accomplished, the interconnection shall be made at either a dedicated circuit breaker or fusible disconnecting means, and the interconnecting equipment will be derated to handle the output of the PV system.

The schematics need to include a three-phase circuit breaker suitable for back feeding in the main distribution panel. The bus of the panel will need to be upsized to accommodate the additional amperage from the PV array. Additionally, to ensure that all equipment can fit, the electrical room equipment locations will need to be coordinated during the design phase with the project's electrical system designer. Batteries are not recommended for this project, as a large quantity of batteries would be required to provide any real benefit to the facility. The inclusion of batteries in the system will not only increase the capital costs required, it will also increase maintenance costs and future equipment costs since the batteries would need to be replaced every 5–10 years.

The project is located within the NSTAR service area. NSTAR (electrical utility) requires, at a minimum, an accessible, lockable, visible-blade disconnect switch to isolate the PV system output from the utility service. While specific location requirements are approved on a case-by-case basis, this disconnect is generally required to be within sight of the main meter for the site and should be accessible to the utility on a 24/7 basis. This can be done either by placing it outdoors or providing the utility with a means of 24/7 access if the disconnecting means is located inside the building.

The inverters that would be selected for this system already contain all of the protective features that are normally required by utilities to ensure the safety of utility service personnel. The units are listed to UL1741 and IEEE 929. It is assumed at this time that additional protective equipment beyond what has been described herein will not be required.

NSTAR will require an application prior to interconnection with the utility distribution system. This application should be submitted once the design process has been completed, array sizes have been determined, and inverters have been selected. Upon receiving the application, the utility will determine whether or not an engineering study is required to determine what impact (if any) the renewable energy generating technology has on the local utility distribution network. If required the utility may request that the customer pay for this study. It is expected that the building will rarely, if ever, be exporting energy, so that it is not anticipated that an impact study will be required. An impact study is generally required only when the generating facility might impact the area's distribution network.

NSTAR allows a generating facility of less than 60kWac to use "net metering." This allows the building's meter to run backwards when the solar production exceeds the demand. Though not expected, any power that is exported from the building would be credited at the full retail value and applied towards the electrical use at times when the building draws more power than the PV arrays generate.

UTILITY NOTIFICATION OF INTERCONNECTION (SDA)

The majority of Massachusetts electrical grid is structured as a radial distribution system; electricity moves from the distribution substation to the individual customers. However, certain areas with high power requirements are better served with spot network and area network systems. In these systems, individual customers are connected to the grid through multiple paths. These systems are designed to ensure reliable power for customers in these areas, and therefore they have complex and sensitive protection requirements. The interconnection process is largely designed for distributed generation connected to radial systems, as opposed to spot or area network systems. Bowdoin-Geneva is located in a radial distribution system.

OPERATION AND MAINTENANCE (SDA)

Operation and maintenance can either be handled by Bowdoin-Geneva's on-site maintenance staff or suitably experienced personnel. In accordance with MTC grant requirements, a five-year full warranty or comparable service contract coverage is to be provided to the purchaser against defects, failures, breakdowns, or excessive degradation of electrical output. The warranty shall cover the full cost, including labor, of repair or replacement of defective components or systems. The service contract is expected to include:

- Annual inspections by a qualified professional (approx. 20 man-hours per year), including:
  - Visual inspection of array and complete system
  - Module inspection from the front as well as from the back (if possible)
  - Wire and connection inspection
  - BOS component inspection
  - System measurements
  - Summary Report including; photo record, system performance assessment, noted issues

- Monthly DAS observation (~4 hours per year)
    - Confirm proper operation of PV system
    - Confirm proper operation of DAS system
    - Report Inconsistencies
- Equipment replacement as required (as discovered in the above inspections)
    - Warranted for 10 years (material, labor covered by inverter manufacturer)

The 5-year warranty for parts and labor, and 5-year service contract from the installing contractor should be requested as part of the bid. Additional service beyond the contract can be determined when the contract expires.

DATA ACQUISITION SYSTEM (SDA)

As part of its grant conditions, the MTC requires a Data Acquisition System (DAS) that automatically reports the amount of energy generated each month to the MTC PTS. Based on the number of potential residents and their guests, the site may present a good location to install a sophisticated DAS to further increase the visibility of the PV installation for less money than is possible with a more costly, and visible building-integrated PV system. Besides recording and reporting kWh production, the DAS can be configured to display the real-time operating parameters of the PV system as well as weather data collected from roof-mounted weather instruments. Weather measurements that are part of this system should at a minimum include ambient temperature, wind speed, and solar irradiance. They can also include wind direction, a rain gauge, and a barometer. This weather station hardware should be mounted somewhere on the roof that is conveniently accessible.

This DAS could simply display its information on the web, or it could include a large dynamic graphic display in a common area (or facing out, so that passersby could see) that shows the instantaneous power output of the PV array as well as the combined kilowatt-hours that have been produced by the PV system since its installation. This display could also easily include information about the green benefits of the PV systems as well as other key features of the building. This display can be designed to cycle automatically through the informational pages and can also incorporate current events of important happenings at the development. A picture of this display is shown below in Figure 7.

To further add to the functionality of the real-time display, the DAS can include a data server that will archive historical data files of system perform-

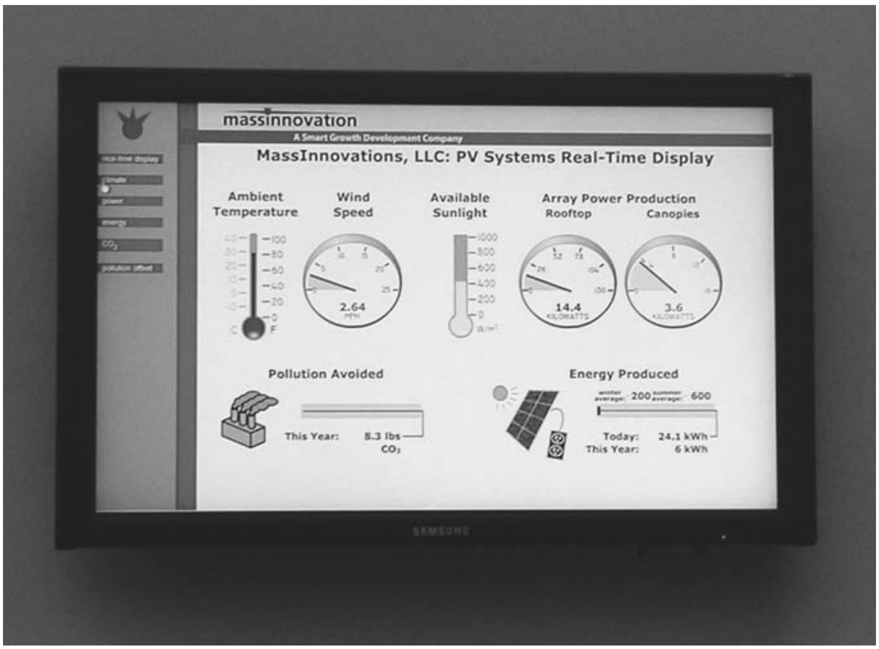


FIGURE 7. Customized informational display reporting solar array production.

ance and weather. This system can be set up so that the historical information that it presents is accessible through the web, along with the real-time display of the PV system performance as described above. This website could be easily integrated with the Bowdoin-Geneva website.

The real-time display and the data files that are archived by this system can serve as an excellent resource for other facilities that wish to research the feasibility of installing similar technologies on their own sites.

There are varying levels of data acquisition systems available, and the price can vary depending on number of points monitored and data presentation. A very simple system that will track and report the production to the MTC PTS may cost around $5,000 installed. The data archiving and custom public display system described above, with five years of web-accessible data archiving, is estimated to cost about $30,000, depending on the level of complexity and display screen desired. This cost is included in the system cost presented in the financial analysis.

COST ANALYSIS (SDA)

A summary of the estimated costs for the project is presented in Figure 8. It is presented for both a non-profit organization and a private, third-party taxable entity. The non-profit organization would not be expected to pay tax on the rebates from the MTC, the revenue from REC sales, and the material for the PV system. The disadvantage for non-profit organizations installing renewable energy technologies is that they cannot take advantage of the tax credits that are currently available for tax paying entities that install similar systems. Generally the tax credits make the system payback and return on investment more attractive for the private entities that can take advantage of the tax credits available. However, the taxable entity would be responsible for the taxes on the incentive money, the material purchased for the systems, and the income stream from renewable energy credit (REC) sales. The difference is not extreme in the case where incentives are received, but is much more dramatic in the analysis without incentives.

The costs presented including design costs, a five-year warranty and service contract, and system commissioning. Costs for installation were estimated with the expected local union labor performing the work. Currently a shortage in PV module supply is causing an increase in PV technology costs.

The two systems presented in this report are eligible for different incentive levels from the MTC. Both are eligible for the base level of $2.75/W and achieve a $0.50/W adder for Massachusetts manufactured components, a $1.00/W adder for the project being in an economic target area, and a $1.50/W adder for being installed on a building that will achieve LEED status. This amounts to a total of $5.75/W. In addition, the sunshade system is considered a building-integrated system and so qualifies for a total of an additional $1.00/W for a total incentive for that system of $6.75/W as calculated from the matrix provided by the MTC. These incentives are capped at $575,000 or 75% of the system cost, whichever is less.

As mentioned, there are other monies available besides tax credits and grants that help offset the cost of PV technology. Renewable Energy Credits (RECs) are an additional value-added feature of renewable energy. Because solar electricity is generated cleanly without the production of CO_2, the electricity is worth a premium on the energy market, resulting in potential income from energy generated by PV systems. The attached financial analysis assumes that Renewable Energy Credits will be paid at the rate of $0.06 per kWhac for solar-generated electricity for

FIGURE 8. Summary of financial parameters.

Organization	Purchase price	MTC rebate—taxes (as required)	Net system cost after rebates and tax credits	Payback with MTC incentives	Payback w/o MTC incentives
DBEDC/FDNH	$685,133	$414,450	$270,683	20.4 yrs	48.3 yrs
Private third party	$708,707	$252,815	$233,360	15.2 yrs	21.8 yrs

the next twenty-five years. These RECs would be sold as a commodity to specific groups, companies, and/or brokers such as MassEnergy (www.massenergy.com). Assuming a 25-year contract for RECs at $0.06 per kWhac, the owner of BGCC would earn approximately $101,182.00 in revenue.

Maintenance costs for PV systems are expected to be minimal and have been included in the payback analysis. The arrays should receive a periodic visual inspection for physical damage. In general, normal expected rainfall will keep the PV panels clean. It is an industry standard for modules to have a 20-year warranty for power production. The other working parts of the PV system are the inverters, which now come standard with a five-year warranty; SDA recommends that an extended ten-year warranty be specified for the inverter equipment. An amount (noted "Maintenance, Hardware Replacement (25 years)") has been included in the payback analysis for potential replacement parts over the life of the system. The PV systems should receive a thorough electrical checkout at least once a year that would require about eight total work hours. The U.S. Department of Energy estimates that the annual maintenance costs for PV systems be between $.005 and $.01 per kW for a typical system. For the purposes of this study the value of $.01 per kW has been used, and has been factored into the payback with the appropriate inflation value assessed over the life of the system. SDA expects that over the next 25 years, the total cost for maintenance and hardware replacement would be about $74,000.

FAST FACTS

The designed photovoltaic system for the Bowdoin-Geneva project has the following capacity and cost characteristics:

- 59.4 kW of low-slope flat roof array
- 10.8 kW of façade sunshade array
- Estimated system construction costs = $685,133.00
- Total system design fees = $81,800.00
- Total expected renewable power production = 67.452 kWh/year
- Total expected power savings based on energy modeling = kW
- Expected pollution reduction based on industry averages = 47 tons CO_2 /year from photovoltaics only + 10 tons from reduced electrical needs based on Green systems
- Total expected utility savings over a 10-year period, based on energy modeling and utility averages = $183,082.00 (based on avg. cost $0.12/kwh/yr)
- Total expected payback = 20 yrs
- Total system maintenance cost = $74,000

THINGS TO CONSIDER

- The process starts with a cost analysis to decide if photovoltaics are a cost-effective solution for your project, so there is feasibility study money to be spent. In the case of Bowdoin-Geneva, these costs amounted to $20,000.00 for the A/E design team and photovoltaics consultant.
- Total buy-in from the developer, users, architect, consultants, and the contractor is critical. Information from the design team needs to be accurate and complete so the Owner can make real informed decisions. Once these systems are installed, they are only as productive as they are maintained and as the building's mechanical and electrical systems are operated and maintained. Allowing the mechanical and electrical systems to run inefficiently will reduce the benefits of the photovoltaics and increase the payback time.
- The contractor's role in a Green building project is expanded to understanding the mission of the design. This is intensified when renewable energy systems are tied into the building operational systems. A commissioning agent to work with the design and construction teams is highly recommended.
- Designing and Installing photovoltaic systems is not overly complicated or time consuming and can be successfully completed by first-timers; however, working with architects and photovoltaic consultants who have the experience and the knowledge of the evolving industry can save time, save costs, and open doors to possible funding sources.

BOWDOIN-GEVEVA PROJECT

Architect:	HMFH Architects, Inc.
Development Team:	Dorchester Bay Economic Development Corporation Federated Dorchester Neighborhood House Bird Street Community Center City of Boston
Photovoltaic Consultant:	Solar Design Associates, Inc.
Mech / Elec Engineers:	Rist Frost Shumay Engineering, Inc.
Structural Engineering:	Foley Buhl Roberts & Associates, Inc.
Location:	Dorchester, Massachusetts
Construction Delivery:	Competitive Bid
Site Size:	1.5 acres
Building Size:	45,000 square feet
Number of stories:	3
Construction Budget:	$13,000,000.00
Renewable Energy:	70.2 kW photovoltaic system

NOTES

1. Ms. Jeanne Dubois, executive director, Dorchester Bay Economic Development Corporation can be reached at 617.825.4200.
2. US Green Building Council can be reached at www.usgbc.com.
3. Massachusetts Technology Collaborative is a state agency dedicated to assisting in the funding of renewable energy sources. For further information: www.mtc.com.
4. Dean Sherwin CPE, ASPE, AIA, professional estimator, construction cost management, can be reached at 610.892.9860 or at www.constructioncostman.com.