Blending Architecture And Renewable Energy

By **Mehdi Jalayerian, P.E.,** Member ASHRAE; and **Steven Eich, P.E.**

The North Exelon Pavilions are among several innovative designs incorporated into Chicago's new Millennium Park. Clad with photovoltaic panels, the building's exterior skin generates electricity that offsets the building's energy use. The two pavilions are a part of an overall city effort to become one of the most environmentally friendly cities in the country. In an effort to foster sustainable architecture and working toward self-sufficiency, the project showcases renewable energy using solar photovoltaic technology. The North Exelon Pavilions have been awarded a Leadership in Energy and Environmental Design (LEED)® Silver rating from the United States Green Building Council (USGBC).

The project consists of two similar pavilions located on the north end of Millennium Park along Upper Randolph Street on either side of the Harris Theater for Music and Dance.

A curtain wall system comprised of photovoltaic panels generates power for use by the Exelon Pavilions in Chicago.

The east pavilion provides access to elevators and a stairwell serving the parking garage located below the park. The upper level houses a gift shop and provides elevator access to a courtyard located on the roof of the Harris Theatre for Music and Dance. Accessible via a bridge from the east pavilion, the courtyard is used for outdoor public functions.

A separate bridge connects the rooftop courtyard to the west pavilion. The west pavilion provides restroom facilities for functions held at the courtyard, as well as access via a stairwell and elevator. The west pavilion also contains park offices and serves as a welcome center providing maps and other information for Millennium Park. An educational kiosk in the west pavilion displays energy produced by the photovoltaic system. The kiosk presents energy production not only in terms of kilowatt-hours, but also in carbon dioxide reduction, sulfur dioxide offset, equivalent trees planted and equivalent homes powered. Energy production is also displayed on a specially commissioned series of 9 ft (2.75 m) diameter mirrored sculptures titled “Heliosphere, Biosphere, Technosphere.”

Energy Efficiency

The exterior skin of the Exelon Pavilions is comprised of a multi-layered construction resulting in overall conductance values that exceed Chicago Energy Conservation Code and ASHRAE Standard 90.1-1999 requirements. The photovoltaic panels are covered with low-e glazing. A layer of foam insulation is installed behind the photovoltaic modules. An air space exists behind the photovoltaic panels. Behind the air space, an insulated gypsum wallboard assembly separates the curtain wall system from the interior spaces.

The roof is comprised of a highly reflective (Energy Star compliant) thermoplastic roofing membrane that is fully adhered to the roofing insulation. The roof insulation is supported by a concrete slab assembly. This roof construction provides a roof insulation rating which exceeds energy code and ASHRAE 90.1-1999 requirements.

Vision glazing makes up about 19% of the total wall area for each pavilion. Vision glazing was chosen with a U-value of 0.299 $Btu/h \cdot ft^2 \cdot °F$ (1.7 $W/(m^2 \cdot K)$). The glazing U-value is 50% better than the energy budget value.

Lighting load densities are maintained below energy code maximum levels by using compact fluorescent lamps throughout the building while maintaining comfortable lighting levels. Office and lobby areas were designed to a lighting density of

About the Authors

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1.05 W/ft^2 (11.3 W/m^2). Occupancy sensors, photocells, and manual switching are provided for lighting control and improved operational efficiency.

Indoor Air Quality

The air-handling design is multiple constant volume units dedicated to each functional area and fully coordinated with varying operational hours. Each system is sized for actual load and is capable of providing up to one-third of system air quantity using outdoor air, which significantly exceeds minimum code required amount for the occupancy type. Added ventilation capability provides for increased indoor air quality and enhanced capability to take advantage of cool outdoor air during spring and fall seasons.

Innovation

Each building's exterior envelope uses a curtain wall system to mount the customized photovoltaic modules.

Architectural elements were incorporated into the photovoltaic modules by modifying the basic design of the modules. The white background where the photovoltaic cells are mounted was changed to black. A black covering was applied over the otherwise visible silver bus bars that connect the photovoltaic cells. Reflective glass replaced the standard matte glass. Combined, these architectural modifications result is a glass-like appearance for the exterior walls.

The electrical ratings of the modules were not modified. Each pavilion contains 459 modules rated at 75 W resulting in a peak installed capacity of 34,425 W (dc) per pavilion. As with a battery, several modules are connected in a series array. The modules comprising a wall were connected in varying numbers resulting in array voltages ranging from 290 vdc to 556 vdc. The dc voltage from each array, or string of modules, is inputted to an inverter that converts the dc power to line voltage ac power.

Fifteen inverters are installed for each pavilion. The output of each inverter is connected to the building electrical distribution system with a circuit breaker located in dedicated metered panel boards.

The power output of the photovoltaic system is a function of sunlight intensity, module shading, air temperature, and wind speed. Over the course of a day and throughout the year, all these factors change. Energy production estimates were developed using data obtained from the National Renewable Energy Laboratory's National Solar Radiation Database. Because most of the modules are not facing south, the theoretical ac output of each pavilion is reduced from the peak installed capacity to approximately 28,900 W.

Operation & Maintenance

The photovoltaic panels are integrated into an exterior wall glazing system providing protection for the photovoltaic

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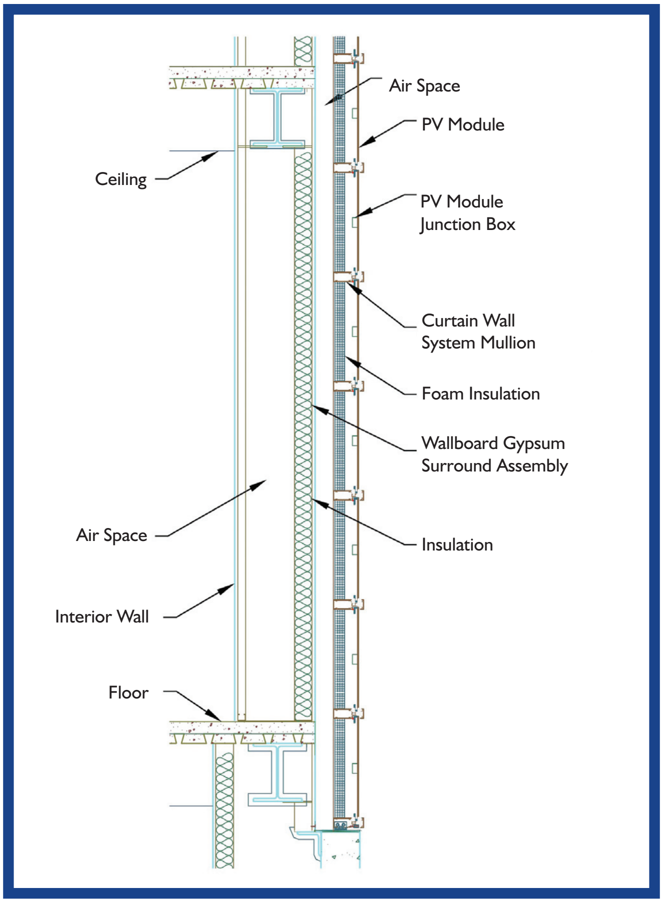
modules from environmental conditions. The panel system is modular and includes modular electrical components for ease of installation and maintenance throughout the life cycle. The only maintenance required is periodic cleaning. The photovoltaic modules are cleaned in the same manner as vision glazing and exterior curtain wall systems.

In the event of a failure, a photovoltaic module can be accessed by removing the curtain wall holding straps. The module can be removed providing access to the system wiring. Modular electrical connections allow for ease of panel replacement and troubleshooting.

Operation of the photovoltaic system is automatic. When the photovoltaic modules are exposed to sunlight they generate a dc voltage that is sensed by the system inverters. The inverters automatically go through a start-up sequence and begin to transfer power, converted to ac, to the building's electrical distribution system. In the event of a utility blackout, the inverters are designed to shut down to prevent back feeding the utility system.

The building's electrical service is equipped with a net metering kWh meter. If the building's energy use is greater than the photovoltaic system energy generation, all of the generated energy is used by the building, offsetting energy use from the utility grid. If the building's energy use is less than the photovoltaic system energy generation, electrical energy is transferred to the utility grid.



The building envelope is comprised of several elements including air spaces that provide a high R value system.

Cost Effectiveness

Integration of photovoltaic modules with the exterior wall system provides economical installation and improved insulating performance. Additionally, decentralized air-handling systems dedicated to each functional area optimized the cost of duct distribution and provided accurate system control at low cost where zone and system control were combined.

System Performance

The expected annual energy production was estimated to be approximately 16,175 kWh/year per pavilion. The expected energy offset for the west pavilion was estimated to be approximately 17% of the estimated 92,504 kWh annual electrical consumption. The project's total energy consumption was evaluated based on the Chicago Energy Conservation Code requirements. An analysis using the Standard 90.1-1999 Energy Cost Budget Method and the LEED Energy Modeling Protocol resulted in an energy use estimate approximately 8% higher.

The photovoltaic system began operation in April 2005 with May being the first full month of generation. Due to a problem with a photovoltaic module, the system was out of service for a portion of September resulting in low generation for that month. For the portion of the year that the system was operating, it generated 8,600 kWh or 3% to 8% of the building's energy use.

Several factors influence the amount of energy generated by the photovoltaic system. Among these factors are: length of daylight, solar declination, shading, air temperature and wind speed. Additionally, the building's energy usage is influenced by operational hours, actual system setpoints, and extensive testing of the systems during the first year of operation.

LEED

The North Exelon Pavilions project has received a LEED Silver Certification Using Version 2 of USGBC's Green Building Rating System, the project achieved 33 points, placing it in the Silver rating category.

Sustainable Sites

Urban Redevelopment. Credit was awarded for urban redevelopment. Making use of existing infrastructure, the pavilions were built on the roofs of an existing railway station and an existing underground parking garage. The east pavilion made use of an existing elevator and stairway lobby that provided access to the underground parking garage resulting is less material hauled to a landfill and less material required for construction.

Alternative Transportation. Transportation facilities are available for pavilion occupants and visitors. An electric railway station is located directly below the west pavilion. Bus stops are located near each of the two pavilions. Indoor bicycle storage and changing rooms are located in Millennium Park near the entrance to the east pavilion. Building occupants can use an existing car pool program associated with the parking garage located below the east pavilion.

Heat Island. Heat island effect is minimized through the use of a highly reflective roofing material was used on both pavilions.

Water Efficiency

Water use has been reduced by over 20% through the use of low flow plumbing fixtures and sensor activated faucets.

Energy and Atmosphere

Optimize Energy Performance. Compared to the energy cost budget developed using ASHRAE 90.1-1999, the design energy performance achieved is 39% better than the energy cost budget. A five point LEED credit was awarded based on this achievement.

Energy savings were realized through:

- Insulation R values greater than code minimum;
- Lighting power density near 1 W/ft^2 (10.75 W/m^2);
- Glazing coefficients lower than code minimum; and
- Significant renewable energy offset.

Renewable Energy. The energy produced by the building integrated photovoltaic system offsets a portion of the building's energy budget. LEED credits were achieved through the installation of this system.

Materials & Resources

Building Reuse. Greater than 75% of the existing structure was reused in the construction of the Exelon Pavilions. The reuse of these structures resulted in significant savings of construction resources.

Construction Waste Management Reuse. Strict recycling procedures during construction resulted in the diversion of over 75% of the construction waste away from landfills.

Recycled Content, Local Materials, Certified Wood. Through careful selection of construction materials, 12% of construction materials are recycled, 74% are locally manufactured, and 100% of the wood used is certified in accordance with FSC Principles and Criteria.

Indoor Environmental Quality

Construction Materials. Low-emitting construction materials were used for adhesives, paints, and carpeting.

Daylight and Views. Windows have been strategically placed within the photovoltaic curtain wall system to allow daylight to reach over 90% of the building work areas.

Innovation & Design Process

Sustainable Design Education. An educational kiosk is located in the west pavilion. The display is designed to educate visitors about sustainable building design and energy generated by photovoltaic modules.

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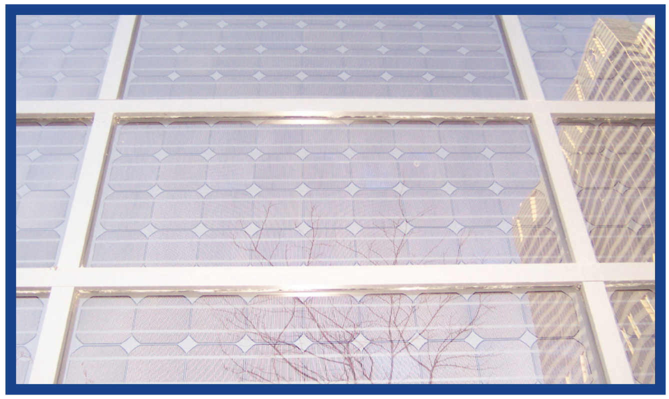

Modifications to the photovoltaic modules result in a glass-like appearance for the exterior wall.

Commissioning

A commissioning plan was prepared and executed that met the prerequisite requirements of the LEED building rating system. The commissioning plan, prepared by the commissioning team, verified the system mechanical design by testing equipment performance and control of the mechanical systems installed in the pavilions. Systems were optimized to provide optimal energy efficiency. A report was prepared documenting the results of the commissioning effort.

Additionally, the photovoltaic systems were thoroughly tested to verify manufacturer specifications and demonstrate system protective functions. Specifically, the local electric utility requires that the anti-islanding protective functions of each system inverter be tested to demonstrate proper operation. The anti-islanding function is critical to the safety of utility personnel because it prevents the photovoltaic generating system from back feeding the utility grid during a blackout. Each inverter was connected to test equipment that could simulate a utility blackout condition and testing for proper operation.

Conclusion

The North Exelon Pavilions project had a goal to foster sustainable architecture and work toward self-sufficiency. Innovative methods were employed to overcome obstacles in the path of this goal. Custom designed photovoltaic panels made it possible to use the panels as the exterior skin of the building. The innovative use of a curtain wall system provided a means of supporting the panels while providing access the back of the panels for troubleshooting, repairs and replacement. The efficient building envelope created through the use of the curtain wall system, air gaps, and insulation allowed building mechanical systems to be sized for optimal effectiveness. Maximizing the use of daylight and using efficient lighting systems and controls resulted in minimal energy usage. Maximizing the use of existing structures resulted in less material being hauled to landfills and less material required for construction.

The North Exelon Pavilions project has shown that through innovation, renewable energy, combined with energy efficient design, can bring a building toward self sufficiency.