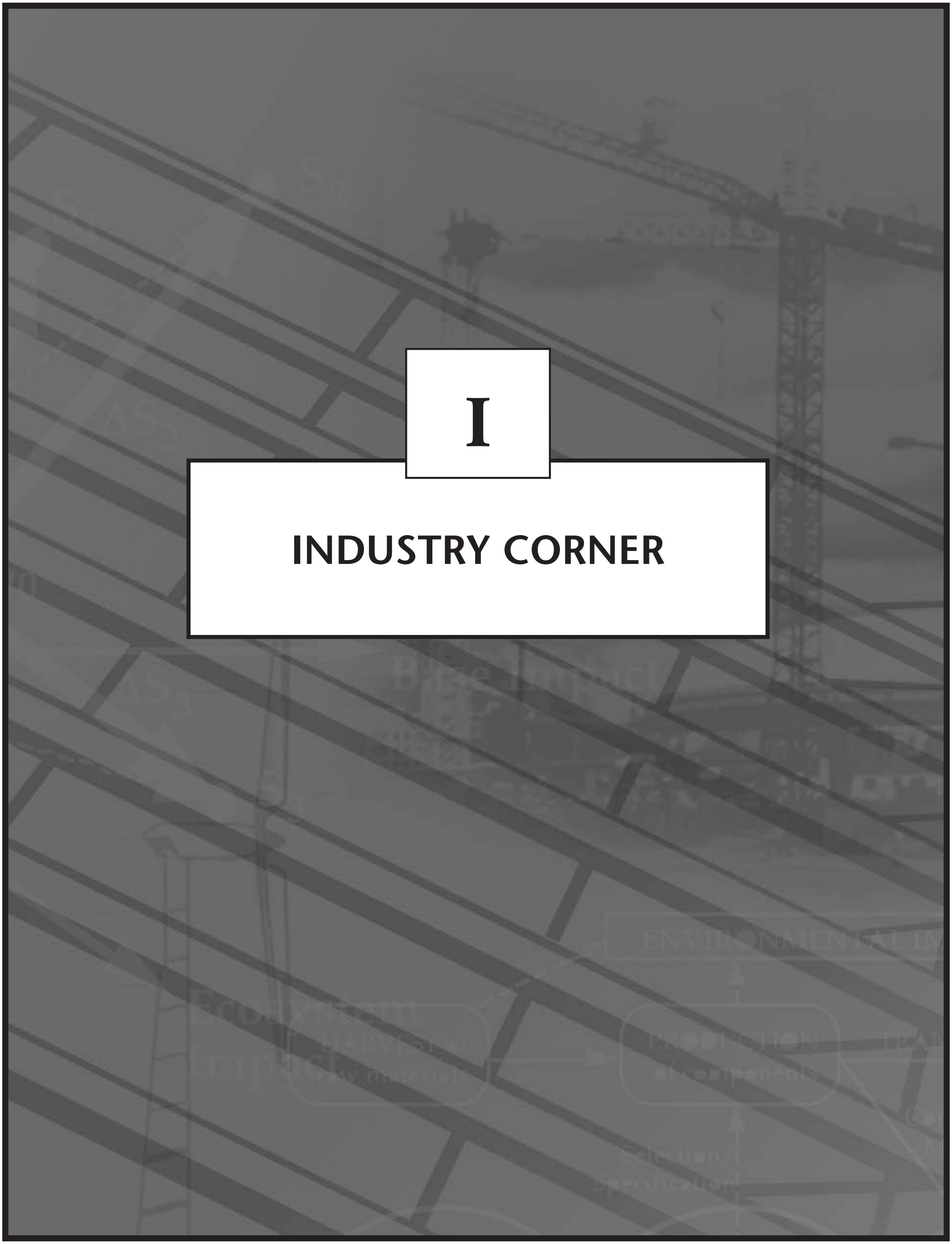

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INDUSTRY CORNER

WALKING THE TALK AND WALKING THE WALK AT THE WOODS HOLE RESEARCH CENTER: Design and Performance of an Award-Winning Green Headquarters

Joe Hackler[1] and John P. Holdren[2]

ABSTRACT

The Woods Hole Research Center's mission in "environmental science, policy, and education for a habitable Earth" means it's important to practice what we preach. A key part of doing that is our very green headquarters—the Center's Gilman Ordway Campus—on Cape Cod. Designed by the noted green architect Bill McDonough, this state-of-the-art scientific research and office facility demonstrates the successful integration of energy- and resource-conserving design, a ground-source heating and cooling system, and a robust renewable-energy supply. The facility was designed with the express goal of being a zero net-energy building (achieving CO_2-neutral operation) and has been instrumented with a whole-facility monitoring system that provides the basis for an on-line educational display system and long-term study of energy performance.

The 1793 m^2 (19,300ft^2) facility used 50.7 kWh of electricity per m^2 from March 2004–February 2005 of which 16.9 kWh/m2 or 33% was supplied by the rooftop photovoltaic system. Electricity is the only externally supplied source of energy. The incorporation of a 100kW wind turbine now on order will provide the remaining balance of the power used by the facility and a surplus for export to the grid.

The building has won numerous awards including selection as one of the American Institute of Architects' 2004 Top Ten Green Projects and a first prize in the 2004 Northeast Green Building Awards, and it is listed in the DOE High Performance Buildings Database.

1. THE DESIGN CHALLENGE

The Woods Hole Research Center (WHRC) is an independent, non-profit, non-governmental organization focused on environmental science, interdisciplinary analysis, policy innovation, and public education on the connections between environment and human well-being. It focuses particularly on clarifying and communicating the impacts of human activities on the planet's vegetation, soils, water, and climate and on promoting practical approaches to their management in the human interest.

Our concern for global climate change and biodiversity loss, coupled with our important mission to reduce tropical deforestation and transforming society's patterns of energy demand, led to a plan for a new headquarters in the late 1990s that would be a model of sustainability. This meant, to us, designing,

FIGURE 1. Aerial perspective of The Woods Hole Research Center's Ordway Campus, looking west southwest. (Aerial photo: Charles C. Benton).

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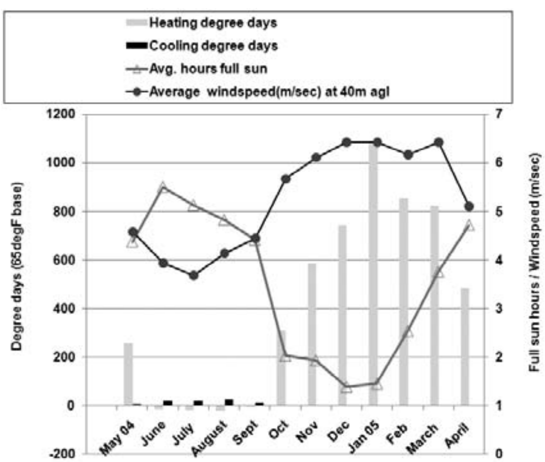
building, and operating a facility attuned to the local natural and built environment, maximally employing recycled and recyclable materials and the use of renewable energy, and minimizing energy waste and use of and exposure to toxic substances.

To be climate neutral with respect to CO_2 emissions was a particularly important design goal. But so also was ending up with a building that would be beautiful inside and out and also not merely functional but inspirational and energizing for the fifty staff members who would work in it. Further complicating the design challenge, WHRC wanted to maintain much of the historic character of the site by retaining the overall aspect of a nineteenth-century captain's house (which still occupied the site when we acquired it) as seen from the Woods Hole Road fronting the property.

Solar and wind resources available to our site are modest in nature, and are seasonally opposite in their availability. A plot of heating and cooling degree-days relative to solar insolation for this site in 2004–2005 (Figure 2) indicates why a purely passive approach to building design is problematic in the U.S. Northeast.

From October through February of that year the site experienced a total of 3580 heating degree days while there was an average solar availability of 1.9 full sun hours per day. On the other hand, annual-average wind-speed at the site is 12.0 mph (5.7 m/sec) at a nacelle height of 40m (130ft). This represents a modest (class 3) wind resource.

FIGURE 2. Heating degree days, and average solar and wind resource levels by month from May 2004–April 2005.



As the architects to work with us in the design of a facility that could meet our demanding goals in the context of this particular site, we chose the firm of Wm. McDonough + Partners, well known around the world for their integrated, whole-building approach to combining energy- and resource-conserving principles with functionality and beauty in design.

2. DESIGN PROCESS AND CRITERIA

The design process was an intensive, iterative interaction between WHRC staff and the architects, as ways of achieving the ambitious multiple aims of the project were explored. A particularly crucial early result of this interaction was the determination that the new facility would combine a bottom-to-top and inside-to-outside renovation of the original building that maintained its captain's house aspect, plus addition of an entirely new, connected annex with comparable-to-greater floor space, located on the north side of the original building largely out of sight from the street (Figure 1).

2.1 Parametric energy modeling

Parametric energy modeling was conducted using Energy-10 software V1.0 to provide guidance during the design process on how energy usage and peak demand requirements are affected by factors such as infiltration, insulation, fenestration specification and placement, and heating-system selection.

A model building was developed that conformed to energy-conservation requirements for new building construction in Massachusetts, largely derived from ASHRAE/IES 90.1 – 1989. This base case building was estimated to consume a total of 84,223 BTU/ft2/yr (265 kWh/m^2/yr) and experience a peak electricity load of 277kW.

2.2 Design Criteria

While energy modeling was an important part of the building design and construction process, we relied heavily on the experience of our architects and a consulting energy engineer (Marc Rosenbaum) to direct the design toward achievement of excellent performance characteristics.

FIGURE 3. Natural lighting in the Commons area.

Maximize natural light. Daylighting strategies were employed to both minimize lighting loads and provide an excellent indoor aesthetic environment throughout the facility (Figure 3).

Tight Building Envelope. A well insulated, tightly constructed building was acknowledged to be a prerequisite to achieve excellent building performance. Several approaches were considered, including densely packed cellulose insulation. In the end a CFC-free expanding spray foam insulation was employed as the most effective way of sealing complex areas of the existing structure and to the provide the insulation and vapor control required.

Passive opportunities. Passive strategies were exploited wherever possible for heating, cooling, and ventilation. A full-on passive solar design was rejected as infeasible here in the Northeast, where there might be little direct sun for weeks at a time (Figure 2). In addition, the desire to retain the historic character of the existing Victorian summer home further constrained solar passive-design opportunities.

Occupant Comfort. We relied on our energy engineer's experience in the selection of triple glazed windows in the new north-facing wing where large expanses of glazing predominate. Even though the incremental energy savings suggested by the energy modeling were not compelling, it was considered critical that people not feel cold when working next to large glazed areas during the winter.

3. BUILDING CHARACTERISTICS

A third-party building commissioning process was conducted for the project. This process proved to be essential in ensuring a high degree of mechanical-systems integration and providing the organization an understanding of the systems' operations, maintenance, and potential for future performance improvements.

3.1 Insulation

To achieve the targeted insulation levels, wall assemblies were constructed using an offset-stud wall system. This eliminated direct thermal transmission to the exterior by any part of the building's structure and provided a sufficient wall-cavity depth (8 to 10″) for the required insulation. Where this was not possible (under the mansard roof of the original structure) 1″ foil-faced polyiso board was installed over the insulated rafter bays (6″ true depth). An HCFC-Free, sprayed-on, polyurethane insulation was used under the roof deck and in all joist and rafter cavities.

Above the roof deck, 4″ of rigid polystyrene insulation board was installed on both the original building and the addition for an insulation value of approximately R-45 when combined with the polyurethane insulation applied to the underside of the roof. Rubber-membrane roofing was installed over the insulation board.

3.2 Windows and doors

High-performance window glazing was selected for the windows and doors. In the renovated building, argon-filled double-glazed windows with a low-E coating were installed (with effective R of 4.1). Exterior doors throughout the facility matched the windows of the renovated building. Where areas of glazing are greater in the new construction, triple-glazed argon-filled windows were used, with a single low-E coating, an effective R of 5.4, and a solar heat-gain coefficient of 0.24.

3.3 Mechanical systems

The HVAC system was designed to meet four objectives:

1. Enable use of passive heating, cooling, and ventilation whenever possible
2. Employ a ground-source heating and cooling system
3. Utilize low-temperature heating distribution systems
4. Recover or reject energy using enthalpic energy-recovery ventilation when the building is in an active mechanical mode

The resulting building is all electric. No fossil fuels are delivered to the site.

The ground-source heating and cooling system is based on a standing-column well. This open loop system extracts source water from the ground near the bottom of an uncased well 365m (1200′) deep and returns the water near the top of the well. Total installed heating capacity in the building is 15 tons (180 kbtu/hr).

A total of 6 heat-pump units are used. Two water-to-water heat pump units (WWHPs) are connected to a hydronic distribution loop, which delivers heating and cooling to all the offices. Four water-to-air heat pumps (WAHPs) provide heating and cooling to large open spaces such as the auditorium, the commons, and the laboratory. All the heat pumps employ highly efficient scroll compressors.

The WWHPs are connected to a buffer tank to prevent short-cycling, and the buffer tank is connected via the hydronic distribution system to individual valance convectors in each of the offices. These valances are connected to a condensate drain line to remove condensate during summer cooling.

Enthalpic energy-recovery ventilators (ERVs, also referred to as energy recovery units—ERUs) are used in the building to recover (or exclude) both sensible and latent heat to and from the building. Each office is supplied with ~20 cfm of pre-conditioned fresh air from the ERV. WAHPs also are supplied with a fraction of fresh air by way of the ERVs.

3.4 Lighting

Occupancy-sensing lighting controls are employed in all of the offices and generally throughout the building. These sensors are connected to electronically ballasted T-8 lighting fixtures or compact fluorescent (CF) lamps. CF task-lighting is provided at the desktops. The originally installed outdoor lighting system used CF fixtures for walkways and the parking area. Parking area lighting has been replaced with higher-output sodium vapor lighting, as there was some dissatisfaction with original outdoor lighting levels in terms of nighttime safety.

3.5 Solar photovoltaic system

A grid-connected solar photovoltaic system of 26 kWpeak (DC rated) capacity is installed. The panels are mounted flush to the roofs surfaces of the south-facing porch and the annex, which are angled approximately 8 degrees (towards the south) from horizontal. The building faces 10 degrees west of due solar south and is not shaded by vegetation or other obstructions. A total of eighty-eight 300-watt photovoltaic panels, totaling 196 m^2, are connected, in series of 8 panels, to eleven 2.5 kW SMA grid-connected inverters.

The system is metered with a revenue-grade meter whose pulse output is directed to the building's energy monitoring system, which records production in 0.2 kWh increments.

The PV system is mounted horizontal to the roof plane for aesthetic reasons (from the street side perspective of the original building), and also due to issues of self-shading, which occurs at low sun angles when mounting to a low-pitch roof structure. Snow accumulation in our region is not typically great, nor do snow accumulations persist for long when they do occur.

3.6 Solar thermal system

A modest, residentially sized solar domestic hot water system was installed. The system consists of three 4′ × 8′ flat plate collectors mounted at a 45° angle. Water serves as the heat exchange medium with freeze protection ensured by a drain-back configuration. A 35 gallon stone-lined storage tank is used with an in-tank ½″ copper finned-tube heat exchanger 20′ in length. The system employs a "head tank" located in the top floor of the building within the conditioned space to minimize the head that the circulating pump must overcome to establish flow. A single ~60 watt circulating pump controlled by a differential temperature controller delivers heat to the storage tank in the basement. The preheated water in the solar-thermal-fed tank is delivered to a standard 120-gallon electric resistance hot-water heater whose temperature is set at 110°F. A secondary hydronic circuit with a small circulator pump circulates heat from the solar tank to the top of the electric water heater when the temperature of the solar tank exceeds that of the electric water. This increases the effective mass of solar storage significantly during warmer periods of the year when the indicated condition prevails. For the period of May through November 2004 the solar thermal system provided 88% (1684 kWh) of the total energy required for domestic hot water.

3.7 Office Equipment

Significant efforts were made to select low-energy office equipment. Desktop computers have largely been replaced with notebook computers, flat panel displays are used instead of CRTs, and docking stations and laser printers are discouraged. Energy Star rated equipment has been selected whenever available, and shared use of printers and copiers is maximized.

4. BUILDING PERFORMANCE CALCULATED FROM METERED ENERGY USAGE

The PV system was installed in the fall of 2002, and independent metering commenced in October of 2003. Electrical usage is plotted in Figure 4 for a two-year period between October 2003 and October 2005.

During the first full year of photovoltaic system monitoring (May '04–April '05) the facility's electrical use was 90,964 kWh. This represents an energy intensity of 50.7 kWh/m^2/yr (16,076 Btu/ft2/yr). As shown in Figure 5, this performance represents a large improvement compared to the national-average energy intensity for offices, as well as compared to the previous WHRC facilities.

Of the total requirement, 60,720 kWh were supplied from the utility grid and 30,244 kWh were supplied by the PV system (33%).

The integration of a building with excellent energy performance and a moderately sized photovoltaic system can significantly reduce the atmospheric burden of pollutants and heat-trapping gases. Using the marginal emissions rate for electrical production

FIGURE 4. Plot of Electrical use from Oct. 2003 through Oct. 2005 from photovoltaic and grid sources.

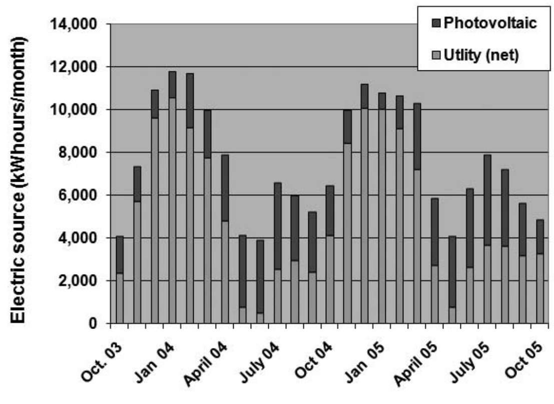
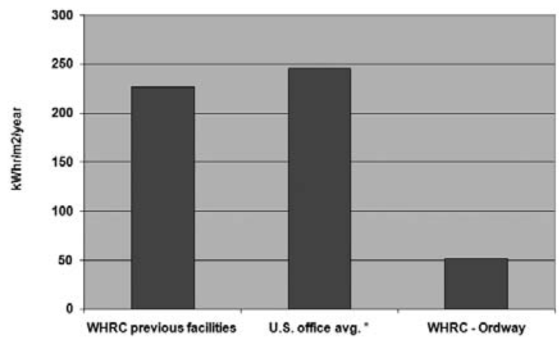


FIGURE 5. The Research Center's energy intensity compared with its previous facilities, and the national average for offices < 25,000 ft^2 constructed between 1990 & 1999. **Source: EIA, Commercial Building Energy Consumption and Expenditures 1999, August 2002, Table C8.*



in the New England region, the atmospheric burden for the Research Center's new facility is compared with its previous facilities, and the national office average. (Figure 6).

The energy intensity of the Ordway campus facility compares quite favorably with two other recently constructed ground-source connected buildings reported in the DOE High Performance Buildings Database (Figure 7). The energy intensity of the Woods Hole building is 43% of the Chesapeake Bay building and 52% of the Oberlin facility (not corrected for potential seasonal variation).

FIGURE 6. Estimated atmospheric burden of pollutants from the Research Center's previous facilities, the National office average and its new facility. *Source:* ISO New England 2002 NEPOOL MARGINAL EMISSION RATE ANALYSIS (http://www.iso-ne.com/Planning_Reports/Emissions/Marginal_Emissions_Analysis_2002.doc).

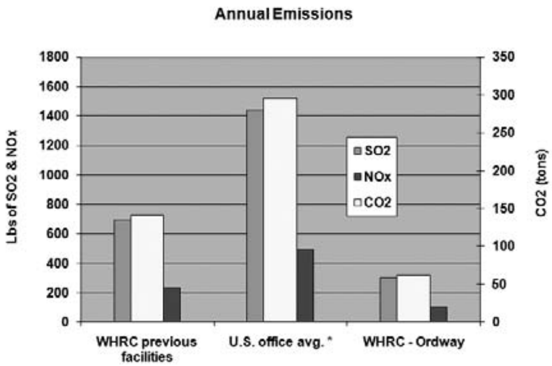
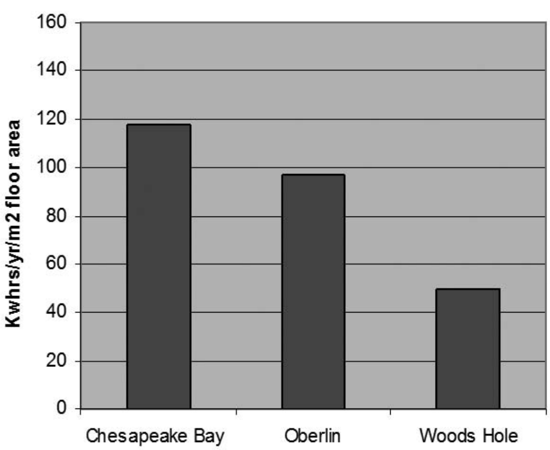


FIGURE 7. Total energy usage of recently built ground source heated facilities normalized by total floor area. *Source:* DOE High Performance buildings database: http://www.eere.energy.gov/buildings/highperformance/case_studies/.



5. WHOLE-BUILDING ENERGY-MONITORING SYSTEM

The facility has been instrumented with a whole-building energy-monitoring system for purposes of research and education. This system (on line since May 2004) was developed to provide a numeric platform for continuous monitoring and research on how the building's various energy generation and recovery systems contribute to overall performance. A web-enabled display system uses data gathered and stored by the monitoring system to educate designers and users of advanced high-performance buildings and the general public about energy flows through a building of this type.

The display system was developed to provide an integrated view of all the energy flows in the building, including the ground-source system, solar PV and solar thermal systems, energy to and from the grid, and energy recovered from ventilation air or rejected to the outdoors or the mass of the earth.

5.1 Monitoring System Design

A total of 72 sensors are connected to one of three sensor interface units located in the building. These sensor interface units are themselves connected to the main RTU (remote terminal unit—a dedicated laptop), which gathers the data, performs calculations, stores the data in a database, and serves as the primary data-acquisition device. Data are collected at one-second intervals, averaged to one-minute intervals, and stored permanently in 5-minute intervals. Calculations for the display system and permanent database are performed at each of these intervals.

The collected data describe the operating states of all the major mechanical equipment, flow rates of the ground-source loop and the solar thermal system, and outdoor basic environmental data. Power transducers are installed at the main electrical distribution panel and each of the seven sub-panels, transmitting the instantaneous power being used at each panel to the data acquisition and display system. Current transducers are installed on each of the heat pump units and circulating pumps, serving as both an on-off status indicator as well as providing an indication of unit operational status, which is useful diagnostically. The ground-water pump has its own dedicated power transducer. Sensors also record the temperature of air and water and the relative humidity of the air flowing through each of the heat pumps and energy-recovery ventilators.

From these logged data, energy flows are estimated, logged to the database, and displayed.

- The photovoltaic system is instrumented with a revenue-quality electric meter which outputs a pulse signal to the monitoring system. The monitored environmental data include: outdoor temperature, relative humidity, flat-plane solar insolation, barometric pressure, rainfall, and wind speed and direction (at 2.5 m above roof plane).

- For those fluid flows that are not directly measured, we rely on rates measured or estimated during the HVAC systems Testing & Balancing procedure. These flows include: airflow for each WAHP and ERV and water flows on the load side of the 2 WWHPs.
- Flow-regulation valves on the ground-source side of each heat pump compressor unit regulate ground-source-side flow rates.
- The total flow through the building from the ground-source well is measured with a flow meter whose output is a somewhat coarse 10 gallon/pulse unit.
- For the display system we've chosen units of electrical kilowatts (kWe) and thermal equivalent kilowatts (kWt) rather than the more customary units of kJ or Btu's. This was done for the sake of uniformity and comprehension by non-technical audiences.

5.2 Monitoring Display

Energy Flow (Figure 8). This page provides an overview of the energy flows through the building and the environmental context.

The data are organized on the page into electrical, HVAC, and environmental parameters.

Performance Trends (Figure 9). This page displays three time-series trend plots, each containing six data sets that provide an historical context of building performance relative to local meteorological trends. The Electric Power section contains a plot of the dominant loads (Light, Plug, and HVAC) and electrical sources (Grid, PV, and eventually a wind turbine), while the HVAC plot shows heat moving into and out of the building. The Environmental plot provides the meteorological context.

The **System Detail Page** (not pictured) displays a mechanistically detailed view of the WHRC facility, and the **Meteorological Trends** page (also not pictured) provides a detailed view of the outdoor environmental trends experienced by the building. http://whrc.org/building/education/SysDet2.asp, http://www.whrc.org/building/education/MetTrd3.asp.

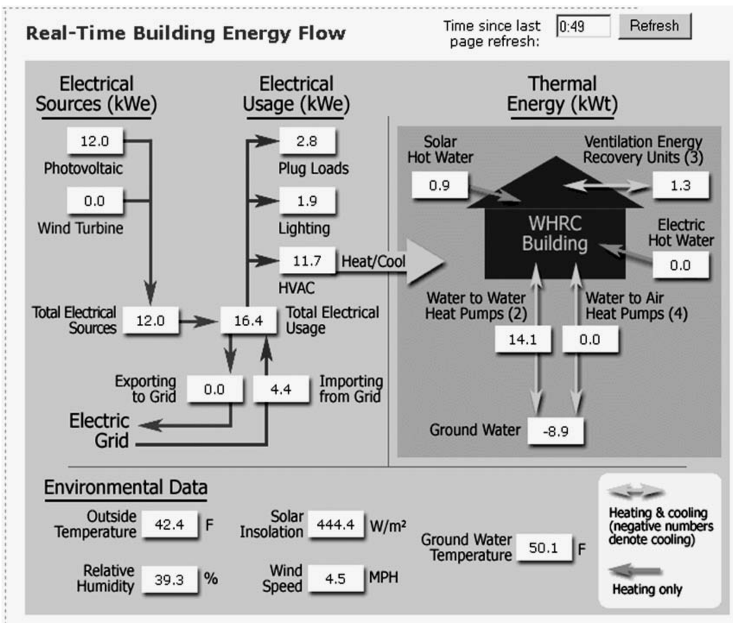


FIGURE 8. A snapshot of energy flows through the Research Centers office facility is displayed in near real time. The Energy Flow page is a schematic overview of the energy flowing through the WHRC facility. http://www.whrc.org/building/education/EngFlw2.asp.

FIGURE 9. Performance trends as displayed by the energy monitoring system. http://www.whrc.org/building/education/PrfTrd3.asp.

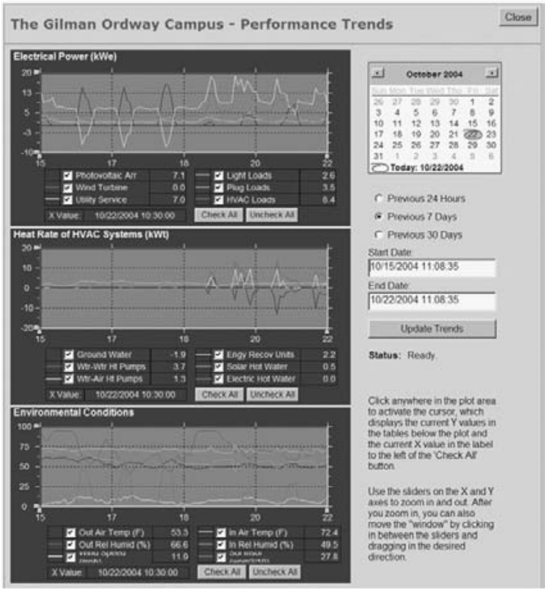
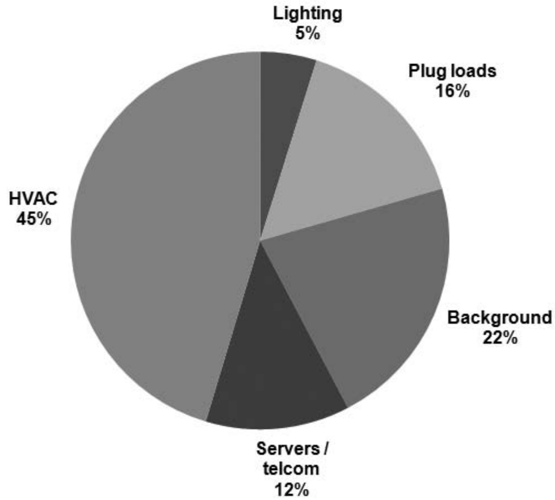


FIGURE 10. Building electrical use by load type.



5.3 Building performance based on the monitoring system

The data provided by the monitoring system enables us to observe the building's energy usage with significantly finer resolution than that of the main electrical meter. The monitoring system has been fully operational and logging data at five-minute intervals since May of 2004.

Monitored Electrical Usage—May 2004–April 2005

Total electrical usage during the first complete year of monitoring (May 2004 – April 2005) was 90,964 kWh (continuous average = 10.38 kW), with 30,244 kWh (3.45 kW average) being provided by the PV system (33%). Separating the electrical loads out by usage we find the distribution generally to be as described in Figure 10. The Server/telcom load was measured to be 1.55 kW continuous, year-round. Lighting loads are quite modest and reflect the serious consideration given to daylighting in the building's design.

Plug loads have been separated from "Background" in an attempt to distinguish cyclic equipment and appliance usage from the significant background/parasitic electrical usage of the building. This background electrical load was observed to be approximately 2.4 kW continuous. This was measured while the building was nominally "at rest," with all lights off, and all HVAC and refrigeration equipment shut down at the breaker panel.

The "background" portion of this load is thus estimated to be 21,000 kWh/yr, representing ~23% of the facility's total electrical usage (more than half of what is produced by the PV system).

The fraction of true parasitic loads (by UPSs & surge protectors, computers and printers left on, copiers, fax machines, and many other devices) relative to those background uses serving a definitive service or control function (like the elevator, HVAC system control, lighting control, smoke detectors and fire safety system, and others) is not known.

The computer server room located in the lower level merits special mention as a useful internal heat source in winter months and a cooling issue outside of the heating season. The continuous load for this equipment was 1.55 kW, and explicit consideration was not made in the design to provide natural cooling for the space. Currently an ERV runs continuously (1.87 kW) to exhaust heat (rather than on the occupancy schedule) and a dedicated mini-AC unit of .46 kW runs continuously in the months of July through September. Therefore, approximately

3,350 kWh/yr are currently required to keep the computer-server facility marginally cool during the summer season.

Ground-source heating contribution

The total estimated heating contribution of the ground-source system to the building was 23,835 kWh-t. The proportional contribution of the ground-source heating to the building's electrical usage from the grid and the photovoltaic system is displayed in Figure 11.

When the ground-source heat contribution is added to the electrical usage 74,815 kWh, the total energy used by the building increases to 98,650 kWh/10 months.

The peak electrical demand experienced by the building this year was 37.1 kW over the five-minute averaging period in February. The 15-minute average demand charge billed by the electric utility was for 34 kW. This compares favorably to the modeled ASHRAE 90.1 base case peak electrical load of 277kW.

Cooling requirements for the building during the initial survey period were quite limited. Approximately 3,200 kWh-t was rejected from the building during the approximately 13 days of cooling system use this past summer. While the summer was somewhat mild (Figure 9), the building's low cooling-season loads reflect the intention to passively cool and ventilate the building as much as possible. Other than the 13 active cooling days, all the major mechanical equipment was shut off at the breaker panel.

FIGURE 11. Total building energy delivery (thermal gains from ground source heating system and electricity).

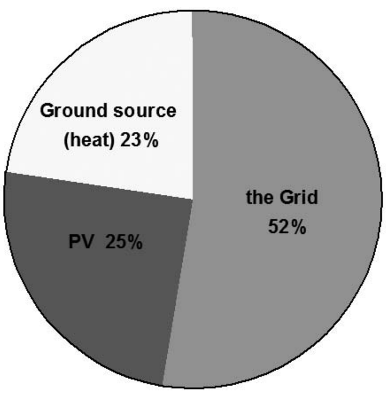
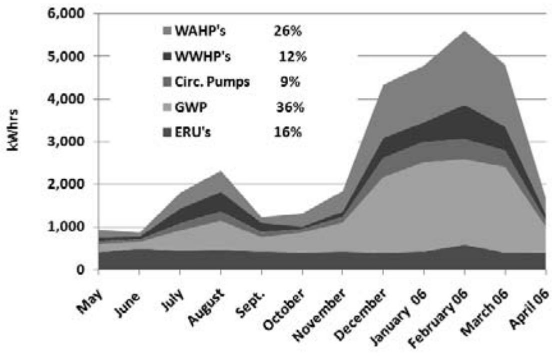


FIGURE 12. Plot of direct electrical requirements for the facility's HVAC systems.



During the heating-season months of October to February the enthalpic-energy-recovery ventilation system recovered 11,700 kWh-t while using 3,800 kWh of electricity, resulting in an estimated Coefficient of Performance (COP) of ~3.1.

The pattern of electrical usage dedicated to HVAC loads is shown in Figure 12.

The production and distribution of the total 23,835 kWh of ground-source heat supplied to the building from October-February required a system-wide total of 17,142 kWh of electricity. Assuming that 25% of the electrical energy used by the heating system amounted to heat gain, then the COP for the ground-source heating and distribution system was ~1.6.

The Water-Water heat pumps provided 45% of the heat delivered and the Water-Air units 55%. A combined unit-specific COP of 4.9 for the Water-Water heat pump units was observed. Including the circulation pumps in the calculation reduces the COP to 3.1. The Water-Air combined unit specific COP is 3.25—which inherently includes electrical requirements for heat distribution.

Long-term building performance

For the first year of monitored operations the facility experienced its most compelling energy performance (50.7 kWh/m2/yr). During this period we operated the building in its passive mode whenever possible.

The number of staff working at the center has continued to expand, from 35 people at initial occupancy in 2004, to its design capacity of 50 people in late 2007. During the same period, significant investments were made to increase the capacity of our computing facilities (speed, computational capacity, and data storage) in support of RS/GIS (forest monitoring) and large scale/high resolution ecological modeling research. Power usage in the server room has more than doubled (from 1 kW to 2.2 kW continuous), with the result that the already problematic passive approach to cooling the server room was overwhelmed—and active mechanical cooling is now required for several months of the year.

For the three-year period from May 2004 to April 2007 the annual electrical power usage averaged 103,445 kWh/yr. This represents building performance of 57.7 kWh/m^2/yr, with the proportion of electricity provided by the PV system contributing 28% of the required total. Electrical usage by load category, as expressed in Figure 13, has increased for all categories, except the “background” term, which has remained constant.

6. WIND ENERGY AND ACHIEVING CARBON NEUTRALITY

Having reduced building energy use to 25% of typical office construction in our region, and providing about a third of that reduced energy requirement from the roof top PV system, we find that the remaining renewable energy supply needed to achieve carbon-neutral operation from onsite sources can be provided by a wind turbine of somewhat under 100 kW (peak) capacity.

The site’s wind resource measured over a two-year period at a height of ~30 m (100ft) above ground level (agl), averages 10.5 mph (4.7m/sec). Using shear factors measured locally between 30 m and 40 m height agl, an average annual wind resource of 12.0mph (5.4 m/sec) at a 40 m height is estimated for the site. A 100 kW wind turbine will produce an average of ~160,000 kWh/yr annually in this class 3 wind regime.

As shown above in Figure 2, the availability of the wind resource is seasonally in opposition to that of the solar resource.

In order to achieve the overarching goal of a carbon-neutral/zero-net-energy facility, we recognized at the outset that the cloudy Northeast winter conditions posed a particular challenge to an all-solar approach given the winter average of < 2 full sun-hours/day.

The estimated daily contribution of wind power (using a 100 kW turbine) to the facility is expressed in Figure 14 relative to our facility’s measured power usage and PV production for the 2004–2005 period. This load-matching correlation between the building’s seasonal peak energy requirements and the winter wind resource availability is compelling.

6. CONCLUSIONS

The performance of the Woods Hole Research Center’s Gilman Ordway Campus facility is excellent (the best of its class in the DOE database) despite

FIGURE 13. Monthly Electrical use by load type, April 2004–June 2007.

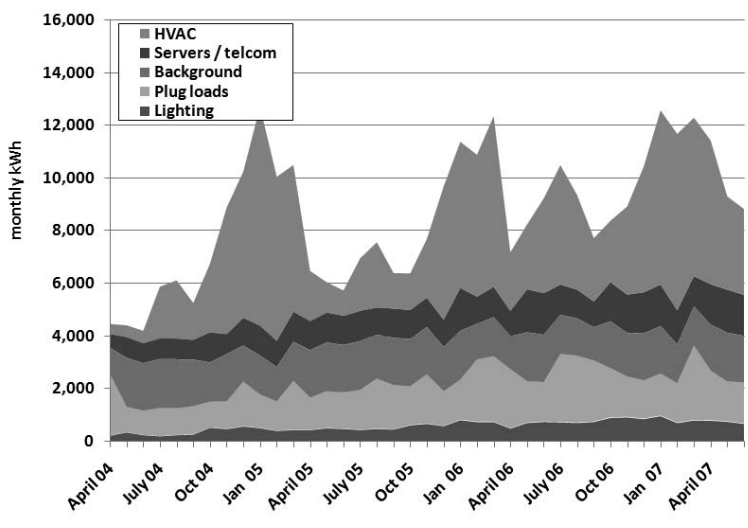
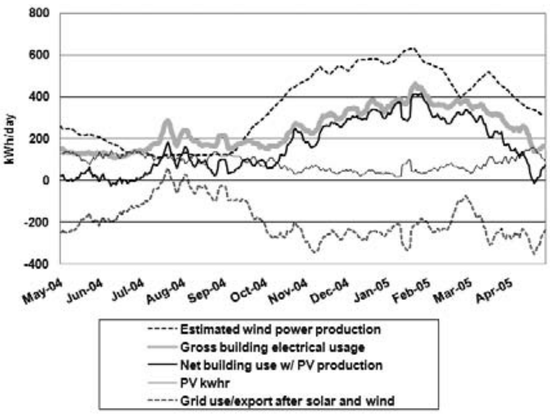


FIGURE 14. The Research Center's measured electrical load profile, and reductions observed with the use of a solar electric, and proposed wind electric system.



shortcomings in the design of the HVAC system, persistent parasitic loads within automated systems and plug loads, and unanticipated heat accumulation in the server/telcom room.

The core building efficiency measures of: very low air infiltration rates (a tight building), good insulation levels achieved through interrupting thermal bridging by the building's structure, enthalpic-energy-recovery ventilation, and low-temperature heating-distribution systems are coupled with a ground-source heating and cooling system to achieve this level of performance.

The fraction of total power supplied by the moderately sized solar PV system is 30% of the facility's total energy requirement, with the remaining fraction, currently supplied by the grid, soon to be provided by a 100kW wind turbine mounted 40m above the ground level.

Achieving excellent building performance is of paramount importance if major reductions in greenhouse-gas emissions are to be achieved with solar and wind installations of reasonable size and cost. WHRC's experience with the Ordway campus is a compelling example of how this can be done in a building that is comfortable, functional, and beautiful. It enables us to "walk the walk" as well as "talking the talk" on the subject of environmental sustainability that is at the core of the Center's research, policy engagement, and educational efforts.

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