A BUILDING THAT TEACHES

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Michael Mathers

Students at Hood River Middle School don't just read about science; they touch and experience it every day. Projects such as working with an electrician to install a solar panel, connecting pipes for a water filtration system, and growing, cooking and selling produce provide opportunities for exploring and applying science, math, writing and social issues. All of these activities take place in the campus' new Music and Science Building, which opened in 2010 and is operating on a net zero energy basis. The building also is providing insight into how occupant behavior impacts building energy use.

The Music and Science Building demonstrates that net zero can be affordable under conventional budgets. Government and utility incentives help reduce the LEED Platinum project's costs for a 20-year or less payback. Also, the building was part of the nonprofit/industry supported Energy Trust of Oregon Path to Net-Zero Pilot Project that aims to refine design strategies to achieve net zero onsite building energy use.

Because the Music and Science Building is situated adjacent to the historic main school building, the designers had two primary objectives: to create a public building that fuses sustainable design with the sustainability curriculum and to carefully integrate the facility into the existing National Historic Landmark site. The design uses gabled roof forms, brick and precast details to reflect the original school building constructed in 1927.

A 2008 construction bond, which funded the project, aimed to accommodate an increasing school population that had forced the music program into an old bus barn outbuilding and to replace the existing outdated science labs with facilities that reflect changes in science teaching technology. The new freestanding building houses a state-of-the-art music facility, a fully integrated science lab, and greenhouse for teaching environmental science programs. Much of the existing historic main school building was renovated for Americans with Disabilities Act (ADA) and life safety code compliance.

Opposite The acoustics of the music room are improved with diffusive and absorptive panels. Sound is isolated from the rest of the building with the thick insulated concrete formwork walls.

Above right A student works on the "biological filter" tanks where fish fertilize rainwater. The water is filtered when it cycles through a hydroponic growing medium where a variety of edible plants are grown.

School as Teaching Tool

The building acts as a living laboratory for the students. It includes a greenhouse where students grow plants using water from a self-contained "biological filter" that uses fish to fertilize water that can then be used for irrigation. (See sidebar on Page 38.)

The project team worked with teachers and students to include and enhance building components that

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BUILDING AT A GLANCE

Name Hood River Middle School Music and Science Building

Location Hood River, Ore. (62 miles east of Portland, Ore.)

Owner Hood River County School District

Principal Use Middle school science and music building
Includes Science and music classrooms and greenhouse

Employees/Occupants 72 full-time equivalent occupants (including students)

Occupancy 100%

Gross Square Footage 6,887
Conditioned Space 5,331

Distinctions/Awards AIA/COTE Top Ten Green Projects, 2012; 2030 Challenge Design Award Winner; LEED Platinum-LEED for Schools 2007, 2012; Insulating Concrete Form Association Gold Award For Commercial Projects, 2011

Total Cost $1.7 million
Cost Per Square Foot $247

Substantial Completion/Occupancy September 2010

Right In the school's Food and Conservation Science program, students get hands-on experience growing, cooking and selling food, while learning lessons about biology, chemistry, business and more.

Below The building's south roof is covered with solar panels. A trellis on which deciduous vines are now growing shades the south-facing windows in the summer months and allows for solar heat gain in the winter.

Bottom right This 1940s structure was originally built to house buses, but had been converted to classrooms due to space shortages. The building was taken down piece by piece, and 97% of it was recycled or reused in the new building. Stout floor beams designed to support buses were sandblasted and used to create the new building's roof trusses.

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ENERGY AT A GLANCE

Annual Energy Use Intensity (EUI) (Site) 26.8 kBtu/ft^2*
Renewable Energy (On-site PV) 27.1 kBtu/ft^2

Annual Source Energy 26.8 kBtu/ft^2

Annual On-Site Renewable Energy Exported 0.33 kBtu/ft^2

Annual Net Energy Use Intensity -0.33 kBtu/ft^2

Savings vs. Standard 90.1-2004 Design Building 100%

ENERGY STAR Rating 100

Heating Degree Days (base 65˚F) 5,883

Cooling Degree Days (base 65˚F) 604

Average Operating Hours Per Week 42.5

*Based on conditioned space.

WATER AT A GLANCE

Annual Water Use 9,720 gallons potable water; 34,959 gallons of reclaimed water

serve as an integral part of the curriculum. One important aspect of this is a transparency of building function.

For example, an exposed section of exterior wall at a bay window seat allows students to see the layers of its assembly. Similarly, a plexiglass covered opening in the radiant slab enables students to see how rebar and radiant slab piping are used.

Students also have access to the heart of the building's mechanical systems, with equipment labeled and metered specifically for classroom demonstration and instruction. Dimming controls on the artificial lighting reveal the impact of daylighting on energy consumption, and carbon dioxide concentration level monitoring teaches the students about air quality and ventilation effectiveness.

Extensive signage posted throughout the building also explains how systems work, and a building dashboard reports real-time energy and water consumptions and production/collection data. As a key element of the science curriculum, students use the dashboard to manage an "energy budget."

The school's sustainability education program is based on the principles of permaculture, which includes the concept of how using more of a resource than one creates leads to a degradation of the system. In keeping with this principle, the design team set a goal to create a net zero energy building that uses no more energy than it produces in a year. Of course, achieving this goal also depends upon building occupant behavior, which dovetails nicely with the idea that students study, experiment with and manage the building's energy use.

Community Connections

The building was envisioned as a community resource where, for example, the stepped floor music room serves

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Right Students work together in the science classroom. The wood scissor trusses were salvaged from the 1940s bus storage barn that previously occupied the site. Leaving the trusses exposed eliminated the need for additional finish materials such as a drop ceiling.

BIOLOGICAL FILTER

In an effort to make the building net zero water as well as net zero energy, the design team looked into treating wastewater with an underground on-site system. Local regulations prevented that from being implemented, but students used a similar concept to design and build a "biological filter" in the greenhouse.

Rainwater was used to fill several tanks, which are filled with fish. The fish fertilize the water, which is cycled through a hydroponic growing medium where a variety of edible plants are grown, filtering the fertilized water.

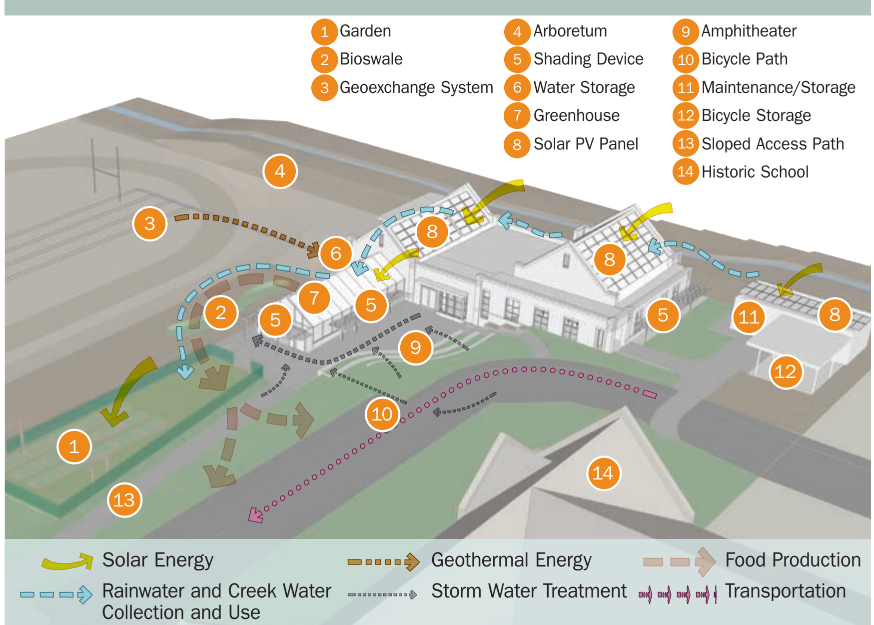
not only classes, but is also available for school and community events. The students' growing and harvesting efforts also serve the larger community; every Thursday students participate in the Gorge Grown Farmer's Market hosted at the school site. A new outdoor amphitheater overlooking the greenhouse is accessible to the public in addition to serving as an outdoor classroom.

Materials

The Music and Science Building's emphasis on conservation of resources began by reducing the amount of material used to build the facility. Material selections needed to be durable, inexpensive and easy to maintain, while minimizing their environmental impact.

One way to decrease material use involved selecting materials that could serve more than one purpose. Exposed concrete floors deliver radiant heating and cooling, require

RESOURCE FLOWS



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Above Students point out where reclaimed rainwater is stored in a 14,000 gallon underground cistern for irrigation and use in the building's toilets.

Below Windows from the science classroom look into the mechanical pump room, where a maze of pipes serve the geoexchange, radiant slab and rainwater treatment systems.

little maintenance and eliminate the need for floor finishes that must be periodically replaced.

Similarly, the wood trusses and roof deck provide an attractive finish without a drop ceiling, and insulated concrete formwork walls eliminate the need for wood formwork and provide a substrate for direct application of interior finishes. All interior materials were selected for low-VOC and sustainable sourcing in compliance with the LEED Platinum criteria.

The Music and Science Building replaced the 1940s bus storage barn that was previously located at the site. After carefully deconstructing the structure, salvaged materials comprising 8% of the new building's materials were used, including the exposed wood scissor truss structure.

Additionally, 96% of the construction waste generated on site was recycled, 22% of the materials used were recycled, 34% of the materials used were extracted, processed and manufactured within 500 miles of the project site, and more than 3% of the materials came from rapidly renewable resources. The design team placed recycling stations around the building. The school composts food waste from the cafeteria in the greenhouse to nurture the plants grown there.

Recycling materials and compost are taken to a nearby new cedar-clad structure designed to provide maintenance storage and serve as a central recycling collection area for the school. Materials are emptied here for collection by the local recycling agency.

Energy Performance and Passive Strategies

The path to a net zero energy building begins by reducing the building's energy demands as much as possible. The team's design goal to meet net zero energy was to achieve an energy use intensity of 24 kBtu/ft^2 · yr as compared with the Standard 90.1-2004 baseline EUI of 56 and the 2030 Challenge EUI of 26.

This target was based on the potential amount of renewable energy that could be produced by PV panels on the structure's limited

BUILDING TEAM

Building Owner/Representative Hood River County School District

Architect Opsis Architects

General Contractor Kirby Nagelhout Construction Company

Mechanical, Electrical Engineer; Energy Modeler; Lighting Design Interface Engineering

Structural, Civil Engineer KPFF Consulting Engineers

Landscape Architect Greenworks, PC

KEY SUSTAINABLE FEATURES

Water Conservation A 14,000 gallon underground cistern collects rainwater and can be supplemented from a nearby stream. The cistern provides all irrigation and water for flush fixtures. Waterless urinals, dual-flush toilets and low-flow sink faucets.

Recycled Materials Salvaged bus storage barn used in construction of building, 96% of construction waste recycled, 22% of all construction materials made from recycled materials.

Daylighting Dimming ballasts serving all classroom and entry lighting fixtures have the capability to continuously dim the fixtures down to a minimum 5% power output based on the amount of daylight in the space.

Transportation Mitigation Strategies To encourage alternative transportation, ample bike and skateboard parking is available in a new bike shed, and dedicated bike lanes have been striped through campus. No new parking was created to service the new facility, and after closing the driveway through the campus during construction, the school decided to make this closure permanent and make the campus a car-free zone.

Composting Food waste from the cafeteria is composted in the greenhouse for plants.

Other Major Sustainable Features Closed loop ground source heat exchange system.

Solar duct, outside air preheating system.

Radiant heating/cooling concrete floors.

Heat recovery ventilation.

Displacement ventilation system.

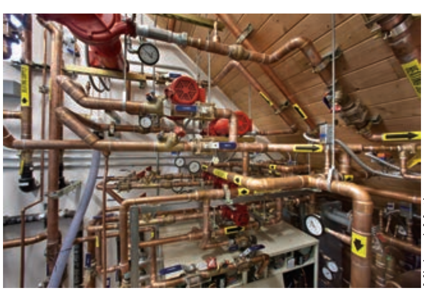
Demand-control ventilation.

Split-yoke receptacles allowing for half of plug loads to be turned off when space is unoccupied.

High efficiency ground source water-to-water heat pumps.

Free cooling to radiant slabs from irrigation water via heat exchanger.

Energy dashboard.



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Above **A student practices in the bay window seat next to an opening in the wall that allows students to see how the envelope is assembled.**

Above left **The amphitheater can be seen from inside the greenhouse, where plant starts sit waiting to be transplanted to the outdoor garden.**

roof space. In the first year after completion, utility data showed the facility was operating at an EUI of 1 kBtu/ft^2 · yr above the net zero goal, which resulted from lower than expected PV electricity production by panels that were improperly installed. The panel installation was corrected during commissioning of the active systems.

Data from months six through 18 indicate an EUI of 0.5 kBtu/ft^2 · yr below the goal, achieving net zero energy status. This result meets the design objective to create a "living laboratory" for students to be able to test their use of the building and how it affects the fine line between energy production and consumption.

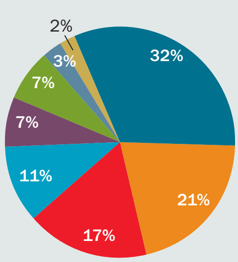
The team paid careful attention to the building envelope, with R-38 rigid insulation (with lapped layers to avoid gaps) on the roof and R-15 insulation under the radiant slab on grade. The insulated concrete formwork walls and concrete slab provide excellent thermal mass that buffers against Hood River's seasonal temperature swings, while their monolithic nature along with careful detailing drastically reduces air infiltration and thermal bridging. Triple glazing helps reduce heat gain and loss at the windows.

The building also reduces resource use by relying on passive strategies. To achieve the optimum level of daylight and energy efficiency in the science and music classrooms, the project team performed multiple detailed daylighting studies, balancing the results with those of the energy model.

The resulting design combines translucent skylights, clerestory windows and traditional windows with deciduous vines for seasonal shading, allowing views in multiple directions from most building locations. Light colored acoustic panels help reflect natural light from the clerestory windows deep into the classroom space.

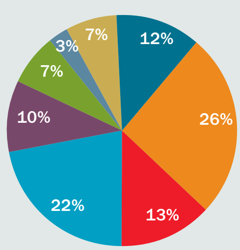
ESTIMATED ENERGY USE BREAKDOWN
BASELINE VS. HOOD RIVER MIDDLE SCHOOL MUSIC AND SCIENCE BUILDING

Standard 90.1-2004 Baseline Building



MBtu/yr (Baseline)	Type of Use	MBtu/yr (Design Estimate)
96.1	Ventilation Fans	14.9
62.8	Interior Lighting	31.5
51.9	Space Heating	15.1
32.6	Miscellaneous Equipment	26.1
21.1	Water Heating	11.7
19.1	Exterior Use	8.8
9	Space Cooling	3.3
6.1	Pumps	8.5
298.7	**Total**	**119.9**

Design Estimate



Estimated Energy Savings from Energy Measures

	Estimated MBtu/yr	Percent of Total Savings
Extra Insulation	24.3	13.6
Efficient Lighting	14.1	7.9
Daylighting	14.1	7.9
Switched Plugs	3.8	2.1
Geothermal/Radiant Slab Heating & Cooling System	56.9	31.8
Efficient Ventilation Fans	15.9	8.9
Sensor-driven Ventilation	7.7	4.3
Passive Solar Ventilation	21.1	11.8
Efficient Water Heating	2.5	1.4
Irrigation Water Cooling System	18.4	10.3

ENERGY USE					MAY 2011–APRIL 2012
	Mechanical Equipment (kWh)	Lighting/ Plug Loads (kWh)	Total Power Consumption (kWh)	PV Energy Production (kWh)	Net Power Consumption/ Production (kWh)
May-11	2,105	1,173	3,278	5,247	–1,969
Jun-11	903	986	1,889	5,651	–3,762
Jul-11	987	778	1,765	5,750	–3,985
Aug-11	1,620	863	2,483	5,814	–3,331
Sep-11	1,372	1,227	2,599	4,248	–1,649
Oct-11	2,143	1,309	3,452	2,305	1,147
Nov-11	2,959	1,294	4,253	1,651	2,602
Dec-11	3,434	1,333	4,767	1,237	3,530
Jan-12	3,611	1,275	4,886	1,131	3,755
Feb-12	3,081	1,331	4,412	2,065	2,347
Mar-12	3,163	1,315	4,478	3,034	1,445
Apr-12	2,276	1,273	3,549	4,235	–686
Total	**27,654**	**14,157**	**41,811**	**42,368**	**–557**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Mixing classroom lessons with hands-on learning in the garden and greenhouse helps engage students in their classes.

A system combining operable low and high clerestory windows and rooftop ventilators provides fresh air and passive cooling to facilitate cross and stack ventilation. A red light/green light indicator informs building occupants when outside temperatures are favorable for natural ventilation, further engaging students in the management of the building's energy use.

The system also passively preheats the air used for mechanical ventilation in a transpired solar collector, or air plenum that sits on a south-facing roof covered by a piece of perforated metal decking and solar panels. Not only does this system conserve energy by using passively heated air, but when hot air is drawn out of the plenum for use in the building, it cools the solar panels that sit above the plenum, allowing them to run more efficiently.

Deciduous vine-covered trellises sit in front of south facing windows to block summer sun, but allow solar heat gain during the winter. The team placed a sundial above the south entry to raise the students' awareness of daily and seasonal natural cycles and help provide a connection between the building and its place.

Active Mechanical and Electrical Systems

The building's main source of heating and cooling energy is through a geoexchange system of tubing that is horizontally looped 10 ft under the school's soccer field. An adjacent stream serves as an additional energy source for summer cooling.

The district uses a portion of the stream's snowmelt runoff for irrigation at the school during the region's dry summers, which coincides with the need for cooling. The irrigation water is simply diverted through a heat exchanger during periods of cooling demand. The floor slab for radiant heating and cooling distributes energy from these sources throughout the building.

Heat recovery ventilators transfer heat from exhaust to incoming air, and use the transpired solar collector to preheat air. CO_2 sensors regulate the amount of fresh air needed to be brought into the building, while a

BUILDING ENVELOPE

Roof
Type Rigid board insulation over wood decking
Overall R-value 40
Reflectivity 15%

Walls
Type Insulated concrete forms (ICF)
Overall R-value 25
Glazing Percentage 29%

Basement/Foundation
Slab Edge Insulation R-value R-15
Continuous Under Slab Insulation R-value R-15

Windows
Effective U-factor for Assembly 0.3
Solar Heat Gain Coefficient (SHGC) 0.3
Visual Transmittance 0.38

Location
Latitude 45.7° N
Orientation Long axis of greenhouse runs E-W; long axis of building runs N-S.

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Above **Students prepare food grown in the school's garden as part of the Food and Conservation Science program. With the help of a visiting artist, students designed and built a wood-fired cob oven, which they use to cook the food.**

Right **Hood River is located in the Columbia River Gorge between Mt. Adams (seen here) and Mt. Hood, and has an excellent climate for a garden.**

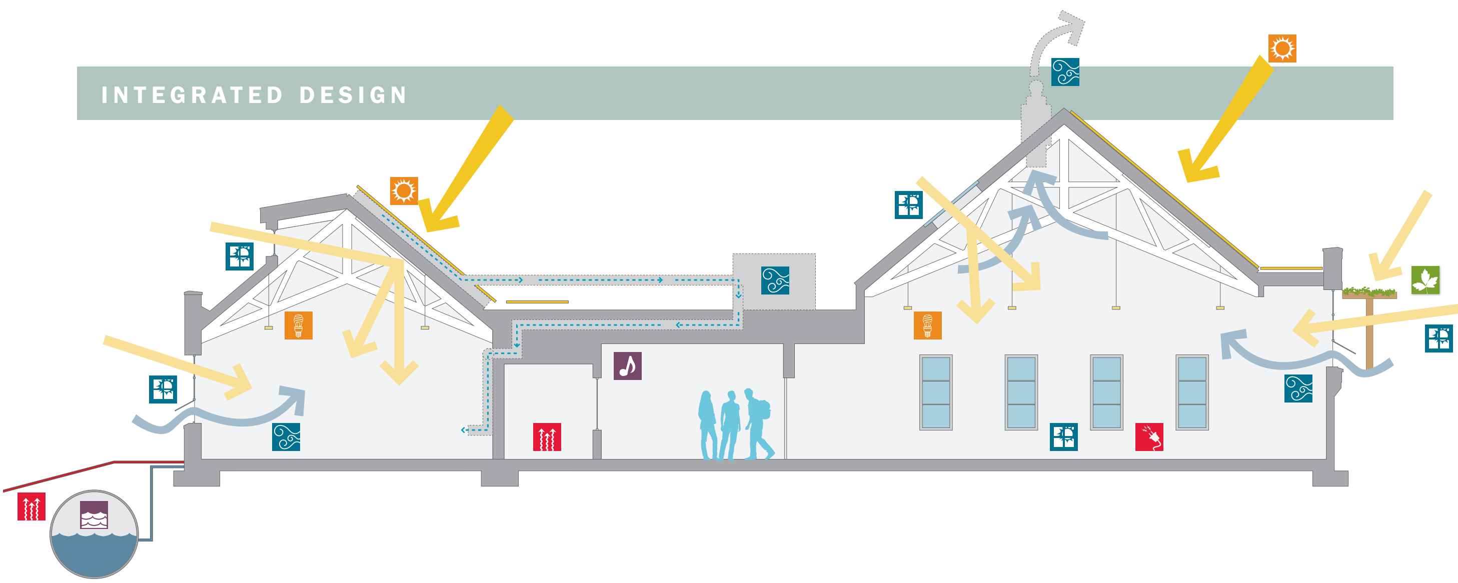
displacement air distribution strategy further reduces the amount of energy used by fans to distribute air and increase ventilation effectiveness.

Displacement ventilation systems require less static pressure to deliver air into the space, reducing the size of the supply fans required. Ventilation effectiveness is increased by supplying air low and exhausting it high, which allows contaminants in the room to be taken out rather than mixed around (as occurs in a conventional overhead air distribution system).

Lighting and Plug Loads

Classrooms take advantage of energy-efficient indirect and direct/indirect fluorescent lighting, with daylight and occupancy sensors to help ensure artificial lighting is only used when needed. To help reduce parasitic plug loads, the building has dual operation outlets with each receptacle containing one unswitched outlet and one switched outlet that shuts off when

INTEGRATED DESIGN



- Solar panels convert sun energy into electricity. Airflow behind the panels is preheated for use in the building.
- Energy-efficient lighting is computer controlled to dim in response to available daylight in the room.
- Deciduous vines growing on an exterior trellis block hot summer sunlight, but allow winter sunlight to warm the building.
- When outside air temperatures are comfortable, a light indicates that windows and rooftop ventilators should be opened to allow fresh air into the building.
- Translucent skylights, clerestory windows and traditional windows create an even distribution of daylight in classrooms, reducing the need for electric lighting.
- Air is delivered at a slow speed low in the room, providing an efficient system that conditions the air where people are.
- A water tank collects rainwater from the roof so it can be reused for toilet flushing and irrigation.
- Many walls are specially constructed with gaps between materials to deaden sound transfer between spaces.
- To conserve energy, bottom electrical outlets shut off automatically when the room is empty.
- Radiant slabs contain plastic piping that distributes hot water for winter heating and cold water for summer cooling. Below-slab insulation minimizes energy transfer into the ground.

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The building was envisioned as a community resource. The stepped floor music room serves not only classes, but is also available for school and community events. A new outdoor amphitheater overlooking the greenhouse is accessible to the public in addition to serving as an outdoor classroom.

the building is not in use, as determined by an occupancy sensor.

These conservation efforts alone allowed the project team to reduce the building's energy demand by 57% below an Standard 90.1-2004 baseline building. The remaining energy used by the building needed to be produced by on-site renewable energy to meet the net zero energy goal and reducing energy demand by 100% compared to the baseline.

The project's location in the Columbia River Gorge, a destination known as one of the world's premier wind surfing sites, led the design team to study wind as a possible energy source. However, after further analysis, solar photovoltaic energy proved to be more economically feasible. The team covered virtually the entire square footage of the roof receiving southern exposure with a 35 kW photovoltaic system.

Water

The project originally targeted a net zero water system for building water use, wastewater, and storm water. All nonpotable water needs (including flush fixtures, exterior cleaning, irrigation, etc.) are met by collected rainwater and supplemented by a portion of a creek running through the site.

LESSONS LEARNED

Wind Energy. The project site is located near one of the best wind surfing destinations in America due to the consistent winds blowing down the Columbia River Gorge. However, wind energy was less cost effective than solar for two reasons: the need for directionally consistent wind available at heights significantly above the objects on the ground that create turbulence and less rewarding incentives. It is important not to assume a resource is feasible until proven.

Photovoltaics. With the building's roof area constraints and the net zero energy goal, the design required a more expensive, higher efficiency panel to achieve the required energy production, which demonstrates the important link between roof area, orientation and net zero goals. The contractor installed the PV panels so they were shaded by the rooftop mechanical unit, requiring the relocation of the panels late in the construction process. This example demonstrates the need to carefully coordinate every aspect of panel installation to achieve maximum performance required to meet net zero goals.

Training Staff. The project team found that training custodial staff on minimizing energy waste (such as not leaving classroom doors propped open during cold weather) was also critical to meeting net zero energy goals. Tuning the building controls to maximize energy efficiency and occupant comfort also requires the time and attention of the facility operators. The team is in the process of doing a full post-occupancy evaluation of the building, including a recalibration of the design energy model using actual energy and weather data and providing additional training for staff.

The team also designed the project for net zero waste using an on-site black water treatment system. Unfortunately, due to regulatory requirements to include a backup tie-in to the city sewer system, the district decided not to spend money on duplicate systems. This system can easily be added in the future by diverting the waste.

Although potable water was originally designed to be provided by treating rainwater, this was also eliminated due to the building's low potable water demand of just a drinking fountain and sink. However, this system can be added in the future since the piping was separated.

Reducing outdoor water use at the Music and Science Building began with 18,100 ft^2 of low-water, native vegetation, which covers nearly all of the landscaped area surrounding the building. The school harvests, collects and stores rainwater in a 14,000 gallon underground cistern. The collected rainwater supplies nearly all of the remaining water needed for irrigation of the students' garden and saves more than 123,000 gallons of potable water annually. The water drawn from the nearby stream eliminates the need for potable water use for irrigation purposes.

Inside the building, low-flow faucets, a waterless urinal and dual flush toilets that use collected rainwater for flushing, save approximately 89% of the annual water used in the building compared to standard EPAct-rated fixtures.

A new bioswale treats 100% of the storm water runoff from the immediate building site as well as the adjacent driveways and campus areas

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Above Students enjoy the fruits of their labor in the garden next to the new building.

Right The accessible path from the main school building to the new Music and Science Building is lined with planting done by students. Planters were created out of hollowed-out tree sections that were salvaged from trees removed for construction.

using native water-loving sedges, grasses and shrubs.

Economics

The project participated in the nonprofit/utility industry supported Energy Trust of Oregon Path to Net-Zero Pilot Project that aims to refine design strategies to achieve net zero onsite building energy use. The nonprofit provided $15,000 in incentives for energy efficiency measures and $45,000 in renewable energy incentives.

The added cost to achieve net zero energy use after incentives was $130,640, resulting in a 19.9 year simple payback. If incentives were not available, the payback would have been 43.4 years, less than the average life of a school building in the United States. This calculation, however, does not account for the escalation of energy costs over the next 43 years, which would reduce the effective payback to closer to 20 years without incentives.

Even with the benefit of the short payback period, the school board had to carefully weigh the allocation of its limited resources for the renewable energy systems against other capital needs. In the end, the board decided that the strong link between the net zero strategies and the teaching curriculum, combined with the building serving as a district-wide learning resource, justified the project's expense.

Conclusion

One important aspect of sustainability and permaculture is that an individual's actions need to serve as a source of improvement for the systems and cycles with which we interact. A net zero energy building offers a living laboratory where students and teachers can better understand and teach the complex interrelationships between society and natural systems.

Students are tapping into the many opportunities the facility affords and taking ownership of its systems in their classrooms by tracking and analyzing energy use, and by building things such as gardens, "biological filtration" systems and cob ovens for future generations of students to use.

The Hood River Middle School Music and Science Building serves as proof that a net zero energy facility can be created on a conventional budget with an excellent return on investment and provide a relevant educational platform for sustainability education. The design team reduced resource use in as many ways as possible and built in a transparency that allows the building users to understand and interact with the building's sustainable features.

Hood River Middle School views the interface between the building and its environmental and cultural landscape as an important part of the curriculum. By serving the needs of the community, the building improves all three aspects of the triple bottom line—environmental, economic and social. ●

ABOUT THE AUTHORS

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