U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy
BUILDING TECHNOLOGIES OFFICE

Zero Energy Building Highlight:

Pittsburgh's Frick Environmental Center

MARCH
2022

FOREWORD

The EERE Building Technologies Office (BTO) within the U.S. Department of Energy's Office of Energy Efficiency and Renewable Energy asked teams from three national laboratories to explore the specific technologies, systems, and approaches used to attain zero energy status in three office buildings located near Pittsburgh, Houston, and Atlanta. This case study examines the city of Pittsburgh's Frick Environmental Center (FEC), planned in conjunction with (and now operated by) the Pittsburgh Parks Conservancy.

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Cover photo: Bohlin Cywinski Jackson

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ACRONYMS

AIA	American Institute of Architects
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
DOE	U.S. Department of Energy
CER	Certified emission reduction
CO_2	Carbon dioxide
COP	Coefficient of performance
COTE	Committee on the Environment, AIA
EER	Energy efficiency ratio
EPA	Environmental Protection Agency
EUI	Energy use intensity
FEC	Frick Environmental Center
GHX	Ground heat exchange
GSHP	Ground-source heat pump
HVAC	Heating, ventilation, and cooling
LBNL	Lawrence Berkeley National Laboratory
LCA	Life-cycle analysis
LEED	Leadership in Energy and Environmental Design
PV	Photovoltaic
REC	Renewable energy certificate
VAV	Variable air volume
ZEB	Zero energy building

CONTENTS

Photo: Nic Lehoux

FRICK ENVIRONMENTAL CENTER (FEC)

Selected Certifications & Awards

- Living Certified, Living Building Challenge v2.1
- LEED Certified (Platinum), 2017
- Leadership Award, Green Building Alliance, 2017
- AIA COTE Top Ten Plus Award, 2019

Energy Use Intensity: 25 kBtu/ft^2/yr

Total cost: $13.75 million ($836/ft^2)

Conditioned floor area: 16,440 ft^2

Construction completed: 2016

Climate Zone: 5A (cool and humid)

Zero-Energy Buildings

Achieving zero energy is an ambitious yet increasingly achievable goal that is gaining advocates across markets to help meet climate goals. A zero-energy building (ZEB) is designed to operate at high efficiency and produce enough on-site renewable energy to equal or exceed the building's annual delivered energy needs. For more information about ZEBs, please see the U.S. Department of Energy (DOE) website.

FEC DESIGN

As part of Pittsburgh's historic Frick Park, the Frick Environmental Center's core mission is to provide environmental education to the public. This mission is reflected in the building's design and the range of sustainability elements woven into its construction and operation. The municipally owned facility's low energy usage and passive interaction with the local environment support its experiential education mandate by raising awareness among visitors and occupants. More broadly, the center showcases zero-energy principles in a public project format. Guided by the Pittsburgh Parks Conservancy, the building was designed by Bohlin Cywinski Jackson and the landscape by LaQuatra Bonci. Construction was by PJ Dick, with engineering by H.F. Lenz, Barber & Hoffman, and RAM-TECH. This document highlights the following ZEB systems:

- Passive design
- Solar power and energy monitoring
- Space conditioning and ventilation
- Ground-source heat pumps
- Life-cycle carbon neutrality.

"By delicately balancing passive and active systems, this environmental center teaches the public about sustainable design through its net-positive energy and carbon design."

Clay Risen, *ARCHITECT Magazine*, November 2019

Photo: Bohlin Cywinski Jackson

PASSIVE DESIGN

A ZEB facility's energy performance depends upon its onsite energy usage relative to its onsite energy generation. Energy usage (demand) is estimated first so that the energy generation (supply) can be sized appropriately.

To minimize demand, the Frick Environmental Center (FEC) design team specified a tight building envelope and prioritized passive strategies and high-efficiency systems. FEC's passive design harnesses the site topography, landscape, climate, and prevailing weather conditions to reduce building energy needs while keeping building occupants comfortable.

The FEC site offered significant opportunities to incorporate energy-saving passive design features. Along with a well-insulated roof, slab, and walls, the design team used passive design principles like building orientation and massing, natural ventilation, and daylighting (Figure 1).

The FEC site's southerly slope afforded design space for a relatively large south-facing façade. Thermal energy management on this side of the building starts with a modest ratio of windows (glazing) to the overall exterior wall area (improving thermal performance) and a highly insulated, wood-clad exterior wall assembly to help keep the building cool in the summer and warm in winter.

To limit the thermal impacts of direct solar radiation on the external wall, a roof overhang shades the facade during peak sun hours in summer, and planted trees provide natural shading at lower sun angles. The low-angle winter sun penetrates the leafless woods, allowing direct sunlight to illuminate the interior and warm the building via solar heating of the windows and external walls.

On the north side, the building presents a narrower, single-story profile as the lower levels of the wedge-shaped

Technical Highlights

Building envelope: Features well-insulated slab (R-10), walls (R 19 to 22), and continuously insulated roof (R-48).

Window-to-wall (WWR) ratio: The relatively modest WWR of 0.37 helps provide better overall insulation.

Window overhang: Overhangs are positioned to block peak summer rays yet let in warming winter sun (at lower angle).

Strategic planting: Trees filter late-day summer sun and permit winter daylighting.

Massing: Setting the north side of the building into the existing hillside takes advantage of the natural thermal regulation provided by the ground mass.

Natural ventilation: Mechanized windows open and close automatically, and manual windows are sequenced via a light notification system for occupants.

Daylighting: When sufficient daylight can be harvested, artificial lighting is dimmed automatically.

Building orientation: Orientation takes advantage of prevailing wind directions.

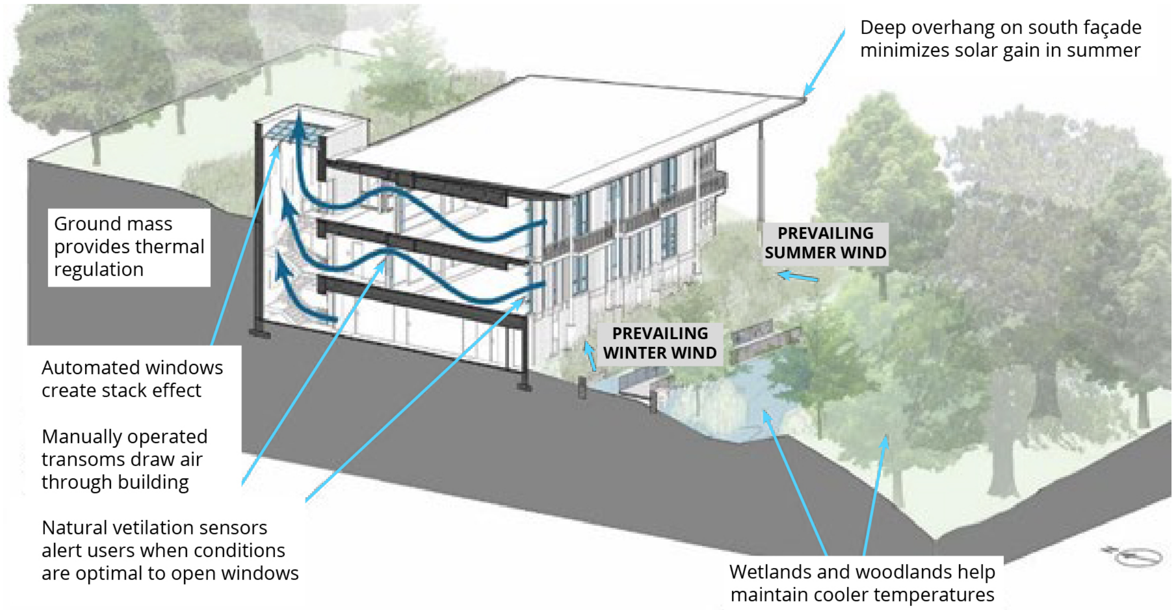

Figure 1. The FEC site offered significant opportunities to incorporate energy-saving passive design features. Image: Bohlin Cywinski Jackson

structure nestle below grade in the hillside. The hill provides seasonal temperature regulation for these lower levels as the thermal mass of the ground remains naturally cooler than ambient temperatures in the summer and warmer in the winter. This design limits envelope heat losses, while continuous insulation across the entire roof area minimizes thermal losses for the whole building.

Natural ventilation takes full advantage of the prevailing summer wind direction and is the primary means of space conditioning. Architectural features channel air through the building—avoiding the need for mechanical cooling except on the hottest days. High ceilings and full-height windows facing south admit the available natural light, which is supplemented by energy-efficient electric lighting only when and where needed.

Occupants also help maintain a high level of energy efficiency, interacting with the passive design elements to achieve full satisfaction with building performance. For example, manual controls for natural ventilation are coupled with a less formal dress code to support occupant comfort. During warm weather, the temperature setpoint in occupied spaces can drift as high as 75°F, and occupants are encouraged to wear lighter clothing. Similarly, while the building is warmed by efficient ground-source heat pumps in cold weather (page 9), occupants are free to wear additional layers to maintain comfort, minimizing the need for mechanical heating.

As a result of the facility's passive design and operation, the heating, ventilation, and air cooling (HVAC) system accounts for only 49% of site energy use. This strategy aligns with the project's sustainability objectives, encouraging occupants and visitors to actively engage with the building to improve its performance and showcase how people can work in harmony with the space.

SOLAR POWER & ENERGY MONITORING

To complement the building's passive design elements, the design team specified efficient mechanical systems, including geothermal heat pumps for space conditioning, low-wattage lighting with occupancy sensing, and efficient computing. As a result, the center's energy usage intensity (EUI) is much lower than that of a "standard" building of the same size (see page 14).

On the supply side, the FEC chose on-site solar generation to meet the facility's electric power needs. The racking for the system supports about 600 glass-bottom solar panels (275 Watts each), which provide shade for the FEC parking area. Eight micro-inverters increase the overall efficiency of the system and convert the photovoltaic (PV) power for distribution to the facility and the grid. Importantly, the Pittsburgh Parks Conservancy decided to purchase the PV system outright with internal funding, rather than finance construction through a power purchase agreement or lease, so the site truly "owns" the renewable energy it generates.

The FEC's large, 161.7 kW PV system is grid-connected and net-metered. When surplus solar electricity is generated, it is fed to the local utility, and when the site needs more energy than the system can provide at a given time, grid electricity is supplied to the building. To meet energy goals, the system is designed to produce more zero-carbon energy than the facility needs each year (Figure 2). In

Technical Highlights

PV panels: The 600 275-W solar panels and racking system help shade the parking area.

Micro-inverters: Eight of these plug-and-play devices convert direct current from the solar panels to alternating current for use in the building.

Enterprise electrical monitoring: System enables remote sub-system monitoring of detailed data and dashboards in real time.

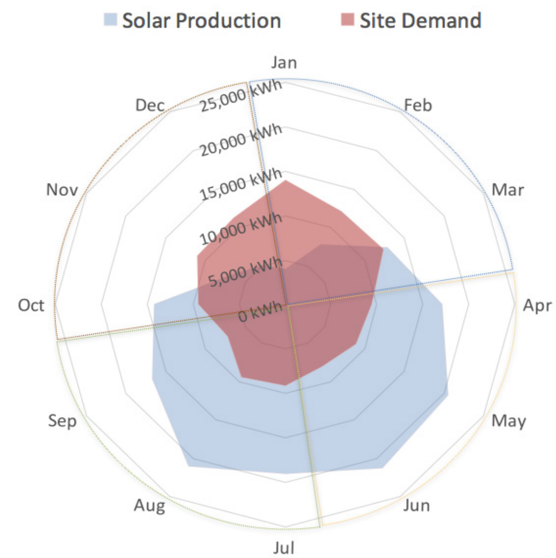

Figure 2. Solar power generated (blue) exceeds FEC energy demand (red) over the year. Source: LBNL

2019 the facility produced 166,452 kilowatt-hours (kWh) while the building used only 122,376 kWh—far surpassing the zero-energy goal.

Ensuring that a building maintains zero-energy performance requires a robust monitoring system that shows the site's balance of energy supply and demand. The FEC's ZEB achievement required validation of on-site energy production and usage throughout a 12-month performance period, post-occupancy.

FEC's custom electrical power monitoring system provides granular, real-time detail on the facility's energy usage and production. Continuous, site-wide monitoring at the subsystem level helps site operators verify that the facility's zero-energy goals are being met each year.

Electricity usage is measured separately and tracked over time for heating, cooling, ventilation, lighting, domestic hot water, elevators, plug loads, and other systems. A public web portal (see Figure 3) provides data on building energy usage and trends. Staff can download selected data series for analysis and for comparison to solar production data or energy use in a prior year (at the system or sub-system-level).

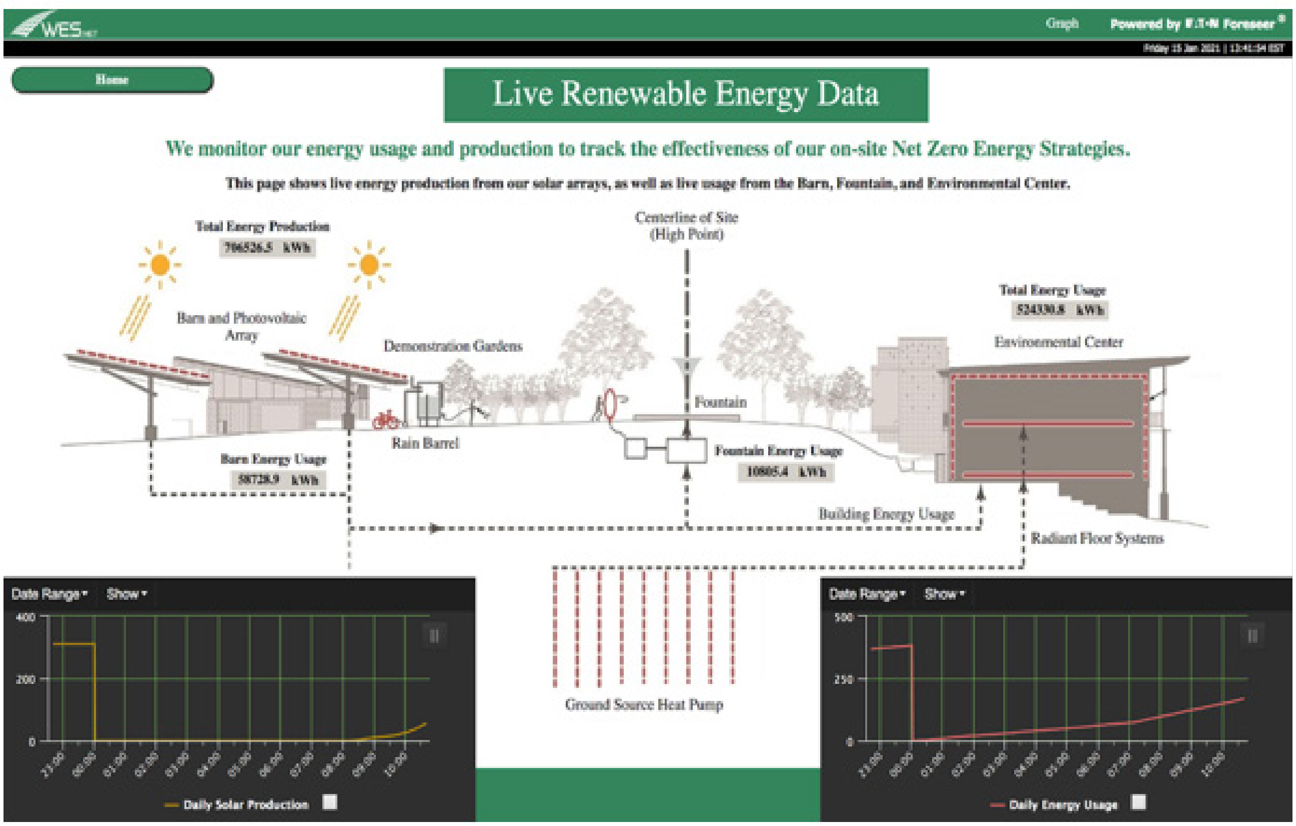

Figure 3. A public web portal provides access to detailed data on the FEC's energy usage and generation. Source: Pittsburgh Parks Conservancy

SPACE CONDITIONING AND VENTILATION

The FEC design relies on mechanical ventilation only when natural ventilation alone cannot meet the building's space conditioning demand. Manual and mechanized windows on the building façade and manually operated transom windows in the building's interior halls help draw fresh air from the lower south wall, through the building, and out the automated windows in the north stair tower using the "stack effect" (Figure 4). The mechanized windows can perform a scheduled night flush to passively expel warm air and draw in cooler outside air (no fan energy required) to precondition the building prior to next-day occupancy. To meet ventilation needs, the building relies on three modes:

- Passive-natural
- Mechanical
- Active-natural (combines passive and mechanical strategies).

In the *passive-natural* ventilation mode, the building's ventilation and conditioning needs are met just by opening windows to take advantage of natural drafts. Operable floor-to-ceiling windows enable this approach. Indicator lights on panels throughout the building show green to alert occupants when conditions are optimal for natural ventilation based on outside and inside air temperature and specific

Technical Highlights

Fenestration: Operable and mechanized windows and operable interior transoms harness natural ventilation to expel heat overnight in warm weather.

Indicator panels: Six zone sensors alert occupants to open or close windows based on temperature and humidity.

Indoor air quality: Zone-level CO_2 sensors activate mechanical assistance or switch to mechanical ventilation.

Dedicated outside air handler: A 3,500 cubic ft. per minute (CFM) unit with energy recovery enthalpy wheel and 12 variable-air-volume (VAV) boxes regulate the volume of air flow.

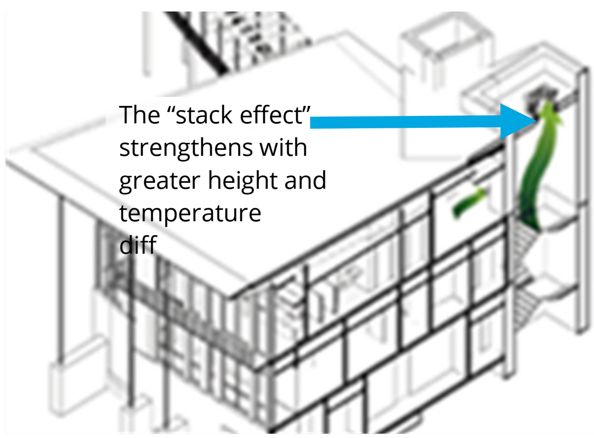

Figure 4. Automated windows in the north stair tower allow rising warm/stale air to exit the building in summer, drawing in cooler night air through louvers near the ground. Image: Bohlin Cywinski Jackson

humidity (determined by six zone sensors). In natural ventilation mode, occupants manually operate most windows in the building, though a small number are automated (Figure 5).

When temperatures and/or humidity are not optimal for natural ventilation, the same indicator panels show a red light. In such cases, the system closes the automated windows, and occupants are alerted to close the manually operated ones. The building then switches to *mechanical ventilation* mode, relying on a dedicated outside air handler to supply air to 12 variable-air-volume (VAV) boxes in the conference room, reception area, offices, lobby, classrooms, gallery, corridors, and basement. If necessary, the air can be pre-conditioned by two of the ground-source heat pumps (see next section). Exhaust air is expelled through dampers atop the stair tower and above an outdoor classroom space.

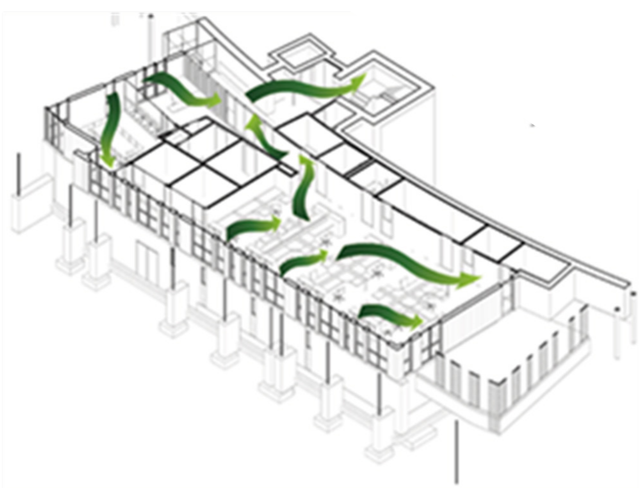

Figure 5. A mix of automated and occupant-operated windows and transoms help draw cooler air into the building on the lower level and expel stale, warmer air through the top of the stair tower. Image: Bohlin Cywinski Jackson

The mechanical system includes a relief air energy recovery enthalpy wheel in the basement, which transfers energy from the conditioned exhaust air (both sensible energy and latent energy from moisture in the air) to the incoming fresh air supply (89% rated transfer efficiency). This effectively preconditions the supply air and reduces the energy needed for conditioning.

Ventilation and conditioning needs are assessed by sensors throughout the building, including 13 zone-level carbon dioxide (CO_2) sensors. A concentration of 450 parts per million above the outdoor air level signals the need for additional ventilation. If the zone CO_2 concentrations or temperatures indicate the need, the mechanical system engages to maintain indoor air quality and comfort. When the building is using natural ventilation, but supplementary conditioning is needed, the *active-natural ventilation* mode is activated.

Occupant interaction is fundamental to the FEC ventilation design. Rather than automating all window controls, which can be costly and mechanically complex, users engage with the building—educating staff and visitors along the way. The ventilation system's reliance on operable windows also promotes access to healthy air and outdoor views, which occupants appreciate.

Human interaction with efficient building systems (e.g., natural ventilation) encourages a culture of stewardship. This works well at the FEC, where the user base is highly engaged. Alternative approaches may be required in other commercial settings, where automated control may be appropriate.

GROUND-SOURCE HEAT PUMPS

The design team chose ground-source heat pumps (GSHPs) to provide highly efficient mechanical heating and cooling for the FEC when passive conditioning is not enough. This technology is less common than other HVAC options (e.g., chillers and natural gas boilers) but is well-proven in the field and has been used successfully for decades. In comparison to air-source heat pumps or air conditioners with gas furnaces, GSHPs offer energy savings in the range of 30% to 60% or more on space conditioning, depending on the climate, technology, and application (DOE 2009).

Rather than relying on gas for heating, GSHPs enable full electrification of the HVAC system. This growing trend supports national sustainability and climate goals as the U.S. power sector moves to decarbonize by 2035.

Geothermal heating and cooling take advantage of ground temperatures that stay relatively constant year-round at about 20 or 30 feet below the surface. A closed-loop GSHP system (ORNL 2019) consists of the following:

- Ground heat exchange (GHX) system, usually with vertical wells
- GSHPs that use the GHX wells as a heat sink/source to efficiently operate the refrigeration cycle
- Air and hydronic distribution systems that use the heat pump 9HP thermal energy to condition the building (FEC uses both).

The constant 55° F underground temperature at FEC provides a heat source in winter and a cool heat sink in summer. Heat pumps use a reversible expansion valve to essentially swap the locations of the evaporator and condenser in the refrigeration cycle based on demand for cooling (heat removed from indoors) or heating (heat rejected indoors). GSHPs deliver

Technical Highlights

Well field: Eighteen vertical GHX loops (1¼" poly-ethylene pipes) circulate glycol/water medium to 520-ft. depth.

Ground-source heat pumps: Five 8-ton water-to-water ground-source heat pumps (GSHPs) and two 1.5-ton water-to-air GSHPs provide space conditioning. The water-to-water GSHPs have a rated coefficient of performance (COP) of 4.3 for heating and an energy efficiency ratio (EER) of 17.8 for cooling. The water-to-air GSHPs have a rated EER of 17.9.

Heat pumps use a reversible expansion valve to run the refrigeration cycle forward or in reverse—enabling highly energy-efficient heat absorption *or* heat rejection, as appropriate to the season.

Hydronic piping: The in-floor zoned hydronic piping system circulates heated water to warm interior spaces.

heating at many times the energy efficiency of a typical gas or electric resistance heater.

The Frick Park location is ideal for commercial-scale GSHPs, offering a large land area for the GHX relative to the building footprint. The GHX system at the FEC includes 18 vertical bores arrayed in a 6 x 3 grid under a broad footpath. A 1¼" polyethylene pipe circulates a glycol/water medium 520 ft. underground with 20 ft. spacing between bores. The glycol prevents freezing in the distribution piping between the bore field and the building during extreme cold weather.

The heat exchange medium is pumped to the basement-level mechanical room, where a total of seven ground-source heat pumps are located (Figure 6). Two 8-ton water-to-water units supply hot or chilled water to the ventilation air handlers. Three more 8-ton water-water heat pumps supply the in-floor radiant heating system (hydronic heat exchange) and chilled water to the fan coil units for additional conditioning in the lobby and reception areas, offices, conference rooms, classrooms, and gallery zones. Two smaller 1.5-ton water-to-air heat pumps provide data center and elevator mechanical cooling.

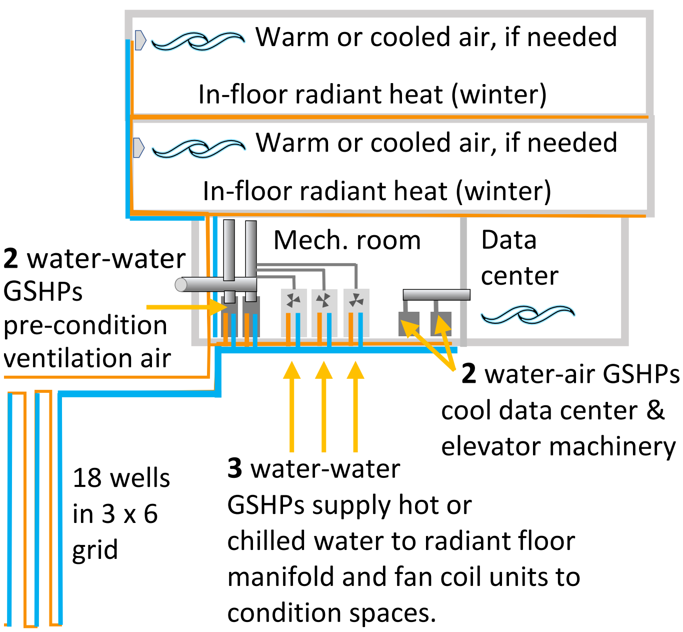

Figure 6. Seven GSHPs of various sizes use 18 closed-loop vertical wells to tap constant underground temperatures for energy-efficient space conditioning.

Collectively, these systems tend to incur higher initial costs and require more complex modeling than competing systems (e.g., versus solar power), yet GSHPs are increasingly specified for small to mid-size office buildings, warehouses, and storage facilities (Craig, 2019). At the FEC, the partnership overcame the upfront GSHP cost barrier by prioritizing sustainability and taking the long view on energy and cost savings. GSHPs can pay for themselves in energy savings in five to ten years. Relative to air-source heat pumps, they are quieter, last longer, need little maintenance, and do not rely on outside air temperature (DOE EnergySaver).

The design team's building information model, which included the GSHPs and site characteristics, confirmed the system's ability to meet facility heating and cooling needs. The team also had to overcome various site challenges for successful installation, including other utilities crossing the system plumbing and interference from physical barriers like rock ledges between the wells and the building.

LIFE-CYCLE CARBON NEUTRALITY

Achieving carbon neutrality required careful planning prior to and throughout the construction and operational phases of the FEC project. A building's net carbon balance includes carbon embodied in the building materials or emitted from processes associated with construction, as well as any carbon emissions resulting from energy use during operations. FEC's zero carbon standard calls for 100% of these carbon emissions to be offset.

Prior to construction, the FEC project team conducted a rigorous planning, scheduling, and material vetting exercise and developed strict design and construction criteria. For example, the team set an upper limit on the distance from which materials could be sourced. This effort occurred prior to widespread acceptance of the materials transparency concept, so product carbon databases were largely absent. The team members had to develop life-cycle analysis (LCA) methods and processes for materials selection.

Rigorous design goals and limited data availability often meant selecting simpler materials already supported by detailed ingredient inventories to enable full accounting of the embodied carbon and sustainability scoring.

Technical Highlights

- **Life-cycle analysis:** The team assessed the embodied carbon of all materials and the carbon impacts of building operations.
- **Materials sourcing:** An upper limit was placed on the distance from which construction materials could be transported.
- **Transport and delivery**. A four-day work week was instituted during construction.
- **Carbon offsets.** Construction-related CO_2 emissions were quantified and offset by purchased credits.

Materials and products were reviewed several times during the design and construction process before they were ordered. At the time, this approach was new to most suppliers, so team members had to act as advocates for the cause. Their processes, methods of engagement, and 'lessons learned' helped build the knowledge base.

During construction, a four-day work week was enforced to reduce travel to the site and limit the carbon associated with material transport and delivery. Strict guidelines governed the operation of large (>25 HP) diesel-fueled vehicles and machinery. To further reduce on-site emissions, suppliers and companies were required to meet the Tier 4 vehicle and machinery emission requirements

A building's net carbon balance includes the carbon that is:

- Embodied in the building materials
- Emitted from processes associated with construction
- Emitted because of energy use during building operations.

set by the U.S. Environmental Protection Agency (EPA 2021). A local grant program helped upgrade vehicles and machinery to lower compliance costs.

Construction-associated carbon emissions were quantified and offset with a one-time purchase of certified emission reduction (CER) carbon credits. These credits were purchased from a local Green-e certified landfill gas-to-energy project by the Lancaster County Solid Waste Management Authority.

During building operations, carbon neutrality requires that design features and occupant behavior minimize energy consumption and that renewable energy be generated on site to offset consumption. To avoid combustion on-site, the design favors all-electric building energy systems and onsite solar energy in the parking structure.

The FEC's solar array ultimately generates and adds *new* renewable energy to the grid (known as renewable energy additionality), as distinct from merely offsetting the use of grid electricity by purchasing renewable energy from existing installations. As part of the ongoing ZEB qualification process, the facility receives renewable energy certificates (RECs) for metered solar power generation, which the owners must retain as proof of the renewable energy produced. The facility has shown that, on an annual basis, it generates more clean electricity on site than it uses.

Figure 7. Best practices to restrict carbon emissions were put in place well before construction began. Image: Creative Commons 495512297

KEYS TO SUCCESS

The Frick Environmental Center design strategies and system technologies highlighted in this document showcase a multi-pronged approach to sustainability: passive design principles, efficient natural and mechanical ventilation and space conditioning, ground-source heat pumps, solar energy, and carbon neutrality. From design to construction, the disciplined planning process produced an inviting and accessible model of a ZEB.

With a renewable energy system correctly sized to meet a normalized energy consumption half that of a standard design (per ASHRAE 90.1-2007 baseline), the FEC surpassed the rigorous ZEB requirements set by the Living Building Challenge, showing what is possible with thoughtful design.

Figure 8. Kid parade to celebrate the Frick Environmental Center. Image: Pittsburgh Parks Conservancy

Shrinking energy use intensity (EUI). Energy modeling during the design phase indicated the FEC could achieve an EUI of 31 thousand British thermal units per square foot per year (kBtu/ft^2 per year) compared to a baseline model EUI of 51 kBtu/ft^2/year (ASHRAE 90.1-2007). In operation, the building has performed even better, achieving an EUI of 25 in 2019, which is 51% below the baseline.

For comparison, the EUIs for small office and primary school prototypes in the same climate zone range from 26 to 40, respectively (DOE Building Energy Codes 2021), while median EUIs for existing office and education (K-12) buildings are 49 and 53, respectively (Energy Star 2021). Given the FEC's combination of uses, spaces, and schedules, it may best fit somewhere between the office and education categories.

By teaching people how to be cognizant of their energy use and impact on the environment with simple steps such as opening a window or turning off a light, FEC will make a real, lasting impact beyond the building itself.

Noah Shaltes,
Project manager with PJ Dick
www.go-gba.org/frick-environmental-center-a-birds-eye-view-of-process-partnership-and-intent/

The building's *net* EUI of -0.7 kBtu/ft^2/yr translates to CO_2 emissions of -0.18 pounds per square foot per year (lb/ft^2/yr), a significant improvement on the estimated 22 lb/ft^2/yr annual CO_2 emissions for commercial buildings of similar size in the same climate zone (LBL Building Performance Database, EPA 2018).

Water conservation. The FEC's philosophy of harmony with the local environment also extends to water resources. Rainwater for use in the building is collected on the north side of the site by the large PV canopies and through pervious paving in the parking area. A large storage cistern feeds the water to and through a multi-stage filtration and bacterial treatment process. It is then utilized in low-flow, high-efficiency fixtures in the building. Processed and treated wastewater is discharged to a local woodland with biosuitable soil.

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