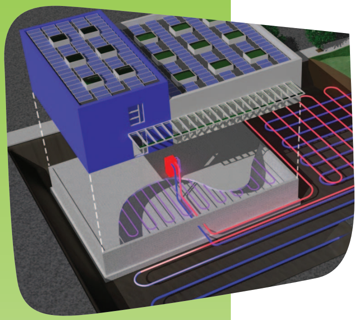

WHITE PAPER

Absolute Zero

Net Zero Energy commercial buildings – an inspiring vision for *today.*

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Introduction

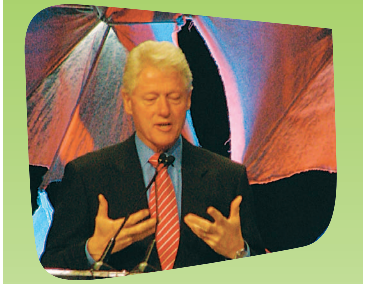
Buildings are both a significant cause of and a potential solution to climate change and energy insecurity. In the United States, buildings consume nearly 40% of the country's energy and are responsible for almost 40% of greenhouse gas emissions.[1] That represents 8% of the world's greenhouse gas emissions, an amount equal to the emissions from all of India.

Many initiatives, including the U.S. Environmental Protection Agency's ENERGY STAR program and the U.S. Green Building Council's LEED rating system, encourage increased energy efficiency in buildings – typically stated as a percent improvement (20% more efficient than a conventional building, or 40% more efficient than ASHRAE 90.1-2007). Such relative improvements save energy and reduce environmental impact, but they lack the simplicity and inspiring vision of an absolute goal like "zero." They also do not guarantee energy sustainability, since even a growing number of more efficient buildings can still burn fossil fuels and produce excessive greenhouse gases far into the future.

In the pursuit of energy efficiency and sustainability, **net-zero energy buildings (ZEB)** are an exciting next step. A ZEB is a residential or commercial building that consumes a net total of zero energy from nonrenewable sources (such as utility electricity, natural gas, or oil). These buildings are so energy-efficient that they can rely mainly on renewable energy generated on-site. They typically use nonrenewable energy such as utility electricity and natural gas at times of year when renewable energy does not meet demand. But at times when the on-site generation is greater than the building's needs, excess electricity is exported to the utility grid. The nonrenewable energy is thus canceled out (offset). A small but growing number of ZEBs exist in the United States, and policies and programs are emerging to support their adoption worldwide.

This white paper discusses the net-zero energy building concept, examines common themes demonstrated by ZEBs, briefly reviews the policy context that will make them increasingly common, and presents case studies of the eight known commercial ZEBs in the U.S. as of late 2009. Johnson Controls was involved in the development of one of these first ZEBs. We support and encourage the development of more ZEBs, knowing that the technology exists and that there is a growing body of expertise to help motivated owners achieve this goal today.

> "In five years, anyone would be crazy to design a building that isn't green. But I'll bet you that Greenbuild in five years won't just be about green buildings. It will be about zero net energy buildings, and about technologies to increase the amount of excess energy building owners can sell on the grid."
>
> FORMER PRESIDENT BILL CLINTON, GREENBUILD KEYNOTE ADDRESS, NOVEMBER 2007



Definitions

Although simple in concept, there is more than one way a building can achieve "zero." Here are four definitions from the National Renewable Energy Laboratory (NREL) and U.S. Department of Energy (DOE) that describe different types of ZEBs.

- **Net-zero site energy.** A building that produces at least as much renewable energy in a year as it uses in non-renewable energy, when accounted for at the site.
  Example: A building uses 2,000 kWh of utility electricity during winter for heating to supplement its renewable energy. But in summer it produces a surplus of renewable energy and exports 2,000 kWh back the grid – the solar energy exported cancels out the utility power purchased.
- **Net-zero source energy.** A building that produces at least as much energy as it uses in a year, when accounted for at the source. To calculate a building's total source energy, imported and exported energy are multiplied by appropriate site-to-source conversion multipliers to account for the energy losses through conversion inefficiencies and losses in transmission and distribution. By one often-cited reckoning, if a building gets electricity from a utility with coal-fired power plants, the site-to-source multiplier is 3.37, because only about one-third of the energy in the coal is actually delivered to the site as usable power. By that same reckoning, the multiplier for natural gas is 1.12, because gas used on site for heating is highly efficient.[2]
  Example: A building uses utility natural gas a supplemental fuel for winter heating and exports solar-generated electricity to the grid during summer. The exported solar energy benefits from the 3.37 multiplier because it eliminates the inefficient burning of coal. Therefore, to achieve net-zero energy, the building has to export energy equal to just one-third the energy content of the natural gas used.
- **Net-zero energy costs.** A building where the amount of money a utility pays the building's owner for the energy the building exports to the grid is at least equal to the amount the owner pays the utility for the energy services and energy used over the year. That is, the owner's net energy *bill* is zero, or negative.
- **Net-zero energy emissions.** A building that produces and exports at least as much emissions-free renewable energy as it uses from emission-producing energy sources annually. "If an all-electric building obtains all its electricity from an off-site zero-emissions source (such as hydro, nuclear, or large-scale wind farms), it is already zero emissions and does not have to generate any on-site renewable energy to offset emissions," according to NREL. "However, if the same building uses natural gas for heating, then it will need to generate and export enough emissions-free renewable energy to offset the emissions from the natural gas use."[3] Carbon, nitrogen oxides, and sulfur oxides are common emissions that net-zero energy emissions buildings offset.

A fifth definition recognizes grid-independent buildings that cannot achieve net-zero status:

- **Near-zero energy.** A building that produces at least 75% of its required energy through on-site renewable energy. Off-grid buildings that use some nonrenewable energy (such as a propane heater and small generator) for backup are considered near-zero energy because they typically cannot export excess renewable generation to offset fossil-fuel energy use.

Buildings can achieve more than one net-zero definition simultaneously. For instance, a net-zero site energy building is almost always also a net-zero energy emissions building. Some have referred to these buildings as Z^2 (or Z-squared), for zero energy, zero emissions.

Although simple in concept, there is more than one way a building can achieve "zero."

The **net-zero site energy** definition encourages aggressively energy-efficient designs, can be easily verified through on-site measurements, and has the fewest external fluctuations that influence the ZEB goal. Johnson Controls considers this the net-zero "gold standard" for buildings. Additional discussion of the relative merits of net-zero/near-zero strategies can be found in a conference paper from NREL, "Zero Energy Buildings: A Critical Look at the Definition" (2006).

Zero-energy buildings achieve their goals best when all parties involved – from owners to architects to contractors – share the zero-energy vision and collaborate throughout design and construction.

Common Features of Zero-Energy Commercial Buildings

The eight zero-energy buildings profiled later in this paper have a number of characteristics and design concepts in common.

They are not large.

All eight buildings are one or two stories tall and comprise less than 15,000 square feet. The authors believe that is mainly because the ZEB concept is new and is being tested – not because it can only work in small buildings. However, a building's size and especially its shape do significantly affect its ability to meet a ZEB goal using only renewable energy generated on-site. Energy modeling performed by NREL and DOE shows that it would be harder for three-story buildings to meet ZEB goals with on-site resources and extremely difficult for buildings of four or more stories.[4] That is because multi-story buildings have relatively higher load densities, relatively less roof area for PV systems, and relatively less daylighting potential. Although this might seem like a major limitation of ZEB design, it does not affect most U.S. commercial buildings, which on average are one story and 8,000 to 16,000 square feet.

Efficiency comes first. Every bit counts.

Energy saved in a ZEB is energy that the building doesn't have to produce. An effective methodology to achieve maximum building efficiency[5] is:

1. Load reduction: Reduce every energy-consuming load to the minimum and eliminate unnecessary loads. In a new building, start with a design that includes only the energy services that are actually necessary.
2. Systems efficiency: Meet the remaining loads as efficiently as possible. Optimize the efficiency of the system as a whole, in addition to the individual components. (For example, make sure that pumps, motors, fans and insulation are optimally specified for the facility.)
3. Regenerative systems: Use waste energy for useful purposes.
4. Renewable systems: Generate power on-site and renewably.

One notable effect of extreme efficiency is that, as lighting and HVAC systems get more efficient, plug loads become relatively more important and a more significant target for reduction. Thus, choosing the most energy-efficient devices becomes essential to achieving net zero energy use.

Integrated design and operation are necessary.

Zero-energy buildings achieve their goals best when all parties involved – from owners to architects to contractors – share the zero-energy vision and collaborate throughout design and construction. Further, facility operators and building occupants, who control system settings and plug loads, must actively participate to make the building achieve its design goals.

On-site renewable energy is a priority.

Renewable energy generated on-site has the most permanence over the life of the building. Land off-site that produces wind or solar energy for the building may eventually become more valuable for other uses, and purchasers of renewable energy from distant sources have less incentive to reduce the building's energy use initially and maintain low use over time. This does not devalue purchases of renewable power – it simply highlights the motivational and permanence advantages of on-site renewable energy generation for those buildings that have this option.

Grid connection makes it possible.

All but one of the profiled net-zero energy buildings rely on grid connections to achieve their annual energy balances. These buildings provide a useful service to the utilities, since they use less power (thus reducing demand) and produce excess power at what tend to be the utility's peak usage times of the day and year. Grid-independent buildings that achieve net-zero status must rely on fairly expensive storage technologies – it is simply less expensive and more convenient for the owners to be connected to the grid.

Monitoring and verification prove the achievement.

Once a ZEB is in use, careful monitoring and verification are needed to back up the design claims and, often, to identify and correct improperly constructed or functioning systems. The owners of buildings that share this monitoring data are helping to disseminate actual information about the performance of ZEBs, and that should reduce the risk and accelerate the construction of new ZEBs.

Renewable energy generated on-site has the most permanence over the life of the building.

Zero-Energy Building Policy

A number of programs and policies now encourage zero-energy buildings. In the European Union, a March 2009 resolution required that, by 2019, all newly constructed buildings produce as much energy as they consume on-site. Also in March 2009, the Massachusetts Zero Net Energy Buildings Task Force released a report detailing strategies for universal adoption of zero net energy buildings for new construction by 2030. California's Long Term Energy Efficiency Strategic Plan, adopted in September 2008, calls for all new residential construction to be zero net energy by 2020 and all new commercial construction to be zero net energy by 2030.

The U.S. DOE's Net-Zero Energy Commercial Building Initiative (CBI) aims to achieve marketable net-zero energy commercial buildings in all climate zones by 2025. Further, Section 422 of the Energy Independence and Security Act of 2007 charges the CBI to "develop and disseminate technologies, practices, and policies for the development and establishment of zero net energy commercial buildings for:

1. Any commercial building newly constructed in the United States by 2030;
2. 50 percent of the commercial building stock of the United States by 2040; and
3. All commercial buildings in the United States by 2050."

Case Studies

The following case studies are copied and condensed from the in-depth analyses presented in the DOE's Zero Energy Buildings Database, http://zeb.buildinggreen.com/. More details as well as project contacts can be found in the database.

Across the country, at least 60 more zero-energy commercial buildings have been designed but not yet constructed.

ALDO LEOPOLD LEGACY CENTER

Primary Design Team Members

Owner/developer; ecologist/timber harvesting expert; landscape architect
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Cedarburg, WI

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Milwaukee, WI

Contractor and LEED consultant
The Boldt Company
Appleton, WI

Commissioning agent
Supersymmetry USA, Inc., Navasota, TX

Energy consultant
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Carpentry contractor
Bachmann Construction Co., Inc., Madison, WI

Photovoltaic, mechanical, and electrical contractor
H & H Group, Inc.
Madison, WI

System controls consultant
Hines & Co., LLC
Winston-Salem, NC

Structural engineer
KompGilomen Engineering, Inc.
Milwaukee, WI

Mechanical and plumbing engineer
Matrix Mechanical Solutions, LLC
Greenfield, WI

Electrical engineer
Powrtek Engineering, Inc., Waukesha, WI

Aldo Leopold Legacy Center, Baraboo, WI

Twentieth-century conservationist and author Aldo Leopold wrote his most famous work, *A Sand County Almanac*, largely at his family's weekend getaway near Baraboo, Wisconsin – a repurposed chicken coop. "The Shack" has long been a pilgrimage site for enthusiasts of Leopold and the modern conservation movement. Now, the net-zero energy, LEED Platinum Aldo Leopold Legacy Center is a fitting trailhead to the Shack and headquarters for the Aldo Leopold Foundation. The Legacy Center's three single-story buildings, completed in April 2007, include office and meeting space, an archive, an interpretive hall, and a workshop, all organized around a central courtyard.

The Legacy Center meets the following zero-energy definitions:

- **Net-zero site energy.** The Legacy Center produces all of its needed electricity through on-site photovoltaics (PV). It does burn wood in the winter for heat, but this resource is harvested locally and is a renewable resource used on-site.
- **Net-zero source energy.** The energy generated on-site through PV and wood is greater than the energy used when accounted for at the source.
- **Net-zero energy emissions.** The excess renewable energy the Legacy Center produces, along with on-site carbon sequestration through its forested land, offsets the carbon emissions resulting from the project's operations.

The 12,000 square-foot Legacy Center was designed to use 70% less energy than a comparable conventional building, and its 39.6-kW rooftop PV array produces roughly 10% more than the energy needed to operate the building over the course of a year.

The main building's long, narrow footprint, oriented along an east-west axis, allows all occupied spaces to be daylit and naturally ventilated. Building overhangs shield sunlight in the summer and allow passive heat gain in the winter. A south-facing, minimally conditioned thermal flux zone provides an acoustical buffer between public and staff areas and allows staff members to manage natural ventilation, solar gain, and glare.

A highly efficient building envelope reduces thermal transfer. Overall, insulation values for almost every part of the building envelope are at least twice the values required by state code.

Ground-source water-to-water heat pumps provide space heating and cooling through radiant slabs. Wood-burning stoves provide spot heating and passive survivability in the event of a power outage. The conference wing is mechanically separate from the main building, reducing energy loads.

An earth-tube system provides 100% fresh, tempered air in all seasons. The air-handling unit delivers only required ventilation air, reducing fan sizes by 80% compared with typical systems. Displacement ventilation, variable-frequency-drive fans, and demand-controlled ventilation reduce energy demand.

The total project cost, excluding land, was $3,943,318. For this project, the Aldo Leopold Foundation defined payback broadly. Following Leopold's Land Ethic[6], the Foundation wanted to take full responsibility for the environmental as well as the economic costs of construction. For example, the decision to harvest trees planted by the Leopold family presented a complex design challenge. To put the finite quantity of this precious resource to the best use, the design team worked backward, matching the building to the available resources. The use of Leopold wood is the most visible, and perhaps the most symbolic, of the team's efforts to design within the resources available on site, including sun, earth, and water. The result was a design process that fully considered the true ecological costs of the materials and resources used for construction as well as those that would be required to operate the building.

To achieve the project's zero-energy goals, the project team emphasized the necessity of strict adherence to a holistic design process and the ongoing monitoring of building systems and performance.

Audubon Center at Debs Park, Los Angeles, California

Located just ten minutes northeast of downtown Los Angeles, Ernest E. Debs Regional Park is a 282-acre urban wilderness owned by the Los Angeles Department of Recreation and Parks. The Audubon Center at Debs Park occupies 17 acres of the park, leased from the City. The Debs Park facility is part of the Audubon Society's focus on establishing centers in urban and underserved communities.

The focus of the project is environmental education. The Center provides educational programs for the 50,000 schoolchildren who live within two miles of the park. It includes a multipurpose Discovery Room for teaching and displays, a library and meeting room, a reception area, a gift shop, and a catering kitchen.

The Audubon Center at Debs Park is a LEED Platinum, **near-zero energy building.** It is a very low-energy building that uses minimal fossil fuel and is not connected to the grid.

Since the building is entirely off-grid, it was essential to keep energy demand as low as possible. The 5,000-square-foot building is expected to use only 25,000 kWh annually (5 kWh/ft^2) due to its energy-efficient strategies. A small generator is used to deep-charge the Center's storage batteries twice each year to extend their lifespan. If the battery charge drops below 20%, the system has been designed to allow rapid recharging using a portable generator brought in on a pickup truck by a local vendor. Since the Audubon Center is not in a remote location and can quickly be serviced by a portable unit, a permanent back-up generator was deemed unnecessary.

The Center's key ZEB design strategies include the use of daylighting, photovoltaics, and thermal mass. The L-shaped building is relatively narrow, allowing light to penetrate throughout. The south and east orientation and well-placed operable windows increase cross-ventilation, natural lighting in all directions, and views of the outdoors. Artificial light is required only in the evening during winter months.

A 25-kW photovoltaic system powers all building systems, including heating, cooling, lighting, computers, and other office equipment. Outdoor recirculating fountains also operate on solar power. A solar thermal system provides domestic hot water.

Exposed concrete walls and floors, along with high windows that open to flush out heat, moderate temperatures throughout the building.

The total project cost, excluding land, was $5,500,000. Since the Center is located more than a quarter-mile from the nearest sewer lines, on-site wastewater treatment cost only slightly more than a sewer connection. On-site treatment and the absence of an electric power grid connection facilitated the building's high LEED rating and near-zero energy status.

The project team emphasized the importance of occupant behavior in making the building's energy budget work. Both photocopying and outdoor power tool use must be limited. They note that by working within the constraints of solar energy, the building works the way nature does.

AUDUBON CENTER AT DEBS PARK

Primary Design Team Members

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Structural engineer
Parker - Resnick
Los Angeles, CA

Mechanical and plumbing engineer
IBE Consulting Engineers
Van Nuys, CA

Electrical engineer
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Culver City, CA

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CTG Energetics, Inc.
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LEED construction and documentation
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Dana Point, CA

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Arcadia, CA

Photovoltaic consultant
Environmental Problem Solving Enterprises
Santa Monica, CA

Solar HVAC designer and builder
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CHALLENGERS TENNIS CLUB FOR BOYS AND GIRLS

Primary Design Team Members

Owner/developer
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Architect
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Santa Monica, CA

Environmental building consultant
Helios International, Inc., Topanga, CA

Contractor
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Culver City, CA

Challengers Tennis Club for Boys and Girls, Los Angeles, CA

The Challengers Tennis Club for Boys and Girls, located in an urban low-rise residential setting, is the latest addition to the Challengers Sports Center in South Central Los Angeles. Challengers Tennis brings neighborhood students together to socialize, train, and develop into champions. The facility occupies a total of about 53,600 square feet and consists of a 3,500-square-foot clubhouse with observer stands, four tennis courts, a small outdoor meeting and eating area, a parking area, pedestrian walkways, and planted space.

Challengers Tennis meets the following zero-energy definitions:

- **Net-zero site energy.** The project produces all of its needed electricity through a PV system that is within the building's footprint. Any small amount of natural gas used for heating is also offset at the site by PV generation.
- **Net-zero source energy.** Challengers Tennis is considered a source ZEB because the energy generated on-site through PV is greater than the energy used when accounted for at the source.
- **Net-zero energy emissions.** The excess renewable energy the facility produces offsets the carbon emissions resulting from the building's operations.

The facility uses 60% less energy than a similar building constructed according to California's Title 24 requirements. To supply energy, the building has a 2,000-square-foot PV array on the roof that provides 100% of the facility's annual electricity. A small amount of natural gas may be needed for space heating.

A number of strategies work together to keep energy use low. The building has no mechanical cooling, but is kept comfortable through natural ventilation, unhindered air circulation, ceiling fans, internal thermal mass, superior insulation and glazing, and appropriate shading. Ample daylighting minimizes the use of artificial lighting, and all lighting fixtures use fluorescent lamps with either photocell or motion-sensor controls. Kitchen appliances and office equipment are Energy Star-rated.

The total project cost, excluding land, was $1,800,000. The calculated energy savings amount to about $4,000 per year, and the calculated payback of the net total investment for efficiency and solar generation is 12 years at an internal rate of return comparable to the yields of the owner's investments. Thus, the owner's green investment in Challengers Tennis is viewed as a portfolio diversification investment.

The project team stresses the importance of educating all project decision-makers as early as possible about the details of innovative designs, lifecycle costing, and environmental benefits. This brought to the surface any concerns and objections and aligned the entire project team with the project goals of improved efficiency.

Environmental Technology Center at Sonoma State University, Rohnert Park, CA

The Environmental Technology Center (ETC) is an interactive and integrative 2,200-square-foot facility at Sonoma State University where faculty, students, and community members can work together in research training, academic study, and collaborative environmental projects. Created through a collaborative design process, ETC is "a building that teaches" about sustainable design.

The Environmental Technology Center meets the following zero-energy definitions:

- **Net-zero site energy.** ETC produces all of its electricity through a PV system within the building's footprint. Any natural gas used for domestic hot water and radiant heat is also offset at the site by PV generation.
- **Net-zero source energy.** ETC is considered a source ZEB because the energy generated on-site through PV is greater than the energy used when accounted for at the source.
- **Net-zero energy emissions.** ETC offsets any emissions for which it is responsible through its PV system.

The Environmental Technology Center was designed to use 80% less energy than buildings built to minimal compliance with California's Title 24 requirements. ETC achieved this through energy-efficient techniques such as a tight building envelope, thermal mass, shading, and natural ventilation. ETC includes a 3-kW rooftop PV system that is tied to the grid and is a net energy exporter. The building uses a small amount of natural gas each year for domestic hot water and radiant heat.

Daylighting is provided through south-facing windows and skylights, minimizing the need for electric lighting. Awnings, a living-canopy trellis, and motorized shades help to keep the building cool during the summer. A clerestory window vents hot air to the north openings while providing enough circulation to cool the building passively. The building uses no mechanical air conditioning.

Concrete masonry units and rammed-earth walls provide thermal mass. Cool night air is stored in the building's floor and walls, heating up only slowly during the daytime. As a result, the building's interior remains at a relatively constant temperature even as the outside temperature changes. Insulated structural wall panels help insulate the building.

The total project cost, excluding land, was $1,116,000. The National Science Foundation, the California Energy Commission, and Sonoma State University were the major contributors to the design and construction costs. Additional support was provided by foundations, companies, and individuals.

For designing a zero-energy building, the project team stresses the importance of an integrated design process, which requires resisting the considerable inertia of the conventional process. Through vigilance at each step of design, documentation, and construction, the synergy of the whole-building design process led to performance greater than would be achieved by the sum of the individual building features. For example, no electric lighting is needed during the day in the classroom and offices since the daylighting was carefully designed for both sunny and overcast sky conditions. The project team also highlights the importance of monitoring and verification to ensure that the building performs as expected.

ENVIRONMENTAL TECHNOLOGY CENTER AT SONOMA STATE UNIVERSITY

Primary Design Team Members

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Daylighting
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Alameda, CA

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Degenkolb Engineers
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Bruce King Structural Engineering
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Hawaii Gateway Energy Center

Primary Design Team Members

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Honolulu, HI

Civil engineer
RM Towill Corporation
Kailua-Kona, HI

Structural engineer
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MEP engineer, lighting and energy consultant
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LEED management
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Boulder, CO

Commissioning agent
Engineering Economics, Inc., Golden, CO

Contractor
Bolton, Inc.
Kailua-Kona, HI

Space frames
Triodetic Space Frames, Inc.
Syracuse, NY

Hawaii Gateway Energy Center, Kailua-Kona, Hawaii

The Hawaii Gateway Energy Center (HGEC) visitor complex, situated on the south coast of Kona on the Big Island of Hawaii, serves the Natural Energy Laboratory of Hawaii (NELH). It is the first building to be constructed on a 6.5-acre campus designed to house research, development, and demonstration facilities for energy and technological fields. The NELH facilities are run by the State of Hawaii under the Natural Energy Laboratory of Hawaii Authority.

The Hawaii Gateway Energy Center meets the following zero-energy definitions:

- **Net-zero site energy.** The PV system on the roof of HGEC produces all the energy required by the building, including the power needed for the cooling pumps.
- **Net-zero source energy.** HGEC is considered a source ZEB because the energy generated on-site through PV is greater than the energy used when accounted for at the source.
- **Net-zero energy emissions.** The excess renewable energy HGEC produces offsets the carbon emissions resulting from the project's operations.

The 3,600-square-foot, LEED Platinum building is designed to consume about 20% of the energy that would be required by a comparable building designed in minimal compliance with ASHRAE 90.1-1999. HGEC employs extensive daylighting, a passive thermal chimney, and a cooling system that uses seawater to reduce energy consumption. A 20-kW photovoltaic system takes advantage of high insolation to provide power. The system is expected to produce 24,455 kWh of electricity annually.

HGEC is designed as a thermal chimney, capturing heat and creating air movement using only building form and thermodynamic principles. The copper roof radiates heat from the sun into a ceiling plenum; the heated air rises and is exhausted through stacks on the building's north face. As the hot air is exhausted, fresh outside air is pulled into the occupied space from a vented underfloor plenum. Incoming air is drawn across cooling coils filled with 45°F seawater and cooled to 72°F. Outside air is moved through the building at a rate of 10 to 15 air changes per hour without the use of a mechanical system. The only energy consumed for cooling is that used to run the seawater pump.

The long axis of the building is oriented east-west for ideal shading and daylighting. There is no need for electric ambient lighting during daytime business hours because the building is entirely daylit. When electric lighting is needed, fixtures are controlled by occupancy sensors and photosensors.

The total project cost, excluding land, was $3,400,000. HGEC was conventionally funded. Therefore, the green aspects of the design (with the exception of the photovoltaic array and energy distribution system) came at no premium, and payback was immediate.

A key to the building achieving its ZEB goals was an unconventional "whole design process," which differed from a "linear design process" in that the architect and the consultants worked in concert from the beginning, evolving the design as a team. This approach was critical to the successful integration of the passive design strategies, including daylighting, induced ventilation, passive cooling, and condensation irrigation.

IDeAs Z Squared Design Facility, San Jose, CA

The new headquarters of Integrated Design Associates (IDeAs) transformed a commonplace building – a 1960s-era tilt-up concrete structure – into something extraordinary. It is believed to be the first commercial office building in the United States designed to achieve a "Z^2" energy efficiency goal: net-zero energy and zero carbon emissions. The design is a proof-of-concept to demonstrate how thoughtful design and a full complement of sustainable design techniques can simultaneously achieve ultra-high energy-efficiency and high comfort for occupants using current technologies while reaching net-zero energy at an affordable price.

The IDeAs Z2 Design Facility meets the following zero-energy definitions:

- **Net-zero site energy.** The IDeAs building produces all of its needed electricity through on-site PV.
- **Net-zero source energy.** The IDeAs facility is considered a source ZEB because the energy generated on-site through PV is greater than the energy used when accounted for at the source.
- **Net-zero energy emissions.** The renewable energy the IDeAs building produces offsets the carbon emissions resulting from the project's operations.

The 6,600-square-foot IDeAs building uses a high-efficiency HVAC system featuring a ground-source water-to-water heat pump system that provides radiant heating and cooling via the floor slabs, and monitoring equipment that gathers data on the energy performance of all building systems. A 30-kW rooftop integrated photovoltaic system, which also uses PV panels for solar shading over the entrance, supplies 100% of electricity needs.

In addition to geothermal heating and cooling and solar PV for electricity, the IDeAs building uses many traditional energy conservation techniques. When the building was refurbished, skylights and windows were added to take advantage of natural light. High-efficiency windows allow light to shine through while blocking infrared and ultra-violet rays to keep the office cool. Multiple sensors automatically turn off lights in empty rooms and shut off select fixtures when sufficient daylight is available, and low-energy fluorescent bulbs take the place of standard lights throughout the building. Low-flow fixtures and waterless urinals are used in the bathrooms. Hot water is provided as a by-product of the heat pump. In addition, the building's security system is tied into the electrical system, automatically shutting down everything in the building when the system is armed.

Managing the plug-load in the building is an ongoing effort. From lighting to office equipment to coffee makers, choices were made to limit the amount of electricity used. Anything that has to be plugged in is tested for actual electrical use before being purchased, and all equipment must be able to handle being turned off at night without adversely affecting start-up and operation during the day. Traditional computer monitors were replaced with LCD flat screens, which consume 50 percent less energy.

The total project cost was not specified, but the project team emphasizes that the project was done with an existing non-green building on a budget and schedule. They note that a major challenge was overcoming the mental resistance to doing things differently at each stage of the project.

IDEAS Z SQUARED DESIGN FACILITY

Primary Design Team Members

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Carroll Engineering
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Architect
EHDD Architecture
San Francisco, CA

Contractor
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Rumsey Engineers
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Mechanical engineer
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Structural engineer
Tipping Mar + associates
Berkeley, CA

ADAM JOSEPH LEWIS CENTER FOR ENVIRONMENTAL STUDIES

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Living Technologies
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Contractor
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Energy evaluation
National Renewable Energy Laboratory
Golden, CO

Owner/developer
Oberlin College
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Building systems consultant
Steven Winter Associates
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Architect
William McDonough + Partners
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Adam Joseph Lewis Center for Environmental Studies, Oberlin College, Oberlin, OH

The Adam Joseph Lewis Center for Environmental Studies on the Oberlin College campus houses classroom and office space, an auditorium, a small environmental studies library and resource center, a wastewater-purification system in a greenhouse, and an open atrium. Upon initiation of the project, Professor David Orr asked three questions that continue to serve as a guiding philosophy for the Lewis Center:

- Is it possible – even in Ohio – to power buildings by sunlight?
- Is it possible to create buildings that purify their own wastewater?
- Is it possible to build without compromising human or environmental health somewhere else or at some later time?

The hope remains that the building will not only serve as a space in which to hold classes, but also, according to Orr, “help to redefine the relationship between humankind and the environment.”

The Lewis Center meets the following zero-energy definitions:

- **Net-zero site energy.** The Lewis Center is an all-electric building that produces all energy on-site using PV.
- **Net-zero source energy.** Because the Lewis Center is an all-electric site ZEB, it also qualifies as a source ZEB.
- **Net-zero energy emissions.** The Lewis Center offsets any emissions for which it is responsible through its PV system, which produces electricity with zero emissions.

The 13,600-square-foot Lewis Center is an all-electric building and was designed with maximum energy efficiency in mind. The Lewis Center generates its own on-site electricity through a roof-mounted 60-kW PV system and a 100-kW PV system located over the “parking lot.

Energy-efficient design measures include a long east-west orientation, a south-facing curtain wall, and optimally placed windows to maximize daylighting and solar heat gain; thermal mass through concrete floors and exposed masonry walls that help to retain and reradiate heat; and advanced glazing and insulation.

Energy-efficient technologies include occupancy sensors and photoelectric daylight sensors to control lighting, carbon dioxide sensors and automated operable windows to control ventilation, window shades, and energy-efficient light fixtures resulting in a 0.9 watt per square foot lighting load.

Closed-loop geothermal wells fulfill most heating and cooling demands in the Lewis Center. Supplementary radiant coils heat the atrium as needed.

The total project cost, excluding land, was $6,405,000. The project team believes that a more accurate measure than conventionally recorded first-cost is one calculated over the life of the building. Spending more money for durable materials, for example, may save in the long run by avoiding the need to replace those materials. Similarly, energy-efficient and energy-generating technologies save significantly on energy bills. Long-term costs were given priority over first costs in the design of the Lewis Center. Additionally, every effort was made to reduce social and ecological costs, which traditionally are not considered. Indeed, a main design principle was to create a building “without compromising human or environmental health somewhere else or at some later time.”

The project highlights the need for continual measurement and adjustment to make sure the building performs as designed. Additionally, the project team notes the extra effort involved in unconventional design and construction. They had difficulty finding markets (especially local markets) for recycled or reused products, and for incorporating products-of-service into contracts.

Science House at the Science Museum of Minnesota, St. Paul, MN

Science House serves as a public environmental experiment facility, classroom, and special event space for the Science Museum of Minnesota's outdoor science park, the Big Back Yard. The project team's challenge was to create a zero-energy building in a region that experiences more climate extremes than almost any other continental center, has an annual temperature range of more than 130°F, and is dryer than a desert in the winter and as humid as a rainforest in the summer.

Science House meets the following zero-energy definitions:

- **Net-zero site energy.** The Lewis Center is an all-electric building that produces all energy on-site using PV.
- **Net-zero source energy.** Because the Lewis Center is an all-electric site ZEB, it also qualifies as a source ZEB.
- **Net-zero energy emissions.** The Lewis Center offsets any emissions for which it is responsible through its PV system, which produces electricity with zero emissions.

Science House's total energy use, including plug and equipment loads, is 60% below that required by code. Additionally, it is an all-electric building and generates all of its needed energy on-site with an 8.8-kW rooftop PV system that annually produces roughly 30% more energy than the building consumes.

Key energy-efficiency strategies in the 1,500-square-foot building included: daylighting to minimize electrical lighting loads; ground-source heat pumps to heat and cool the building and to supply its hot water needs; passive solar design to minimize loads on the heat pumps; multi-modal natural ventilation; and continuous computer monitoring and control of mechanical systems to enhance indoor air quality while reducing energy consumption. The building's southern orientation, selected for its solar benefits, also allows the building to face the Mississippi River, the main thematic element of the Science Museum's Big Back Yard.

The total project cost, excluding land, was $650,000. The project received contributions including cash, materials, discounts, and professional services.

The project team notes the design trade-offs inherent in a zero-energy building. Science House's PV system's capabilities and module size directly affected the size and shape of the building. The building's window placement, in contrast to being based exclusively on views and facade composition, was based almost entirely on its impact on the building's energy efficiency through passive solar and daylighting strategies.

SCIENCE HOUSE AT THE SCIENCE MUSEUM OF MINNESOTA

Primary Design Team Members

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Minneapolis, MN

Solar consultant and installer
Innovative Power Systems
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Structural engineer
Mattson Macdonald Young Structural Engineers
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Conclusion

By shifting the focus from a percent energy savings goal to an absolute goal of "zero," net-zero energy buildings offer a clear and inspiring goal for new buildings, and a significant way to improve building energy sustainability and to reduce the environmental impact of buildings.

As this paper shows, net-zero energy commercial buildings exist today. In some cases they have been shown to be cost-effective when compared to traditionally constructed buildings. In other cases, building owners have invested in ZEBs to demonstrate their commitment to renewable energy, the climate, and other nonmonetary values. The proof of concept provided by these buildings, combined with the increasing efficiency and lower costs of renewable energy technologies, should lead to the growing adoption of ZEB techniques and technologies within the commercial building marketplace. More experience with zero energy buildings will also lead to an awareness of best practices that will drive the cost lower and reduce the perception of risk associated with the concept.

Aiming for "near-zero" in larger commercial structures would seem a worthy goal, both achievable and financially attractive when considering the long-term cost of operating a commercial building. Net-zero and near-zero commercial buildings offer exciting and rewarding opportunities for economic development and new jobs, and the advancement of America's climate and energy security goals.

...designers need to define what services the building *must* provide – and then define the design problem around only what must be provided.

About the integrated design process

When compared to traditional design and construction, integrated design techniques allow for much greater efficiency improvements, sometimes at a lower capital cost, by tightly connecting functions of various building components. Typical thinking suggests that each unit of energy savings costs more than the previous unit of savings. While this might be true at the component level, it is no longer relevant at the system (or building) level. For example, properly designing the levels of insulation, solar gain, and thermal mass might allow a building to eliminate much of the capital cost related to heating and cooling systems.

In order to achieve radical increases in energy efficiency, the right steps need to be taken in the right order in the design or renovation process. First, and most important, designers need to define what services the building *must* provide – and then define the design problem around only what must be provided. Providing services that aren't desired or necessary, or are of higher quality than needed, will make it harder to achieve a net zero result. For example, how much space is really needed? How much lighting is necessary for the space?

After the design problem is closely defined, it is essential to look for ways in which the necessary services can be provided for free (daylighting, passive heating/cooling/ventilation). If the services cannot be provided for free, then ways must be found to provide them most efficiently. In the process of designing the most efficient system, it's important to think about how systems can be coupled together so that waste streams from one can be used as inputs elsewhere (thermal integration, gray water recycling, etc). After the loads are reduced, then the supply system should be sized and integrated into the rest of the design.

About Johnson Controls

Johnson Controls is the global energy efficiency leader that brings ingenuity to the places where people live, work and travel. By integrating technologies, products and services, we create smart environments that redefine the relationships between people and their surroundings.

Our team of 140,000 employees creates a more comfortable, safe and sustainable world through our products and services for more than 200 million vehicles, 12 million homes and one million commercial buildings. Our commitment to sustainability drives our environmental stewardship, good corporate citizenship in our workplaces and communities, and the products and services we provide to customers.

Johnson Controls helps facility designers, contractors, owners and managers get the most from their buildings through a comprehensive approach to sustainability – from energy-efficient equipment and control systems to green buildings and renewable energy to managing campuses or portfolios of facilities in a sustainable manner. We believe that energy efficiency is the fastest, cheapest and best way to reduce the cost of operating buildings and improve our impact on the environment. We need efficiency now.

www.johnsoncontrols.com/efficiencynow

Resources

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Footnotes

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[3] “Zero Energy Buildings: A Critical Look at the Definition,” National Renewable Energy Laboratory, June 2006.

[4] Griffith and Crawley, 2006.

[5] Presented by Malcolm Lewis, CTG Energetics, at the ASHRAE conference “Countdown to a Sustainable Energy Future: Net Zero and Beyond,” March 2009.

[6] The essay “The Land Ethic” appears in Leopold’s *A Sand County Almanac* (1949). A key passage is, “Quit thinking about decent land-use as solely an economic problem. Examine each question in terms of what is ethically and esthetically right, as well as what is economically expedient. A thing is right when it tends to preserve the integrity, stability, and beauty of the biotic community. It is wrong when it tends otherwise.”

Printed on recycled paper.

P. O. Box 423, Milwaukee, WI 53201
Printed in USA PUBL-6240 (09/09)

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