The team needed a fully integrated design process, in which the different design disciplines and the general contractor make key decisions together to optimize the building as an integrated system. For example, carefully designed sun shading and state-of-the-art glazing would allow the team to make many incisions into the roof and concrete walls to harvest more daylight. This would reduce the need for electric lighting and its attendant energy consumption, while also providing outside views for building occupants.

Team members collaborated on specifications for features such as skylights, accounting for their impacts on not just the daylighting design, but on the architectural, lighting, electrical and HVAC design. The result is a sophisticated design that uses simple controls to maximize energy performance while providing an excellent working environment and its attendant energy consumption. A well-designed sun shading system, monitoring equipment, rooftop and canopy photovoltaic system, ventilation, and its attendant energy consumption. A well-designed sun shading system, monitoring equipment, rooftop and canopy photovoltaic system, ventilation, and its attendant energy consumption.

Back in 2005, when the status quo in commercial building design was protected by the prevailing belief that green design principles were too expensive to be practically applied, electrical design firm Integrated Design Associates (IDeAs) made it its mission to prove otherwise. It purchased a nondescript tilt-up building that was a relic of the 1960s and hired collaborators at EHDD Architecture and Ramsey Engineers to help turn this 1.5-story former neighborhood bank branch into a high performing 21st-century building suitable for housing and inspiring IDeAs’ design staff.

Less Than Zero

BY DAVID KANEDA, P.E., AIA; PETER RUMSEY, P.E., FELLOW ASHRAE; AND SCOTT ASHRAE; and Scott Ashrae; and Scott Ashtep E. Kaneda, P.E., and Peter Shelly, P.E., ASHRAE; and Scott Ashtep E. Kaneda, P.E., and Peter Shelly, P.E., ASHRAE.

The team needed a fully integrated design process, in which the different design disciplines and the general contractor make key decisions together to optimize the building as an integrated system. For example, carefully designed sun shading and state-of-the-art glazing would allow the team to make many incisions into the roof and concrete walls to harvest more daylight. This would reduce the need for electric lighting and its attendant energy consumption, while also providing outside views for building occupants.

Team members collaborated on specifications for features such as skylights, accounting for their impacts on not just the daylighting design, but on the architectural, lighting, electrical and HVAC design. The result is a sophisticated design that uses simple controls to maximize energy performance while providing an excellent working environment within a reasonable budget. The integrated design process emphasizes the importance of getting it right the first time, since few opportunities exist to make substitutions or to eliminate parts of the design without affecting the whole system. IDeAs Z2 Design Facility was ready for occupation in late 2007. Today, with nearly three years of energy and occupant comfort data collected, the project demonstrates the viability of net zero energy buildings. This daylit, well-ventilated low-rise with no gas connection is carbon neutral, with carbon offsets purchased to cover the embodied carbon of the building materials used in the renovation. At less than one-fourth of the energy use of a typical office, IDeAs Z2 is one of the most efficient commercial office buildings in the world.

Building at a Glance

<table>
<thead>
<tr>
<th>Name</th>
<th>IDeAs Z2 Design Facility</th>
</tr>
</thead>
<tbody>
<tr>
<td>Location</td>
<td>San Jose, Calif.</td>
</tr>
<tr>
<td>Owner</td>
<td>Integrated Design Associates (IDeAs)</td>
</tr>
<tr>
<td>When Built</td>
<td>mid-1960s (originally a bank branch office)</td>
</tr>
<tr>
<td>Renovation Scope</td>
<td>Skylights, window walls, upgraded insulation and glazing, high-efficiency HVAC system, high-efficiency lighting and office equipment, rooftop and canopy photovoltaic system, monitoring equipment</td>
</tr>
<tr>
<td>Principal Use</td>
<td>Commercial office</td>
</tr>
<tr>
<td>Occupants</td>
<td>15</td>
</tr>
<tr>
<td>Gross Square Footage</td>
<td>7,000</td>
</tr>
<tr>
<td>Total Renovation Cost</td>
<td>$2,521,097</td>
</tr>
<tr>
<td>Cost Per Square Foot</td>
<td>$360</td>
</tr>
<tr>
<td>Distinctions/Awards</td>
<td>2010 ASHRAE Technology Award, First Place: Commercial Existing Buildings</td>
</tr>
</tbody>
</table>

Virtual Tour: www.z2building.com
U.S. The actual measured energy use intensity for this building in 2009 was 21.17 kBtu/ft²·yr (with a 21.72 kBtu/ft²·yr contribution from the photovoltaic array for a net of –0.55 kBtu/ft²·yr).

Daylighting and Views
Daylighting is one of the key strategies for significantly reducing energy consumption. Seventeen skylights were installed into the roof to light the main studio and the second floor office space. One advantage of the original building’s 18-ft high ceiling was excellent distribution of light throughout the workspace below.

The skylights are sized to maximize hours of daylight for conditions on short winter days. The framing is sloped to minimize any shading on the rooftop solar panels.

The team factored in solar heat gain effects when estimating cooling system requirements. The architect selected the size, placement and glass type for the skylights to carefully balance the daylight needs with their thermal impact. The daylight designers selected a high performance spectrally selective glass to block unwanted heat with a light-to-solar heat gain coefficient of 2.33.

The glass allows useful visible light wavelengths to enter the building, while blocking most heat-producing infrared and ultraviolet radiation. A photovoltaic canopy mounted over the sliding glass doors and windows on the south side of the building provides a classic passive solar shade and protection from rain in the winter, while also generating additional electricity for the

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building. This glass offers the primary views out from the main studio into an entry courtyard.

The canopy blocks direct sunlight from entering the building during the hot summer. Conversely, as the sun angles lower in the winter, direct sunlight penetrates as deep as 16 ft into the building, warming the concrete radiant floor.

The east façade houses a window wall that was the original entrance to the building. This façade posed a difficult challenge to the design team since it exposed the office to low-angle morning sun, which would stream directly in, causing glare problems. Interior blinds would have solved the glare issue, but don’t block the solar heat gain and tend to remain closed after the glare problem is gone. Exterior automatically operated blinds were considered high maintenance and are expensive.

The solution implemented is an electrochromic window. This glass offers the primary views out from the main studio into an entry courtyard.

The south side of the building opens onto the courtyard, which replaced the former parking lot. The ground-source heat pump pipes are laid under this area. Photovoltaics using solar cells are incorporated into a canopy (bottom).

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KEY SUSTAINABLE FEATURES

- Daylighting: Skylights, 18 ft ceilings, shading, electrochromic window
- Renewable Energy: Building-integrated photovoltaics
- HVAC: Radiant heating/cooling with ground-source heat pump
- Plug Load Reduction: Energy-efficient office equipment, occupancy-controlled power strips
- Lighting: T8 fluorescent lamps, daylight and occupancy sensors

COST ANALYSIS

Energy-efficient upgrades

- Upgraded glass $20,000
- Radiant mechanical system over traditional system $97,500
- Concrete for radiant floor $38,000
- PVs (after rebates and tax incentives) $45,500
- Total cost of energy-efficient upgrades $201,000
- Design fees related to energy-efficient upgrades (soft cost) $40,000

Total energy-efficient upgrades cost including soft costs $241,000

Construction costs

- $2,264,607
- Design fees (soft costs) $256,490
- Building purchase $2,100,000
- Total gross cost $4,621,097

Construction costs and design fees only (not including building purchase) $2,521,097

Estimated premium for energy-efficient upgrades

- Premium on gross cost 5.22%
- Premium on construction and design fees (including soft costs, excluding building purchase) 9.56%

Notes:
- Total gross cost is cost before any federal and state government incentives are deducted.
- Gross PV cost = $568,879 which included all supporting structures and equipment.
- PV panels only = $233,063.
- Not included in the cost are: interest, property taxes, etc., paid during construction.
The performance and comfort of the building, IDeAs has experimented with various types of sunlight control concepts to manage direct-beam sunlight entering through the skylights during summer months. One approach has involved installing prismatic acrylic diffusing panels on the outside of skylights in spring and removing them in autumn. The panels diffuse the intense, focused beams of light characteristic of summer sunlight to a softer, more dispersed light. The slight reduction in daylighting from adding the panels is acceptable in the summer when the building interior is actually over-lit, reducing heat gain from entering the building and reducing the summer cooling load. This technology was expensive, but its cost has decreased, and it was selected as a demonstration element, since it could be a widely used strategy in the near future.

As part of its ongoing post-occupancy research efforts to maximize the performance and comfort of the building, IDeAs has experimented with various types of sunlight control concepts to manage direct-beam sunlight entering through the skylights during summer months. One approach has involved installing prismatic acrylic diffusing panels on the outside of skylights in spring and removing them in autumn. The panels diffuse the intense, focused beams of light characteristic of summer sunlight to a softer, more dispersed light. The slight reduction in daylighting from adding the panels is acceptable in the summer when the building interior is actually over-lit, reducing heat gain from entering the building and reducing the summer cooling load. This technology was expensive, but its cost has decreased, and it was selected as a demonstration element, since it could be a widely used strategy in the near future.
with the added benefit of reducing the cooling load with minimal increase in electric lighting energy.

The daylighting design coupled with the high efficiency electric lighting design was estimated to reduce energy consumption for lighting by 60%. Actual measured data for 2009 shows lighting energy consumption to be a miniscule 10% of the energy use of the building—a fact made more remarkable by the HVAC and plug load data, which also measures much lower than a conventional office building.

HVAC
The HVAC system is key to the net zero energy and zero carbon emission philosophy of this building and features a high efficiency radiant heating/cooling slab system with an electric, ground-source heat pump. Chilled or hot water supplied by the heat pump to the dedicated outside air handler conditions the air delivered to the space.

The ground-source heat pump system’s exterior cross-linked polyethylene (PEX) pipes are laid under the open landscape area of the 34,014 ft² site. Heavy equipment was already on site to remove asphalt paving from this area, so the added cost to excavate for the ground-source piping was affordable. The system takes advantage of what the earth naturally provides: a constant below-ground temperature of about 58°F.

The energy efficiency for the HVAC, envelope and lighting is about 40% below California’s Title 24 Energy Efficiency Standard, 2005. Insulation was upgraded to an R-19 value in the walls and an R-30 value for the roof, which helps to reduce the heating and cooling loads.

The electronic control system controls the floor cooling flow rates and temperature to provide the maximum performance for the lowest pumping power and warmest chilled water temperatures. Likewise, when heating, it adjusts the heating flow rates and temperature to optimize performance at lowered hot water temperatures.

Pumps are kept at their lowest demand speed using power inverter technology based on actual demand. If high humidity is detected when the system is in cooling mode, the chilled water temperature delivered to the air handler is adjusted to dehumidify the air in the space to mitigate the formation of condensation on the exposed concrete slab.

The radiant floor topping slab contains 50% fly ash, thus reducing the amount of cement (and embodied carbon) required. The radiant system below is comprised of PEX tubing. Operable windows and doors installed throughout the building allow the occupants to tailor their comfort levels by adjusting the openings. However, when outside air temperatures are too cold or hot and the windows or doors are not used, the dedicated outside air handler provides the required ventilation on an as-needed basis. Ventilation air is distributed by a displacement ventilation system with vents placed lower on walls. The vents are relatively large to deliver air at low velocity, compared to traditional forced-air systems. The exhaust ducts are placed, near the ceiling, and there are no returns with the 100% outside air system.

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For example, if someone coughs, cleaner and healthier for occupants. Ventilation is that occupied air stays pants. One benefit of displacement ral heat plumes that surround occu-
heated by factors such as the natur-
low. The air warms and rises when ambient air, so it's denser and stays

Entering air is slightly cooler than ambient air, so it's denser and stays low. The air warms and rises when heated by factors such as the natu-
heat plumes that surround occup-
ants. One benefit of displacement ventilation is that occupied air stays cleaner and healthier for occupants. For example, if someone coughs into the air, germs move up into the open space away from coworkers. The displacement ventilation also complements the radiant heat-
ing and cooling slab; heating and cooling provided at the occupied zone level is not disturbed by the air, as compared to a conventional air handler system in which the air in the space would be completely mixed. Thus, the radiant heating and cooling slab maintains accept-
able thermal comfort at wider ranges of indoor air temperatures. The temperature setpoint in the zones during the winter is 69°F and 78°F during the summer, which is within ASHRAE Standard 55-2004’s acceptable range of comfort.

Occupants perceive temperatures at the edges of this range as com-
fortable because they sense heat or cold transfer from the radiant slab in a direct and immediate way.

**Lighting**

In a high performing building such as this, an electric lighting system must provide high lighting quality while minimizing lighting power density. To succeed, lighting design-

high efficiency sources and fixtures, and only place light where it is needed, when it is needed and at the appropriate level and quality.

To accomplish this, designers need to have specialist knowledge of active daylight-sensing lighting control systems, motion detectors, astronomic timelocks, dark sky concepts, task ambient concepts and human visual system concepts. At the same time, they should minimize use of toxic materials such as mercury in lamps and PVC. Due to the daylighting design, IDeAs' lights are mostly illuminated at night. It uses light sources with the best combination of high effi-
ciency, good color rendering and long life for indoor applications—currently linear fluorescent lamps.

In the main studio, three sets of identical suspended linear fluo-
rescent fixtures are installed with different ballasts. They all use high efficiency T8 lamps. One set of fixtures is equipped with a high efficiency ballast that is switched by a daylight sensor and occupancy sensor; another is equipped with a 0 to 10 volt dimming ballast, dimmed by a daylight sensor and switched by an occupancy sensor; the third set of lights in the trio is dimmed by a digital ballast similar to a DALI-control system.

These systems were installed to allow testing and measurement of the relative efficiencies and com-
fort provided by each lamp ballast combination.

A final set of sophisticated light fixtures installed along the north wall of the main studio incorporated onboard light sensors, set to dim electric light output as daylight became available. This system incorporates onboard infra-
red occupancy sensors set to turn off lights when unoccupied. Instead of light switches, the system was,
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controlled by software installed on the user’s personal computer that allowed users to adjust light levels, occupancy-sensor time-out period and daylight settings.

These light fixtures, however, proved to be problematic because of frequent software conflicts with user’s computers, occupancy-sensor false tripping, daylight harvesting controls that dimmed but could not shut off lights when adequate daylight was available, and dimming ballasts that reduced light levels to 10% but only reduced energy consumption to 30%.

These lights have been retrofitted with a more elegant wireless control system provided by a different manufacturer. The lights have similar functionality but more reliable Internet-based controls offer a more easily understood interface and dashboard. Importantly, lights switch off completely when adequate daylight is available.

People determine how bright they perceive a space to be based on a number of criteria. In addition to contrast levels and age, a key factor affecting this perception is the luminance of the main surfaces in the visual plane. In a typical office, 40 footcandles on an empty desk does nothing to affect an occupant’s impression of brightness, while placing the same amount of light on a white wall in the occupant’s visual plane will.

Therefore, a key strategy in the design of the studio was to use high reflectance (80%) acoustic ceiling tiles and high reflectance (89%) paint on the walls, and then light them. The design for the studio space uses primarily daylight as a light source during daylight hours. However, during the evening indirect fluorescent lights provide an ambient light level, directing light on the ceilings and walls.

These lights provide about 15 footcandles on the desks at night. Although well below IES recommended levels, very few staff use additional LED task lighting.

Plug Loads

IDeAs phased out older computers in favor of newer dual-core and quad-core computers with high-efficiency power supplies. CRT monitors were replaced with low power LED screens with incorporated speakers. Data and telecom flows are transmitted through CAT6A
Another key to large plug-load savings is reducing or eliminating office equipment phantom loads—the energy consumed during long hours of standby. For example, IDeAs found that even its ENERGY STAR-rated laser plotter has no actual off switch, and consumes 30 kWh in standby mode. The solution is to tie the plotter’s circuits to the building security system, so that when the machine is shut down when the security system is armed at night and turned on the next day when the security system is disarmed, giving it time to warm up and avoiding any impact on productivity. To further reduce office equipment phantom loads, workstations devices are now plugged into occupancy-controlled power strips. The power to task lights, PC monitors, speakers and other non-essential peripherals will shut down when users leave their desks. The PC itself uses software to go into sleep mode.

Monitoring

The building incorporates panel boards using a power harness to monitor the performance of the building circuit-by-circuit. This allows the design team to monitor each component of the HVAC system, each lighting circuit and each receptacle circuit, collecting data to measure performance of the various systems. The design team performs in-depth analysis on the interaction of various systems. The collected data is being used to measure the accuracy of the daylighting and energy modeling software, leading to improvement of these tools for integrated designs.

The system also will allow energy monitoring data to be automatically posted online. Eventually, IDeAs would like to make this data available to interested researchers. The backbone of the building’s electrical energy system is the inverter that converts the dc power coming down from the rooftop solar source into ac power to run the office equipment and infrastructure. The photovoltaic system is monitored including real-time ac voltage, current, and watts; real-time dc voltage, current, and watts; and cumulative ac and dc energy generated.

At less than one-fourth the energy use of a typical office (CBECS 2003), IDeAs Z2 is one of the most efficient commercial office buildings in the U.S. Daylighting with high performance windows, a radiant slab with an electric ground-source heat pump, natural ventilation, efficient lighting, plug load reductions and an energy monitoring system all contribute to the low energy use.

Photovoltaics

This all-electric building is powered by a roof-integrated, grid-tied, net metering photovoltaic system. It was sized to deliver 21 kW ac for an estimated 56,000 kWh per year. Building-integrated photovoltaics (BIPV) using solar cells incorporated directly into a single-ply PVC roofing membrane are used due to their light weight and low cost of installation. The design team estimates that a traditional photovoltaic system of equal size would require approximately 200 roof penetrations for structural supports. With this system, a support structure is unnecessary, and each panel serves as both a photovoltaic power source and a roof membrane.

A second BIPV system is incorporated into the sunshade over the main entrance at the south side of the building. The modules allow filtered light to pass through, and occupants can view the photovoltaic cells in the modules from below when entering or exiting the building.

An important lesson in technology risk is that the BIPV manufacturer recently entered bankruptcy, raising concerns about the warranty and longevity of a system that was expected to last more than 20 years. This is an important consideration when designing systems using high-cost components that are expected to last for decades.

Lessons Learned

Seek out and eliminate unnecessary drains on electricity. Do circuit-by-circuit monitoring to determine what circuits are being used and when. Continue monitoring to determine equipment and systems that are not performing as expected or that have failed or malfunctioned.

Integrated design makes value engineering more difficult. Use of integrated design principles on this project meant that substituting lower cost components affected the performance of other systems. For example, using a lower cost glass did not affect light levels but did increase solar heat gain, subsequently increasing the size of the HVAC system and PV arrays.
Summary

The sunny, temperate microclimate of the inland San Francisco Bay region was one inherent advantage of this project. Another was that the target occupants were experts in achieving energy efficiency and fully committed to doing what it would take to achieve a net zero building. For example, IDEAs and Rumsey Engineers carved away at plug loads, a slice of the total energy-use profile that is typically outside the realm of architects and engineers.

In typical commercial projects, designers have little control over future tenants’ equipment choices or eventual energy use. However, as the owner and building occupant, IDEAs was able to align its design with energy-saving equipment and operations.

It was also understood that the building would be a learning lab for students of sustainable design, so the building monitoring system was emphasized and thought was even given to leaving certain areas of construction unfinished to give exposure to infrastructure. In most other ways, however, IDEAs’ sustainable solutions are applicable to small office buildings in any part of the world. This building demonstrates that a net zero goal can be achieved. Minimizing building loads first, then evolving the design with efficient systems and renewable energy sources is the path to take for zero energy. The modest scope of this project demonstrates that zero energy buildings are feasible on many scales, and they can be done affordably and practically.

References