IDeAs Z^2 Design Facility: Design for a Net Zero Energy Building

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ABSTRACT

This is a case study of the design of the **IDeAs Z^2 Design Facility,** a remodel of an office building in San Jose, California. This building is designed to use renewable energy from photovoltaics for 100% of its net energy requirements and additionally will not generate carbon dioxide. This will make the building net zero energy and zero carbon emission or "Z^2", one of the first commercial buildings of its type.

This case study of the building focuses on various issues related to energy consumption and generation including:

- coordination by the project team during the design process to successfully maximize energy efficiency.
- thermal envelope modifications.
- a high efficiency mechanical system design using a radiant heating and cooling floorslab.
- techniques and automatic controls used for driving down energy consumed by plug loads.
- high efficiency lighting, lighting controls and daylight harvesting technology.
- the photovoltaic (PV) system.
- energy monitoring and goals for data gathering and ongoing performance analysis.

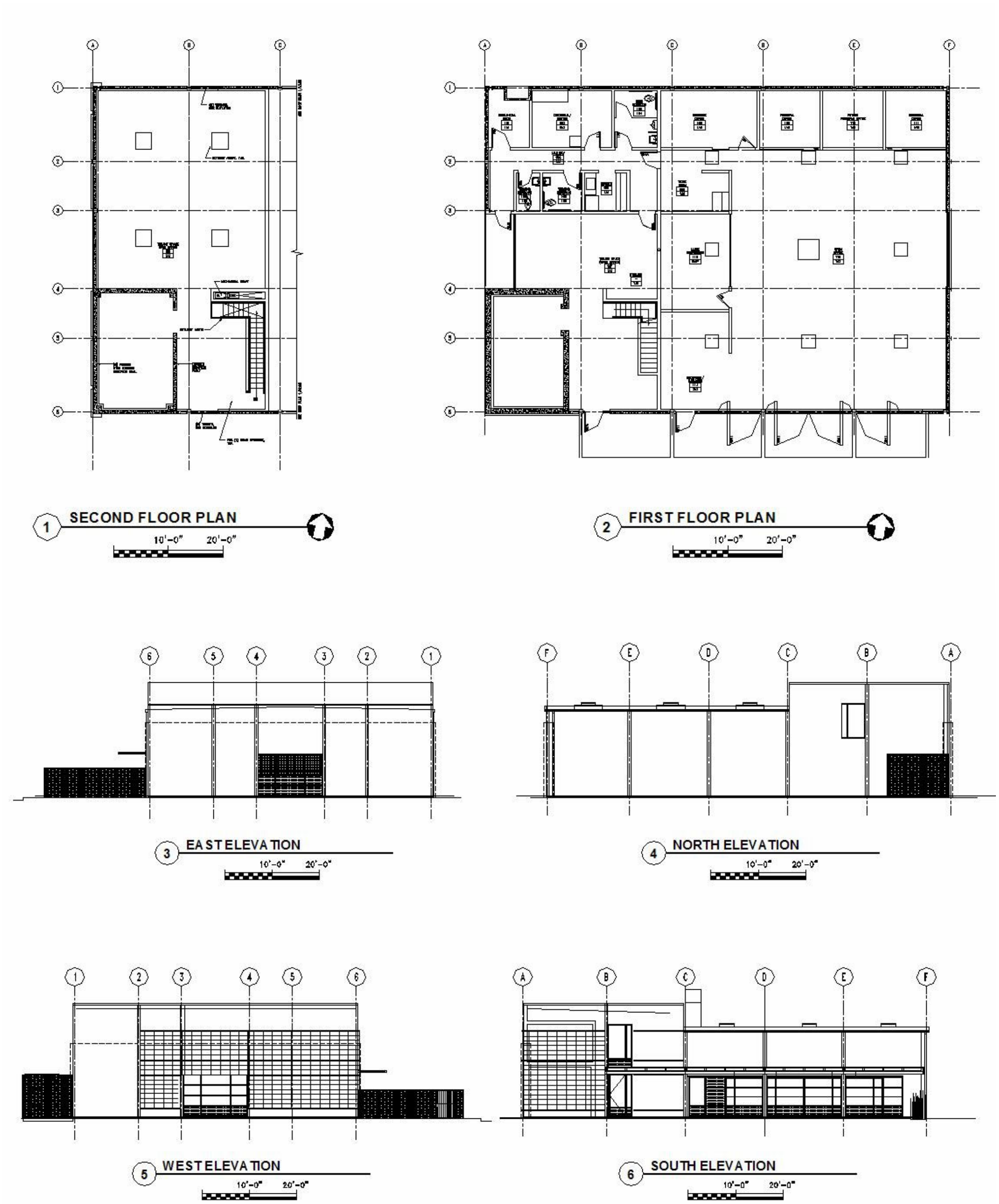
Introduction

The **IDeAs Z^2 Design Facility,** scheduled to be completed in August 2006, is a design for an office remodel in San Jose, CA. This building will be the new headquarters of Integrated Design Associates, Inc. (IDeAs) an electrical engineering consultancy specializing in sustainable design. The building is designed to be net zero energy and zero carbon emission or "Z^2", using renewable energy (PV) for 100% of its net total energy requirements and not generating CO_2 on site. We believe that it will be one of the first commercial buildings of its type in the United States.

Background

The subject building is an existing 7,200 ft^2 office building that is approximately half single story and half two story, originally constructed in the 1960's (Figure 1). About 60% of the building will be fully fit out and the remaining 40% will be leased to a tenant. The existing building is constructed of tilt up concrete panels in a steel frame, and has virtually no windows. The site includes a large parking lot with interlocking parking easements on adjacent properties.

Figure 1. Building Floor Plans and Elevations



Design Process

Although the process conceptually followed the process outlined in "Designing for Sustainability" (Hayter et al. 2000), due to the small size of the project, the experience of the team and the compressed design/construction schedule, the process was modified and greatly abbreviated.

Team. The first key decision for the project was selection of a design team with solid experience in sustainable / highly energy efficient design. The owners' experience in sustainability helped to identify potential design team members for this project. EHDD Architecture, Rumsey Engineers, and Integrated Design Associates (IDeAs) were selected as the core of the team because of their proven knowledge, design approach, previous team experience and history of creative solutions.

Concepts. Early concept discussions focused on two issues: developing a budget and choosing between LEED Platinum or "Z^2" energy efficiency goals. The building remodel budget estimate is $1.26M or about $175 per ft^2, excluding site and soft costs. Although a LEED rating will be pursued, "Z^2" was selected as the primary goal. It was the view of the owner and design team that a LEED Platinum rating on a project of this small scale would require the design to incorporate features that were costly relative to their environmental value purely for the sake of gaining additional LEED points, whereas a "Z^2" energy efficiency goal would focus the team on designing an high efficiency building with demonstrable benefit to the environment.

Goals. Once a "Z^2" goal was agreed, focus shifted to energy efficiency (Hayter, Torcellini, Deru. 2002). Key goals of the project are:

- design a highly energy efficient, all electric building that provides exceptional occupant comfort.
- provide renewable energy through on site PV to cover 100% of the building's net energy requirements.
- provide detailed ongoing monitoring of electrical systems to gather data on the performance of various energy efficient systems and concepts.
- make the building a learning lab to test theories and simulations verses actual performance, to better understand how building components interact.
- create a great working environment through creative design and effective use of technology.

Conceptual charrette. The design process began with an initial two day conceptual design charrette with the owner, architect, structural, mechanical, and electrical engineers, and the contractor, to lay out the key goals and strategies for the project. This charrette covered brainstorming and conceptual design and relied heavily on the deep experience of the design team to quickly narrow options. The team's approach was to effectively integrate the architectural, mechanical, and lighting systems to incorporate as many practical energy measures as possible to maximize the total efficiency. During the charrette, options and tradeoffs were discussed, relying on experience rather than computer modeling to select options.

Final design. After the charrette, the architect completed an abbreviated schematic design, while the contractor developed preliminary pricing. The mechanical engineer further developed the mechanical scheme and worked with a local mechanical contractor specializing in radiant systems as a design build team, while the architect, electrical engineer and structural engineers moved right into design development / bid documents. Computer models were developed to optimize the daylighting / HVAC / lighting design during this phase. Subsequent to the initial charrette, the coordination of the energy design was done primarily via phone and email. The process was lead by the architect and required close coordination with the owner, electrical and mechanical engineers and contractor.

Energy Efficient Strategies

The project uses a number of innovative technologies and design strategies to try to wring every watt available out of the building, without impacting occupant comfort. The energy model for this building was run using EnergyPro 4.1 for California Title 24 Nonresidential Performance compliance (EnergyPro 2002). and Energy Pro 3.144. for LEED 2.1 compliance. EnergyPro uses DOE-2.1E as its calculation engine. Estimated energy consumption is 43% below California Title 24, 2005 requirements and 60% below ASHRAE 90.1 1999.

Building Envelope

The final design is composed of a 3,100 ft^2 open studio with 18 ft ceilings and a 4,100 ft^2 two story section that will contain leased tenant space as well as shared service space. Other than the existing entries on the east and west sides of the building, the main openings cut into exterior walls will be four double width pivoting glass doors cut into the south side of the concrete tilt-up walls which will provide views and a connection to a new landscaped entry courtyard located on the south side of the studio. The courtyard doors can be opened to take advantage of the mild northern California climate to create an indoor/outdoor work environment. Due to limited views, along with budget and seismic considerations, few other wall opening will be added.

Roof and wall insulation. To maximize envelope performance existing walls and roof insulation will be upgraded to R-30 insulation in the roof and R-19 in the walls. The existing exterior walls are 5 in thick tilt up concrete, with wood furring and gypsum board on the interior, and included no insulation. The interior finish will be removed and replaced with 2.5 in metal studs at 24 in o.c. held 3 in off the tilt-up panels, with R19 fiberglass batts for insulation.

Fenestration. All glazing for this project with the exception of the east storefront will use the excellent new spectrally selective glazing from PPG, Solarban 70XL Sapphire with a solar heat gain coefficient of 0.27 and a visible light transmission of 0.63. It has the highest light to solar gain ratio available (2.33), to minimize the solar heat gain accompanying daylight. The U-value is 0.29 winter nighttime and 0.27 summer daytime (Solarban 2005). All skylights will be custom fabricated using Solarban 70XL Sapphire. Of the 17 skylights, 13 will also incorporate a clear, prismatic, diffuser below to spread the light.

Electrochromic glass. The east storefront window will test electronically shaded glazing from Sage Electrochromics. The technology used to make SageGlass® is a ceramic coating on the glass that is electronically tintable using solid-state controls. (SAGE 2006a) The glass can be darkened or lightened using an electrical current creating an effect similar to photogray sunglasses. The project takes advantage of this variable tint to reduce direct sunlight transmittance and the resulting glare during morning hours. The SageGlass® Classic can be darkened reducing transmittance from 62 % to 3.5 % and reducing solar heat gain coefficient from 0.48 to 0.09. The U-value is 0.28. (SAGE 2006b) A photocell controlled low voltage controller will reduce transmittance and the associated glare from direct sunlight. The advantage of using this glass is that unlike traditional blinds it can block sunlight before it enters a building and has no moving parts so it should be low maintenance. It allows unobstructed views and daylight on overcast days or after noon due to the east elevation.

The cost of the glazing is around $12,500, or $150/ft^2$. Though obviously still very expensive, we believe there is potential for the cost to come down significantly over time and that it has significant potential to improve daylighting, and reduce the associated solar heat gain penalty in future projects.

Mechanical Systems

The IDeAs Z^2 Design Facility uses an innovative HVAC system that consumes significantly less energy than standard systems. The mechanical engineers strived to maximize performance, energy efficiency and indoor air quality while keeping the HVAC construction costs comparable to more traditional designs.

Radiant floor system. A topping slab will be installed containing cross-linked polyethylene (PEX) radiant tubing for both heating and cooling. The use of water to convey heating and cooling to a space as compared to the use of air, as in a forced air system, uses less energy to provide the same amount of conditioning. Radiant floor systems typically use relatively higher water temperatures for cooling and lower water temperatures for heating compared to forced air systems allowing the equipment providing the water to operate more efficiently.

Heat pump. The use of a 18 kW electric, water-source heat pump to produce both chilled and hot water will be utilized to maintain the net zero energy and zero carbon emission philosophy of this building. The chilled or hot water will be provided to both the radiant slab and a dedicated outside air handler to condition the space. The heat pump has a cooling energy efficiency or EER rating over 19.

Cooling tower bypass. A 5 hp cooling tower will be utilized as a means to reject or absorb heat as the heat pump produces chilled or hot water. On warmer days, the cooling tower will be operated independent of the heat pump during nighttime hours in bypass mode to directly precool the building and the slab for the next day.

Dedicated outside air handler with CO_2 sensor. Operable windows and doors will allow the occupants to tailor their comfort levels through tuning the openings. When the windows or doors are not utilized due to outside air temperatures being too cold or hot, a 1 hpe dedicated outside air handler will operate only when CO_2 levels rise past 800 ppm.

Electrical Systems

Plug loads. In 1999, the US Department of Energy estimated office equipment to be about 18% of a US commercial building's electrical load (EIA 2003). This is second in magnitude only to HVAC and lighting loads.

Desktop personal computers (PC's). Based on a survey of existing IDeAs equipment, the largest office equipment electrical loads (plug loads) will be from PC's. Currently existing PC's average 160 W per workstation. One alternative considered was to replace PC's with laptop computers. Several laptops were measured and averaged 40 W.

IDeAs' key software for production work is AutoCAD®, so most computers in the studio must be capable of running the program. The difference in cost between a suitable PC and equivalent laptop to run the program is about $1,200. This is greater than the cost of the photovoltaics required to offset the additional load, so additional photovoltaic capacity was designed into the system.

Miscellaneous plug loads. Electrical loads for printers, scanners, copiers, fax machines refrigerator and dishwasher were evaluated. A sample of potential ENERGY STAR® rated equipment costs 20 to 100% more than standard equipment with additional energy savings of less than 10%. Our conclusion was that wholesale replacement of equipment was not cost effective. Instead high efficiency equipment will be purchased only where new equipment is needed (such as a refrigerator). One final item: the coffee maker will be replaced with a single cup coffee maker, which only heats a cup at a time and has no warmer.

Plug load control. Control of "phantom loads" in office equipment is a key strategy for conserving power. Infrequently used equipment, such as microwave ovens, can consume more energy in standby than in use. Three strategies will be employed to reduce phantom loads:

Items such as printers, plotters, fax machines and copiers have a long startup time, and would be inconvenient to turn on prior to each use. In the worst case, a Lanier LW-310 laser plotter was measured to consume 39 W in the sleep mode, and 25 W when manually switched to "standby" (there is no actual "off" switch). These will be turned on during working hours, however to ensure that equipment is not left on, the security system will automatically turn off this equipment when armed. Equipment will be manually switched back on each morning.

PC's are routinely left on all day, but will be set to automatically go into sleep mode when not in use. Staff will also be strongly encouraged to turn off PC's at night.

Watt Stopper's innovative Isole occupancy sensor switched, surge protectors (Isole 2006) will be used at each desk to automatically turn off power to computer monitors, speakers and other non-essential peripherals when a user leaves his work area.

Upsized wiring. All branch circuits carrying large continuous loads will be upsized to reduce wiring losses. This will reduce the actual electrical energy consumption of a circuit and also associated cooling loads.

Daylighting Design

Daylighting is one of the key strategies for significantly reducing energy consumption while providing superior light quality. Daylighting will be provided via skylights in the studio and second floor of the tenant space. Although new windows and glass doors will be added to the building, the design philosophy was to keep the amount modest and use it primarily for views. Based on computer models and projections of working hours, the design team estimated energy savings of about 60% of the lighting load during occupied hours. This number would have been higher still except for the fact that IDeAs staff regularly work late, increasing evening use of electric light.

A number of design tools were used to size and locate the skylights in the studio, including a physical daylighting model, AGI32 lighting/daylighting software (AGI32 2006) and SkyCalc skylight design software (Skycalc 2005). The studio design consists of a 3 x 3 grid of 40 in x 40 in skylights, plus an additional row of three 21 in by 72 in skylights along the north wall. The skylights provide an average of 100 footcandles (fc) at solar noon in summer, and 36 fc at solar noon in winter, (see Figure 2). The skylights were slightly oversized to try to provide more hours of complete daylighting with no electric lighting on short winter days without significantly effecting summer cooling loads. The 18 ft high ceiling allows excellent distribution throughout the workspace below.

Figure 2

SkyCalc: Skylight Design Assistant - Graphic Results

Company Name: IDeAs Design Facilities
Project Description: Daylighting

Effective Aperture = 1.69%, Skylight to Floor Ratio (SFR) = 4.33%

Average daylight footcandles (fc)

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Jan	0	0	0	0	0	0	0	1	10	20	30	38	39	35	25	14	5	0	0	0	0	0	0	0
Feb	0	0	0	0	0	0	0	4	15	29	43	49	53	51	41	25	12	3	0	0	0	0	0	0
Mar	0	0	0	0	0	0	2	12	28	46	61	67	67	63	54	39	21	7	0	0	0	0	0	0
Apr	0	0	0	0	0	0	8	22	42	60	76	84	79	76	67	52	30	13	2	0	0	0	0	0
May	0	0	0	0	0	3	14	31	51	69	87	96	96	93	81	63	41	19	5	0	0	0	0	0
Jun	0	0	0	0	0	4	15	33	54	73	85	95	99	96	86	68	47	24	9	1	0	0	0	0
Jul	0	0	0	0	0	2	12	29	54	77	92	99	100	96	85	68	47	24	8	1	0	0	0	0
Aug	0	0	0	0	0	0	9	23	46	68	86	95	97	92	81	63	39	17	4	0	0	0	0	0
Sep	0	0	0	0	0	0	4	17	37	59	75	83	84	78	64	44	23	7	1	0	0	0	0	0
Oct	0	0	0	0	0	0	2	11	26	42	54	62	64	57	43	24	10	0	0	0	0	0	0	0
Nov	0	0	0	0	0	0	0	5	15	27	40	46	46	39	26	13	4	0	0	0	0	0	0	0
Dec	0	0	0	0	0	0	0	1	9	18	27	34	36	29	20	11	1	0	0	0	0	0	0	0

Design Illuminance = 35 fc

< 3.5 fc; < 17.5 fc; < 35 fc; > 35 fc;

Several strategies will be tested as an ongoing research project to reduce excess heat gain through the skylights in summer, including seasonal modifications to the skylights such as exterior sunshades or shade cloth, pyramidal skylights and external reflectors. The design team plans to collect measured data on the performance of test skylights.

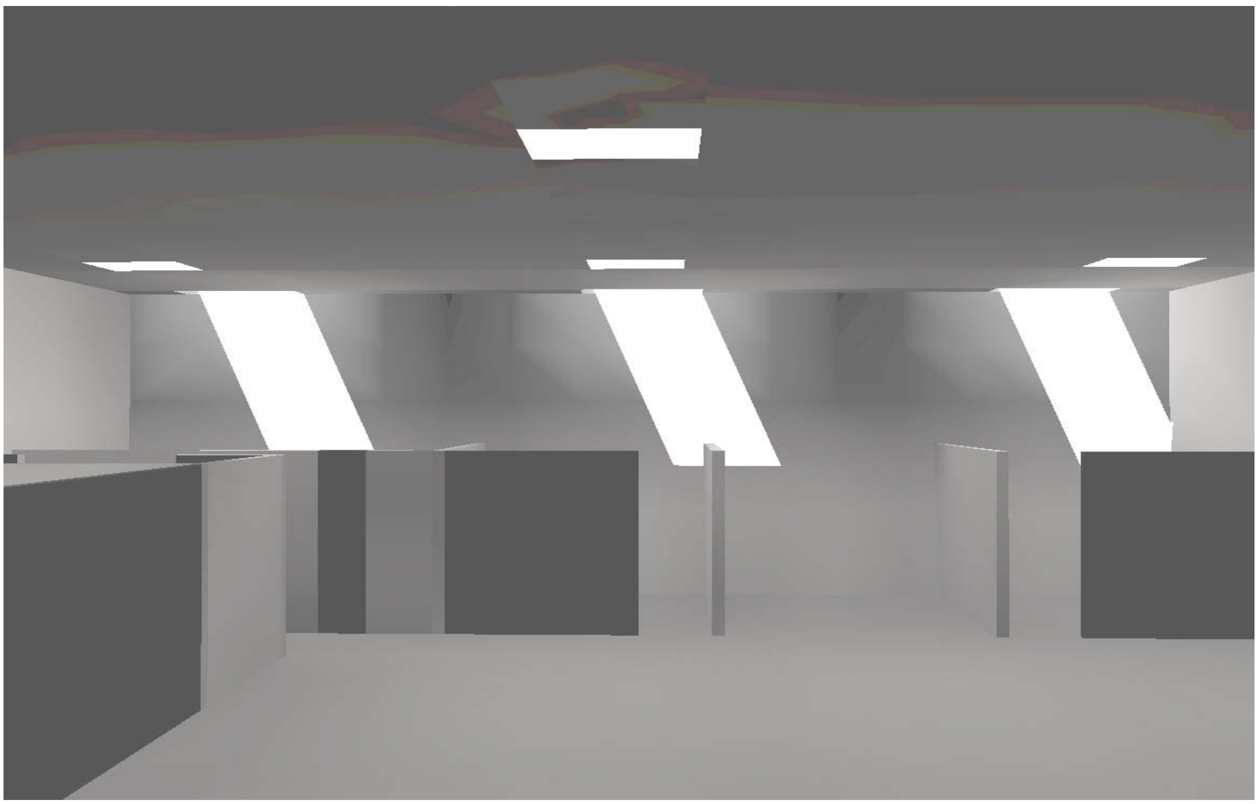
Dynamic daylight. One issue discussed by the design team is that a typical design using diffusing skylights in a high ceiling can provide uniform lighting at desk height that appears visually flat, similar to lighting conditions on an overcast day. On the other hand, direct beam sunlight in an office can cause local overheating, and glare.

As a test, a row of clear skylights will be introduced along the north wall of the main hall. These skylights will introduce a small amount of direct sunlight into the space using Solarban 70XL glazing to minimize the heat gain. The intent is to only allow direct sunlight to strike the north wall, which will be painted white and used to reflect light into the space (see Figure 3). This direct light will dynamically move across the north wall as the sun travels across the sky.

Electric Lighting

The goal of the electric lighting design is to provide outstanding lighting quality while minimizing energy consumption. Key techniques used for achieving this goal include: paying close attention to perception issues, using high efficiency sources and fixtures, and using task ambient lighting concepts.

Figure 3



AGI32: Summer direct sunlight penetration study.

Perception issues. Building occupants determine how bright they perceive a space to be based on a number of criteria including the luminance of the main surfaces in the visual plane. In a typical office, designing 30 to 50 fc at empty desks does nothing to create the impression of brightness, while putting the light on a high reflectance wall in an occupant's visual plane does. A key strategy in the design of the studio is to paint the walls with an 87% reflectance paint and ensuring that they are lit. Floors will be sealed concrete and estimated to be 30% reflectance.

Fixture efficiency and lamp/ballast selection. We believe the light sources with the best combination of high efficiency, good color rendering and long life are linear fluorescent.

The IDeAs lighting designers compared fixture efficiency for various linear fluorescent light fixtures and discovered that there appears to be a 4% increase in efficiency between light fixtures using T5 lamps and light fixtures using T8 lamps. We surmise that smaller diameter T5 lamps may allow fixture designs to be more efficient. However, when accounting for the total efficiency of a lamp, ballast and light fixture combination, T8 lamps still appear to be slightly more efficient.

Reviewing lamp ballast literature, the highest efficiency combination that we found is 102 lumens per input watt (LPW), using a T8 lamp and an instant start, high efficiency, electronic ballast. The best T5 ballast has an efficiency of 92 LPW and the best T5HO ballast an efficiency of 85 LPW.

The dimming ballasts are less efficient than non-dimming ballasts. The best T8 dimming ballast has an efficiency of 94 LPW, the best T5HO dimming ballast has an efficiency of 85 LPW and the best T5 dimming ballast has an efficiency of 79 LPW. Although less efficient, dimming ballasts allow immediate energy savings when daylight is available in daylight harvesting systems.

The installed watts per ft^2 in the studio is 0.47 watts per ft^2.

Task / ambient lighting. In the studio, a relatively low reflectance wood slat ceiling was designed for acoustical reasons, making heavy use of indirect lighting impractical. Direct / indirect linear fluorescent lighting will be used for low level ambient lighting. Ambient light will be augmented by individual task lights that are occupant and occupancy sensor controlled.

Two types of task lighting have been are used. One is an individual locally controlled fluorescent desk lamp. Each lamp is controlled via an individual Watt Stopper Isole occupancy sensor switched, surge protector (Isole 2006) at the desk. The other consists of the direct portion of an integrated suspended linear fluorescent fixture computer controlled by the user.

Lighting Control Systems

In addition to using high efficiency sources and light fixtures to maximize the electric lighting efficiency, a second strategy for minimizing electrical consumption is based on turning lights on only when they are required and at the levels that are required. A variety of automatic control devices have been employed for various applications.

Occupancy sensor lighting controls. All lighting in the building will be controlled via occupancy sensors, so lights are turned off a few minutes after a room becomes vacant, making them highly energy efficient.

Exterior lighting controls. Exterior lights for the courtyard and pedestrian circulation in parking areas will be controlled by a manual timer and occupancy sensors in combination with an astronomic time switch. This allows lights to be turned on either by timer for occupants exiting the building or by occupancy sensor for occupants entering the building from the parking lot but only after dark.

Integrated computer controlled light fixtures. The north row of lights in the studio will use the Edapt™ light fixture with integrated Ergolight® control system by Ledalite. This sophisticated, suspended linear fluorescent system provides 30% uplight and 70% downlight. The ambient, uplight component of the fixture is group controlled via a timeswitch, on-board occupancy sensor (after hours) and on-board daylight harvesting photocell to provide a uniform appearance across all such fixtures in the office. The task downlight component is individually dimmed and switched by the occupant via a computer interface. It also uses the on-board occupancy sensor to automatically turn off the task light if the occupant is not present and is dimmed by the same daylight harvesting photocell that controls the uplight (Ergolight 2006).

Integrated lighting controls. The rest of the light fixtures in the studio will be high efficiency linear fluorescents provided by Finelite. All will include daylight harvesting controls and manual on / automatic off occupancy sensors. One section will be outfitted with the Lutron® EcoSystem™ dimming control system. A second section will use a Watt Stopper Lightsaver® LCD dimming control system. Both sections will dim the lights in the studio, then switch off lighting after a time delay when daylight levels are high enough. One final section will be outfitted with a Watt Stopper Lightsaver® LCO switched control system which switches off lighting when daylight levels are high enough.

It is our intention to compare the efficiency of these lighting systems and their energy performance to try to determine the relative energy savings of dimming vs. switched daylight harvesting systems, as well as what factors effect them.

Nightime light levels. During the day, light levels in the studio should exceed 30 fc most of the year. However, we believe that low exterior light levels and circadian cycles will combine to make lower light levels acceptable in the studio after dark, so levels in the studio will be tuned to provide about 15 footcandles for ambient lighting at night.

Photovoltaic System

After integrating the design to optimize overall energy efficiency through lighting, daylighting, HVAC and plug in equipment, a photovoltaic system was designed to provide net 100% of the building's energy requirements. The estimated size to supply the building's energy requirements is 30kW (DC), which will provide an estimated 56,500 kWh per year.

Building Integrated Photovoltaic System (BIPV). 2,600 square feet of SolarSave™, a unique roof membrane integrated PV system manufactured by Open Energy Corporation, was selected for use on this project. The product combines a single ply PVC, fire rated, white, waterproof roofing membrane with high efficiency SunPower A-300 monocrystaline solar cells (SolarSave 2006). These cells have one of the highest efficiencies (20 to 21.5%) of any mass produced solar cell. The product is light weight (2.5 pounds per ft^2) and does not require special support structure, ballast or structural penetrations, further reducing cost. This system allows savings through both the elimination of the need for a support structure and the dual use as both a PV panel and roof membrane.

A second BIPV system using PV's in a laminated glass entry canopy also made by Open Energy Corporation will be installed over the main entrance at the south side of the building. The glass will allow filtered light to pass through the module and to allow occupants to view the PV cells in the modules from below when entering or leaving the building. The shade will block direct sunlight from entering the studio during the hot summer months without obstructing views of the courtyard as well as provide protection from rain in the winter.

Renewable energy incentives. A key impediment to reaching our 100% net energy generation goal is the high cost of photovoltaic systems. However recent incentives have made the cost for the system much less prohibitive.

Currently the California Energy Commission (CEC) offers a $2.80 per watt rebate for systems less than 30kW. In addition the Federal Government offers a 30% federal tax credit and 5 year accelerated depreciation for photovoltaic systems from January 1, 2006. We estimate that these state and federal incentive programs together will reduce the cost of the photovoltaic system by approximately 80 to 90%.

Building Energy Monitoring System

One of the goals for this project is to monitor the actual energy consumption of the various systems installed in the building to better understand their performance. As designers of sustainable and high efficiency electrical and lighting systems, IDeAs is aware that there is a dearth of actual measured data on various control systems and energy efficiency strategies and their actual effectiveness. The building has an electrical energy monitoring system that will allow collection of detailed data on the actual building performance.

The building incorporates a Powerlink power monitoring system by Square D built into the electrical panelboards to monitor performance of the various systems in the building and interface it onto internet. This allows the design team to monitor each component of the HVAC system, each lighting circuit and each receptacle circuit and develop data to measure performance of the various systems. The building also will monitoring: real time AC voltage, current, and watts, real time DC voltage, current, and watts, and cumulative AC and DC energy generated for the Photovoltaic System. Finally it will monitor relevant weather data that effects the performance of both the PV system and the building as a whole including: ambient temperature, PV cell temperature, wind speed and direction, and external irradiance. The web interface will be provided by Integrated Building Solutions. The design team anticipates using this data to perform in depth analysis to research how various systems interact, to compare the accuracy of daylighting and energy modeling software to the actual building and to better understand how to fine tune an integrated design.

Conclusion

The IDeAs Z^2 Design Facility is estimated to use approximately 56,000 kWh of energy annually, 60% below ASHRAE 90.1 1999 standards. It is designed to be both highly energy efficient and net zero energy, zero carbon emission. The design team hopes the building will inspire and educate both its occupants and the industry to do better design.

In addition to energy efficiency, its large courtyard provides a comfortable, secure, compound that will blur the line between inside and outside, serving as main entrance and extension of the studio. The studio with whiteboard walls, heliodon, sophisticated controls and energy monitoring system will serve both as a research lab and a design office, and with a bocce ball court, foosball table, and outside movie projection wall will live up to the IDeAs work hard - play hard ethic.

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