Zero Energy Economics

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ABSTRACT

The highest hurdle that a building owner faces is cost. However, when striving for a net-zero energy building, is it more cost effective to spend money on energy production or spend the capital on improved building equipment that uses less energy? This paper discusses the economics of achieving a net-zero energy building through a case study of the **IDeAs Z^2 Design Facility,** a remodel of an office building in San Jose, California striving to become a zero energy, zero carbon-emission (Z^2) building. A variety of concepts and methods to maximize energy production and reduce energy consumption will be addressed. Specifically:

Production

- On-site energy production options to achieve zero energy and zero emission building.
- System costs (initial and maintenance) of solar energy.
- Affects of rising utility rates and available funding sources.
- Cost impacts of building-integrated photovoltaic systems.

Conservation

- Energy efficient lighting design to reduce connected electrical load.
- Cost effective control strategies for lighting system.
- Plug load reduction opportunities from the computer system.
- Reducing energy losses through upsized wiring.
- Selecting the correct appliance to save energy while minimizing the first cost.

Introduction

The goal of the net zero energy building is to produce enough power on-site to equal the facility's power consumption over the course of a year. A net-zero energy building is not removed from the utility grid, but rather takes energy from the utility grid at certain times of the day and replenishes the utility grid with excess energy at other times. Therefore the building in essence becomes responsible for its own energy usage.

There has been a large emphasis recently placed on self generation of electrical power. However, such generation is inherently expensive. Therefore it is important to both maximize the ability to produce power on-site as well as reduce the consumption of the building itself in order to become a net-zero energy building. This notion becomes even more important as a building, such as the IDeAs Z^2 Design Facility, strives to become a zero-emission building as well as a zero-energy building. Removing emissions from the building creates an additional burden on renewable energy production as the building is required to rely on electricity for all heating applications whereas in a conventional building, gas would be used.

Assessment

Energy Production- Minimizing Cost and Maximizing Potential

There are several methods of on-site power production including combined heat and power generation (CHP), hydrogen fuel cells, hydraulic generation, wind generation and photovoltaics (PV's). Although CHP and fuel-cells produce power on-site, the technologies do so by taking a fuel from an outside source and using it to create electricity while harvesting the heat from the production cycle. These systems are more efficient than taking both utilities (electricity and fuel) individually from their respective sources, however by using them we have not taken any large steps towards achieving a zero-energy (let alone zero-carbon) building- instead we simply relocated the energy production from utility providers to within the site. True on-site energy production comes from a non-diminishing natural resource that is present within the property boundaries of a given site. These resources include water, wind, and sunlight. Using water and wind to create electricity involves harvesting kinetic motion to drive a turbine to create an electric potential. This process takes a large amount of space on-site and involves mechanical drives causing a large amount of continued maintenance. Sunlight on the other hand can be harvested through the photovoltaic effect where sunlight incident upon certain materials can release electrons and create electrical current. A PV system has no moving parts creates no emissions or noise as by-products, and have minimal space requirements making it an ideal choice for on-site generation.

Currently there are several types of silicon-based PV modules available on the market. In general, the cost of a traditional module is based on the rated power output of the cells that comprise it and not the physical size of the panel. After obtaining several price quotes from various PV installers in the bay area, regardless of the technology- the cost of the PV system for IDeAs Z^2 Design Facility would be around $10/watt of rated AC power. So how does this translate into a cost to the owner? According the ENERGY STAR® Guidelines, the average commercial office building in a climate similar to San Jose, CA would consume 55.6kBtu/sqft annually. Therefore if the 7000 sq ft. IDeAs Z^2 Design Facility was renovated to meet an "average" building performance the PV's would need to produce 100,000kWh annually. Using PV Watts (on-line photovoltaic production calculator produced by NREL), this production would require an 58kWac PV system. In order to reach net-zero energy a building owner would have to spend $580,000 to install a PV system

Recognizing that installing a PV system takes a large financial investment, the State of California and the federal government has established programs to assist building owners to overcome this initial cost. IDeAs new office will be served by PG&E making it eligible for one of two rebate programs depending on final system size. If the system is over 30kWac and is comprised with certified equipment, PG&E offers a rebate of $2.50/Wac through the Self Generation Incentives Program. If the system size is 30kWac or smaller, the project can receive a rebate of $2.80/Wac through California Energy Commission's (CEC) Emerging Renewables Program. In addition, the Energy Policy Act of 2005 established a federal incentive program where the building owner may receive 30% of the installed cost of the PV system as federal tax credits. It is the goal of the design team to make enough improvements in building conservation that the IDeAs Z^2 Design Facility will require a PV system smaller than 30kWac. After taking both the CEC rebate and Federal Tax Credits off the cost of the installed PV's, the system will have a cost of $5.04/rated watt of AC power under PTC (PV USA test conditions).

According to PV Watts, San Jose receives an average of 4.76 sun hours per day (amount of time with 1000W/m2 incident upon a surface). Therefore a 30kWac system laying flat on the roof will produce approximately 37,710 kWh annually, which alleviates $6034/year from purchased power (using the A-1 rate schedule from PG&E). One way to increase the PV production is to tilt the panels allowing more daylight to fall onto the panel. Building a support structure to tilt the panels by 30 degrees increases the same 30 kWac rated PV system output by 6000kWh (increase of 16%). Keeping the energy consumption a constant allows us to reduce the size of the PV array by 4.7kW. This simple modification results in a first-cost savings of nearly $24,000 as well as an annual energy savings of $960.

Up to this point we have been operating under the assumption that the PV system is an additional layer to the building and is independent of the building shell (modules attached to sleepers above finished roof). However, are there any cost savings if we integrate the PV system into a building member that would have been installed regardless if the building had PV's or not? One example of Building Integrated Photovoltaics (BIPV) is the Solar Save SP480 module from Open Energy Corp. This module takes the highest efficiency solar cells on the market and attaches them directly to the top of a single-ply membrane roofing material and vacuum seals it for a final waterproof product, which a contractor can then install as the final layer of the roof itself. Although, the combined system saves on overall material, the majority of the financial savings to the owner is found in the reduced installation cost. Instead of hiring two separate contractors to install the roof and then install PV modules attached to the roof, the entire installation can be accomplished by the lone roofing contractor. Using Open Energy Corp's new Solar Save module at IDeAs Z^2 Design Facility, the PV system will cost around $8.50Wac- a savings of 18% over a traditional PV installation.

Energy Consumption: Minimizing Usage and Maximizing Options

Like any other office building, the major electrical loads for the IDeAs Z-squared Design Facility consisted of mechanical, lighting and plug loads. The reduced energy consumption from the mechanical system came from the ideas derived from EHDD Architects and Rumsey Engineers. Several envelope improvements as wells as an efficient mechanical process attributed to a large portion of the energy savings expected for the project, however these issues are not the focus of this paper. As the electrical consultants on the design team and the future users of the building, our firm had a vested interest to create cost effective ways to reduce the lighting and plug loads to drive down the daily energy consumption of the building in order to meet our zero-energy and zero emission goal.

Lighting Loads

Energy reduction in the lighting system comes from efficient equipment, responsible design and automatic controls. Each element provides energy saving opportunities, but also has associated costs to implement.

Design. The key to an energy efficient lighting design is to provide light only where it is needed and avoid overlighting a space. First, a layer of low level ambient light should be provided in order to meet the minimum light level requirements to perform the most basic visual tasks within the space, such as facial recognition and safe travel. Secondly, a separate task lighting system should be provided to provide additional light in a defined local area so that more intense visual tasks may be performed.

As an example, instead of providing 30fc throughout IDeAs' new Z-squared Design Facility (as recommended by Illuminating Engineering Society of North America, IESNA, Illuminance Category "D" for typed visual tasks), it was decided to provide 15fc of ambient light (IESNA Illuminance Category "C" for non-critical and large scale visual tasks) with suspended direct/indirect luminaries and supplement this with individual, highly-efficient task lights at each desk. The reduced amount of ambient light saved the office (2) rows of suspended direct indirect fixtures saving $17,000 and saving 4.3kW of overhead lighting. The individual tasklights (15 total at 13W each) added $1500 to the budget and 195W to the lighting load. As you can see, the task/ambient approach saves both the budget and energy. In addition, this decrease of power consumption is reflected in the PV system where another 5.7kW of panels can be eliminated from the roof.

Controls. There are two ways to reduce the overall energy consumption on a given lighting system. The easiest and most cost effective method is to simply turn the lights off when they are not being used. Occupancy sensors are an effective solution to turning off lights when the space is not in use. The second way to reduce the lighting load is to harvest natural daylight. Photocells placed within a space can detect the amount of natural daylight in a space and shed the lighting levels accordingly by either turning portions of the system off, or by dimming the lights.

The IDeAs Z-squared Design Facility implemented both occupancy sensors and automatic daylighting controls. A typical occupancy sensor costs about $250 to install and is expected to save 10% of light in an open office (As published by The WattStopper). In addition, individual occupancy sensors are placed under each desk and control devices such as the individual task light and computer monitor. The Isole from Wattstopper (which consists an occupancy sensor tied to a plug strip) costs $90 and is expected to save 400kWh of lighting and plug loads. Openings in the building's shell were designed so that sufficient daylight is provided for the majority of the year. The automatic daylighting controls consisted of both a switched and a dimmed portion for a future energy saving comparison. Using SkyCalc (a daylight analysis tool from Heschong Mahone Group, Inc.) to determine energy savings the dimmed system, which adds $1,100 to the cost, is expected to save 1800kWh ($380) annually. On the other hand, the switched control system, which adds $800 to the cost, is expected to save 1600kWh ($256) annually.

Plug Loads

The largest plug load, by far, in a typical office building is the computers. Therefore any reduction of instantaneous power consumption or overall daily energy usage in the computers will have a significant impact on the building's plug load. So what are some cost effective strategies to reduce the computer loads? We can answer this question by looking at the components individually as well as together.

Monitors. The nature of monitors allows them to have specific power consumptions in each of their three modes- active, stand-by, and off, without intermediate settings. The power control for the monitors lies within the hard drive that they are connected to. Therefore the to reduce energy consumption of the monitors themselves you need to either adjust the settings when the monitor is active or exchange the monitor itself to a more efficient model.

The first step to reduce the power consumption of the monitors is to analyze the existing equipment used at IDeAs. Currently, the design staff at IDeAs use two (2) 17" CRT monitors (measured as consuming 80W each) side-by-side for an expanded view of their desktop. Obviously, the monitor load could cut in half if we simply take away one of the monitors and used a traditional workstation with only one monitor per person. However, it was determined that a two monitor system helped increase the productivity and accuracy of the design staff- so an alternate energy saving strategy was required. Unfortunately, there were no other ways to reduce the energy consumption using the existing equipment.

In order to reduce the power consumption of the monitors IDeAs would have to upgrade to newer equipment. Looking at several available monitors on the market, an LCD screen uses the least amount of energy. An equivalent 17" LCD monitor consumes 30W. Once it was determined that IDeAs would upgrade their monitors, it was agreed to reduce the screen size from 17" to a 15" monitor (consuming 18W). Again, this reduction in screen size will most likely impact productivity, however we would argue that this decrease is very small (especially compared to the elimination of an entire screen as previously mentioned). The effect of upgrading the entire office (15 workstations- 5 with single monitors and 10 with two monitors) to 15" monitors would save 2.5kW of connected active load and predicted annual savings of 5000kWh or $817 (as well as 2.9 kW of PV reduction).

Boxes. The same methodology used for the monitor analysis was used on the boxes (as reference to all components other than monitor, keyboard and mouse- CPU, power supplies, network cards, etc). Initially, what are some changes that could be made using the existing equipment at the IDeAs office? An easy method to reduce the overall energy consumption (watt-hours) of the computer is to use software to automatically turn off or reduce energy consumption when the computer is not in use. Like most new computers, the operating system used at IDeAs is already equipped with energy saving settings. The "Power Options" menu on the control panel allows users to automatically turn off the monitor as well as put the hardrive into standby mode if the system is inactive for a set amount of time.

Again, like the monitors, the second option to minimize the power consumption of the box is to look at available upgrade options. Unfortunately, all of the desktop computers that were analyzed basically had equivalent power consumption numbers.

System. As a whole, the most efficient workstation consisting of a hard drive and a monitor comes in the form of a laptop computer, where the two components are integrated into one. The power consumption of several laptop computers were measured. The most efficient model only drew 50W in active mode and 23W in idle mode. Clearly this is a more energy efficient system- even with an additional LCD screen to allow the side-by-side monitors for the design staff. Assuming 15 workstations, converting the entire office to a laptop-based system would cut 3,664kWh of annual energy. This equates to a 2.91kW (and $14690) reduction in the PV system. So how does this compare to the price of a laptop computer? Allowing the owner to cover the first cost of an entire network upgrade, the budget for laptops would equal the first cost reduction of the PV system, around $14,960. Taking the savings and dividing by 15 workstations shows that in order to convert the computer system to individual laptops plus LCD monitor would need to cost less than $980 per workstation.

In our experience, an equivalent laptop computer with the ability to run intensive computer applications such as Auto CAD and AGI32 (lighting/daylighting calculation software) at the same speed of our current desktops would cost well over $2000. Therefore changing the workstations one-for-one is not a cost effective solution. However, changing the computers on a replacement basis could be accomplished at a $980 premium over the cost of replacing a desktop. In addition, if employees using very basic computer programs such as typical Microsoft Office applications an off the shelf laptop would suffice. Therefore only office principals and receptionists will upgrade their workstations to laptops at this time.

Miscellaneous

Throughout the design process, several other energy efficient measures were explored.

Upsized wiring. When designing energy efficient systems, it is easy to focus only on the appliances and devices that are consuming electricity. It is easy to assume that power is only wasted at items such as pumps, fans, or receptacles. However, any current running through a material naturally looses energy due to resistance. By simply upsizing the feeders on loaded circuits, a building can actually consume less energy because the electricity has an easier path to each device.

Let's take only one of the lighting circuits at IDeAs Z^2 Design Facility. According to the National Electric Code, the minimum wire size for a lighting branch circuit is (2) #12 AWG cables. These cables have an internal resistance of 1.7 ohms/1000ft. Assuming the circuit has 20 fixtures each containing (2) 32W T8 lamps lights in the open office runs for a total of 12 hours per day and the total circuit length is 200 ft, the energy losses in the power cabling alone is 121kWh annually. Simply by upsizing the power cable to (2) #10 AWG cables (internal resistance of 1.0 ohms/1000ft) the building can save 49.8kWh. The cost to upsize this wire is very small (#12 current price is $5.60/100ft and #10 current price is $12.80/100ft). Therefore upsizing wire for continuous, highly loaded circuits is an easy way to save energy.

Appliances. A new kitchen is also included at the IDeAs Z^2 Design Facility, including a dishwasher, microwave and refrigerator. Because of its continual use, the refrigerator was targeted as a large energy consumer. According to the National Appliance Energy Conservation Act (NAECA) a minimum annual energy use for a refrigerator the size we wanted was around 430kWh. This will serve as our benchmark for energy upgrades. After researching efficient refrigerators it was determined that the Sunfrost R-19 was the most energy efficient model on the market. The R-19 model uses 204kWh annual energy and costs $2,600. Assuming we could find a bulk standard refrigerator around $800, the premium for the Sunfrost R-19 resulted in $7.96/kWh. It was determined that the Sunfrost refrigerator was not a cost effective solution. Another alternate was the Kenmore 940-6056 refrigerator that uses 376kWh annually and costs $1,100. This refrigerator was slightly better and has a premium of $5.55/kWh. It was determined that the cost effective solution was to purchase a standard ENERGY STAR® refrigerator for the use in the new office.

Conclusion

The task of designing a zero energy and zero carbon building such as the IDeAs Z^2 Design Facility is a difficult enough task with unlimited funds. However, due to the reality of a budget, it is necessary to prioritize the energy efficiency strategies to reduce the cost of installing expensive energy producing systems in a building. Although building a support structure to slope the PV modules would be an inexpensive way to maximize the power output of the system, the site constraints of the new office would not allow it. When modules are sloped, adjacent rows need to be separated in order to avoid shadows of a neighboring row. With a footprint of only 5000 sq ft., a system with sloped modules took too much real estate to meet our Z^2 goal. Therefore, it was decided to use the BIPV modules from Open Energy.

The greatest cost savings that the electrical design team offered was an efficient lighting design using a task/ambient approach. Not only does it alleviate the production burden from the PV's, but in this case, comes without a premium as the additional task lights cost less than the removed overhead lighting. In addition, once an efficient lighting system is installed, the additional cost for occupancy and daylight harvesting controls coupled with the energy savings from these controls far outweighs the installation of PV's to overcome the same amount of lighting load.

Additional opportunities where energy consumption is less expensive than PV production can be found with the plug loads. First, all building owners should require the power option settings for their computer's operating system be used. Typically this feature is already on the system, and is therefore a free way to save energy when computers are idle. Upgrading the computer monitor can also be an option- especially if the existing computer system uses outdated CRT screens. Although it seems like a large investment, replacing monitors is still a less-expensive strategy then installing additional PV's to cover the energy consumption. Further upgrades to the computer system, including the use of laptop computers instead of desktops, can also be a cost effective strategy in lieu of additional PV's. However, the price of a laptop for the specific use as well as potential loss of employee productivity must be analyzed before making this decision. In general, if basic computing tasks are being performed, the energy savings to upgrade to a laptop and reduce the size of PV system are justified. Small energy savings are also found with the use of upsized wiring. Although it is difficult to see its effects on a building-wide basis, increasing the wire size for continuous, highly-loaded circuits will continue to save energy through the life of the building with a small up-front cost. Additionally, the selection of the correct appliances including a refrigerator will also affect your energy consumption. However, due to the success of the ENERGY STAR® program, the most cost effective solution for a refrigerator is simply a standard model with ENERGY STAR® rating regardless of manufacturers.

The IDeAs Z^2 Design Facility is estimated to use approximately 56,000 kWh of energy per year. This is 31% below the 2005 California Title 24 energy budget and about 50% below the 2001 Title 24 energy budget in use when the project started. It is truly a cutting edge, ultra-energy efficient building, that the design team and client believe will inspire and educate both its occupants and the industry to do better design.

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