Plug Load Reduction for a Net Zero Energy Building

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ABSTRACT

Due to the current high cost of onsite power generation, demand side reduction of electrical loads is critical for success of the design of a net zero energy building. Integrated Design Associates' (IDeAs') net zero building is only economically possible through stringent control of all building loads, especially plugged in utilization (end-use) equipment.

IDeAs' staff measured the load on every plugged-in device and evaluated energy saving alternatives. In this real life situation, the biggest load was the desktop personal computers (PC's). Some of the desktop PC's were replaced with laptop PC's to reduce the load by 75 percent. Financial analysis shows that the cost of the laptops is less than the cost of additional photovoltaic cells in some cases.

Other items included using an energy efficient refrigerator, using an energy efficient microwave and eliminating the dishwasher. Staff has agreed to replace the coffee machine with sun tea. The number of fax machines, copiers and printers are limited to the minimum number necessary for efficient operation, and are the most energy efficient on the market. All equipment has sleep mode (use reduced energy when not actively in use).

Finally, all circuits are monitored and the energy management system (EMS) shuts off breakers at night in case equipment is inadvertently left on and to limit phantom loads.

Staff education is key to limiting the use of unnecessary equipment. Continuous measurement of the system keeps staff up to date on where we stand providing encouragement to be efficient.

Overall, IDeAs expects to reduce plug load energy use by over 50 percent over a "normal" office with the same number of employees. This should result in an annual savings of 30,000 kilowatt-hours (kWh).

Introduction

There has been a lot emphasis recently on self generation of electrical power. However, the cost of electrical power produced on site is almost always more expensive than purchasing from a utility as individual producers do not have the economy of scale that utilities have in generation (ASU 2006). That said, there are several commercially available methods of producing on site power including wind, photovoltaic cells, and cogeneration which can prove to be cost effective given the right conditions and a building owner willing to accept a long payback period (Rawson, M. 2004).

Regardless of the method of power generation, the equipment size and payback period can be minimized through reduction of the electrical loads. Building electrical energy usage can be broken down into three major areas: lighting; heating, ventilating and air conditioning (HVAC) equipment and utilization equipment. In an office environment, the utilization equipment constitutes all of the equipment plugged into receptacles, hence the term "plug loads".

Based on 25 years of experience living and working on three continents, we have observed that America's fixation on low cost products, coupled with a relatively low cost of energy, has generated a plethora of electrical products that are not inherently energy efficient. The following research shows that typical offices are populated with electrical devices that use more energy than needed. Some of these devices operate around the clock unnecessarily. Other devices have operating components which continue to use electrical power when the device is turned off. These are known as phantom loads. A common example would be the LED on a television or stereo system that is lit (using power) when the appliance is turned off.

This paper describes how a strategic assessment of energy usage can be accomplished for a small to medium sized office environment, focusing on the facility's plug loads. It describes how to selectively use the most energy efficient equipment available on the market as well as the use of energy management software to insure that equipment is turned completely off when not in use. This comprehensive approach can result in a high efficiency building, making the net zero energy approach both a feasible and cost effective reality.

Assessment

Integrated Design Associates (IDeAs) is a small, 12 person engineering firm that designs building electrical systems. The company is located in San Jose, California. The owners of the firm recently purchased a 7,600 gross square foot, two story building of which the firm will occupy 4,000 square feet, leasing the remainder to a company or companies who have a commitment to sustainable buildings.

Early in the design process for the new facility, it was decided to make the building a net zero energy facility. Another goal was to make the building a net zero carbon dioxide emission facility. This goal precluded the use of fossil fuel burning electrical generators. As wind is not a feasible energy source in this location, a photovoltaic cell system was selected to generate power.

The goal of a net zero energy building is to produce enough electricity on site to cover the facility's electrical needs for the year, with no payment due to the electrical utility at the end of the year. Since photovoltaic cells can not generate electricity during all hours of building operation, the system must be oversized to generate more power than needed during the day, effectively running the meter backwards to compensate for the utility use at night or during off-peak hours.

California utilities are mandated to use net metering agreements which allow end-users to credit self generated power back to the grid. However, the utility are not required to purchase any power above what the end-user actually uses, resulting in a net zero scenario. Because additional generated power will not be purchased, the ideal economic situation is for the building to produce exactly the amount of energy to be used on an annual basis. Any additional power produced will not be used or reimbursed and the cost of the photovoltaic cells creating that energy is a wasted expense.

IDeA's current office is a rental space in an office park, where utilities are included in the rent. Therefore, there is no available historical data, such as utility bills, detailing the company's power usage. In addition, to maximize the design of an energy efficient building, it is necessary to have information on each individual piece of equipment.

An in-depth analysis was performed on the office equipment, measuring the power (in watts (W)) used by every electrical device. It was found that the measured data did not match the nameplate ratings, with nameplates being generally much higher. A complete list of the results can be found in Table 1. The equipment totaled 10.298 kilowatts (kW).

Usage

As the goal of the study is to reduce plug loads, it is necessary to evaluate the amount of time each device is used. The typical annual operating hours for each item was estimated. This is the most difficult part of the process, and also the most subjective. There was not enough time to put a recording meter on every device, although this was done for certain equipment such as a typical personal computer and the office refrigerator. Previous research done on the use of occupancy sensors for lighting control shows that there is a tendency to over estimate the usage of various equipment. (NEMA 2001). This was taken into account during the process.

An important unknown to be accounted for is the anticipated growth of the company. It would do no good to base the design of a building's electrical system on today's usage, only to see a 50 percent increase in employees and the resulting increase in electricity usage. Therefore, while the company currently has 13 employees, a value of 20 was used for the calculations, which is the estimated number that can comfortably fit in the office as currently designed.

The result of this evaluation is shown in the Table 1.

Table 1. Initial Load and Usage

Type	Quantity	Active Load (W)	Active Demand (hrs/day)	Idle Load (W)	Idle Demand (hrs/day)	Energy (kWh/yr)
Computer	20	260	24			32,448
Fax	1	480	2	6	22	284
Large Copier	1	1000	1	30	23	439
Printer-2100	1	408	1	30	23	285
LCD	1	200	0.1			5
Laptop	1	50	0.1			1
Small Copier	1	1140	0.5	30	23.5	332
Printer-8150	1	1080	0.5	30	23.5	324
Refrigerator	1	60	24			526
Microwave	1	1000	0.5			130
Dishwasher	1	1000	0.1			26
Coffee Maker	1	850	2			442
Plotter	1	1440	0.5	30	23.5	371
Servers (Total)	1	1000	24			8,760
Vacuum	1	700	1			182
Tenant Space	W/sq ft.	1	10			7,800
Total kWh						52,355

Evaluation

The initial usage, assuming no change to the system, would result in the need for 58 kW of photovoltaic capacity. At a cost of roughly \$9.00/W, this results in an expense of \$522,000 before rebates. (\$300,000 after rebates and tax incentives – a 14 year payback, plus it put the project over budget.) In addition to a basic desire to keep the cost to a minimum, if the photovoltaic cell array could be reduced to 30kW, this would result in easier access to rebates.

The lighting and HVAC components of the design had already been reduced as much as possible. To achieve the desired goal, the plug loads needed to be addressed with a two step process, first, reduce the total plug load to a minimum, then, minimize the operating hours of each device.

Plug Load Reduction

The majority of the plug load equipment energy is consumed by personal computers. Therefore, it was likely that this would be an area where the greatest savings would occur.

Each desktop computer averaged 160 W. One energy saving alternative is to replace the desktop computers with laptop computers. Laptops are designed efficiently to maximize battery life while decreasing battery size to reduce the weight of the device. Several different laptop computers were measured and on average were found to consume one quarter of the power of personal computers (40-75 W).

An economic decision is required to determine whether it is cost effective to replace all of the desktop computers with laptops. IDeAs uses two types of computers, an administrative computer which primarily runs Microsoft Office © software and an engineering computer which runs AutoCAD © and design software requiring additional processor and memory requirements. Assuming a life span of 5 years, a 25 year life cycle and an 8 percent discount rate, the net present value of the premium cost of the administrative laptop computer (premium being the difference between the laptop and the desktop) is about $410. Similarly, the net present value of the premium cost of the engineering laptop computer is about $1835.

These values are compared to the value of the photovoltaic cells required to power the less efficient desktop computer. The net present value of the required cells to power the additional 120 watts, after rebates and economic incentives, is $638. Therefore, the cost of the photovoltaic cells exceeds the cost of purchasing the administrative laptops ($420 is less than $638), while the opposite is true for the engineering laptops ($1835 is greater than $638). Based on this analysis, IDeAs will replace the administrative computers with laptops, but will retain the engineering computers. As the costs of computers declines, the analysis will need to be revised and the decision might change in the future.

Among other equipment evaluated, it was determined that an ENERGY STAR rated refrigerator would save 400 kWh over the current standard refrigerator. In addition, purchasing a new microwave oven was discussed but there was no evidence that the lower wattage microwave was more energy efficient.

Another user of electricity is the coffee pot which stays on "warm" all day and occasionally is left on overnight. It was noted that less than half of the staff actually drinks coffee and most of those that do wouldn't mind drinking something else. One possibility includes eliminating the coffee maker and make sun iced tea instead. Another option is to have coffee drinkers visit the coffee house across the street, although this would simply transfer the load and reduce worker efficiency.

A coffee product that clearly saves electrical energy is the Aerobie ® Aeropress ❶ Coffee Maker. This device requires the user to heat one cup of water to 165 degrees F in the microwave and then press it through the machine. Making one cup of coffee at a time eliminates potential waste of making a whole pot for one or two people plus it does not need to be kept heated all day.

On a similar note, it was agreed to eliminate the dishwasher in the kitchen. The employees decided that they would rarely use it anyway, and since there would only be a few dishes at a time, washing tem by hand would not only save electricity, but also water.

While a very minor load, clocks will be battery operated type. While this is less environmentally friendly than plug in clocks, it avoids both a continuous energy use and the requirement for dedicated circuits, as most circuits will be automatically turned off (see below). The cost of $250 for the dedicated circuit far exceeds the cost of less than $1 per year to power two clocks.

Printers, plotters, scanners, copiers and fax machines were also evaluated. The research concluded that the cost of ENERGY STAR rated equipment was significantly more (20 to 100 percent cost premium) than the existing equipment. The energy savings of less than 10 percent made immediate replacement not cost effective. When equipment of this type needs to be replaced due to age or becoming obsolete, the use of ENERGY STAR rated equipment will be re-evaluated on an individual basis.

Control

Control of the equipment is a key element. There is no reason for a copy machine, printer, or other equipment to be running when no one is in the office, regardless of whether they are in "sleep" mode and only using 3-4 W each. To make sure the equipment is not inadvertently left on, the energy management system signals the circuit breakers feeding this equipment, turning them off during non-occupied hours. Employees have the option of overriding the off cycle for a limited time period.

Similarly, desktop computers are routinely left on all day, but only used a portion of the time. Most computers and monitors have a sleep mode which decreases the power requirement, but does not eliminate it. Occupancy sensors can be placed on the monitors to turn off the power to monitors, speakers and other non-essential peripherals when the user is not at the desk. The computer will not be turned off via an occupancy sensor due to the time it takes to restart. This is not a problem for the monitor, speakers, and peripherals. Turning these devices off results in a savings of 100 watts per workstation.

There is a debate as to whether it is wise to automatically shut off power to personal computers when the building is unoccupied. The theory against it is that work that may have been left uncompleted on the computer would be lost to save a few watts. However, almost all current software has a built in auto-save feature, eliminating the potential to lose a significant amount of work. The energy management system (EMS) can turn off the computer circuit just like any other circuit, saving a significant amount of phantom power over the course of a year. In the rare case that a program needs to run all night, the system needs to have the ability to allow the users to override that circuit as required.

Continuous Loads

There are several loads that can not be turned off. The fire alarm and security systems need continuous power to function properly. The fax machine cannot store information, and since faxes routinely come in during off hours, the benefit of leaving the fax machine running outweighs the cost of running it in sleep mode. If an office has several fax machines, it may be possible to turn off all but one of them and have all calls transferred. This is especially useful if certain fax machines are designated as "outgoing" only.

The final continuous load is the server. IDeAs currently maintains five servers that do not get turned off. These include the data server, backup data server, telephone server, plotter server and email server. These five computers represent a large percentage of the building's energy load due to the continuous operation. The plotter server has no function after hours when the plotter is turned off, so this will also be powered down during off peak times. The email and telephone servers will be combined into a single server to permanently save the cost of operating one computer. This reduction to three full time servers and one part time server will reduce the energy requirement for servers about 25 percent.

The total final load for IDeAs' office, taking all of the preceding reduction strategies into account is 22,121 kWh, as indicated in Table 2.

Table 2. Final Load and Usage

Type	Quantity	Active Load (W)	Active Demand (hrs/day)	Idle Load (W)	Idle Demand (hrs/day)	Energy (kWh/yr)
Computer	13	160	9	100	1	5205
Fax	1	480	2	6	22	284
Computer	1	160	2	100	8	291
Large Copier	1	1000	1	30	9	330
Printer-2100	1	408	0.5	30	9.5	127
LCD	1	200	0.1			5
Laptop	6	40	10			624
Small Copier	1	1140	0.1	30	9.9	107
Printer-8150	1	1080	.5	30	9.5	215
Refrigerator	1	14	24			123
Microwave	1	1000	0.55			143
Plotter	1	1440	0.5	30	9.5	261
Servers (No Plotter)	1	650	24			5694
Servers (Plotter)	1	200	10			730
Vacuum	1	700	1			182
Tenant Space	W/sq ft.	1	10			7,800
Total kWh						22,121

User Commitment

An important component in the success of a net zero energy building is that the building occupants must be committed to the program. As noted above, it helps to have the staff make concessions on non-essential items such as dishwashers and coffee machines.

If the users do not buy into the program, it could still fail despite a conscious decision to use low energy equipment and installation of automatic shut off controls. For example, if each employee brings in a stereo system and runs it all day, a large portion of the savings will be negated.

One way to increase users awareness and promote energy savings is through constant feedback to the occupants. IDeAs is currently setting up a web site that will be tied to power monitoring equipment both on the photovoltaic system and individual equipment, allowing instantaneous information on energy usage and conformance to the project goals. A monitor displaying the information will be placed in a high traffic area to insure regular inspection by the occupants. It is expected that the feedback will serve as a constant reminder to conserve energy.

Conclusion

The result of this analysis is that it is possible to make a significant reduction in a building's plug loads which will improve the economic feasibility of a net zero energy building. However, as every building is unique in its usage, each building needs to be individually evaluated to determine the most appropriate strategy.

In addition, economic evaluation is required to determine the cost effectiveness of proposed solutions. While laptop computers may be more economical than purchasing photovoltaic cells to power desktop computers in most cases, if expensive high powered laptops are required the economic decision could be reversed. As the cost of both photovoltaic systems and computer equipment change, the economics must be re-evaluated. However, this is a viable option that should be investigated.

The use of ENERGY STAR equipment for all appliances is generally a wise idea. In this study, it was found that for certain equipment the additional cost did not justify the minimal power savings. Each item needs to be individually evaluated.

It is also imperative to have an energy management system to insure that the efficient equipment is not left operating when not in use. Control strategies can include occupancy sensors for non-essential items like monitors. Other options include remotely operable circuit breakers which can be turned off on a time-of-day scenario. Controls need to have user overrides to allow occupants to work during off hours.

Combining energy efficient equipment with automatic controls can result in savings of up to 30 percent or more, making the net zero energy building more economically feasible. In the case study in this example, IDeAs was able to reduce its plug load from 52,355 kWh to 22,121 kWh, a reduction of 57 percent. The office is currently under construction and will be carefully monitored to determine if the load reduction strategies result in a net zero energy facility as anticipated.

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