Energy Savings from an Active Daylighting Retrofit and Impact on Building Practices

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This paper presents the preliminary results of a daylighting retrofit experiment undertaken in the summer and fall of 1993 on one floor of a year-old commercial building. The purpose of the experiment is to establish the potential for savings from a distributed daylighting technology when used in a commercial retrofit application in the upper Midwest; to understand the extent to which savings may be influenced by the location of the sensors relative to the various faces of the building; to learn how occupant manipulation of window blinds and other features of the environment might influence the operation of a distributed daylighting system; to understand how the number and placement of sensors may influence the effectiveness of a daylighting system; and, to serve as a model to promote the use of daylighting in other state facilities. Estimates of annual savings are not yet available but there are savings on several circuits on short winter days. The preliminary data indicate that occupant manipulation of the window blinds may reduce savings. Window treatment systems may need to be designed and installed in conjunction with daylighting retrofits in order to achieve maximum benefits and minimize costs. Some preliminary observations for the effective use and placement of controls are identified. Preliminary analysis of the data from the sensors suggests that effective control could be managed with fewer sensors than are presently installed.

Introduction

There is a great deal of interest in daylighting as a way to reduce energy consumption in commercial structures. The tendency has been to think of daylighting technologies as most appropriate for new buildings. However, new technologies have emerged, particularly new ballast and sensor systems, which significantly reduce the cost of daylighting control systems and make it possible to apply the technologies in retrofit situations where older, less efficient systems are being replaced with more efficient systems.

During the summer and fall of 1993, the state of Wisconsin, Department of Administration, Division of Facilities Development, initiated a retrofit demonstration project on one floor of a year-old state building as part of its ongoing effort to improve the lighting efficiency of state buildings. One goal of the project was to measure the energy savings and levels of occupant satisfaction associated with the conversion of fluorescent troffers with T-12 bulbs and magnetic ballasts to T-8 bulbs and electronically dimmable ballasts controlled by signals from ambient light photo sensors. This paper reports some preliminary results from the retrofit of a pilot system in a commercial office building in Madison, Wisconsin.

The choice of location for this demonstration is an important factor because this floor houses the state design engineers and architects who specify and manage the construction and retrofit of state buildings. The demonstration will give these designers the opportunity to observe first hand the effects of modern daylighting technology. One of the purposes of the demonstration is to use this floor as a laboratory for learning about daylighting technology. It is quite likely that the lessons learned from this experience will be incorporated immediately into the state's specifications for the retrofit of old buildings and for the construction of new buildings. This is significant because the state of Wisconsin occupies and manages over 40 million square feet of office space, consuming over 75 million kilowatt-hours of electricity for lighting annually. If daylighting resulted in a 10 percent reduction in lighting use in state-owned buildings, this would yield an annual electricity savings of $750,000.

This demonstration is also likely to impact other segments of the commercial sector. As a result of their need to work with the state, most of the representatives of the major architectural and engineering firms doing commercial work within the state visit this facility. The major trade allies will benefit by having to work with the revised specifications and also by having an opportunity to view the results.

Issues in Daylighting

Only a few well-documented evaluations of daylighting have been conducted. The best of these are studies for buildings in California (Rubinstein 1991; Benton 1989). Although utilities have conducted some studies of daylighting in the upper Midwest, generally results from these studies are not publicly available. Reports from a number of these studies and the California studies have shown that daylighting controls can be effective in reducing energy consumption. Rubinstein reports summer savings of 75% for treated areas compared to untreated areas.

A number of barriers to the adoption of daylighting controls still exist. Rubinstein identified the costs of ballasts and controls as a major barrier to acceptance. Part of this issue is a matter of first cost. But there are other aspects to the cost issue, such as the dependence of benefit/cost ratios on the number and placement of sensors.

Further, there are significant differences in how control is effected. Systems recently entering the market are beginning to rely more on distributed control mechanisms and less on central controllers. The system at the state of Wisconsin Administration Building (SWAB) requires only one sensor to control up to 10 compatible ballasts. Control can even be managed at the individual fixture level. A new ballast currently on the market has a built-in photo sensor and a controller that controls an individual luminaire. Thus, we need to examine the cost-effectiveness of various degrees of distributed control, ranging from a single sensor controlling a large number of luminaires to individually controlled luminaires.

It is also clear that features of building systems can influence occupant behavior, which in turn influences the operation of daylighting systems. Rubinstein comments that window orientation, window treatments, and occupant behavior are often ignored in the design of conventional static lighting systems. Heerwagen and Diamond (1992) point out that people adapt their behaviors and their environments in response to discomforts such as glare on computer screens and excessive heat or illumination from direct sunlight. These adaptations can and often do interact with control systems in ways that defeat the purposes of the control systems. For example, the manipulation of blinds may cause the daylighting controls to increase lighting levels even though the ambient light is at acceptable levels without the addition of increased illumination or task lighting.

There also are reports that building users do not respond well to daylighting controls. Heerwagen and Diamond (1992) report that "... in all buildings with daylight controls, the control system was made inoperable." The controls referred to in this study switched lights on or off in response to sensed data rather than continuously dimming them. Systems that use distributed dimming may overcome the problems of switched systems, but they may also engender new responses from occupants.

Calibration and tuning were significant issues for early daylighting systems. The more recent distributed systems may have helped to reduce these problems.

Finally, Rubinstein notes that "the application of sophisticated, dynamic lighting systems will not be widespread until designers" and others learn how to apply dynamic lighting design concepts. Further, he notes that there is a need for improved computer tools for analyzing where controls can be used cost-effectively. The experience and the data to develop the tools will only come from experimenting with and monitoring real installations.

With these issues in mind and with some of the early data from the SWAB project, this analysis presents some preliminary insight into the following questions:

- What is the potential for savings from a distributed daylighting technology when used in a commercial retrofit in the upper Midwest? What are the benefits and costs of the use of daylighting controls?
- To what extent are savings influenced by the location of the sensors relative to the various faces of the building?
- To what extent does the manipulation of window blinds and other features of the environment influence the operation of a distributed daylighting system? What does this tell us about the design and operation of daylighting systems and window treatment systems?
- To what extent do the sensors located in the same ranks or different ranks track each other and how might this influence our understanding with respect to the optimal number and location of sensors?

The Site

The state of Wisconsin Administration Building sits near the state capitol in downtown Madison, Wisconsin. This year-old structure is a 10-story building overlooking Lake Monona. Like many contemporary buildings, the exterior of the building is dominated by glass. On the interior, most floors have large, open work areas that surround a central service core containing elevators, stairwells, utility closets, and restrooms. The open architecture and modular furniture allow views to workers on all sides of the building. Because of the glass, a significant amount of natural light enters the building from all sides.

Description of the Lighting

Figure 1 depicts the layout of the lighting on the 7th floor of SWAB. The principal lighting on the 7th floor is composed of three-tube fluorescent luminaires aligned in ranks parallel to the outer wall. The building's north, south, and east faces have four ranks of lighting between the outer wall and the walls of the inner service core.[1] The west side of the building has three ranks of lighting. On each face of the building, the rank of lighting closest to the service core provides illumination for paths of access and egress. The luminaires in these areas are equipped with fixed ballasts. The electrical circuits serving the luminaires are designated by the dotted enclosures.

Figure 2 provides a slightly different view of the lighting system showing the location of the photo sensors, the motion detectors (east face) and the luminaires controlled by these sensors (areas enclosed by dotted lines). The reader should note that electrical circuits and controlled luminaires do not correspond to one another.

On the east face, three ranks of lights are divided into three sections; each section is controlled by a photo sensor for a total of nine sensors. Each sensor controls either three, four, or five luminaires. The ballasts controlled by a sensor are connected by a low-voltage cable. The east face also includes three occupancy sensors.

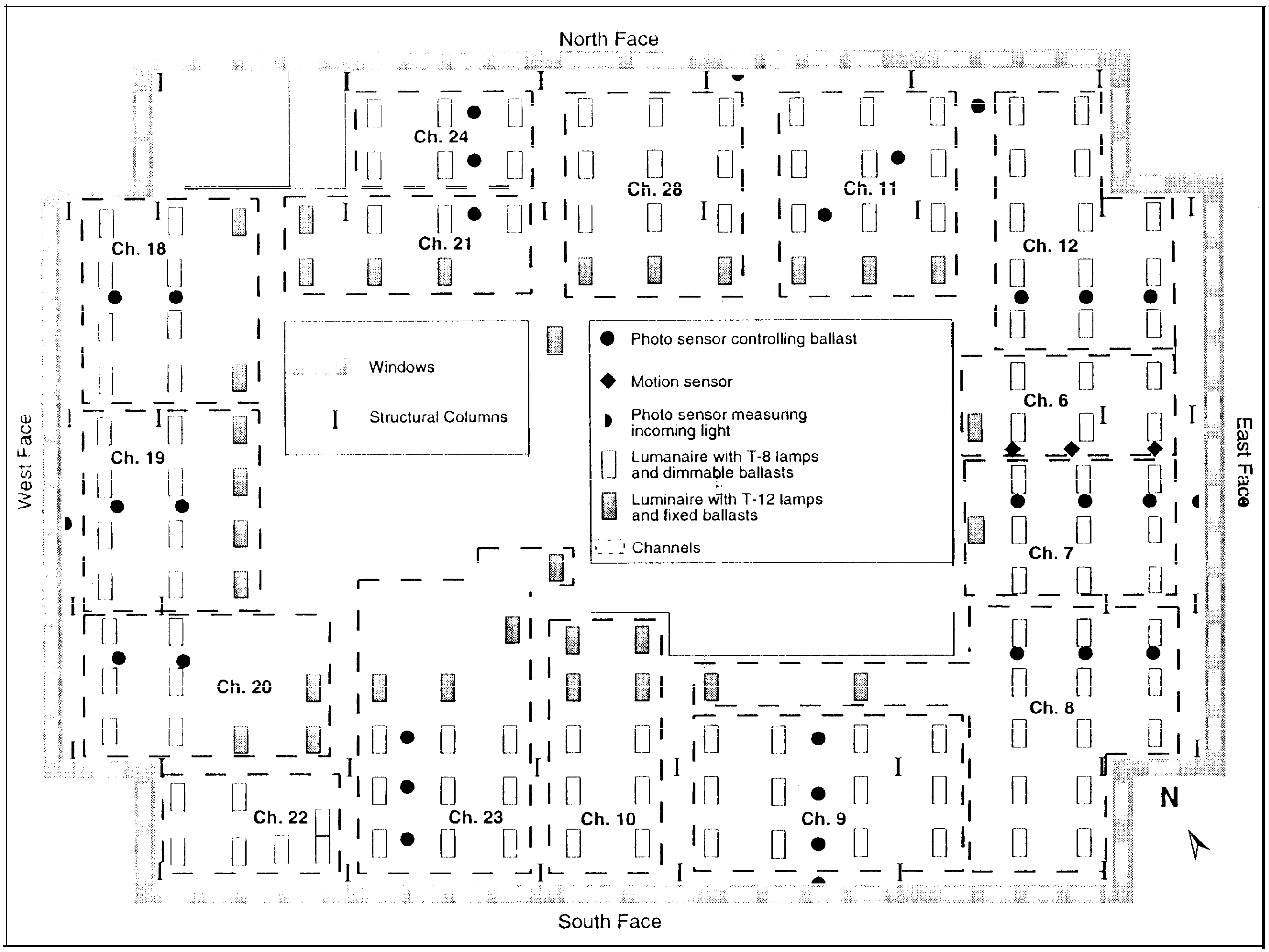

Figure 1. Schematic Depiction of the Monitoring Channels, 7th Floor of the SWAB

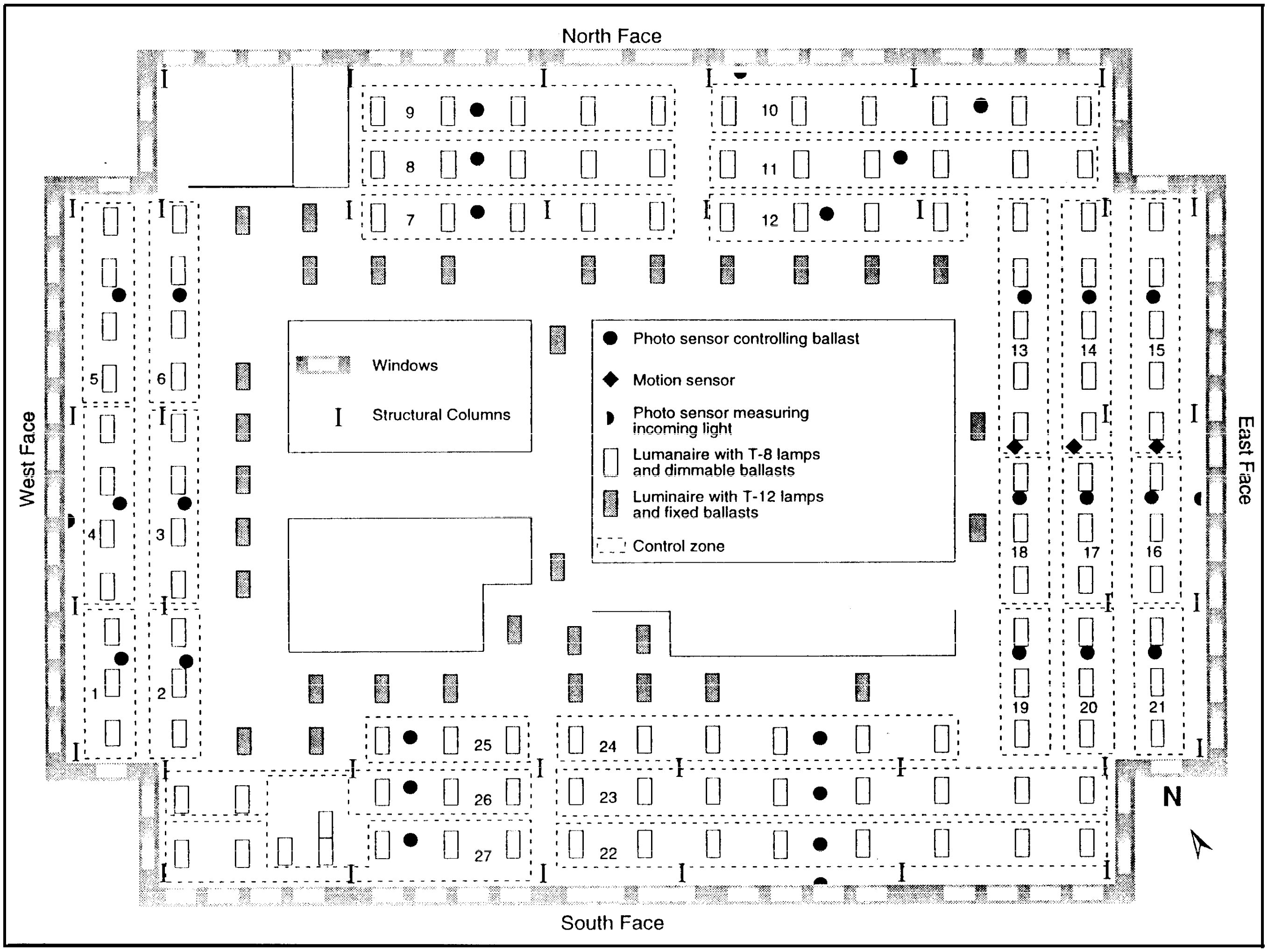

Figure 2. Schematic Depiction of Lighting System, 7th Floor of the SWAB

The north, south, and west faces each have six photo sensors controlling the ranks of lights nearest the outer wall. There are three ranks, each with two zones of lights, on the north and south sides of the building and two ranks with three zones of lights on the west.

The level of illuminance in any area is a combination of the light from overhead and the amount of daylight entering from one or more sides of the building. Because of the open plan, an area can receive daylight from more than one face of the building. For instance, the southeast corner of the floor receives daylight from both the east and the south, as well as the luminaires in the ceiling.

As previously described, all four sides of the building have blinds. The amount of daylight in any given location is directly impacted by the use of these one-inch, horizontal, black venetian shades. The shades were specifically designed to enhance the appearance of the building and must be either fully raised or lowered. They cannot be locked in a partially raised position without modification to the locking mechanism. The blinds can be rotated 180° from fully closed to open to fully closed again. At least one instance was observed of “creative” blind management in which a blind was raised to a half-window position. The amount of light entering through the east and south faces is so great that occupants often manipulate the blinds to reduce the light, heat, and glare. Occupants on the north side often have their blinds fully raised to obtain an unrestricted view throughout the day.

The luminaires are typical three lamp parabolic troffers. Prior to the retrofit, T-12 lamps were used in the luminaires. Troffers equipped with T-12 lamps and fixed ballasts are represented by shaded rectangles (Figure 1). There are 32 troffers with T-12 lamps and fixed ballasts, 116 troffers with T-8 lamps and dimmable ballasts (represented by white rectangles in Figures 1 and 2) and 9 troffers with T-8 lamps controlled by both photo sensors and occupancy sensors (channel 7 on Figure 1).

The dimmable ballasts are Advance Mark VII controllable integrated ballasts, which can regulate the light output of the fluorescent lamps between 20% and 100% of nominal in response to remotely activated signals. The ballast provides its own 0 - 10 V DC signal directly to the photo sensor control unit through low-voltage wiring. Light output varies in response to signals between 2 and 10 volts and is linear through this range. The photo sensors are Linthonia LEQ DPC Dimming Photocells. The photo cells are ceiling-mounted. Figure 3 shows a wiring diagram for a ballast, lamps, and photo sensor.

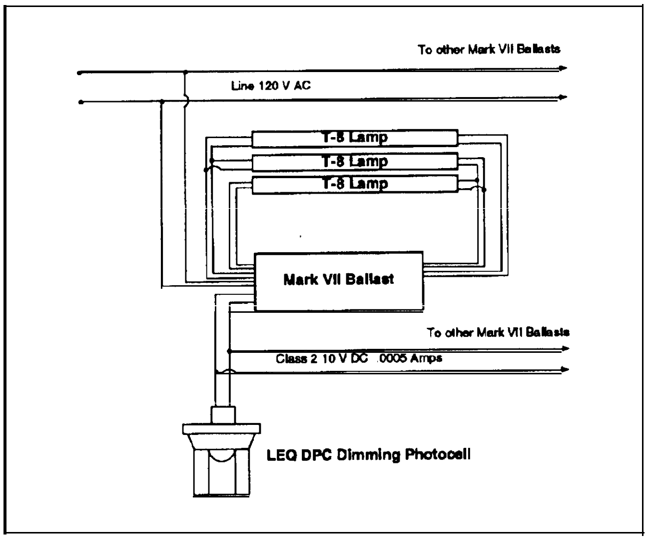

Figure 3. Diagram of Photo-Controlled Fixtures

Monitoring Activities

Pre-retrofit monitoring to obtain baseline energy use data was collected at 15-minute intervals for all of the electrical circuits on the east face of the building and for half the circuits on the north and south. Monitoring was initiated in October 1993. The pre-retrofit monitoring concluded with the installation of the new ballasts and T-8 bulbs in December 1993.

The equipment used for the pre-retrofit monitoring remained in place from mid-December 1993 through January 1994. In late January 1994, an augmented monitoring system was installed. This monitoring system is to remain in place through June 1994. The augmented system uses two 32-channel data loggers to monitor the operation of the daylighting system. The data logger is a Timeframe TF32-A Analog Monitoring Controller. Each of the data loggers records bus voltages for each phase on three channels. Current transformers connected directly to the data logger are used to monitor the current on each of the 13 lighting circuits.

A photo sensor is mounted between the window and the blinds on each face of the building (four sensors) to record the amount of light entering the building through the windows. These photo sensors are Licor model LI-210SA attached to EME LICL-Y amplifiers and then to the data loggers with plenum wire.

The low-voltage wiring that connects the photo sensors controlling the ballasts has been tapped and a low-voltage plenum wire run from the tap to a filter and then to an amplifier, which is connected to an input channel of the data loggers. The 27 sensors are monitored separately. It was initially thought that a tap from the low-voltage wiring could be attached directly to the data logger. However, at installation it was discovered that the photo sensor produced a pulsed DC signal (hence the filter) and that the metering device caused the ballasts to dim to their lowest point (hence the amplifier). Tapping the low-voltage lines allowed for the installation of the monitoring equipment without opening the luminaires and without rewiring. It also meant that all wiring for the monitoring system could be installed using low voltage plenum wire hung in the ceiling.

The data loggers are accessible through a modem for reliability checks and data transfer. The data from the two loggers are retrieved and archived daily. The data are sampled at 15-minute intervals and represent the average value for the interval. The daily retrieval schedule helps to ensure data integrity and early detection of problems with the monitoring equipment.

In addition to the data provided by the automated monitoring system, periodic walk-throughs are used to assess illumination levels, task-level lighting use, and blind management. A grid has been created and 106 monitoring points established throughout the area where lighting is being controlled. The walk-throughs are conducted at random times on randomly selected days, approximately three times per week through June 1994. Readings of illuminance at 30” from the floor are taken at the predetermined grid locations using an EXETECH photometer aimed at the ceiling to determine work-level illumination. Readings of illuminance with the photometer aimed at the floor are also taken immediately adjacent to each of the photo sensors to determine illumination levels incident on the photo sensors. Two special sensor extension handles have been fabricated to prevent the shading of the sensor by the person taking the measurement.

During the walk-through, the position of each blind is recorded using an 8-point scale. The points of the scale correspond to the position of the inside edge of the vane in 300 increments. A “1” means that the blind is closed tightly with the inside edge of the vane pointing to the ceiling. A “4” means that the vanes are in a horizontal position, and an “8” means the blind is tightly closed with the inside edge of the vane pointing towards the floor.

All readings are recorded in a spreadsheet on an HP100SX palm-top computer. A blank worksheet with the prerecorded locations is used. As data for a location are entered, a date-time stamp is automatically recorded. Data are uploaded to a database upon return to the office.

A survey of occupants' perceptions of lighting is to be conducted. The survey will focus on perceptions of lighting and the operation of the lighting. Preliminary anecdotal comments indicate little awareness of illuminance dimming, which implies general acceptance.

The Inputs and Outputs of the Luminaires

During the installation of the monitoring system, a number of measurements were taken as part of the verification procedures. In particular, the consumption of the various lighting appliances were verified by taking independent measurements using different instrumentation. The assumption was that the T-8 lighting fixtures would require less energy than the T-12 fixtures.

One fixture with T-12 lamps and a fixed ballast, and four fixtures with T-8 lamps controlled by photo sensors, were selected. The energy inputs of the controlled fixtures were measured under four conditions: fixture at maximum light output (sensor covered with black tape for one minute), fixture at maximum light output (sensor covered with black tape for two minutes), fixture reduced to minimum output (20% of light output achieved by aiming a flashlight directly at sensor for one minute), and an undisturbed reading. The measured consumption of the fixture with T-12 bulbs and magnetic ballasts was 86 watts after warm-up. Based on these measurements, the average energy input to a three bulb luminaire with dimming ballast was 96.25 watts after one minute at full output, 95.45 watts after two minutes at full output, and 36.3 watts after one minute during which light output was reduced to the minimum.

Two important points can be made based on these data. When light output is reduced to the minimum (20% of maximum), actual energy input is reduced by about 60 watts or approximately 38% of maximum (36.3 watts/ 96.25 watts). Put differently, the maximum reduction in illuminance results in a 62% reduction in energy input. Thus, if all luminaires in the system were of the controlled type, the maximum reduction of energy would not be greater than 62%. These data are consistent with the ballast manufacturer's specification sheet.

We also concluded that at maximum light output, the troffers equipped with T-8 bulbs and this particular dimmable electronic ballast increased energy consumption by approximately 11% compared to troffers equipped with T-12 bulbs and magnetic ballasts.[2] This finding was confirmed by comparing pre-retrofit energy consumption at the circuit level with post-retrofit consumption using a difference curve (Figure 4). In this case, the difference curve is the difference in circuit-level consumption before and after the retrofit. The area above the O point on the Y axis represents savings, and the area below represents increased consumption. If the new bulbs and ballasts used less energy or the same amount of energy as the older ballasts and bulbs, then all values of the curve would fall in the area of savings, whether control was exercised or not. If the new bulbs and ballasts used more energy than the old, the curve would fall in the area of increased consumption except when the savings from control exceeded the difference in energy use between the new and the old equipment.

This finding suggests that when compared to the original ballasts and tubes, this specific combination of ballast, tube, and photo sensor may not result in net savings of energy if used in locations where only marginal reductions in energy inputs can be achieved through control. If this combination of control equipment is used in areas with consistently low levels of illuminance, maximum input of energy may be required for long periods of time and the incremental energy required to operate this equipment, compared to an efficient, fixed-ballast alternative, may be greater than the savings from the control exerted by the equipment. Designers choosing new equipment need to understand the patterns of illuminance in the areas to be lit. In those areas with very low illuminance, and assuming comparable light output, a fixture with an efficient fixed ballast might be preferable to a fixture with a dimming ballast. With experimentation, some rules of thumb for such circumstances could be generated.

Daylight Entering the Building

Figure 5 shows the amount of light entering through the windows on each face of the building for a clear and overcast January day. The horizontal axis is the hour of the day and the vertical axis is illuminance in kilolux (klux). For reference purposes, a comfortable level of illumination on a work surface is in the range of 0.5 to 1.0 klux (50 to 100 foot-candles). Good design practice is that ambient light in the workspace should not be less than 33% of task illuminance (Eley 1993). The reader must keep in mind that the building is not oriented in the cardinal directions.

On clear winter days the slight rise in klux between 7:00 and 8:00 am reflects the easterly orientation of the north face. The curve for the east face shows a very rapid rise until about 10:00 am when the sun begins to affect the south face. The direct light rounds the southeast corner at

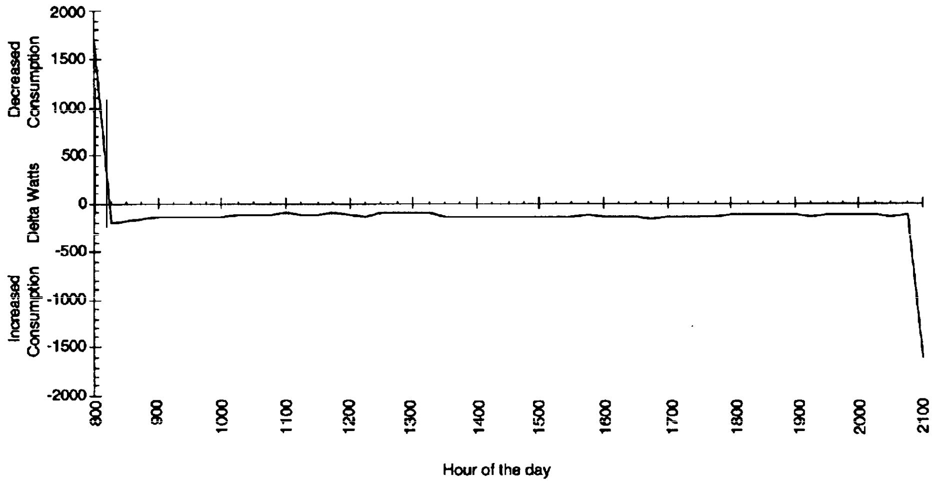

Figure 4. Comparison of Pre- and Post-Retrofit Baseline Consumption Prior to Activation of Distributive Photo-Control System

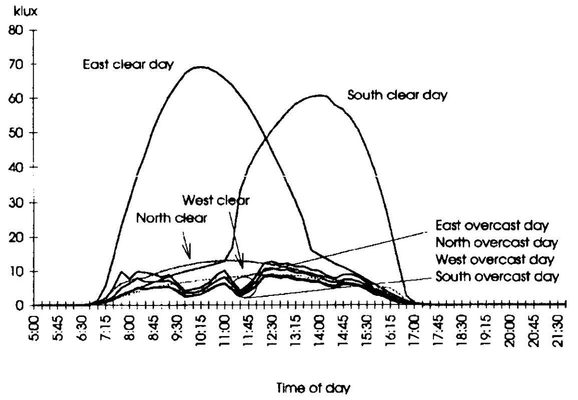

Figure 5. Comparison of Available Sunlight for a Clear and Overcast Day

about 10:30 am as is evidenced by the inflection in the slope of the south-face curve. Also, the amount of direct light begins to decline on the east face at this time. The west face curve shows a slight “bump ‘r similar to the one observed on the north face late in the afternoon as the light from the sun becomes direct. Because this is a winter afternoon, the effect on the face is minimal.

The set of data available for this paper was recorded on mid- to late-winter days. From this set of data, the maximum amount of light entering from the various faces was 21 klux from the north, 73 klux from the east, 63 klux from the south, and 16 klux from the west. Most of the results reported in this paper are based on a single day, January 31, 1994, when the amount of light entering the building was near the winter maximum.

Operation of the Daylighting Controls

Figure 6 shows the operation of the daylighting controls for electrical circuit 6 (Figure 1) which is governed by sensors 13, 14, and 15 (Figure 2) on the east face of the building. The solid black line represents the demand (in watts) for the 7 fixtures (6 dimmable and 1 fixed ballast) on the circuit. The little hitch between 6:45 and 7:30 am (see circled area) represents the difference between start-up consumption and consumption once the fixtures have warmed for about 45 minutes. This warm-up occurs when the lights are first energized and again when they are raised to the maximum level after periods of control (see Figure 7). The broken line with dashes represents an estimate of the lighting level without controls. It is estimated that this circuit consumes about 660 watts (7 fixtures) when there is no control.

Daylighting controls become effective at approximately 7:30 am when luminance entering from outside the building reaches approximately 10 klux. Between 7:30 and 8:45 am, energy consumption on this circuit is reduced in stages as the sensors at different distances from the windows cause the ballasts attached to them to dim the lamps. In this case, the maximum reduction appears to be just under 50% and is reached about 8:30 am when consumption is slightly over 300 watts. Since the estimated maximum achievable reduction in consumption on this circuit is approximately 305 watts, the reduction occurring at this time on this circuit is at maximum for the equipment.

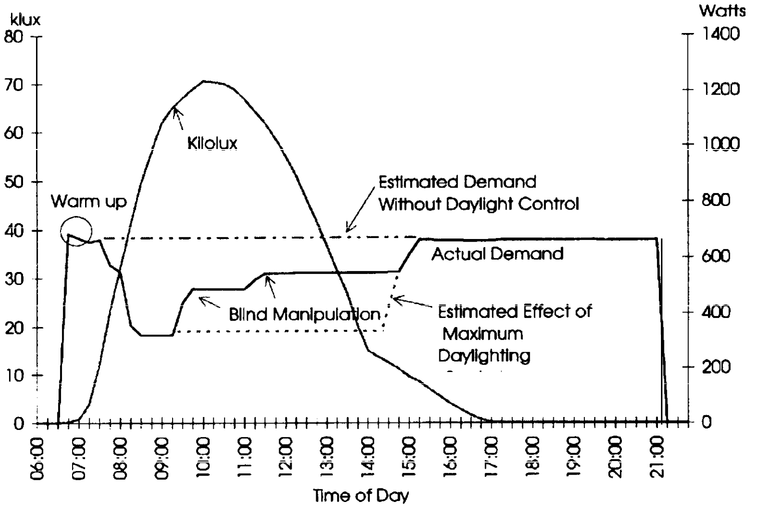

Figure 6. Channel 6 Power Consumption vs East Face SWAB Daylightin (Jan. 31, 1994)

At about 9:30 am, consumption begins to increase. We believe this is due to changes made to the window blinds. We will be able to verify this once corresponding data from the walk-throughs are available. There is another ramp at approximately 11:00 am, which probably reflects further changes in the blinds, although the direct daylight has now moved to the south face.

The circuit returns to full consumption at about 3:30 pm when the level of luminance from the windows drops below 10 klux. For this east-face circuit and this mid-winter day, the controls reduced estimated consumption by 1.25 kWh. If the blinds had not been manipulated, the consumption curve would have been much lower (see dotted line) throughout the afternoon and would have resulted in greater savings, approximately 2.0-2.40 kWh for this circuit and day.

For purposes of comparison, Figure 7 shows the result of daylighting controls on electrical circuit 9, which is on the south face of the building. The controls on this circuit have the potential to reduce energy input to about 450 watts. Minimum consumption on this circuit is approximately 700 watts on this day or about 66% of the total potential reduction. Because of the use of blinds, the photo sensor closest to the inner core does not cause a reduction of consumption on this circuit. The reader may recall that window blinds on the south face are

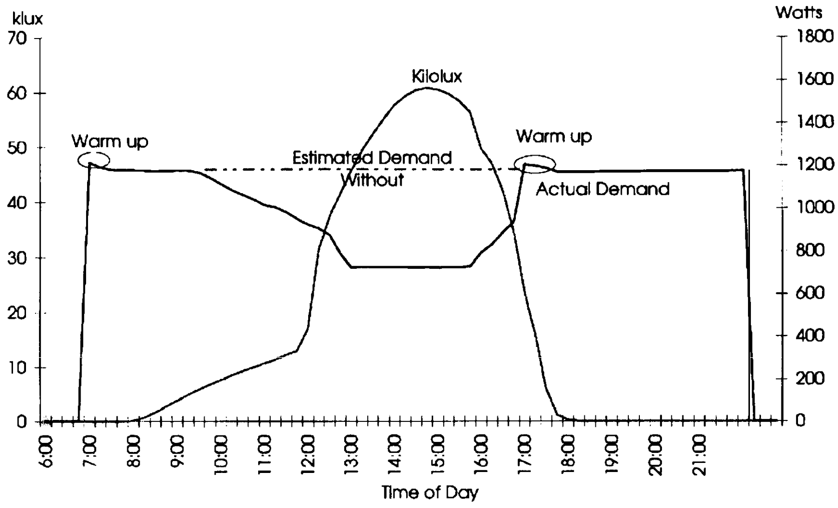

Figure 7. Channel 9 Power Consumption vs South Face SWAB Daylighting (Jan. 31, 1994)

manipulated to a greater extent than on other faces. As an aside, the reader might also note that there is another distinct warm-up period when the photo sensors release control at about 5 pm.

These findings illustrate an important point. The operation of automated controls is significantly influenced by human manipulation of other aspects of the building system. Thus, if maximum reductions in energy use are to be achieved through the use of automated controls, the design and layout of the controls must take into account that some features of the environment, such as blinds, may need to be designed better to meet the needs of the inhabitants while coordinating with the control systems. In this situation, stationary projecting reflective arrays (Stiles 1994) or some other window treatment might be designed so that light would be projected to the inner core, while cutting heat and glare but not obstructing the view. A significant use of the blinds is to reduce glare on computer monitor screens. Modification of work station layouts to reorient screens away from a window-facing orientation might also reduce the use of blinds and increase savings.

Interaction Between Daylighting Controls and Motion Detectors

Figure 8 shows the combined effects of daylighting controls and motion detectors (control circuits 16, 17, and 18) on the banks of lamps on electrical circuit 7. For this circuit, the demand in the absence of control is about 940 watts. If daylighting controls fully reduced illuminance from the lamps in this area, the expected demand would be about 420 watts. The actual effect of the daylighting controls is perhaps best represented by the reasonably consistent set of values between 7:15 am and 2:00 pm exclusive of the slight dip between 8:30 and 8:45 am. The average demand during this period is reduced by about 150 watts. This is a little less than a third of the total potential reduction in demand (530 watts) on this circuit.

The times when motion detectors reduced the consumption during the day are identified in Figure 8. The lights on this circuit are lit between 6:30 and 6:45 am by an employee moving to a work area, which is just outside the detection area of the motion sensors. As a result, the lights are lit and then, because there is no motion in the area, consumption is reduced briefly around 7:00 am until other workers arrive. Also, no one is in the zone around 8:45 am, causing the slight dip in consumption at that time as well as between 2:45 and 3:15 pm. Finally, energy consumption is significantly reduced in response to the lack of motion when workers leave for the day at 4:30 pm. The spikes in consumption around 7:30 pm represent the movements of cleaning crews through the detection zones.

For this east-face circuit and this mid-winter day, the reduction in consumption in a 17-hour period was about 1.2 kWh for the daylighting controls and 2.4 kWh for the motion detectors. In this instance, the reduction from motion detectors was about twice that for the daylighting controls. However, this result is a function of the amount of daylight. During the high summer season, this pattern might be reversed because the daylighting controls nearest the windows could be active for 10 or more hours a day.

Changes in Consumption on Each Side of the Building

The amount of available daylight and the time during which daylight can displace artificial light varies from one face of the building to another. Figure 9 illustrates the effects of daylighting controls on the four faces of the state of Wisconsin Administration Building. This is an area chart, so that each piece of the chart is additive. The maximum savings on this day are to be found on the south face. As might be expected, there is more control on the east face in the morning, more on the south face in the afternoon, and a fairly constant amount of regulation throughout the day on the north face. There is almost no control occurring on the west face. The savings in these four zones is approximately 4.8 kWh. The savings for this day for the entire floor exceeded 12 kWh. It should be remembered that the period of daylight on January 31 is relatively short. Later in the year, as the number of daylight hours increases and the days become brighter, we expect to see the savings increase as the length of time that the controls are active increases. From late spring to early fall, the sensors closest to the windows are expected to regulate inputs throughout most of the day.

Differences in Regulation Within Ranks and Zones

The manufacturer claims that one photo sensor can regulate as many as 10 ballasts. Thus, an issue of interest is the degree to which photo sensors on the same side of the building at the same distance from the windows provide a common degree and a common pattern of regulation. A comparison of the output of the photo sensors on the east face of the building indicates that photo sensors controlling the rank of lights nearest the windows track to a certain extent, although the sensor in the middle of the building regulates the lighting fixtures for a longer period of time than do the sensors on either side. As demonstrated in Figure 10, the sensor in the middle of the building (16) begins regulating first thing in the morning,

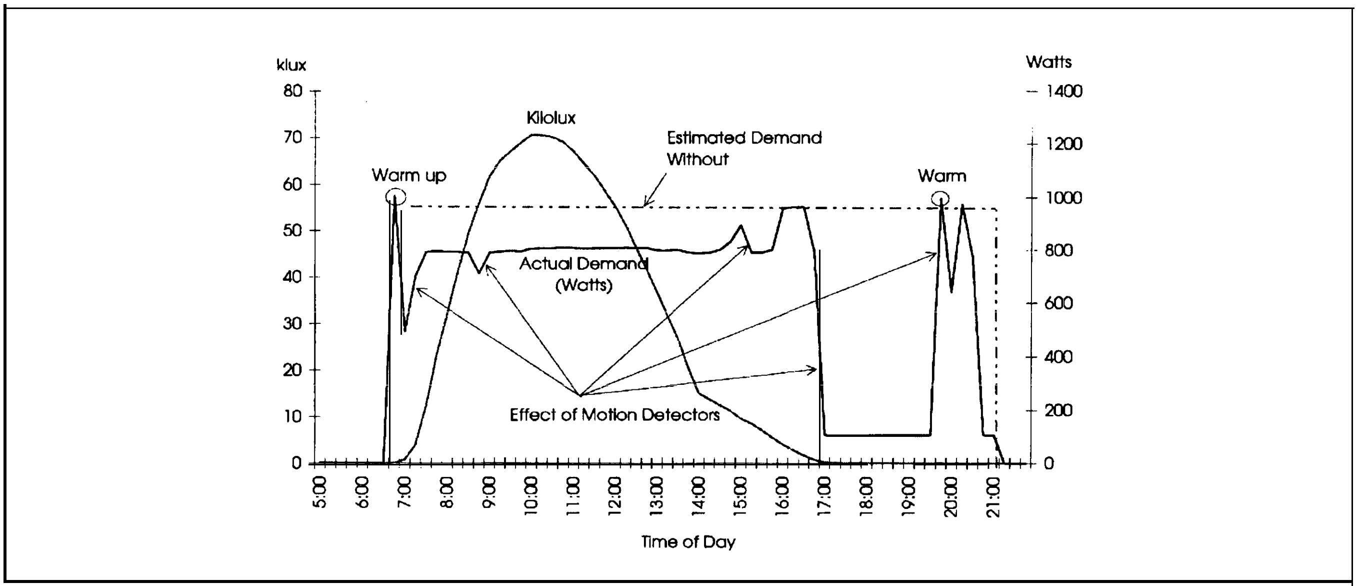

Figure 8. Channel 7 Power Consumption vs East Face SWAB Daylighting (Jan. 31, 1994)

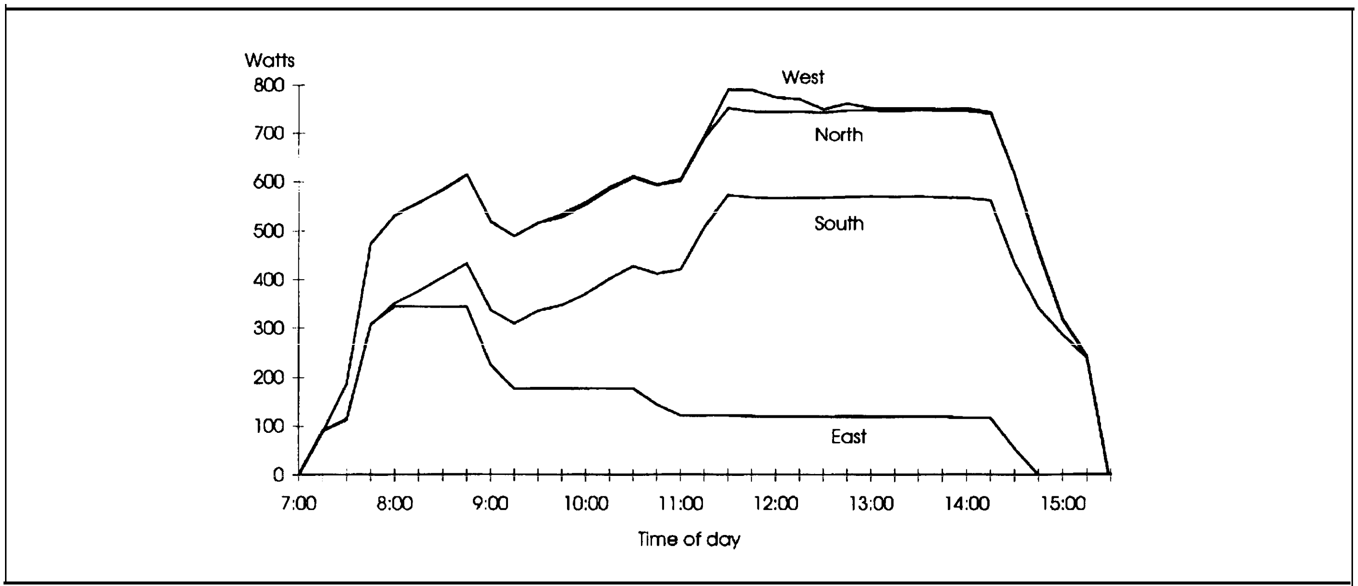

Figure 9. Savings from Daylighting on 4 of 15 Circuits in the SWAB on Jan. 31, 1994

followed by a sensor in the northeast corner of the building (15) and then the sensor in the southeast corner (21). The latter sensor is partially obstructed by an architectural support in the outer wall and an internal supporting column during the morning hours. In early to mid-afternoon, structural features shield light from the sensors at the corners of the building but not from the sensor in the center of the building. Thus, if the goal were to maximize the control on the east face at this time of year, the sensor in the middle of the building would be the best choice to regulate the ballasts nearest the window. We will have to await the analysis of the walk-through data to be sure, but we suspect that there is ample ambient light near the windows along this entire face so that using the middle sensor to regulate all lights would not be a problem.

For March 11, we also found there was very little regulation in zones 13, 17, 18, 19, and 20. This means that the sensors that fall in a line perpendicular to the windows did not track each other on this day. Again, we will have to await an analysis of the walk-through data to determine whether these luminaires might better be controlled by sensors nearer to the windows.

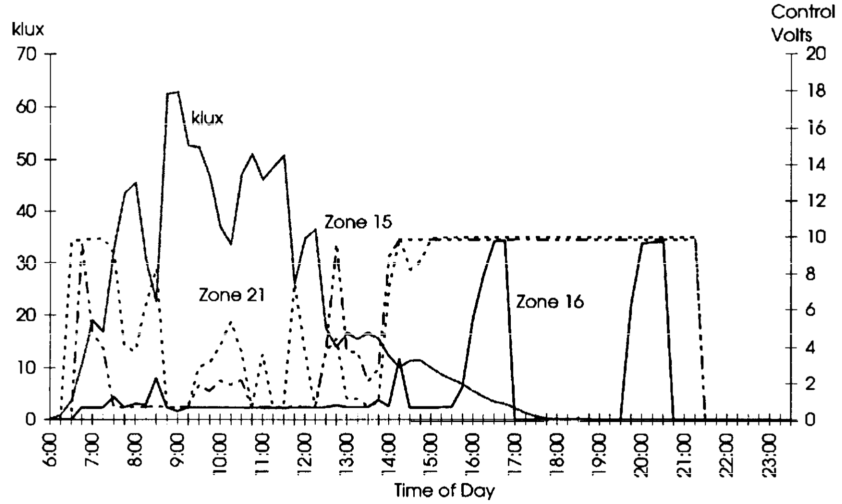

Figure 10. East Face Zones 15, 16, and 21 and East Face Daylight Levels for March 11, 1994

Summary and Discussion

This paper describes the preliminary analysis of data for a daylighting system that has been retrofitted to an existing available technology that makes it possible to install a decentralized daylighting control system fairly inexpensively. Based on some preliminary analysis, it is estimated that the control system saved more than 12 kWh on a fairly bright mid-winter day. It is expected that the savings will increase substantially as the days become longer. Because part of the goal of this study is to understand something about the number of sensors that may be required, more sensors were installed than might be necessary. At this time of the year when the sun is low in the sky, it appears that the sensors closest to the windows and in the center of the building face are doing the most regulating. We will have to wait to see if this pattern holds for other times of the year. If it should, the number of sensors used in this building might be reduced by one-half or more.

In the winter months, it appears that motion detectors might reduce consumption in certain areas more than daylighting controls. However, most of the benefit from the motion sensors is a function of reductions in consumption in the late afternoon and early evening. The motion detector led to little reduction in consumption during working hours. During the longer mid-year days, this disparity may be reversed, with the daylighting controls reducing consumption a great deal and motion detectors contributing less because daylighting controls will be regulating during most of the hours when the lights are on.

Because this retrofit occurred in a building that was just a little over a year old, the ballasts and lamps were already quite efficient. During periods of full operation, the dimmable ballasts and T-8 bulbs that were installed as part of the retrofit actually consumed slightly more energy than did the ballasts and lamps they replaced. This would not be true for most retrofits since the ballasts and lamps being replaced would be older and less efficient. However, there is a lesson to be learned from this experience in that this specific type of dimming ballast and lamp should probably not be used in locations where there will only be marginal regulation of lighting. In this case, leaving the T-12s in place at these locations might have been the best choice.

The preliminary analysis pointed to the fact that the window treatments used to control light entering the window need to be coordinated with the daylighting system and should probably be considered as part of any daylighting system retrofit. In the case of SWAB, we will be experimenting with some alternatives to the existing blinds. The most desirable solution would be a system where the vanes could act like shelves to reflect light off the ceiling to darker parts of the floor while reducing light, glare, and heat in the areas immediately adjacent to the windows. This needs to be accomplished without restricting the views of the building occupants. Some of the manipulation of the blinds results from glare on computer screens. Alternative work station layouts will be reviewed to determine the potential for reducing glare on the work surfaces and computer screens.

The major work in this project is just now under way. By mid-summer, we should have gathered sufficient data to understand the impacts of this particular daylighting system on this particular building and how to modify the system to achieve the greatest benefits while minimizing costs. We anticipate conducting a number of experimental manipulations in the building on weekends when we have full control over the arrangement of the lighting and the blinds. These experiments might include temporarily blocking portions of the windows using different shapes to simulate the effects of other fenestration systems. We also anticipate that we might experiment with some custom shading treatments to simulate alternatives to the existing blinds. Finally, it is our hope to produce an interactive multimedia report, which will allow the user to interactively explore the lessons from this project rather than just reading about those lessons.

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Endnotes

1. For the sake of parsimony, we refer to the orientation of the building using cardinal directions. However, the north face of the building is oriented to about 450 east of north. Thus, when we refer to the east face, the orientation is really an east southeast face, and when we refer to a south face, the orientation is really south southwest.

2. The maximum light output of the two systems may not be the same.

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