Avoiding Fluorescent Dimming Pitfalls for Daylight Harvesting

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ABSTRACT

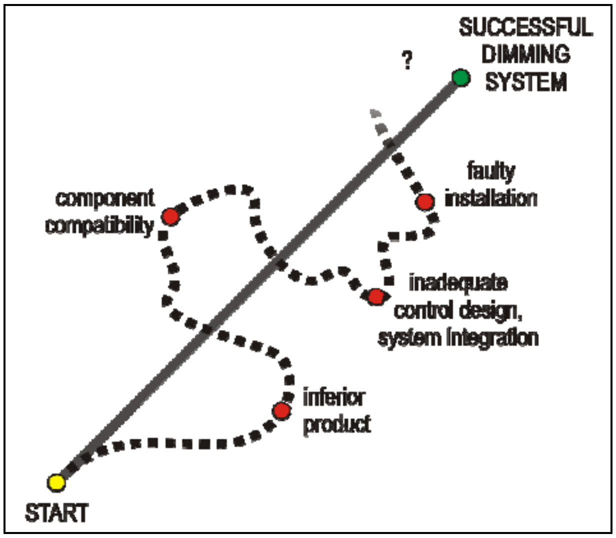
Energy savings are possible by switching or dimming electric lights when sufficient daylight is present. These savings, however, are often not realized due to problems with the specification, installation, or operation of the photosensor, lamps, ballasts, and/or luminaires. Indeed, many systems fail to provide the predicted energy savings or exhibit unexpected lamp replacement costs. This paper summarizes lessons learned from three separate projects involving extensive laboratory testing of 14 photosensor products currently on the market, four field evaluations of buildings with chronic problems with their daylight dimming systems, and life testing of 864 lamp and ballast combinations for dimming. Examples of pitfalls include shortened lamp life, improper installation, non-proportionality between a reduction of power and light output, and ineffective integration with other lighting controls. Guidelines to avoid these pitfalls are presented in order to help recover the full daylight harvesting benefit intended by these systems.

Introduction

Over the past several years, many commercial and industrial buildings have had daylight harvesting and fluorescent dimming installations applied in an unsuccessful attempt at energy conservation and lighting optimization. The idea behind daylight harvesting is essentially the decreased use of electrical lighting, through dimming or switching, in the presence of increased natural daylight. Knowledge of how to successfully deploy daylight harvesting dimming systems is often based on anecdotal information. This occurs because the information on how to get each component to work well together in any one facility is distributed over each components manufacturer; there are so many components that go into making up a system, often with many diverse manufacturers who cannot give installation instructions for every possible scenario in which their equipment may be utilized. Consequently, early lamp failure and dissatisfied occupants are often the first signs of faulty information, even though, of course, they may not be the source of the problem.

Several factors are key for a successful daylight harvesting dimming system. First, quality products are needed that meet performance specifications and lifetime claims. These include lamp holders, lamps, ballasts, and photosensors. Second, the components chosen must be compatible when operating together in the system. Third, the design of the system and component integration must adequately meet the lighting requirements and energy use goals for the particular site. Finally, proper installation is imperative. Unfortunately, we have seen inadequate attention to this fourth factor. For a given installation each of these factors on their own may account for only a small percentage of failures or problems, but evidence from the field reveals that contributions from all these factors are often present and lead to the application being considered a complete system failure. Problems in each of these areas are all steps off the path to a successful dimming system, as illustrated in Figure 1. This article will therefore address issues of what to avoid when it comes to inferior products, component compatibility, inadequate control design/system integration, and faulty installation.

Figure 1. Illustration of Detours from a Successful Dimming System



Source: Lighting Research Center (LRC)

Inferior Products

As previously mentioned, the quality of the four main components used in a dimming system—lamp holders, lamps, ballasts, and photosensors—are vital to a successful deployment of the system.

Lamp Holders

Lamp holders are critical components in dimming systems. In addition to mechanical support, they electrically connect the lamp pins to the ballast. Just considering one lamp, there are eight connections that have to be made correctly (four lamp-pin-to-socket connections, and four ballast-lead wire-to-socket connections). Any one of them done improperly will result in the lack of electrode heating during dimming, resulting in short lamp life. A lamp holder selected for dimming should allow for easy lamp installation, and require little mechanical insertion force, while providing a low resistance electrical contact with the lamp pins. The holder should also maintain a good electrical connection with the ballast lead wires when the lamp is installed. This is verified by tugging slightly on the wire to make sure it is held securely. Some examples of lamp holder problems are discussed below under the system integration section.

Lamps

Lamp performance information is supplied from manufacturers. In some cases, lamps may not be appropriate for dimming applications. For example, many energy-savings, or lower wattage T8 (25, 28 and 30 watt) lamps are not recommended for dimming since the lamps may not perform reliably when dimmed. For some high output T5 lamps, manufacturers recommend contacting them before using their lamps in a dimming system.

Some luminaire and ballast manufacturers suggest seasoning (aging) the lamps for 100 hours at full light output prior to using them for dimming, though there has not been any published research demonstrating the need for such seasoning. This practice is likely misguided and based on anecdotal information.

Ballasts

Dimming ballasts have been successfully installed in many applications, but in some cases there have been instances when some of the ballasts stop operating prematurely. One example is a retail application with skylights employed 1350 luminaires (fixtures), four lamps each, with dimming ballasts used for energy conservation. After 24 months of operation, 10% of the store's luminaires had at least one failed lamp. A sampling of 39 of the failed systems were investigated in detail. Of the fixtures examined, 41% had ballast failures. Failed ballasts were cold to the touch, yet voltage measurements across the input lead wires indicated power was available. Therefore, it was deduced that an electrical malfunction inside the ballast was responsible. While proper wiring was an issue for this facility (which will be covered under the "Faulty Installation" section of this article), the possibility of a poorly manufactured batch of ballasts must be taken into consideration for such a high rate of early ballast failures. Unfortunately, whether dealing with ballasts or lamps, or even photosensors, if the fault lies with the batch of products purchased, it may not be immediately evident that the product is of poor quality. A good rule of thumb is to make sure that the ballasts selected meet the appropriate standards provided by the American National Standards Institute (ANSI). It is also important to note that there currently are no ANSI standards for dimming systems as discussed in the "Component Compatibility" section.

Photosensors

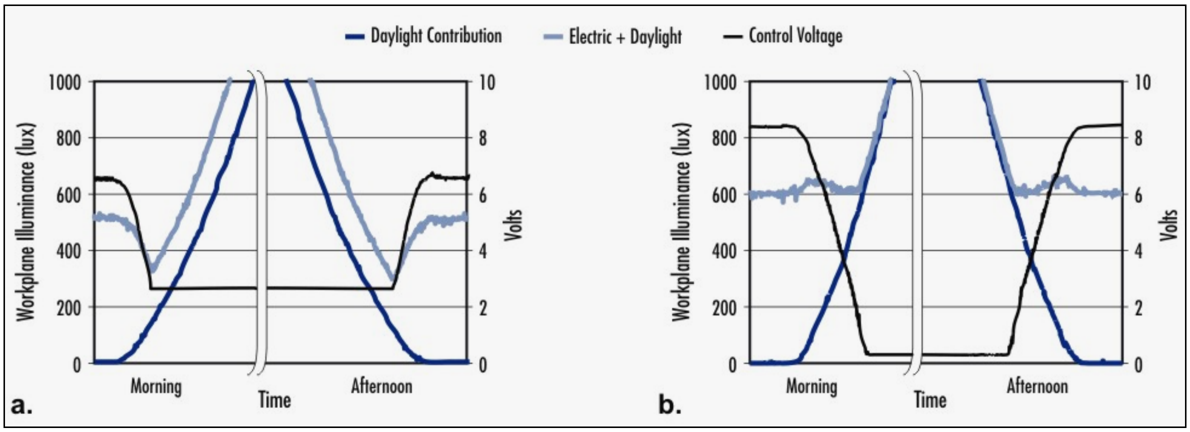
Integral control photosensors do not work well in daylight harvesting systems because of the changing distribution of light within a space illuminated by both daylight and electric light of varying amounts (NLPIP 2007). In one investigation of dimming problems at a newly built public school with a design emphasis on daylight harvesting, the plans specified a proportional control photosensor for dimming the fluorescent lighting in rooms with ample daylight from both windows and a large roof monitor. During construction, however, an integral photosensor was installed, likely one that was considered an equal substitute. The installed photosensor operated very differently from the one specified, and though product substitutions are common in the building industry, in this case the choice of substitution had a detrimental impact on the system performance and likely contributed to the dimming problems.

Integral control is designed to maintain constant illuminance on the photocell and must be operated in a closed-loop configuration to function properly. Constant illuminance on the photosensor does not correspond to a constant illumination on the work plane where the illumination matters most. With the photosensor located on the wall of the roof monitor, it received much more daylight than the work plane. Consequently, very little daylight was needed to fully dim the electric lighting and so the electric lights operated fully dimmed throughout the day.

Proportional response photosensors are better for daylighting systems because they allow the amount of dimming to be proportional to the illumination on the photosensor, and the proportion can be adjusted as needed for the particular space and photosensor location. Therefore, positioning the photosensor up in the roof monitor would not have been a problem since adjustments to the proportionality constant would have accounted for the large differences in daylight illumination between the roof monitor walls and the work plane below.

Testing of current market products demonstrates the difference between integral control and proportional control. Figure 2 shows one product using integral response and the other using proportional response. The proportional response photosensor maintained work plane illuminance as daylight levels changed for the particular setup much better than the integral.

Figure 2. Bench Test Results for both Integral (a) and Proportional (b) Response Photosensors



Source: National Lighting Product Information Program (NLPIP) (2007)
a. An integral control photosensor dimming the electric light too much as daylight increases, causing the work plane illuminance to drop from approximately 500 lux to 300 lux.
b. A proportional response photosensor maintaining nearly constant illuminance on the work plane throughout the dimming range.

In addition, the two photosensors would likely result in different amounts of energy savings. As shown in Figure 2a, the integral response product limited the minimum dimming control voltage to approximately 2.4 volts while the photosensor in Figure 2b obtained the minim control voltage for the same daylight condition. For the integral control system the photosensor was the limiting factor for power reduction even though the ballast was capable of additional dimming.

Component Compatibility

Compatibility problems are notoriously hard to troubleshoot after a system is up and running. The labor costs associated with determining the reason for system failure when it is not caused by a particular device, but rather is due to the incompatibility of components, will assuredly delay the planned economic savings that the dimming system was supposed to bring about, at least in the short term. In other words, it will take a much longer time to see a return on investment in choosing the more expensive dimming system over a non-dimming system if the energy savings of dimming goes towards paying for labor and equipment to assess and fix the systems problems.

The key components for compatibility within a dimming system are the lamp and ballast. Lamp designs for a particular lamp type (e.g. F32T8) are not identical and neither are ballast designs, so the combined performance can vary depending on what lamp and ballast are selected for an application. These combinations become more important for dimming systems, since the lamp and ballast are going to be operating over a wide range of power levels. The critical issue is if this lamp and ballast pairing results in lower than rated lamp life. Higher maintenance costs arise in tackling shortened lamp life, thereby increasing the cost of ownership, as mentioned above.

In general, the light output of a fluorescent lamp increases with current. Reducing the current will dim the lamp. Light levels as low as one percent of the rated light level can be obtained. A number of mechanisms limit the lifetime of fluorescent lamps, including consumption of electrode emissive coating, consumption of mercury, and degradation of the phosphor. For any electrode design, there is a "rated current" where the electrode coating loss is by evaporation and is in accord with rated life. When dimming, the electrode is operating below rated current and so supplemental electrode heating current is necessary to ensure expected lamp life. However, the question of how much supplemental heating current is required for all lamps is unresolved. If too much heating is applied, excessive evaporation of the electrode coating will occur, which shortens lamp life. If too little heating is applied the electrode coating is damaged due to sputtering, or erosion, which will also reduce lamp life. There is, therefore, an optimal region where electrode heating will maintain lamp life at its rated value.

There are currently no industry standards for dimming fluorescent systems. To this point the members of the National Electrical Manufacturers Association (NEMA), with the corporation of the Lighting Research Center (LRC) performed an "ongoing life test for dimming fluorescent systems" in order to "identify a region of satisfactory performance for lamps and ballasts" under a dimming system. The output of this effort will be used to develop a dimming standard. The test was conducted on T8 dimming systems, with full-wattage, argon-filled F32T8 lamps that were Toxicity Characteristic Leaching Procedure (TCLP) compliant. The ballasts used in the test were representative of current commercial dimming ballast designs, but modified to provide specific fixed experimental conditions relative to the test. Each ballast operated a single lamp at a specific dim level and electrode heating voltage. Different elements of the dimming system were tested, including various "electrode heating voltages, lamp currents, ballast manufacturers, and lamp manufacturers" (Duffy et al). Experiment conditions are documented in Table 1.

Table 1. Experimental Design Factor Settings.

Factors	Values	Controls
Electrode Heating Voltage	1.5, 3.0, 4.5, 6.0	0.0, 3.0
Lamp Current (mA)	20, 50, 80, 110	180
Ballast Mfr.	A, B, C, D	A, B, C, D
Lamp Mfr.	X, Y, Z	X, Y, Z

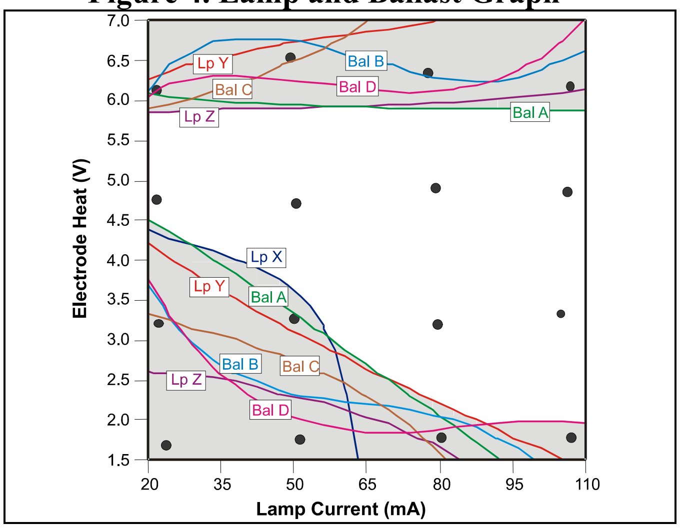
Source: Duffy et al

Four levels of lamp current, ranging from 20 mA to 110 mA defined the dimming region, which corresponds roughly to a range of dimming light levels from 10% to 60%. Four levels of electrode heating voltage, ranging from 1.5 V to 6.0 V were tested. The 16 combinations of electrode heating voltage and lamp currents were tested for every combination of lamps from three manufactures and ballasts from four manufactures for a total of 192 experimental conditions. Each condition was replicated four times for a total of 768 systems. In addition, two control points containing four replications of every combination of lamp-ballast type at 180 mA lamp current, one with and one without 3.0 V electrode heating, were included to represent non-dimming operation of rapid-start and instant-start system operation (Duffy et al).

After 11,620 hours of lamp operation there were 161 failures recorded. Failures occurred in both under- and over-heated electrodes. There was 100% failure within 940 hours in lamps set to 1.5V 20mA. Lamps set at 3.0V 20mA and 1.5V 50mA were considered at risk of failure between approximately 6500-6700 hours. The life for lamps at lower currents tended to range between 1062 and 2162 hours. The control groups at 180 mA had no failures.

Lamps X, Y, and Z were combined with ballasts A, B, C, and D in these tests. The graph below (Figure 4) is a stacked plot of individual graphs for each lamp and each ballast. The lines are the boundaries of good and bad performance for each, plotted against lamp current and electrode heat. The white area represents the region in which all of the tested lamp/ballast combinations performed satisfactorily.

Figure 4. Lamp and Ballast Graph



Source: Duffy et al

The major finding of this experiment is that electrode heating voltage and lamp current look promising for defining a region of operation for many lamp and ballast designs. A relatively large region in the experimental design space has been identified as having satisfactory performance when assessed at 11,620 hours into the experiment.

From the time that this project was originally published the experiment continued to run until slightly more than 20,000 hours had elapsed, at which time the experiment was stopped. The data from this experiment was turned over to the lighting industry which is currently working on developing a standard for dimming fluorescent lamps.

Inadequate Control Design and System Integration

As mentioned earlier, successful deployment of a dimming system begins with a fully worked out plan for product choices and their installation, and the plan must be customized to the facility and the needs of its occupants. In the field, we have come across instances of both poor planning, as well as good planning with poor execution. Examples of this run the gamut from control problems where lighting systems are nearly always fully dim, but never shut off, to fixture designs that do not allow enough clearance for proper lamp installation.

Control System

As discussed in the "Inferior Products" section, choosing the appropriate control algorithm for photosensor control is important, but the design specification does not end there. Other controls, such as occupancy sensors and manual dimmers, must be integrated with lamp life issues in mind. In the school example discussed previously, motion sensors were also installed that would switch the lights off several times a day when the classroom was unoccupied. Since the photosensor kept the lights at the full dim level throughout the day, the lamps were frequently switched when at the full dim level. Follow-up testing at the LRC using a samples of the actual ballasts used at the school confirmed that starting the lamps at the minimum dim level led to excessive lamp end blackening and short lamp life for this lamp-ballast combination. A solution to this problem involves the integration of the motion sensor with the ballast and photosensor controls. If the dimming control voltage is always brought to the full-output level when the motion sensor switches off the lights, the lamps would always start at full power and the damaging effects of starting at the dim level would be avoided

Luminaire Integration Issues

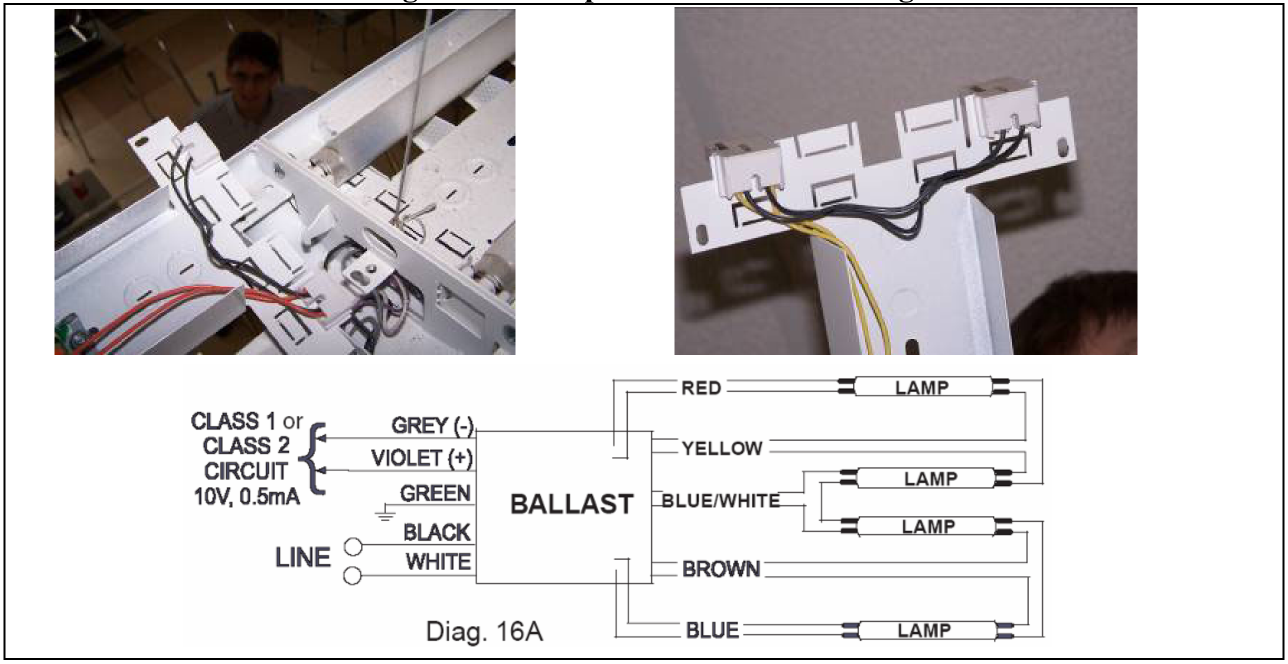
Combining the lamp, lamp holder, and ballast components together is accomplished by the luminaire manufacturer. Lamps are usually not included when purchasing a luminaire and would be added during the installation of the luminaire in the field. For dimming systems the interconnectivity is very important since every electrical connection matters to the overall success of the system. Just one incorrect or broken connection can lead to shorter lamp life. Interconnectivity problems are not always obvious, especially when the lamps start and the system is operated at full output. Interconnectivity can be compromised due to incorrect wiring, broken connections, and the mechanical design of the luminaire.

Incorrect wiring. In the case of incorrect wiring, the common issues that we saw were wires installed in the same side of the lamp holder instead of one on each side, incorrect jumper connections to adjacent lamp holders, and adding parallel heating connections in adjacent lamp holders when the ballasts were designed for them to be in series. In the first two cases electrode heating was removed and dimming operation caused premature damage to one or more lamp electrodes. In the last case, the result of the incorrect wiring actually doubled the heating voltage, which led to excessive evaporation and short lamp life.

Figure 5 shows two examples of incorrect wiring of adjacent lamp electrodes. Also shown in Figure 5 is the ballast wiring diagram showing the lamp connections of the 4-lamp dimming ballast. The lamps were to be wired in series, and the electrode heating for the lamps was also supposed to be in series, but as the images show, they were in parallel. The lamps that were installed in these positions had failed as was evident in their extreme end darkening.

Recently, there has been some ballast design changes on how the electrode heating is connected. The electrode heating for this same ballast model for a 3-lamp ballast has all the electrode heating in parallel. The luminaire manufacturers need to take care in making sure how this wiring is designed so the ballasts are installed correctly.

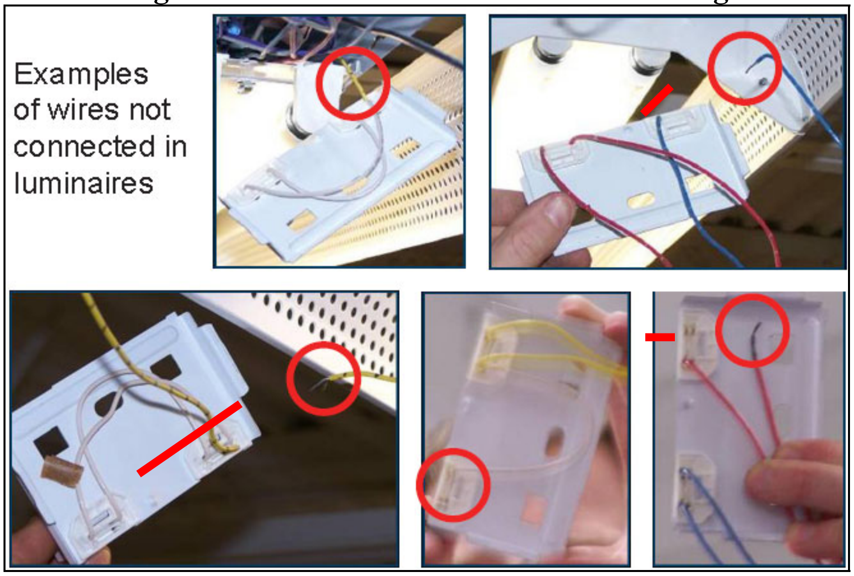
Figure 5. Examples of Incorrect Wiring



Source: NLPIP (2006)

Broken connections. In most lamp holders the wire makes contact with the holder via a push-in wire connection that relies on friction from a leaf spring to keep the wire in place. The use of inferior lamp holders can result in wires easily becoming disconnected from the lamp socket. This could happen due to improper wire installation in the lamp holder or from small vibrations during shipment of the luminaire or during luminaire installation. A way to check for proper wire installation is to tug on the wire slightly to make sure that the lamp holder and wire are securely connected. Figure 6 shows some examples of wires that were not connected to lamp holders upon internal inspection of several luminaires.

Figure 6. Non-Connected Luminaire Wiring



Source: NLPIP (2006)

Mechanical Design

In some cases the assembly of the luminaire can interfere with the installation of lamps. If all four pins of a lamp are not connected the lamp electrode heating cannot be applied properly and the lamp life will be compromised. Figure 7 shows an example of a luminaire where the louvers were hitting the lamp (arrow) preventing the lamp from being pushed completely into the lamp holder. In this case either the mounting of the lamp sockets were too low or the louvers were mounted too high preventing proper lamp installation. In this luminaire the lamp was installed with only one pin making contact with the lamp holder.

Figure 7. Flawed Luminaire Design

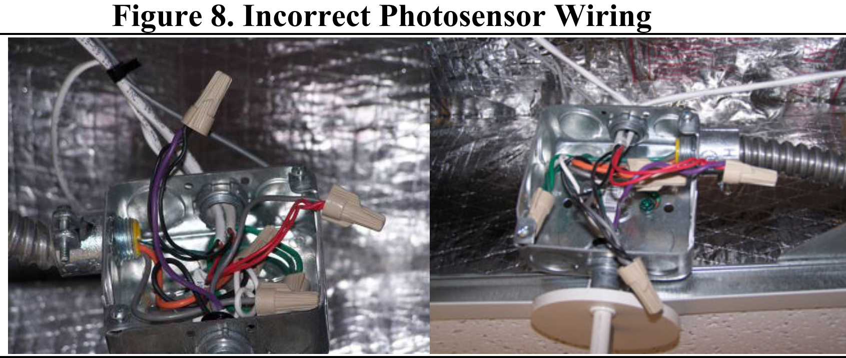
Source: NLPIP (2006)

Faulty Installation

Poor workmanship has been another cost factor impacting dimming system failure. Many electricians are unaware that dimming systems are more susceptible to installation shortcuts and mistakes than non-dimming systems. Installation issues include luminaire wiring, photosensor wiring, lamp installation, photosensor placement and photosensor commissioning.

Improper luminaire wiring issues are usually easy to identify and resolve. Photosensor wiring can be more difficult. An example is shown in Figure 8. The image on the right side shows that the purple wire from the ballast is connected to a black wire that was installed by the electrician. The image on the left shows another junction box further down the circuit where the purple wire from the ballast is connected to a black wire. This wiring mishap effectively shorted out the dimming signal from the photosensor and lighting was always in the lowest dimmed mode even when there was little or no daylight resulting in lower than designed light levels.

Figure 8. Incorrect Photosensor Wiring



Source: NLPIP (2006)

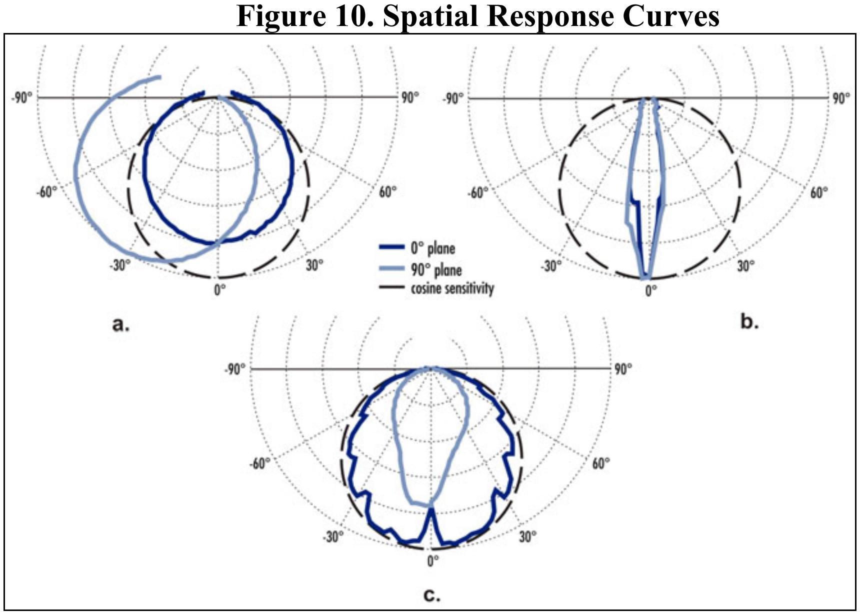
Lamp installation was also problematic in some luminaires. Many times that lamp was not rotated, or pushed completely into the lamp holder so that all four pins for a given lamp were electrically connected to the lamp holder. As mentioned above, there were some luminaires where the luminaire actually prevented proper lamp installation, but there were also plenty luminaires where the lamps were just not installed correctly. This type of problem can go unnoticed since such lamps will light-up when the luminaire is operated at full light output, but over time operation at dimmed levels will cause the lamp to fail prematurely. Figure 9 shows one luminaire where the lamp was actually dangling out of the lamp holder.

Figure 9. Lamp out of Socket

Source: NLPIP (2006)

Photosensor placement can impact how much energy savings is possible, and it is closely tied to the spatial distribution of the photosensor. Figure 10, shows the spatial response of three tested photosensors (NLPIP 2007). The three products differ dramatically in their spatial response yet from visual inspection alone these differences are not readily apparent. Knowing the spatial distribution of the photosensor is necessary for a systematic approach to the placement and orientation of photosensors to achieve intended performance.

Figure 10. Spatial Response Curves



Source: NLPIP (2007)

These curves depict photosensors with a wide, asymmetrical sensitivity (a), with a very narrow sensitivity (b), and with a wide sensitivity along one direction (0° plane) and narrow in the direction perpendicular to this. The cosine sensitivity is shown to compare the sensitivity curve to that of an illuminance meter.

In addition to installation, all photosensor systems need to be set up, or adjusted, to perform as desired. This setup procedure is part of commissioning a control system. Photosensor setup procedures differ greatly for different products making it impossible to have a standard setup/commissioning procedure that can be universally applied to all products. Each of the 14 photosensor products tested had a unique method of setup and adjustment. The manufacturers used different terminology, number of steps, procedures and user interfaces. This variation in the commissioning processes increases the chances that photosensor systems will not be properly set up or verified for proper operation. Improper setup can result in excessive dimming, which exacerbates other potential problems with the dimming system. On the other hand, improper setup that results in too little dimming erodes the energy savings.

Conclusion

Despite all the pitfalls mentioned here, we want to make it clear that successful dimming applications for daylight harvesting are possible. By success, we mean that an installed lighting system can work under dimming and non-dimming operation, where lamp life is not compromised, and energy savings is provided in a reasonable time to justify the added initial cost of the dimming system. When facilities experience pitfalls, the blames lies in inferior components, component incompatibility, inadequate control design and system integration, or faulty installation. What is noteworthy here is that all these pitfalls exist in dimming applications, unlike the less sensitive non-dimming applications. The end result of having numerous issues that can go wrong is what we see in the field today, and what is often passed around in anecdotal information—that dimming systems have a high failure rate with no simple, fix-all solution. With the current state of the technology though, careful design, attention to detail, and going the route of no shortcuts, including the selection of products, one can have a successful dimming system for daylight harvesting.

References

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