Expanding the Market for Commercial Skylighting

Jon McHugh & Lisa Heschong, Heschong Mahone Group

ABSTRACT

Well-designed skylighting can substantially reduce commercial building energy consumption, and improve occupant performance and enjoyment in the space. With the skillful application of skylights, electric lighting and photocontrols, whole building energy use and peak load reductions are possible in all continental climates. Approximately 60% of existing commercial floor area in the US is directly below roofs, and up to 90% new construction commercial floor area may be single-story in California. Thus, there is a huge opportunity to reduce energy costs with skylights. In addition, substantial increases in human performance in daylit buildings have been observed.

This paper describes an integrated market transformation effort to expand the market for commercial skylighting in California and subsequently, the rest of the country. The project began with an assessment of barriers to greater use of skylighting for each of the key market actors. Results from this assessment, along with a baseline study of attitudes towards skylights by market participants, helped to formulate the project elements. This effort has included: research to document the non-energy benefits of skylighting; the establishment of an industry association to promote commercial skylighting; development of a calculation tool to help designers optimize energy and lighting performance; design guidelines and workshops to train designers how to successfully design skylighting systems; and general publicity and outreach.

The overall, long-term market transformation strategy is presented along with impacts observed to date.

Introduction

This paper discusses the development of a set of coordinated market transformation activities directed towards promoting energy savings through the effective use of skylighting systems in commercial buildings. By skylighting systems we include consideration of unit skylights, skylight wells, building geometry, interior surface reflectances, electric lighting and photocontrols. This skylighting market transformation strategy is based upon a staged process:

- gathering information on the strengths and weaknesses of the technology
- characterizing the market
- evaluating the critical barriers
- developing strategies for overcoming market barriers
- applying the strategies to the market
- evaluation of the effects of the market transformation activities
- application of the lessons learned to continued transformation activities (if needed)

Skylighting Strengths and Weaknesses

Technical Energy Savings Potential

The market potential for widespread application of skylights and photocontrols is dramatic. Of 686 million square feet of the new commercial buildings constructed each year in the United States, it has been estimated that 46% of the total floor area is single story, 62% of total commercial floor area is directly under a roof and therefore potentially available for skylighting[1]. The amount of low-rise construction, spreading in the suburbs, may be low visibility, but it is enormous.

Some estimates suggest that daylighting can reduce electric lighting consumption by as much as 50% to 70% (Selkowitz & Lee 1998). These estimates are probably based on offices, which are predominately occupied and electrically lit during the day. Most commercial buildings have longer occupancy patterns, including more nighttime hours. Therefore we conservatively estimate that the potential skylighting energy savings for the entire class of commercial buildings average around 1/3 of total lighting energy in the daylit zone. The lighting electricity consumption for each year's new commercial construction in the US is 4.6 Billion kWh/yr (15.6 Trillion Btu/yr) (DOE/EIA 1998, Table EU-1). Given these assumptions, the technical energy savings potential for adding skylights and photocontrols over the next 10 years on half of the floor area directly under roofs in new commercial buildings could yield an energy savings on the 10th year as high as 4.7 Billion kWh/yr[2].

Note that these savings are dependent upon a properly functioning photocontrol system, which turns off or dims electric lighting in response to the availability of daylight on relevant tasks. Improperly designed skylighting systems with too many or too few skylights, inappropriate skylight selection, incorrect design or installation of photocontrols, could potentially increase whole building energy consumption.

The energy savings potential of skylights is primarily in non-residential occupancies. Commercial and industrial occupancies are good targets for energy savings from skylights since they have high lighting power densities, extensive lighting use during daytime hours, and whole building energy consumption that is relatively insensitive to envelope thermal transmittance (U-factor). Residential buildings, on the other hand, are not likely to see energy savings from skylights for the opposite of all the reasons from those listed above.

A Robust Form of Daylighting

Skylighting is very appropriate for deep, single-story buildings with open space plans, which are very common in current new construction. Skylighting can provide exceedingly uniform, diffuse lighting, which integrates well with today's open space lighting systems. As illustrated in **Figure 1**, sidelighting has a strong gradient from window to interior that requires special consideration in the design of the lighting and control system. We have found that photocontrol systems for skylighting are easier to design and maintain than sidelighting from perimeter windows.

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[1] Percentages based upon 1990-1992 data, total new floor area based upon one third of 1993 - 1995 data. *(DOE/EIA, 1998, Table BC-11)*

[2] (10 years of new construction) x (4.6 Billion kWh/yr lighting energy consumption added from each year's new construction) x (0.62 fraction of new construction directly under roofs) x (1/2 fraction area directly under roofs that can be readily skylit) x (1/3 fraction of lighting energy saved) = 4.75 Billion kWh/yr.

Sidelighting typically must involve substantial solar controls to avoid glare, especially when windows are facing either east or west. In contrast, fairly simple designs of the skylight well, the shaft between the underside of the skylight and the ceiling plane, can effectively shield glare from diffusing skylights regardless of building orientation.

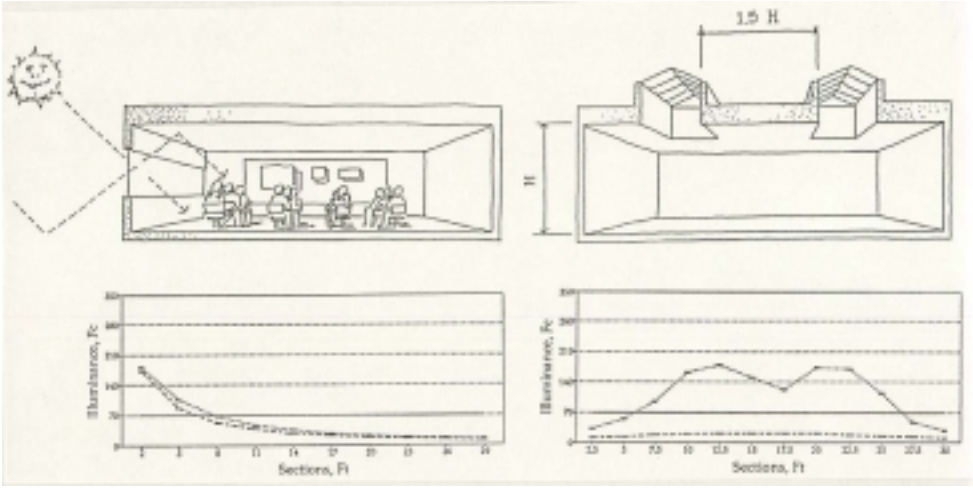

Figure 1: Sidelighting and Skylighting Illuminance Distributions (CEC)

Daylight and Human Happiness

In the past, there have been many anecdotal reports of the desirability of daylighting. A key indicator is the high correlation between proximity to windows and status in an organization – senior personnel usually get the windowed office. In addition, informal studies have been published that purport to show improved test performance in daylit schools. (Nickas & Bailey, 1997). and improved retail sales in skylit buildings (Romm & Browning, 1994).

Though productivity is hard to quantify, it is of key importance in the decision of whether to install any apertures in a building. The current practice of installing windows in buildings without any photocontrols increases energy consumption, but is an established desirable feature for most buildings and is required for all offices and schools in some European countries (Wotten 1998). Similar expectations for daylighting the core zones of a building are not yet established.

The 1995 average annual energy cost for the entire US stock of commercial buildings was $1.19/SF(DOE/EIA, 1998, Table CE-2). In contrast, the salary and overhead costs of office workers range from $100 - $400/SF; for Federal government workers the average is $165/SF (Harris et al. 1998). Annual retail sales are of a similar magnitude: the average annual sales for non-food retail is $153/SF[3] of floor area and for supermarkets $490/SF of sales floor area (Food Marketing Institute 1999). Thus, building features that can reliably increase human performance or retail sales have several orders of magnitude more economic potential to impact than energy efficiency measures. With well-executed daylighting, we believe there can be both energy efficiency and productivity gains.

[3] Non-food sales in 1995 were $1.9 Trillion/yr, (US Census 1998). Mercantile and service floor area is 12 Billion square feet (DOE/EIA 1998).

Delineating the Problem

Though there are great opportunities for applying skylights, and the potential energy and productivity benefits are huge, skylights have been greatly underutilized. CBEC's reports that skylights exist on less than 1% of the commercial US building floor area (CBECS 1998). The great divergence between potential and actual markets indicates that there are some severe market barriers to greater use of skylights. We conducted structured interviews with market actors (manufacturers, architects, engineers, lighting reps, utility reps and building owners) at different times and on different aspects of skylighting to better understand the functioning of the market for skylights.

Skylighting Market Barriers

In 1997, we conducted initial interviews with 16 proponents of skylighting (manufacturers, utility reps and architects) and asked them their thoughts on what factors that have helped or hindered greater use of skylighting (HMG 1997). Their responses can be summarized as follows:

- The "Wal-Mart skylight story" - a highly publicized story of greater sales under skylights, dramatically increased the interest in skylighting among big box retailers and grocery stores.
- One of the most frequently listed concern is the fear of leaks, even though none of the interviewees had witnessed a leaking skylight.
- Skylights are perceived as unusual, and thus are seen as a marketing risk for selling a building with this atypical feature.
- Skylights are seen as a "second-class" form of lighting, associated primarily with warehouses.
- Architects don't know how to specify or size the skylighting system, and feel uncomfortable relying on the advice of the manufacturers.
- Electrical engineers don't like photocontrols; they require too much design and supervision time.
- Building owners are concerned about security and safety issues -- stories about a burglar falling through a skylight and suing the owner are well-remembered.
- The best selling feature of skylights is improvement in the quality of light in the building. This is best shown by taking the client to a daylit building -- an inefficient market tool.

In 1998, we performed a formal baseline study of attitudes towards skylights held by a randomly selected sample of 95 building professionals including building designers, building owners and appraisers (HMG 1999a). Many of the barriers listed above were supported by this later study. We found that while building professionals had a generally favorable view of skylighting, they had very little actual experience with it. Most importantly, we found that those who were the most likely to specify skylighting in their buildings were also most likely to believe that there were human performance or occupant satisfaction benefits to be obtained from skylight buildings.

Photocontrol Market Barriers

Skylighting can only save energy if electric lighting is dimmed or turned off in response to available daylight. In many skylit buildings, photocontrol systems have been

specified and have worked without a hitch. However, we have observed many instances of skylights being specified without the accompanying photocontrols. In other cases, photocontrol systems have failed or have been disabled. We conducted a survey of 67 market participants (designers, contractors, building operators and manufacturers) to understand how photocontrols get specified and what are the elements of a successful photocontrol installation (HMG 2000).

Outside of the manufacturers, most of the respondents had only a limited amount of experience with this infrequently used technology. Those practitioners with the most experience tended to specialize in photocontrol systems for primarily retail and warehouse buildings with skylights. This is in contrast to most published information about photocontrols, which covers dimming applications in perimeter side-lit offices, one of the most challenging applications. There is little literature or publicity about simpler systems.

Thus, to capture the energy savings potential of skylighting, designers and specifiers need to know what factors improve the maintained performance of photocontrols. Communicating this information is a necessary aspect of a comprehensive skylighting market transformation effort.

A Fragmented Industry

There are no major advocacy groups for skylighting to sponsor research or support market outreach. Skylight manufacturers are very small, even marginal, businesses compared to the window and glass industry, or the electric lighting industry. They market primarily through the traditional architectural specification route, providing product catalogs to architects and contractors. A few of the more aggressive companies market directly to building owners. Their markets are generally local, primarily in their own state or region.

Manufacturing of daylighting controls is an even younger and less mature industry. Spawned by the recent technological advances in dimming ballasts, control sensors, and intelligent systems, new small companies have been formed to address the new market. There are also a few large controls and electronic companies who have also invested in daylighting control products. For these large, national corporations who are primarily more experienced in HVAC controls, daylighting is a minute portion of their market.

Because of the fragmentation and multiple players involved in a skylighting system, and the small market segments of each, there was no organization promoting research or assembling information on how to design effective skylighting systems.

Market Barriers Hypotheses

From the previous market studies and the combined experiences of our project team, we hypothesized several market barriers to further use of energy efficient skylighting systems.

1. The industries that stand to benefit from wider application of skylighting were not organized to undertake mutually beneficial activities.
2. The non-energy benefits of skylights have not been quantified. Many people instinctively know that natural daylight is preferred to electric lighting and that it potentially could increase human performance. However, before making the financial decision to add skylights, many building owners need an analytical justification based upon payback with supportable numbers on the economic value of productivity gains.

3. Negative perceptions abound about skylighting: they leak, they are a security hazard, they increase energy consumption, etc.
4. Little independent literature exists on how to specify and size skylighting systems.
5. Skylight performance is not well characterized by manufacturers.
6. Much of the daylighting literature is focused on sidelighting offices with perimeter windows. This may be the most challenging geometry and occupancy to daylight effectively. The emphasis on this difficult application has resulted in many failures leading many to conclude that daylighting is problematic.
7. Architecture schools in general do not teach how to design energy efficient buildings with skylights.
8. There has been little funded research on the performance of skylights or skylit buildings.

Smoothing the Path to Skylit Buildings

Given the obstacles noted above, we have initiated skylight market transformation efforts with a number of partners throughout the United States. These market transformation efforts were initially focused on removing barriers to commercially available skylighting technologies. However, one of the spillover benefits of these activities is that some of the information generated may also result in innovation, improving the technologies used in skylighting systems.

In response to the variety of market barriers, our approach to affecting the market has been multi-faceted. These activities include: development of an industry group which is forming new alliances to promote skylighting, directing a statistical study that quantifies the non-energy benefits of skylighting, creating design guides and software that take the guesswork out of designing skylighting systems, and publishing case studies that demonstrate the desirability and simplicity of integrating skylighting into typical building types.

Skylighting Collaborative

The Skylighting Collaborative was formed to develop a research and marketing agenda to promote greater market penetration of skylighting in commercial and industrial buildings. It brought together a variety of participants in the industry--manufacturers of skylights, daylighting controls and dimming ballasts-- to discuss possible improvements in the industry and shared marketing goals. Currently, most of the skylight manufacturers in the western United States are members of the Collaborative. They are joined by several lighting controls and electronic ballast manufacturers.

Since the Skylighting Collaborative was formed, some of the members have expanded their horizons and participated in activities that were not traditionally in their marketing scope. Some members have recognized that skylights are primarily a lighting product, not a roofing product. Some have participated in planning research with the Department of Energy (DOE lighting road mapping) or are making business alliances with lighting or other product manufacturers.

The Skylighting Collaborative contains a wealth of experience in the various fields that are encompassed by skylighting. Members have provided invaluable input on many of the market transformation activities described below.

Retail and Classroom Productivity Studies

As mentioned earlier, the primary economic benefit from skylights is likely the improvement in productivity that arises from working or learning or shopping in a well designed environment that includes daylight. In the past this benefit was described anecdotally (such as Wal-Mart's experience with one store) (Romm & Browning, 1994).or based upon a sample size that was too small to be considered statistically significant. This type of argument may work for some people, but if the market is to be expanded to the larger universe of people who are skeptical of anecdotal evidence, more compelling evidence was clearly needed.

We proposed to perform a statistical study to quantify any relationship between daylight availability and human productivity. These types of statistical studies need an objective metric of productivity and many subjects to provide statistical certainty that an effect measured was not an artifact of random variation. Our study considered the effects of daylight on the test scores of 20,000 elementary students (HMG 1999b) and the effect of skylights on sales from of 109 similar stores owned by a single chain retailer (HMG 1999c).

When comparing student test scores in three school districts, and after correcting for confounding factors such as demographics, this study found that significant improvements in test scores (20+%) was strongly correlated with daylight in classrooms. Similarly, when the sales figures were compared between skylit and non-skylit stores after accounting for the income in the area around the stores, the hours of operation and the size of the store, skylighting was correlated with 40% higher sales.

Outreach and publicity were critical if the study was to affect the market instead of being merely an academic exercise. Luckily, press interest was very high. The study on daylighting and productivity has been summarized and reported in newspapers, Internet, radio, and TV news around the country. Over fifty newspapers, international and national, have issued an article on the study. More targeted presentations of this study have been made to professional societies and building designers. Approximately 200 requests for copies of the study have been received.

A second level of expanding outreach is occurring through third parties. One skylight manufacturer is distributing the productivity report as part of their marketing materials. Other daylighting advocates have incorporated the findings of this research in their training courses and presentations to architects.

Design Tools

Once a demand for skylighting is created, how do we assure that these systems will actually save energy? If a skylighting system is undersized it does not achieve the desired illuminance for enough hours to be worthwhile. If a skylighting system is oversized, the solar gains and heat losses can consume more energy than the energy saved by turning off the electric lighting system. Correctly sizing skylights is somewhat complex, as it must consider local climate, occupancy and building design. To address this problem, we proposed to create a set of design tools and guidelines to aid architects and engineers in successfully designing skylights.

Skylighting Guidelines. There was a clear need for reliable advice on the design of skylighting systems. The earlier *AAMA Skylighting Handbook* had lots of useful information

and a tedious hand calculation procedure for estimating the energy impacts in one of 5 climatic zones for the United States (AAMA 1987). However the *Handbook* was 10 years old and needed updating. Current products and photocontrol systems were not addressed. Originally, the *Skylight Handbook* had included a spreadsheet program for calculating savings, called AAMASKY1, but this program no longer worked under the Windows computing environment.

We updated the *Skylight Handbook* into a new design guide called the *Skylighting Guidelines*. The *Guidelines* (HMG 1998):

- Describe opportunities for energy savings and good lighting design
- Dispel myths about skylighting
- Explain how to integrate skylights with other building elements
- Show how to estimate energy and dollar savings
- Help designers avoid costly mistakes

Like the Skylight Handbook, the *Skylighting Guidelines* include a companion spreadsheet, called *SkyCalc®*, which calculates and graphically displays the optimal skylight area for energy and cost savings. The *Skylighting Guidelines* and *SkyCalc®* as well as other design tools for efficient buildings are available for free download from a number of sources.

***SkyCalc®* skylight sizing spreadsheet.** Our objective in designing *SkyCalc®* was to take a complex physical problem, simplify the inputs and summarize the outputs graphically so that skylighting systems can be sized quickly with little user effort. *SkyCalc®*, is a free, simple computer tool that helps building designers determine the optimum skylighting strategy that will achieve the optimum illumination and HVAC energy savings for a building.

The spreadsheet format was used to overcome the learning curve barrier of new software. Only 30 basic inputs are required on a single input page without multiple screens or special keystrokes. The spreadsheet displays three key graphical results for the designer: 1)average daylight footcandles, 2) total energy savings optimization graph and 3) total energy savings optimization graph.

Daylight availability is highly variable. As shown in **Figure 2**, the average daylight illuminance graph indicates of how bright the interior of the skylit space would be for a defined skylighting system over the course of a year by plotting the indoor daylight illuminance in for each hour of an average day for each month.

The total energy savings and total energy cost saving optimization graphs in **Figure 3** show how close the designed skylight area is to the whole building energy optimum. With all other variables held constant, the graphs vary the skylight to floor ratio (SFR) from 0% to 12% - a range that encompasses the skylight area of most skylighting designs.. A 10,000 ft^2 room having a total skylight area of 1,000 ft^2, has a SFR of 10%. The resulting performance curve is plotted both for whole building energy savings and dollar value of those savings, allowing the designer to quickly assess their design.

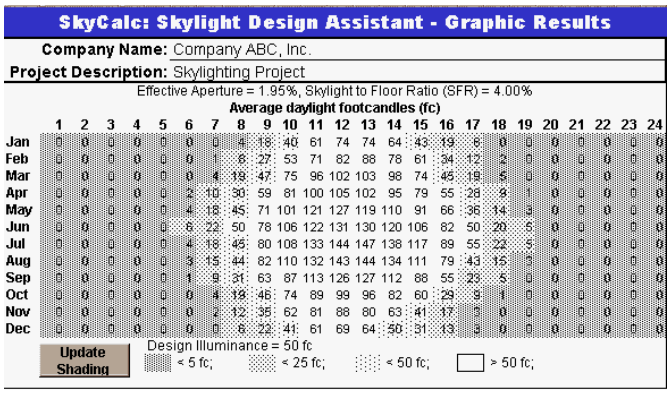

Figure 2: Average Daylight Footcandles Graph

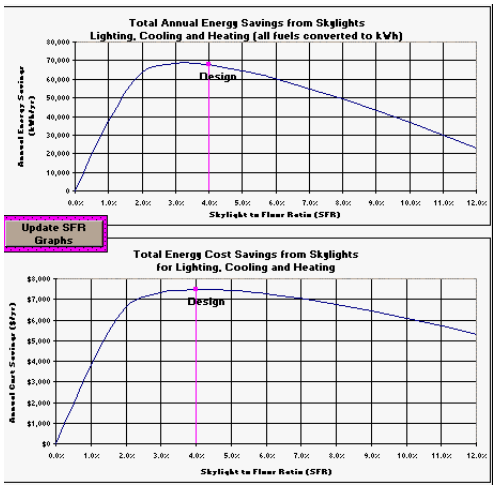

Figure 3: Skylight Optimization Graphs

Acceptance of *SkyCalc®* has been high among all designers who have been exposed to it. *SkyCalc®* is regularly used by some utility staff who are promoting skylighting, and skylight manufacturers who have trained their sales staff to use *SkyCalc®* as part of their sales and design tools. The quick graphical results that can model most simple skylighting systems have also provided insight to researchers and engineers into the energy impacts of various skylight design choices.

Originally funded by Southern California Edison, its geographical range was originally limited to southern California. Subsequently, additional sponsorships from Pacific Gas & Electric and the Northwest Energy Efficiency Alliance (NEEA) expanded it's applicability to all of the West Coast. Most recently, New York State Energy Research and Development Authority (NYSERDA) and Northeast Energy Efficiency Partnership (NEEP) have supported expansion to the northeastern section of the United States and the American Architectural Manufacturers Association (AAMA) has funded an expansion so that all remaining major geographic regions of the US are now represented.

Case studies. As part of the information-based market transformation program, Southern California Edison funded us to create four skylighting case studies as part of the Energy Design Resources (EDR) materials. These skylighting case studies include a skylit school, big box retailer, manufacturing and a warehouse.

Designers who are unfamiliar with a technology prefer to have actual buildings they can see first hand or as second best have a case study they can refer to. Case studies allow the designer to learn from the efforts of the designer of the case study. They can see for themselves what works and what could use improvement. Case studies help overcome the barrier that skylights are a new and unproven technology or that they have some unknown problems. One caveat about case studies is that designers realize that what works for one building may not work for another. Thus a case study of a skylit classroom is not going to be useful for someone who is considering designing a skylit store.

Pattern guides for advanced lighting. Recognizing that many designers will not have the time to assimilate the information contained in the 100 page *Skylighting Guidelines*,

we are producing a set of simple repeatable patterns - layouts and specifications of skylighting systems that provide reliable energy savings and a high quality visual environment. This work is funded by NEEP and builds upon their existing Design Lights Consortium lighting KNOWHOW series of pattern brochures of high quality energy efficient electric lighting designs for a variety of typical commercial spaces. These brochures will be distributed to a network of professionals and tradespeople who are involved in the design and construction of commercial buildings.

Future Work

Integrated Ceiling Project

Expanding upon the concept of creating skylighting patterns assure standardized performance for a given climate, we are commencing work for the California Energy Commission (CEC) to develop designs and equipment protocols for a highly efficient integrated ceiling system. This ceiling system, to include skylighting, will provide visual and thermal comfort while minimizing installation, energy, and maintenance costs and will be aesthetically appealing. We will be working with the manufacturers of skylights, grid ceiling systems, lighting and HVAC equipment so that equipment can be standardized and easily integrated into existing building systems.

Skylight Testing

To support the design analysis of skylights, we have also been funded by the California Energy Commission to test unit skylights for their thermal and photometric properties. Whereas a great deal of effort has been expended over the past four decades on research and testing of advanced window products, skylights have been ignored. For the first time, we will have same luminance distributions from skylights as lighting designers currently receive for most lighting fixtures.

Productivity Studies

Additional productivity studies will be pursued with CEC funding to see if the same productivity enhancing effect of daylighting is also found in manufacturing or office environments. More in-depth analysis will also be undertaken with some of the school performance data and at another retail site.

Conclusions

Installing appropriately specified skylights and photocontrols on new and remodeled commercial buildings can save tremendous amounts of energy. Over a relatively short period of time, we have been involved in a series of market surveys that have allowed us to develop a coherent market transformation plan for skylighting. The projects that we have delivered to date have made use of the power of information to transform markets. Observed market affects include:

- Interest in skylighting has spread to other researchers, educators, and funding agencies.
- Skylight manufactures have expanded their markets and their product lines.
- Public interest in the human performance benefits of daylight has been enormous.
- Designers have guidance on how to design skylighting systems that yield a net savings of energy.

- Designers and owners have documented examples of skylighting systems that work in their climate and can be replicated.

The path of getting better-designed skylighting systems to market has been smoothed, but many obstacles remain.

- *SkyCalc®* and the *Skylighting Guidelines* are still regional publications. We believe that this methodology will not be extensively taught in design schools or regularly applied at design firms unless these tools are expanded in sufficient detail to a nationwide basis.
- Many photocontrol systems are not working as designed over the long term. The promise of sustained energy savings from skylighting or sidelighting will not be realized until automatic photocontrols are widely available that are: easy to design, install and commission, are universally accepted by occupants, and produce reliable, persistent energy savings.
- Replication of the productivity studies for a wide range of occupancies will be required before productivity benefits are accorded anywhere near the confidence of estimates for energy savings.

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