CABA Continental Automated Buildings Association

Impacts of Automated Shading in Building Projects

A CABA WHITE PAPER

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CABA Intelligent Buildings Council

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ABOUT CABA

The Continental Automated Buildings Association (CABA) is an international not-for-profit industry association, founded in 1988, and dedicated to the advancement of intelligent home and intelligent building technologies. The organization is supported by an international membership of over 390 organizations involved in the design, manufacture, installation and retailing of products relating to “Internet of Things, M2M, home automation and intelligent buildings”. Public organizations, including utilities and government are also members. CABA's mandate includes providing its members with networking and market research opportunities. CABA also encourages the development of industry standards and protocols, and leads cross-industry initiatives. CABA's collaborative research scope evolved and expanded into the CABA Research Program, which is directed by the CABA Board of Directors. The CABA Research Program's scope includes white papers and multi-client market research in both the Intelligent Buildings and Connected Home sectors. www.caba.org

ABOUT CABA’S INTELLIGENT BUILDINGS COUNCIL (IBC)

The CABA Intelligent Buildings Council works to strengthen the large building automation industry through innovative technology-driven research projects. The Council was established in 2001 by CABA to specifically review opportunities, take strategic action and monitor initiatives that relate to integrated systems and automation in the large building sector. The Council's projects promote the next generation of intelligent building technologies and incorporate a holistic approach that optimizes building performance and savings. www.caba.org/ibc

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1. INTRODUCTION

Maximizing the benefit of windows, namely daylight, views, ventilation, and thermal comfort, while minimizing the impact on building energy consumption have been goals for building owners and designers alike. The common desire is to have an energy efficient building that also connects occupants with the natural world outside and provides an inspiring space for living and working. Several studies have established that the right combination of window-design elements results in optimized energy performance while preserving occupant comfort. Some in the building industry, particularly in North America, view this as an exercise in "fine tuning" the energy performance of a building. However, decisions about window design impacts more than energy savings. They can affect some of the key performance indicators for occupant health, alertness, and productivity. This paper discusses some of the recent research studies on this topic and shows that good window design, augmented by automated shades, can offer improved occupant comfort, productivity, and energy savings. The goal of this paper is to introduce the reader to these key benefits and identify resources to help building managers realize these benefits in their own buildings.

2. IMPORTANCE OF WINDOW SHADES IN WINDOW DESIGN

People spend over 80% of lives inside buildings (Klepeis, et al. 2001). Windows are essential elements of buildings and play a key role in determining overall indoor experience. Views provide a link to the outside world, and exposure to daylight kickstarts occupants internal circadian cycle that regulates health and wellbeing (Young 2007). Light, heat, and glare from a window changes multiple times over the course of a single day, and at times in unpredictable ways. This necessitates some form of control be provided to the occupants, so they can adjust their visual or thermal environments during periods of discomfort. This has been traditionally done with window attachments such as manually operated blinds and shades. These window blinds and shades (called "shades" for brevity) give occupants a level of much-needed control over a window.

However, studies have documented that occupants are far from ideal in the way they operate window shades. A recent study from University of Oregon (Nezamdoost and Wymelenberg 2017) documented manual operation of window shades from six high-rise commercial buildings, found that 51percent of occupants did not change their window shades position even once. Only six percent of users were actively adjusting shades daily; 24% were seasonal users; and the remaining 20 percent only adjust the shades once or so annually. Another study funded by Pacific Gas and Electric Company of California (Saxena, Berkland and Turnbull 2014) found that individuals have

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different reasons, based on their unique preferences or priorities, to operate shades. Some leave the shades down most of the time to reduce the need to move them every few hours, while others leave them open because they "like the view" or are not bothered by the sun for a few hours on their desks and computer screens. At times, occupants may leave window shades either open or closed for days or months, simply because they do not have easy access to the shade controller or find it too cumbersome to change. All this results in suboptimal conditions – for both the occupants, as well as the building mechanical systems that are designed to provide comfortable lighting or thermal conditions for them.

2.1 Energy Benefits of Shades Automation

By automating the operation of window shades, one can reduce the need for occupants to consistently produce an optimal indoor environmental condition in the building. Automation takes much of the unpredictability out of the equation. This results in more reliable and predictable indoor environmental conditions, such as:

- **Indoor illuminance** – Window shades can be deployed only when direct beam sunlight hits a window, converting it to useful, diffuse daylight. The shades can then be retracted when the sun has moved away from the façade to restore views and admit diffuse light from the sky. Over the course of a typical day, this can result in a reduced swing from "too bright" to "too dim" conditions. Automated shades can thus effectively result in a more consistently uniform daylit space.

- **Occupant Comfort** – As window shades are automatically deployed to block direct sun, they reduce the windows solar heat gain that can be uncomfortable for occupants, especially for those near the window. This can have significant positive consequences for occupant comfort and productivity. It can also lead to fewer complaints from occupants – either in the perimeter zones or the core zone – about the building being "too hot" or "too cold" as the automated shades effectively produce a more uniform thermal environment.

- **Building Envelope Heat Exchange** – Automated window shades reduce solar heat gain more consistently and predictable than manually operated shades. Since the heat exchange from the building envelope can now be predicted more reliably, the HVAC systems can be designed and sized accordingly. This can lead to significant energy and peak demand savings, as well as savings in first costs resulting from smaller sized HVAC systems.

Automated window shades add reliability and ensure the successful operation of electric lighting systems in buildings by adding controls for daylight harvesting.

As discussed earlier, when shades are automatically deployed at the right time, they can block and diffuse direct beam sunlight, turning it into useful daylight illuminance. This can displace the need for electric lighting, thus resulting in energy savings and peak demand reduction from electric lighting. Automated shades also allow the window to transfer naturally diffuse light from the sky or when the sun is behind clouds, adding to the lighting energy savings.

In the absence of automated window shades, window shades operation is unpredictable. This can result in the room being sometime "too bright", especially near the windows – when shades are left open exposing the window to direct sunlight, or "too dim" when shades are left closed while naturally diffuse daylight is available. This situation is further complicated by the fact that in a larger open room multiple windows on the same wall can have shades in different positions. This results in uneven levels of daylight across the same room even when the outdoor conditions on those windows are the same.

This situation presents an extremely challenging environment for daylighting controls to perform optimally. In field studies we see evidence of daylit spaces producing energy savings that are much lower than expected, as well as many cases of disabled photocontrols. A large field study of 123 building with windows and daylighting controls funded by the Northwest Energy Efficiency Alliance from 2005 (Heschong Mahone Group 2005) found that only 23 percent of the expected lighting energy savings from daylighting controls in sidelit daylit spaces were being realized on-site. Additionally, the study found that in 52 percent of the spaces, photocontrols had been disabled or were non-functional.

We postulate that eliminating the unpredictability and the non-uniform daylight levels with automated shades can result in a lighting environment that is much more suitable for the successful operation of daylighting controls. This will result in increased realized energy savings from daylighting controls. With greater uniformity in light levels, the electric lights will not need to dim or switch as often and as severely as they would without automated shades, which is one of the leading reasons occupants complain and request disabling of daylighting controls. A greater acceptance from occupants will then increase the acceptance and continued use of the daylighting controls.

These were conclusions of an emerging technologies evaluation report funded by Pacific Gas and Electric Company (TRC Energy Services 2014), which documented the energy savings potential of automated shades, compared to manually operated shades for an open office situation. The study measured on-field daylight levels continuously for several months in two similar side-by-side open offices and found that the consistent daylight levels delivered by automated shades could increase lighting energy savings by 37 percent above those with manually operated window shades.

Perhaps the most well documented example of energy savings from automated shades is the New York Times building in Manhattan, which incorporated an advanced sun tracking and glare management system to automated shades across the curtain wall façade of the building. Studies since the building was first occupied in 2007 have documented energy savings from dimming controls (daylighting and setpoint tuning) of 20 percent relative to an ASHRAE 90.1-2007 baseline (Fernandes, et al. 2013). This project used a control system with a high degree of sophistication. It certainly isn't indicative of what one must use on all automated shade projects, but clearly illustrates what could be achieved in energy savings by utilizing such technology, even in a simpler form.

2.2 Productivity Benefits of Shades Automation

While these benefits of energy savings from automated shades can be substantial, the benefit of greater productivity for the building occupants can easily dwarf those of energy savings. A rule of thumb is that an organization pays per square foot, in terms of total occupancy costs: $3 for utilities, $30 for rent and $300 for their employees' salaries and benefits (Jones Lang LaSalle, Inc. 2016). This is widely known as the '3-30-300 Rule'. Building designers and facility managers typically focus on the 3 and 30 portion, utilities and rent, as the area they can make the largest impact. However, any improvements made to a building that increase employee productivity directly impacts the 300 portion and can be substantial. In other words, if we can put people in an indoor environment that improves their productivity by 10 percent, then 10 percent of 300 is savings equal to the cost of rent!

Several well-regarded studies (Loftness, et al. 2003) have shown that well daylit environments, especially those that are free of disturbing glare, can result in increased productivity. A California Energy Commission – Public Interest Energy Research study (Heschong Mahone Group 2003) found that having access to views from windows, more daylight, and less glare were all consistently associated with better office worker performance. Call center workers were found to process calls six percent to 12 percent faster, while office workers were found to perform 10 percent to 25 percent better on tests of mental function and memory recall. On the flip side, greater glare potential was associated with worse office worker performance, with their scores on mental function and memory recall tests dropping by 15 percent to 21 percent.

Another complimentary study on daylighting and student performance (Heschong Mahone Group 2003) found that students in daylit classrooms progressed 7% to 21% faster, year-to-year than those in non-daylit classrooms. The study looked at test scores from math and reading for 8,000, third through sixth grade students in 450 classrooms. Very interestingly, the study also found that "better view out of windows" resulted in a positive impact, while "glare, sun penetration and lack of visual controls" resulted in a negative impact on the statistical model's outcome of student performance. Importantly, both these are features that can be controlled and optimized using automated shades.

Continental Automated Buildings Association (CABA) funded a research study(Newsham, *et al.* 2017) entitled *Improving Organizational Productivity with Building Automation Systems*. This study found that "better buildings" strategies that typically incorporate building automation have positive effects on multiple organizational productivity metrics, which were on par with other corporate strategies affecting employee health, well-being, and performance. The study conducted by the National Research Council of Canada, studied more than 4,000 abstracts and 500 peer-reviewed publications on the effects of various productivity metrics. The researchers found that buildings featuring building automation can result in lower employee absenteeism, lower employee turnover, and increased self-assessed performance and increase job satisfaction. By quantifying these effects, the study provides a means to monetize these benefits and to make a compelling case for automated shades to building owners and corporations.

3. INCORPORATING AUTOMATED SHADES IN BUILDING DESIGN

While the efficiencies and health benefits from good daylighting design delivered by automated shades are desired by all, incorporating an efficient automated shading system into a building project may seem overwhelming to those who are approaching these projects for the first time. Some basic ideas and concepts of how automated shading systems can be designed are provided here as resources for architects, building owners, and designers.

Aside from the functional requirements of each building based on intended use (i.e., hospitals, schools, office, retail, museums, and so on), the following three considerations should be proposed when starting a project:

1. How will the shades be automated and to what extent?

2. Will occupants need override control? And to what extent?
3. What is the appropriate shade material to interact with the glass in order to provide the desired effect?

For autonomous control of shades, there are different levels of control at different price points. At the high-end of the automated shade spectrum, there are robust control systems that not only account for the actual position of the sun (sometimes referred to as sun tracking), but also the shade created by adjacent buildings, and other permanent objects such as trees that shade the subject building. These high-end control systems make incremental shade adjustments based on the profile and azimuth of the sun and shadows cast on the building façade. Even cloudy conditions are detected by these systems, and the shades are programmed to adjust accordingly. At the other end of the spectrum, shades can be easily and effectively controlled with simple timers and solar sensors attached to the glass. Although lacking some of the nuanced adjustments that sun tracking provides, these systems tend to perform well in spaces such as hotel lobbies, libraries, or airport concourses where there are transient occupants who are less likely to be bothered by a few intermittent conditions of glare or direct sun that inevitably occur. Shades can also be controlled through most building automation systems that are also controlling the buildings HVAC, security, and lighting using protocols such as BACnet, LonMark, Modbus, etc. While some automated-shade manufacturers have proprietary control systems, most shade motors (sometimes called drives) today will integrate with most of these automation systems. The integration of shades into these building control systems allows the shades to be controlled in tandem with other building systems, such as heating and cooling, electric lighting, and ventilation. This integration opens opportunities for interoperable systems and system-wide optimized operation.

While automation can manage the task of moving the shade for most conditions, there are still unpredictable or programmatic situations where occupants will need to override the automation with manual controls. Therefore, it is important to discuss the requirements for manual override that should be provided for every building project. Most automated-shade manufacturers provide options for override that can last a couple of hours to an entire day. Some manufactures even provide “smart” or “learning” systems, which can learn to control shades better based on initial overrides by occupants. These systems are likely to get even smarter as the field of Artificial Intelligence develops.

Of equal importance to the motors and automation is the selection of the shading material. Like motors and automation, advancements in shading materials have improved performance significantly. Low emissivity coatings and materials can selectively reject near-infrared radiation. There are also new dual-sided metalized shade materials where, regardless of the color of

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the shade facing the inside of the room, the side facing the sun is coated with aluminum. This reflects and scatters a large portion of the full solar spectrum back out through the glass before it is absorbed and converted to heat inside the building. The terms long and short-wave energy are often used when describing the interaction between glass and shading material. Simply put, most types of glass will let most of the short-wave radiation (heat associated with sun light) through, but block most of the long-wave radiation (warmth associated with a heated object). This results in what is commonly known as the greenhouse effect – where short-wave radiation from the sun gets into the building through the window glass, and once absorbed by the building interior, converts to long-wave radiation, which cannot escape back out through the glass. Although counterintuitive, it is not necessarily true that incorporating high-performance glass with a high-performing shade material (the glass and shade combined is referred to as the fenestration assembly) will create a "super" high-performing fenestration assembly.

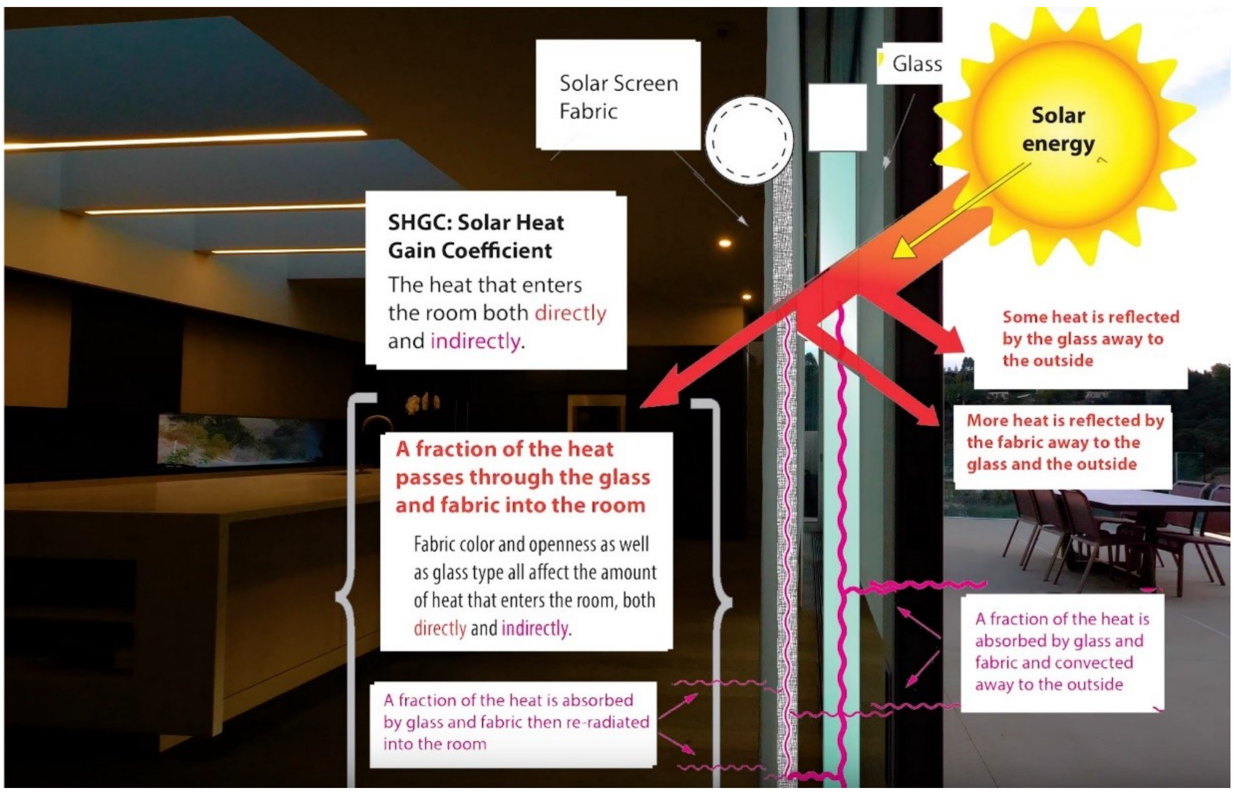
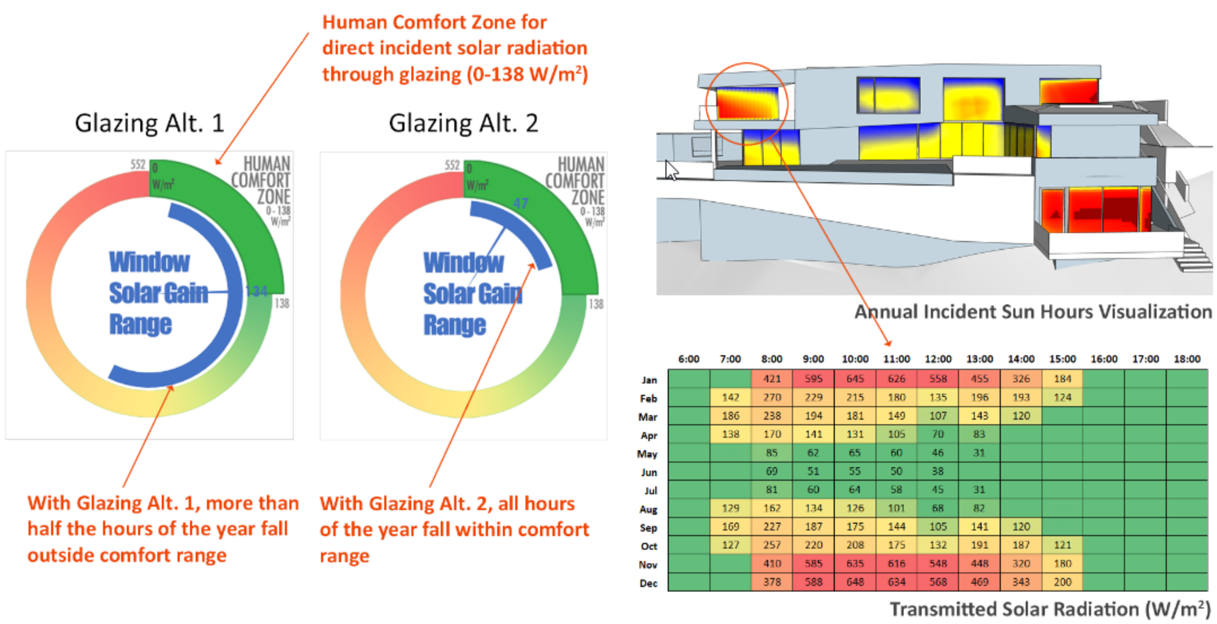


Figure 1: Understanding heat exchange between glass and shade is critical to designing a good fenestration assembly (Image courtesy – Window Products Management, Inc.)

For example, if the goal is to reduce direct solar heat gain through the glass to improve comfort and reduce cooling load, some glazing materials that have been heavily tinted, or that have coatings designed to reduce the sun's penetration, can now work against reflecting the sun back out through the glass with a high-performance shade material. Often times, the individuals selecting the shade materials are not well informed about the heat exchange between the glass and the shades, nor do they understand the performance values of the materials. This is unfortunate, not only because it leads to underperforming assemblies, but because it is avoidable if professionals are employed who understand how these materials work together. Often times, high-performing assemblies are no more expensive than low-preforming assemblies; it is just a matter of knowing what materials to combine. One of the most underutilized tools at the design stage are computer simulation tools such as WINDOW, COMFEN, RESFEN, Radiance and AERCalc (LBNL 2019), that focus on the performance of the fenestration assembly. These simulations not only provide an indication of how the building will behave with respect to light, heat, and glare through the glass, but they can also perform side-by-side fenestration assembly comparisons so that the building designers can see what combinations of glass and shade material will perform the best. They are also extremely useful in determining where shades should be installed and when they should be operated. Beyond comfort, simulations are also useful for retail stores where businesses display products that might fail when they are exposed to direct sun by overheating, such as smart phones and computers. These businesses cannot present their products to the public if they can't be turned on. Identifying solar heat problems at the conceptual stage, and then designing shading systems into the architecture to mitigate equipment failures makes the relatively low-cost of these simulations well worth the investment.



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Jan			421	595	645	626	558	455	326	184			
Feb		142	270	229	215	180	135	196	193	124			
Mar		186	238	194	181	149	107	143	120				
Apr		138	170	141	131	105	70	83					
May			85	62	65	60	46	31					
Jun			69	51	55	50	38						
Jul			81	60	64	58	45	31					
Aug		129	162	134	126	101	68	82					
Sep		169	227	187	175	144	105	141	120				
Oct		127	257	220	208	175	132	191	187	121			
Nov			410	585	635	616	548	448	320	180			
Dec			378	588	648	634	568	469	343	200			

Figure 2: Computer simulation-based analysis can provide actionable information to make design choices for glazings, shades and automation (Image courtesy – Vistar Energy Consulting)

Here is a summary of considerations before starting your project:

- **Specify Materials and Identify Shade Locations using Computer Simulations** – As discussed, integrating different "high performance" glass and shade materials do not necessarily net a "super" high performing fenestration (window) assembly. The best performing automated shading systems are planned at the conceptual or design stage and consider the entire fenestration assembly interacting as a whole. In order to achieve optimum glass and shade performance, the most advanced designs rely on computer simulations that analyze various shade and glass combinations to help the team specify materials that complement each other. Simulations are also useful in identifying where shades should be located, as well as providing invaluable operating information – when the shades should be raised and lowered to achieve the greatest control over direct beam sunlight, while allowing desirable diffuse sunlight into the building when the windows are not sun-struck.

- **Consider Team Experience and Knowledge** - If the team designing the building does not have experience working in the field of fenestration or automated shading systems, it would be beneficial to find a consultant or contractor who can offer advice and experience working with different manufacturers, suppliers, and systems. Aside from performance and functionality, the team should also consider cost, quality, inventories, and technical support during and after construction. Contractors performing the work should be certified by the shade motor supplier or shade manufacturer selected for the project to assure that they are familiar with each system and have the expertise to perform the work. On projects where shades are being integrated with complex control systems, the motor manufacturer or third-party consultant, may be involved in the commissioning of the shades. Commissioning involves the incorporation of the shades with the automation system so that each shade will independently (or in groups) follow preprogrammed commands based on the location of the sun or other predetermined requirements. There are also less complicated automation approaches that will not require commissioning based on the budget and level of control desired. As mentioned above, window shade motors, coupled with sophisticated automation systems, have the ability to move shades incrementally so that only the portion of glass that needs shading is covered; and depending on the orientation of the window, it may be possible to maintain views while at the same time shading direct sunlight. Building the right team of people around your automated shade project is the first step toward designing and implementing a successful installation.

- **Consider Different Shade Materials, Motors and Automation Systems** – It is important to keep in mind that there is no one "best" motor, shade material, or manufacturer that will address every fenestration challenge. Some design professionals become comfortable working with, or representing, the same products and manufacturers on a repetitive basis and therefore do not look for other sources. We suggest encouraging the design team to explore different options, materials, and manufacturers to find the best fit for their project. Some automated roller shade manufacturers only provide the shade materials that they sample and are either unaware or unwilling to work on a COM (customer's own material) basis. This is unfortunate, because many of the most architectural and high performing shade materials are not sampled, and unless your building designer knows where to source them, the team will not know they exist.

4. TECHNOLOGY ADVANCES IN AUTOMATED SHADES

Technology has advanced in the shade motor industry so that motors are not only "smarter," they are also smaller and quieter. Generally speaking, a smart motor is one that not only accepts a command to move but also communicates back to the control system where it is in the process. As a result, someone controlling a shade on another floor of their building, or at another elevation, will know if the shade followed the command and where it has come to rest in the window. Older "dumb" motors only accept a command, and while these motors are still in use today, they do not possess the same level of functionality that their smart counterparts do, because while they can "hear," they cannot "speak."

Other advancements include battery powered motors that provide more force to displace larger material bands allowing building designers the opportunity to cover more glass with fewer motors. This reduces the cost of motorization. Although not a solution for every commercial application, because there may be control and distance limitations, battery powered shades that receive commands via radio frequency signals can eliminate both power and data wires. Battery powered motors are now available that can be recharged by plugging them into a standard wall receptacle and, depending on the type of glass in the building and the window orientation to the sun, the batteries can be charged by photovoltaic cells that are placed in the window.

Hard-wired motors (either standard building current or stepped-down low-voltage power) can drive larger shades than any battery motor and therefore reduce the amount of motors needed to cover large glass window walls. Motorized shades can also drive bands of material coupled together on non-motorized shades much like a locomotive pulling a train. But rather than pulling the line of coupled shades behind it, the lead motorized shade turns a series of shades using just one motor. This design greatly reduces the amount of motors needed to cover a wide span of glass.

Another technology advancement is the onset of Power over Ethernet (PoE) to control shades. This new technology provides a truly “plug-and-play” function using Ethernet cable to deliver both networking data as well as the power needed to operate the automated shade motors. The ability to provide both network addressability for shade motors in a building-wide network, and the significant cost reductions that come from eliminating the need to run line voltage power cables, makes this a very promising technology. This is especially useful in retrofit projects, where access to existing power outlets near windows has been a significant limitation. Since network cables do not require a qualified electrician and can be located anywhere, the system can be set up entirely by the contractor providing the automated shading system.

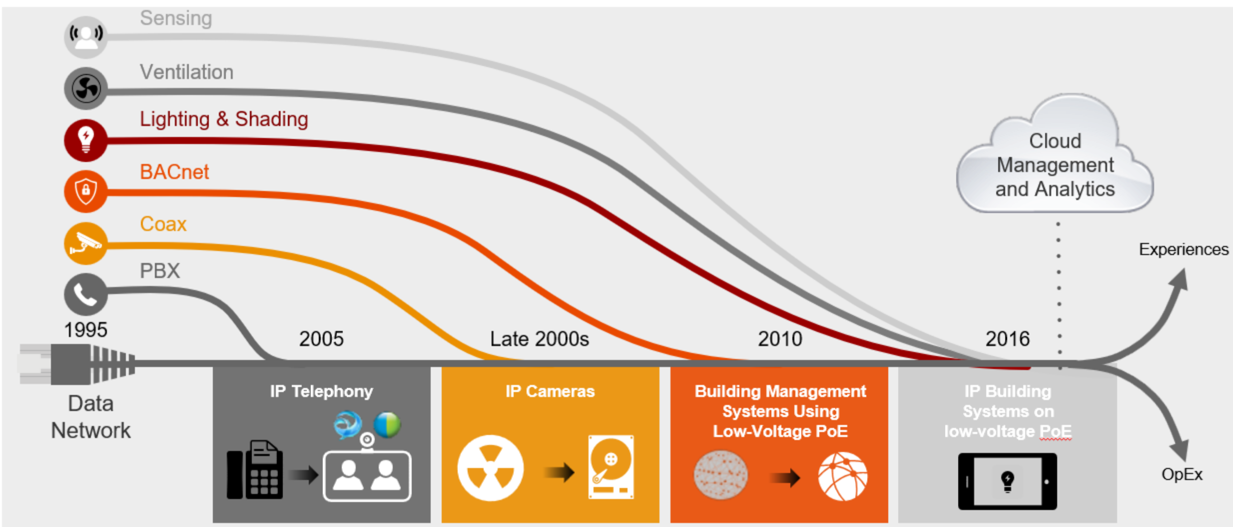

Figure 3: Convergence of various building function to a data network, including automated shades, has the potential to drive digital building applications of the future (Image courtesy – Somfy Systems, Inc.)

There is a control system for most every budget, and while they have varying degrees of functionality, they will all get the job done. Regardless of what system is employed, automation is a better alternative than leaving shade control in the hands of the people who occupy the building. Imagine life without a thermostat controlling your HVAC system, where keeping the room temperature at a comfortable constant would require someone manually turning the system on and off throughout the day. As burdensome as this would be, it seems equally illogical to people who understand the benefits of automating shades to imagine a building full of people all acting in harmony to raise and lower shades efficiently, when in fact we know that they will not. Automating the shades is the solution.

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There was a special presentation on this White Paper at a recent Intelligent Building Council (IBC) webinar. The presentation slides and webinar recording can be found at: www.caba.org/ibc.

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