Building Controls Integration for Comfort and Energy Efficiency

By Konstantinos Papamichael and Nicole Graeber

In the earliest days of architecture, strategies like daylight harvesting and natural ventilation were the driving forces in shaping buildings to work effectively in their microclimate. Local sun paths and prevailing winds were key considerations for the design of daylight apertures in terms of orientation and shading devices, to provide illumination, ventilation, and natural heating and cooling, while minimizing glare and unwanted solar heat gain.

The introduction of electric lighting and HVAC systems had a dramatic effect on building design and construction, making daylight harvesting and natural ventilation, cooling and heating obsolete. Daylight harvesting was limited to providing view through low-transmittance glazings, which also took care of important daylight harvesting challenges, such as glare and thermal discomfort from direct solar radiation.

It wasn't until the energy crises of the 1970s that the traditional architectural strategies were revived, and during the last four decades they have been increasingly incentivized by energy efficiency programs or required by building codes. While the strategies remain the same, the technologies to realize them have changed dramatically. Today's technologies have the potential to realize comfort and energy efficiency optimization, through integration of controls for dynamic fenestration (windows and skylights), electric lighting and HVAC systems.

MANUAL AND AUTOMATIC

Controls integration is essential for optimizing comfort and energy efficiency, addressing not only interactions among different systems, but also harmonization of manual and automated operation of dynamic systems. Manual operation is most important as occupants should be able to adjust fenestration, electric lighting and HVAC systems based on their needs and desires. However, it has very limited effectiveness for energy efficiency, for two reasons:

- Most often, occupants respond to nuisances but not to opportunities, i.e., they adjust shading systems to block unwanted direct solar penetration, which often results in lower daylight levels and potentially increased electric lighting, but they do not readjust shading systems after the sun penetration ends, to admit more daylight and reduce electric lighting output. The same is true when occupants adjust shading systems for different needs or desires, such as privacy and view, and leave them in that state after the need or desire has passed.
- Most often, adjustments to fenestration, electric lighting and HVAC for energy efficiency are needed during vacancy, i.e., during periods that there are no occupants in the space, including nighttime and weekends.

Automated controls are thus essential for energy efficiency and can also address nuisance situations, such as glare and solar heat gain, through appropriate sensing of environmental conditions. Automated controls for electric lighting and HVAC controls are relatively simple and autonomous, as effective operation requires sensing light levels and temperature, respectively. In contrast, fenestration controls are significantly more complicated, as effective operation requires knowledge of the status of the electric lighting and HVAC systems, and also the potential for daylight glare from direct solar radiation.

Today's controls and communications technologies have the potential to achieve complete building controls integration. However, such integration happens only in high-profile buildings that have the required budget, knowledge and expertise to bring all systems together, as individual systems are usually developed to operate independently.

The California Lighting Technology Center (CLTC) is engaged in research and development that aims to make building integrated controls common practice. The efforts are focused on integrating existing commercial fenestration, lighting, HVAC and controls technologies, through development of control algorithms that harmonize manual and automated operation considering indoor and outdoor en-

Figure 1. CLTC's Integrated Building Controls Laboratory (IBCL), shown without wall elements on the façade to allow view of the daylight-changes simulator.

Figure 2. IBCL setup with added wall segments for the development of the integrated controls algorithms.

vironmental conditions, including the state of each individual system.

ALGORITHMS DEVELOPMENT

The development of the integrated building controls is taking place in CLTC's Integrated Building Controls Laboratory (IBCL), which includes a space that is large enough to represent a single open office space or two individual office spaces, along with an internal façade that can accommodate windows of different shapes and sizes (**Figure 1** and **2**).

The façade is illuminated by an array of individually dimmable linear fluorescent lamps, which are mounted on a wall facing the façade. The lamps are controlled by a computer to simulate various scenarios of daylight changes, such as sunrise, sunset and partly cloudy sky conditions. IBCL also accommodates a skylight, which is illuminated by a separate array of linear fluorescent lamps mounted above it, which are synchronized to the wall lamp array.

Development of the integrated controls algorithms is focusing on harmonizing manual and automated control of four dimmable LED luminaires controlled by a room controller, two electrochromic glass panes, an operable window with a rolling screen shade between glazings, an operable skylight with a rolling opaque shade and a dedicated HVAC unit. The configuration also includes motion, photo and temperature sensors, which provide information about indoor and outdoor conditions that is critical for reliable automated operation. The automated and manual controls interfaces are shown in **Figures 3** and **4**, respectively.

The key criterion for selecting the individual systems was support for the BACnet MSTP communication protocol, which is commonly used in the buildings management industry (*www.bacnet.org*). A Java application control engine (JACE) is used as the primary system controller due to its ability to collect all components' operating status and its well-documented and versatile programming structure. The system control logic is developed using the Niagara framework software (*www.tridium.com*), which is embedded in JACE. The integration is based on a simple overall control strategy that prioritizes comfort during occupancy and energy efficiency during vacancy.

AUTOMATED OPERATION

Vacancy. Automated operation during vacancy is relatively easy, as all systems are set to extreme states that minimize energy requirements,

Figure 3. Automated control hardware in the IBCL.

Figure 4. Manual control hardware in the IBCL.

i.e., electric lighting is turned off or to a minimum, and windows and skylights are set to maximum or minimum solar heat gain, to reduce heating or cooling loads, respectively. Natural ventilation and cooling are also set for nighttime, based on the difference between indoor and outdoor thermal conditions.

Occupancy. Automated operation during occupancy is significantly more complicated. Electric lighting operation is based on indoor daylight levels, and HVAC operation is based on indoor temperature. Window and skylight operation is focused on adjusting daylight transmission, based on the state of the electric lighting and HVAC systems, and also the potential for glare from direct solar penetration, which is determined from the signals of the networked photo sensors. Glare prevention takes priority, followed by the state of the electric lighting and the HVAC system. Daylight transmission is maximized while there is no potential for glare and the electric lighting is on or above its minimum output. After the electric lighting is minimized, daylight transmittance is adjusted based on the status of the HVAC. During heating periods the daylight transmittance is kept to a maximum level that does not produce glare. During cooling periods the transmittance is adjusted to maintain interior light levels at which the electric lighting reached its minimum or off state.

ISSUES AND CHALLENGES

There are two key issues that are being addressed during development of the algorithms. The first is reliability in determining indoor and outdoor conditions, which is very much related to sensing. The second is the harmonization of manual and automated operation, which applies to all systems, i.e., lighting, fenestration and HVAC.

CLTC has been conducting research and development on increasing reliability in determining environmental conditions, such as occupancy and daylight changes, since 2005. Both have been successfully resolved through redundant sensing, i.e., using signals from multiple motion and photo sensors to determine occupancy and daylight changes, respectively. CLTC has also developed algorithms for automated, continuous calibration of photo sensors, which account for long- and short-term changes in the controlled space, such as changes in the geometry and reflectance of interior surfaces and moving occupants, respectively. These approaches have been tested successfully in the laboratory in the past, for both electric lighting and fenestration controls.

Harmonization of manual and automated operation is more challenging. The key issue is developing criteria to switch from manual to automated operation, when the manual operation results in increased energy requirements. Potential resolutions include combinations of occupancy/vacancy states, time delays and ramping functions. Ideally a variety of options should be included, along with support for easy customization by occupants.

COMMERCIAL POTENTIAL

The results of these research and development efforts will be high-level algorithmic models that achieve the desired optimization of comfort and energy efficiency. Implementation of these algorithms can vary significantly in commercial offerings. While the current configuration will certainly be directly applicable to space-level applications, the same results can be achieved with different configurations that have the potential to be easier to install, significantly less expensive and more reliable.

The current IBCL configuration is using a single main logic controller to make decisions and send commands to individual systems based on their state and the signals from the sensors. While this approach can certainly work, it requires commissioning in terms of sensor placement, zoning of luminaires and windows, etc. Alternatively, the same algorithmic approaches can be implemented to work with "smart" luminaires, windows and skylights, each of which has its own logic controller, sensors that sense their immediate environment and communication capabilities to be networked for space-level operation.

The smart components approach can be significantly less expensive, because it dramatically reduces commissioning, especially the positioning of sensors, which will be optimized for each component at the factory. Automatic calibration can include establishment of the network and sharing of information so that each individual logic controller has access to all of the information that is relevant for effective and reliable operation of all systems. Smart components also address zoning issues, providing control granularity at the level of individual luminaires and windows, which can further increase comfort and energy efficiency.

CLTC has developed prototypes of smart luminaires and windows in past projects. Unfortunately, there are no available commercial products that can support integration at this point. CLTC plans to realize such integration in the laboratory after key high-level integration issues are being resolved through the current project that is using off-the-shelf commercial products.

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