LUMINAIRE LEVEL LIGHTING CONTROLS AND THE FUTURE OF HEALTHY BUILDINGS

Introduction

Alvar Aalto's Paimio Sanatorium and the effects of the 1918 influenza pandemic on architecture.

It could be argued that we have planned cities and constructed buildings to support human health for millennia. In our recent industrialized history, it is clear to see how the 1918 influenza pandemic sparked a design movement (Modernism) that was co-mingled with increased access to light and air, and elevated awareness of the value of connection to nature, all in an effort to minimize disease transmission [1]. As is often the case throughout human history, the pendulum swung back, as exemplified by the 1973-74 oil embargo and our collective reactions to reduce energy use and therefore force a disconnection with nature by closing the dampers on building ventilation, and shuttering windows [2]. Unsurprisingly, these actions shocked our physiology, what some describe as an evolutionary mismatch, and we quickly observed the dawn of "sick building syndrome" [3,4]. Thankfully, the pendulum is slowly moving back to a focus on human health indoors; however, this time the focus includes a balance of energy efficiency and healthy building standards. A century later, the COVID-19 pandemic has once again increased awareness of the critical role that buildings play in our personal health, well-being, and happiness [5,6,7]. This paper develops a vision for a healthy building future that attempts to balance three critical priorities; 1) the need to dramatically and rapidly reduce building energy consumption to reverse global climate change, and 2) to increase indoor air quality to reduce the risk of indoor disease transmission and 3) to increase overall indoor environmental quality to build up robust human immune function. To avoid repeating history and guard

The 1973 Oil Embargo resulted in building owners and operators minimizing energy use as seen by a reduction in window size.

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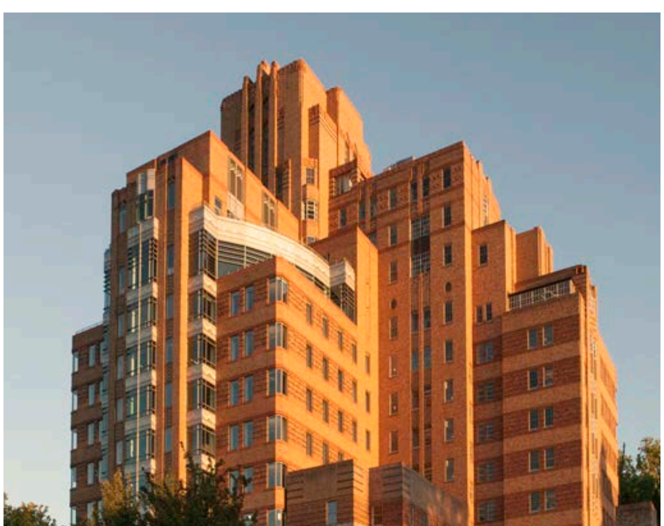
against the possibility of "over-correcting" (overreacting), we pose a vision that balances the use of technology in buildings with the understanding that visceral human connection to nature is an essential part of beneficial human health outcomes and therefore must be woven into healthy buildings. In some respects, we pose that healthy indoor spaces may be measured by how closely they resemble outdoor spaces. Now, here is the plot twist: we explore this nature-enmeshed vision for a healthy building future through the lens of distributed sensors, embedded into novel lighting systems called luminaire level lighting controls.

Luminaire level lighting controls (LLLC) describes lighting systems in which each LED fixture can independently modulate light intensity, apparent color, and sometimes even spectral distribution, often through on-board controllers and sensor packages [8]. This typically includes a single multi-type sensor for occupancy and daylight harvesting, with some also including air temperature sensors. These systems enable high-resolution, responsive lighting control and facilitate nuanced automated approaches. LLLC systems are typically deployed in commercial settings. Because each fixture is capable of sensing and responding to ambient conditions, LLLC systems provide light only where it is needed, saving **significant amounts of energy** while maintaining high levels of occupant comfort [9]. So "what is the big opportunity for healthy buildings," you might ask? It's simple: LLLC have on-board sensors that can be used for far more than controlling light intensity; they can be leveraged to support improved building operation potentially improving both health outcomes and energy savings. They are also inherently distributed throughout buildings due to the spatial resolution required to deliver light and therefore provide a far more useful awareness of indoor environmental parameters than typical building automation system sensors. In this paper we explore potential alternative applications of current LLLC sensor data streams, as well as those that are still in development or show promise for future development, to help us progress toward buildings that support human health and reverse climate change.



LLLC system installed in Pacific Tower, Seattle

Applications of LLLC

LLLC technology is a competitive choice for new construction [9,10]. But, if we want to integrate these technologies to help reverse climate change and support human health broadly, we need to implement them at scale, and that means into existing buildings as well as new construction. A **recent study** was conducted comparing LLLC one-for-one (1:1) retrofits to a full lighting redesign approach. The findings showed that LLLC 1:1 retrofits provided similar energy and light quality performance at roughly one-third of the cost of a full lighting retrofit [9]. The energy savings, cost savings, and comfort improvements are reason enough to recommend LLLC, however we believe that these systems can enable an array of secondary applications enhancing occupant comfort, safety, and operational efficiency. LLLC systems provide fine-grained occupancy data which could be used to optimize HVAC and dynamic facade controls or improve security. Paired with Wi-Fi or Bluetooth connections, luminaires could help track assets or facilitate spatially resolved contact tracing. Low-resolution infrared or visual cameras could supplement fire detection systems or help fine-tune visual and thermal comfort [11]. In this paper, we will explore the potential of these different information streams.

Existing applications of LLLC technology are mainly centered around automated lighting controls in commercial office spaces and schools with the primary goal of optimizing energy consumption while maintaining comfortable lighting levels and quality for occupants. Occupancy sensing has been a widely adopted and studied control strategy that has enabled significant lighting energy savings in modern commercial buildings and residential homes [12]. Daylight harvesting has enjoyed a similar profile, although it has been primarily applied in the commercial sector. Given the prevalence and advancement of occupancy sensing and daylight harvesting over the past few decades, alongside related technologies like Building Automation Systems (BAS), expanding these capabilities to alternate uses has become much more realistic.

LLLC system installed in Pacific Tower, Seattle

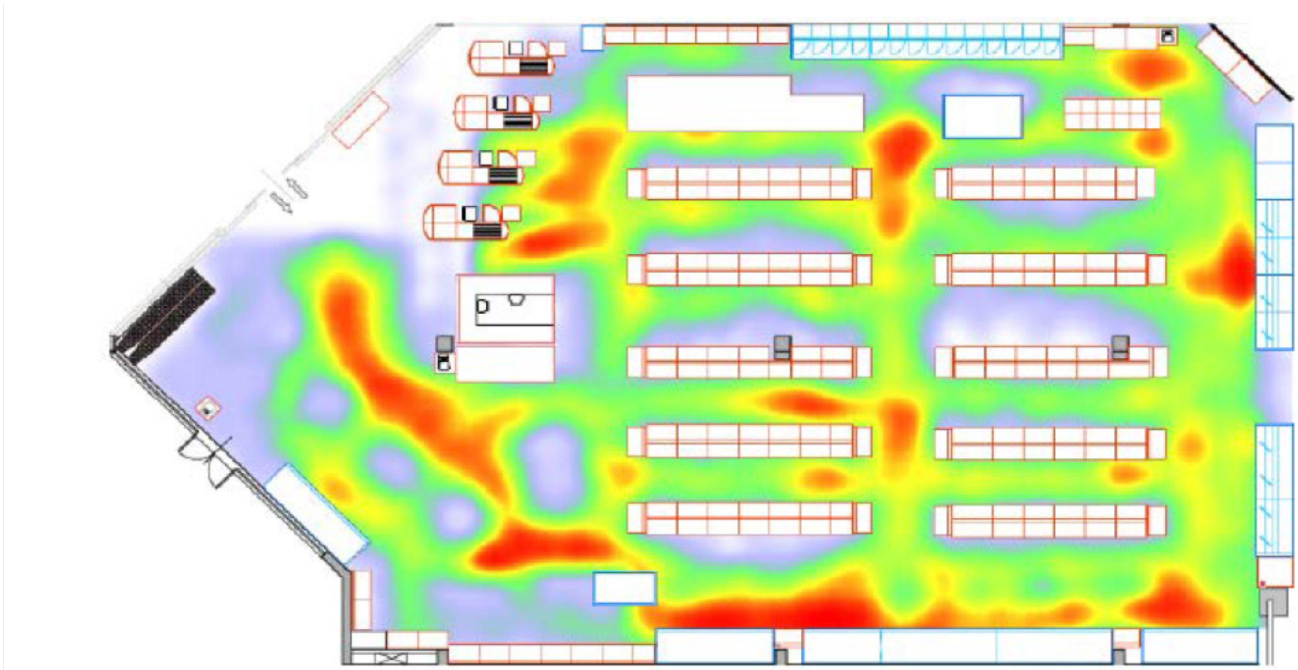
LLLC technology has potential to serve as an apparatus (network backbone) that can facilitate communication between controls logic, building systems, and various environmental sensing technologies via the LLLC distributed sensor network. Compared to more comprehensive networked lighting control (NLC) systems, LLLC offers a low touch and cost-effective alternative approach to maintain updated distributed sensors in buildings [9]. LLLC also has the potential to support additional technology innovations, some of which are outlined in Table 1. While this would also require standardized protocols for interfacing and networking across manufacturers and products, a form of universal compatibility across LLLC systems would further encourage development of new and emerging building controls technologies and help define the future of healthy buildings. Communicating these potential benefits to manufacturers is paramount as it all depends on their willingness to develop standardized data formatting and interface tools to help pave the way toward a form of universal system integration across the industry.

SUMMARY OF PRESENT AND POTENTIAL FUTURE USES OF LLLC DISTRIBUTED SENSORS IN BUILDINGS

CATEGORY	PRESENT LLLC USE CASE	FUTURE LLLC USE CASE
SPACE UTILIZATION & OPTIMIZATION	• Occupancy sensing and occupant density mapping.	• Scheduling and dynamic alerts for space availability and maintenance needs. • Personalized optimization of circadian exposure dosing.
ASSET TRACKING	• Management of equipment, spaces, and personnel. • Optimization of energy consumption via demand response.	• Plug load control optimization/ automation based on occupancy/ vacancy status, operation schedules, and/or demand response signal. • Equipment utilization rate and status.
SECURITY	• Motion/Infrared/Ultrasonic occupancy/ vacancy sensing.	• Motion/Infrared/Ultrasonic sensor(s) for security alerts and security systems.
SAFETY	• Automated switching lighting and equipment to prevent hazards in and around buildings. (Emergency lighting, path/circulation lighting to avoid tripping hazards and improve visibility)	• Camera-based motion sensing with frame-by-frame pattern recognition. (Fire/smoke detection) • AI-based pattern recognition of faces, figures, and objects for more complex environmental monitoring.
VENTILATION & THERMAL COMFORT	• LLLC not integrated with HVAC controls.	• Demand predictive and demand responsive ventilation. • Thermal mapping and dynamic setpoint control via distributed air temperature sensors.
VISUAL COMFORT & CIRCADIAN DOSING	• Illuminance sensors not utilized for visual comfort or circadian dose management. • Luminance cameras are not incorporated into LLLC fixtures/system.	• In-fixture camera-based sensors and integrate secondary devices with available cameras incorporated into sensor network. (Laptops and smartphones) • Monitoring of indoor glare and controlling dynamic blinds/shades. • Monitor light intensity and spectrum for circadian dose.

SPACE UTILIZATION & OPTIMIZATION

The modern workplace is becoming increasingly decentralized as workers explore the advantages of working remotely while staying connected via the Internet. However, not all disciplines benefit from the shifting paradigm of remote work. Offices and meeting spaces will most likely remain in demand to support teamwork and effective communication. However, it has been estimated that 30% to 50% of the available space in a typical office building remains unoccupied over the course of a business day [13]. LLLC occupancy data streams can be leveraged to track and optimize space utilization by



Visualizing peak usage areas in a retail setting

giving occupants real-time feedback on space availability via occupancy/vacancy tracking. This is often referred to as "hot desking" or "hoteling" of private and open offices, as well as other shared spaces like conference rooms and classrooms. Successful implementation of these strategies makes it possible to reduce energy consumption by increasing space use efficiency. For example, specific wings or zones of a building can be prioritized for increased utilization to allow other zones to have wider temperature deadbands and avoid tripping on other occupant-centric energy loads.

If automated guided space utilization is not appropriate, a more basic space utilization approach with near real-time BAS control response to occupancy shifts can help optimize energy consumption of electric lighting dimming/switching, HVAC operation, and plug loads. Likewise, occupancy signals can provide space utilization trends and occupant density mapping to guide targeted maintenance of spaces and reduce the personnel cost of cleaning crews. Space utilization trends could also be leveraged to evaluate spatial needs over time and reduce leasing costs of under-utilized real estate. Finally, as noted above, real-time occupant counting and mapping can support dynamic zonal occupant density allowances based upon community risk thresholds for pathogen transmission.

ASSET TRACKING AND SITUATIONAL AWARENESS

Intelligent building asset management holds the potential to optimize utilization of costly resources, especially space and objects, and can be facilitated through an integration of LLLC and BAS. Quickly locating movable equipment (AV carts, wheelchairs, etc.) and available equipment and space (empty conference rooms, available "hot desks", etc.) can support improved equipment and space utilization, and save staff time. In some settings, wearable devices or smartphones can be integrated to improve awareness of employee work patterns and exposures to thermal and illumination conditions. Potentially, wearable devices could also track exposures to toxicants or biological agents. Asset tracking strategies can also support improved situational awareness in emergency events (fire, active shooter, pathogen exposure). In non-emergent situations, which will be far more common, these strategies can support more efficient business operations, and have the potential to save energy.

LLLC can be used for tracking medical carts in hospitals and senior living facilities, or tracking machinery in industrial and warehouse settings.

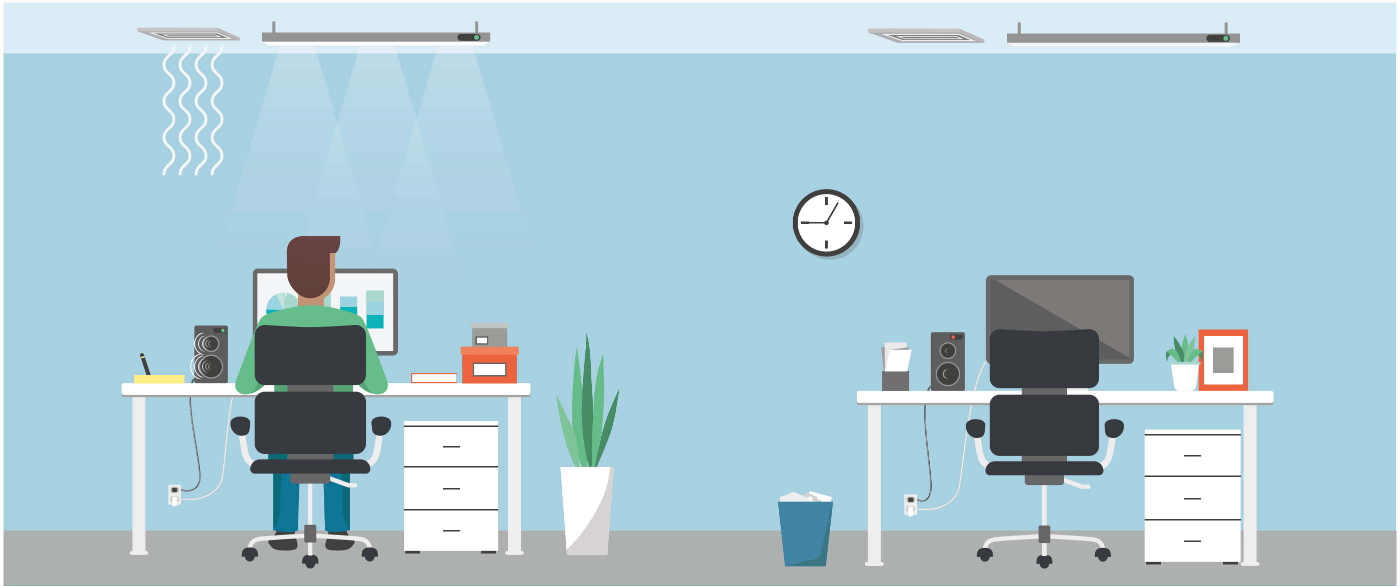
"Demand response" is an energy optimization approach that takes advantage of active feedback from electric utilities to shift a building's electricity usage to avoid peak consumption and take advantage of favorable time-based pricing and financial incentives. If integrated with LLLC and BAS, these demand response signals can be effectively communicated with building occupants to guide further behavioral actions or improve acceptance of automated controls. For example, subtle indicator lights could be integrated into overhead light fixtures, or systems furniture, or more information rich content could be displayed on computer screen interfaces to guide user behavior and increase acceptance. These cues could guide behavioral actions related to turning off excess plugged equipment or operate windows or blinds manually, or to make users aware of automated overrides of equipment, lighting, or thermal conditioning. If properly implemented these strategies could promote improved energy-related behaviors to reduce plug loads and increase use of passive strategies like natural ventilation and daylighting, while reducing energy consumption during peak periods. In the event that the BAS automates demand response actions (automated blind operation, electric lighting dimming, increased thermal deadbands or changed setpoints), the increased communication with building users could improve acceptance of these short-term changes to building operation. However, care should be taken so that excessive control overrides do not stretch the thermal or visual comfort zone too far, or for excessive periods of time. This can have substantial negative impacts on occupant comfort, well-being, and potentially even health outcomes, regardless of how well the decisions are communicated. An even better approach would be if the integrated LLLC+BAS platform could allow users to override the automated controls and track these changes to feed a computation learning algorithm that would guide improved automation decisions in the future.

SECURITY & SAFETY

Automatic stairwell lighting and integrated cameras and detectors.

LLLC systems have promising potential to become networking backbones in buildings by facilitating integration between a variety of control systems and sensors. This includes existing technologies already integrated into LLLC solutions, such as occupancy and illuminance-sensing, and emerging technologies such as in-room photo-optical sensors, smartphones, and a variety of wearable devices. These technologies can already be leveraged to support several important functions that are not fully utilized by typical BAS, such as visual comfort and circadian dosing via wearable or workstation specific illuminance-sensing, air quality via occupancy and distributed or wearable CO_2 or VOC sensing, thermal comfort and cardiovascular health monitoring via temperature, heart rate, and other data commonly available via wearables. High Dynamic Range (HDR) imaging can be used to guide improved visual comfort by automating blind controls to manage solar glare or electric lights to minimize glare from electric sources. In total, these data can be used to optimize for health, comfort, or energy utilization; or strike a balance among these priorities.

Additional applications of image-based sensing include luminance and infrared mapping, motion detection, fire/smoke detection, and security monitoring. Outside of occupied hours, occupancy sensors or image-based sensors, could also function to support security measures and monitor for unexpected occupants. This is primarily a programming challenge to take advantage of the existing motion, infrared, and ultrasonic sensing technologies used as occupancy control signals. Utilizing HDR sensors in this manner would require implementation of image and logic processing that is inherently different from HDR-based processing of luminance data. Namely processing methods that are based on object recognition such as human faces, figures, and motion detection between image frames. They often involve machine learning integration and programming and tend to raise concerns around privacy in the workplace and security of the data streams. Intentional use of low-resolution cameras/ lenses is one possible mitigation strategy to curb privacy concerns. However, it presently comes at the cost of sensor accuracy and limits applications that depend on image resolution and detail. Strict network security measures may also ameliorate privacy concerns for some organizations. This can include implementing tamper-resistant hardware, secure coding practices of software (e.g., user input validation and/or user access privileges), network intrusion detection and prevention, use of firewalls, Virtual Private Networks (VPN), and data encryption [14].



Personalized temperature controls at occupied work stations.

HVAC & THERMAL COMFORT

Pairing LLLC and HVAC systems is one of the most promising and readily achievable expanded uses of the technology. Most buildings have separate lighting and air-handling sensing and control systems with little or no cross-communication. This is largely due to lack of intention and lack of communication interoperability. HVAC data is often communicated through Building Automation and Control networks (BACnet) via application programming interface (API) integration. Real-time LLLC data could be integrated through BACnet, which would provide the next level of HVAC integration and facilitate improved occupant counting. Pairing HVAC data streams with the increased spatial (and temporal) resolution available via LLLC data streams, namely occupancy sensing, could significantly improve HVAC responsiveness which is limited with current stand-alone HVAC sensors.

For example, the spatial resolution of distributed occupancy sensors on LLLC fixtures is far more precise than present CO_2 sensing for managing ventilation rate (demand control ventilation). Improved and more real-time occupant density mapping provides tremendous potential to gauge whether a space is at low risk or high risk for pathogen transmission, simply based upon occupant density. This could be an even stronger use case if these occupant counts were paired with any data available from facility efforts pertaining to human disease screening or broader community disease screening. For example, if facility or community human diagnostic disease positive test rate were included as an input to the people counting platform, a reasonable estimate could be made of the likelihood of the building population to include an infected individual at any given point in time.

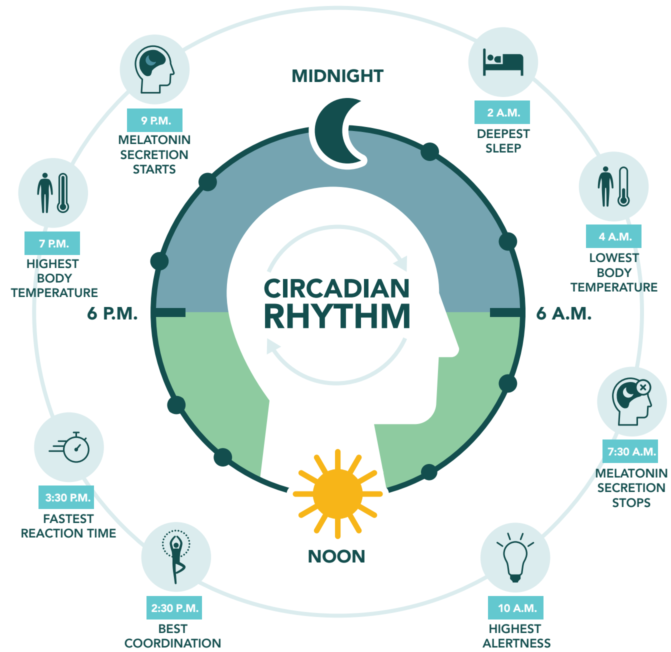
In addition to the future use case of increase pathogen awareness, LLLC+HVAC data integration could improve present management of CO_2 levels. CO_2 levels are impacted by in-room ventilation dynamics, sensor drift, and occupant activity, potentially creating misleading approximations of occupant density and provision of inadequate fresh air. Indoor CO_2 readings also have an inherent time lag as CO_2 accumulates within a space, often taking minutes or hours before elevated thresholds are reached depending on zone volume and occupant density and activity. Instead of waiting for CO_2 sensors to detect heightened concentrations or detect occupancy, LLLC motion sensors and occupant density mapping could gauge occupancy levels and preemptively ramp up ventilation as occupants enter a space, and potentially facilitate predictive ventilation control instead of reactive control. Previous research has shown potential for improving occupant cognitive performance by maintaining lower indoor CO_2 levels [15,16]. Furthermore, improved occupancy responsiveness will also help drive down HVAC energy consumption by limiting the amount of air that needs to be conditioned and moved through a building during periods of low occupancy.

Distributed temperature sensors can be integrated for improved overall space thermal conditioning and occupant comfort. Distributed LLLC sensors are less likely to miss important temperature differences across a single large zone when compared to relatively sparse HVAC temperature control sensors. Zonal temperature set points could be managed dynamically in conjunction with occupant density or spatial and temporal thermal disparities. Simply put, some zones need more dynamic thermal control than is presently possible to realize or anticipate given the spatial resolution of HVAC thermal sensors that is commonly used at present.

LLLC+HVAC data integration can improve ventilation and thermal responsiveness compared to stand-alone systems presently implemented. Improved ventilation responsiveness also holds the potential to reduces indoor disease transmission risk. This is particularly important in healthcare settings like hospitals, clinics, and assisted living facilities that routinely see individuals with a variety of infections. Additionally, elevated ventilation awareness and occupant density would be advantageous to any building type in the event of a public health crisis, such as community spread of an airborne virus. As such, LLLC+HVAC data integration and associated strategies could enable improved performance in general, and dramatically improve the level of readiness for future health crises. This is particularly important in public buildings and the commercial sector, which are presently ill-equipped to respond to the demands of airborne disease transmission.

VISUAL COMFORT & CIRCADIAN DOSING

Integrating cameras and images, or rather luminance-based data capture and mapping using HDR imaging, could be another facet of the next generation of automated controls to improve the accuracy of visual glare detection, promote visual comfort, and optimize circadian dosing for occupants in buildings. These add-on camera modules could be implemented as in-fixture integrated sensors, or auxiliary sensors, that can be positioned independently and connected wirelessly to the LLLC distributed sensor network. It may also be possible to incorporate fixed cameras from secondary devices such as laptops and computer screens. Existing automated lighting controls rely primarily on ceiling-mounted horizontal illuminance sensors, while automated shading controls rely on façade or rooftop illuminance or irradiance sensors. These signals are then used as part of a control system that adjusts electric lighting dimming levels to meet a calibrated illuminance setpoint and close blinds to limit direct sun penetration depth. Conversely, luminance-based sensors focus primarily on the vertical field of view, which is a more accurate proxy for how people experience interior spaces compared to illuminance or irradiance sensors [17,18,19]. Accuracy of image-based luminance sensors can be additionally increased depending on its positioning. The closer it represents the field of view as experienced by occupants, the more accurately it can assess potential perceived glare. An independent Wi-Fi and/or Bluetooth enabled HDR luminance sensor could be integrated with an LLLC system as an optional module, or it could be positioned separately from the system/luminaire for instances where more accurate representation of the vertical field of view is needed.



The circadian rhythm is a natural physiological function associated with the human sleep-wake cycle and exposure to light.

HDR luminance sensors or illuminance sensors in the vertical visual field can be used for active tracking of occupant circadian dosing and provide another layer of information for control decisions for electric lights and automated shades. Circadian dosing is an important factor in optimizing the body's mental and physical processes, and to support restorative sleep. It is most often discussed in the context of alertness, sleep and the sleep-wake cycle. During the day, light exposure prompts the body's internal clock to send signals that keep the body awake and active. In the evenings, lack of light prompts the body to generate melatonin, the hormone that, for humans, promotes sleep. Tracking circadian dosing could be implemented through workstation-specific sensing, or via wearables, and programmed to communicate with LLLC systems via Wi-Fi or Bluetooth. Illuminance sensors presently located in LLLC fixtures can also be used for basic indoor circadian dose mapping but are limited to approximations of circadian exposure based upon the ceiling location. Including vertical illuminance measurements would provide a more accurate representation of areas that most effectively meet circadian dosing needs and can be layered into management and prioritization strategies for shared workspaces. Tracking circadian dose by area or by person could also inform automated operation of blinds/shades or electrochromic ("smart") glazing by adjusting available daylight based upon occupants' circadian needs.

POTENTIAL APPLICATION ACROSS SPACE TYPES

The modularity of LLLC systems offers flexibility of installation and operation, particularly through lighting retrofits and at lower cost than typical lighting redesigns. [9] As such, LLLC can be advantageous in a variety of space types. They have shown substantial energy savings potential in

Applicable spaces include:

Schools

Healthcare Facilities

Warehouses

Offices

commercial and civic office spaces, and are also applicable to schools, healthcare facilities, storage warehouses, and industrial facilities. Similar control logic and networking could be useful in smaller scale residential applications as relevant.

LLLC systems could be used to simplify and standardize lighting design and layouts in a wide range of commercial and education space types that do not often have access to a lighting designer. These include open offices, private offices, conference rooms, classrooms, common spaces, and circulation corridors. Lighting operation can be effectively tailored to each space via task tuning, occupancy sensing and daylight harvesting to suit the unique occupancy patterns of each space while reducing energy consumption overall. Light levels are generally tuned for horizontal (paper-based) tasks and based on ceiling-mounted illuminance sensors, however vertical (computer-based) tasks are just as important, if not more dominant in contemporary commercial spaces. Emerging technologies are exploring how to effectively account for the demands of the vertical visual field, namely via image-based luminance sensing discussed in section 2.5.

In addition to offices and schools, healthcare and senior living spaces could greatly benefit from some of the novel attributes suggested for future LLLC systems by providing additional safety measures and health-related monitoring (or light intervention). Automated control of light to support wayfinding and reduce risk of falls at night, and the management to avoid excessive light and blue light at night to support sleep are some examples. Occupant and asset tracking can be especially helpful for healthcare personnel to keep track of mobile patients and residents in senior care or other healthcare settings, and expensive equipment (wheelchairs, diagnostic carts, etc.) in a range of healthcare settings. Wearable technologies can also be used to monitor vital signs of residents in healthcare settings, which can be integrated via the LLLC distributed sensor network and paired with the BAS to optimize thermal and visual environmental parameters to support overall improved health outcomes. These environmental data can also be paired with other health outcome data in clinical settings to better understand environmentally mediated factors that may correlate with healthcare-associated infections, so long as health outcome data are only integrated in a HIPPA-compliant de-identified manner. Pairing big data about human health outcomes with big data about relevant environmental parameters, together with object and space utilization can help to support improved health outcomes and avoid higher risk operational scenarios.

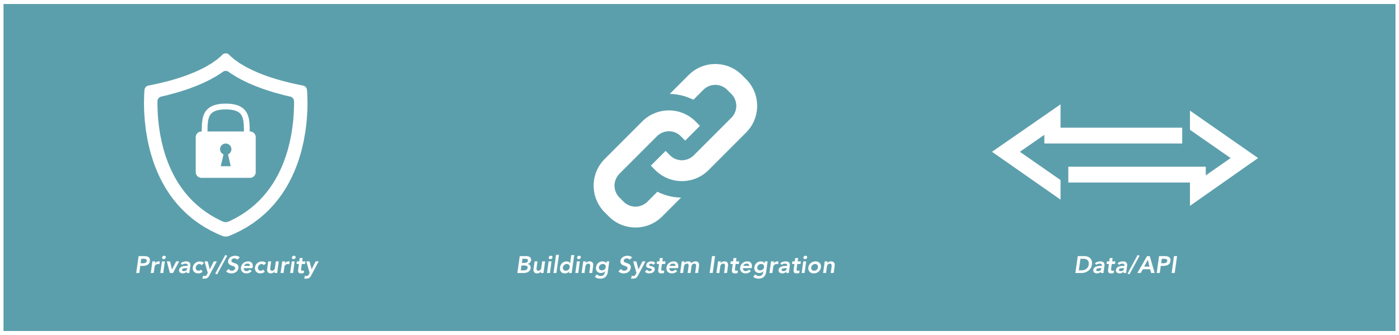
CHALLENGES & NEXT STEPS

One of the more significant technical challenges currently limiting the potential of LLLC systems is the lack of a universal data format and therefore a lack of interoperability across sensors and systems. Many of the current LLLC products on the market keep data and controls in a proprietary "black box" which cannot be accessed directly without substantial modification of the hardware and/or software. Convincing manufacturers to forego proprietary interfaces may be difficult but exploring additional ways to leverage this data and its associated added value to customers may be one of the best ways to spur increased interoperability. Several LLLC manufacturers also produce BAS hardware and software. At times even LLLC and BAS products from the same manufacturer struggle with hardware and software interoperability, and multiple interfaces and project-specific data integration plans are presently required.

Beyond basic interoperability, privacy concerns are becoming increasingly relevant and could hinder certain future LLLC+BAS data integrations and advanced applications [20,21]. There are justified worries about the proliferation of cameras in the public sphere and while camera-based lighting controls show great potential for predicting occupant visual comfort, they also pose a privacy and security risk. Low-resolution or AI-modified visual data could potentially address these concerns but may introduce additional difficulties as more complex controls systems are needed. Asset tracking, pathogen source contact tracing, and any other applications in which objects or people are geospatially located or tracked as they move through a space equipped with LLLC can also pose privacy risks. Large companies are already collecting information on their employees on their own terms, which may have negative impacts on a company's culture and the confidence between employees and managers in the long-term. Likewise, occupants are averse to being tracked and tend to disapprove of cameras in the workplace. Security is also a concern as image-based sensors could provide unintentional access into potentially sensitive spaces if not implemented carefully. However, this is avoidable by prioritizing robust cybersecurity in BAS and/or LLLC networks. It is important to establish transparency around potential risks and measures to minimize the likelihood of misuse by ensuring systems are installed properly and maintained regularly to keep up with software and hardware updates.

One of the main challenges in utilizing LLLC systems as a network backbone in buildings is interfacing and networking compatibility with add-on sensors/modules, and particularly with third-party wireless devices. As such, it would be paramount that LLLC manufacturers develop and agree upon a standardized interface with an API and software development kit (SDK) to enable developers of third-party IoT devices to make their devices compatible with LLLC networks. This would provide additional value to manufacturers of LLLC systems, the building owners and managers using them, and the controls industry by encouraging research and development of new and emerging building controls systems applications.

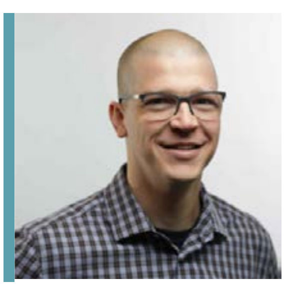
Much of the current trajectory with building automation sensors and the "internet of things" is to continually add greater spatial sensor resolution, type, and number. It is, however, possible that continually greater sensor resolution is simply not warranted. As this work progresses, and increased rollout of distributed sensors occur, the useful resolution and redundancy should be evaluated and unnecessary resolution and redundancy avoided. It is possible that with integration of BAS and LLLC sensors that we will optimize distributed sensor networks to result in fewer, if not more useful sensor networks.



Conclusions

We have described ways to improve utilization of the presently disparate LLLC and BAS data streams to support energy efficiency and improve human comfort and human health outcomes. Three key potential benefits are improved ventilation management to support improved cognitive function, improved vertical field lighting scene management to reduce glare and improve circadian exposure, and data integration and situational awareness to support building operations that will reduce pathogen transmission risk. There are however substantial challenges, including poor hardware and software interoperability, privacy and security concerns, and a need to optimize the number and types of sensors in a network. Nonetheless, we hope that sharing this vision for how LLLC and BAS can be integrated to support improved health outcomes, and reduce energy consumption, will help spark the necessary technological advancements to realize the vision.

Who We Are



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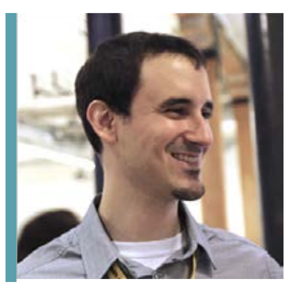

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