REFLECTIONS ON Sensor Utilization, Limitations, Evolution, and Data Analysis

BY RYAN KRUG

How will buildings of the future look?

Buildings will have smaller mechanical systems due to requirements for higher-performing thermal envelopes, but will include more components in order to minimize energy loss.

They will optimize lighting controls based on current weather conditions to balance thermal loads. Occupancy sensors will identify if maximum solar gain/rejection can be made to unoccupied spaces and, when occupied, to balance shades/overhead lighting to produce the optimal occupancy comfort with the minimal energy usage.

Buildings will monitor electrical loads at the plug level and store site-generated energy in battery banks to be utilized during peak hours in order to minimize stress on the grid. The on-site battery banks can then also be recharged during off-hours to balance generation loads.

Building structures will introduce fresh air based on air quality measurements, precondition it through heat-recovery systems, and circulate it with the minimum amount of energy necessary to bring it to the heating, ventilating, and air conditioning (HVAC) set point.

They will utilize occupancy polling to crowdsource HVAC set points. Any variable—such as temperature, humidity, lighting, air circulation, or noise—will be adjustable, based on the frequency of occupancy polling, within predefined ranges.

Structures will also identify preventative maintenance items such as leaks in membranes or wall assemblies, condensation formation in cavities, or impending lighting failures.

Such building evolution can be glimpsed at in the edifices receiving technology and performance awards today, such as the Bullitt Center in Seattle, Washington; the Edith Green Wendell Wyatt Federal Building in Portland, Oregon; or the Iowa Utilities Board and Office of Consumer Advocate building in Des Moines, Iowa (*Photo 1*). While widespread adoption of innovations utilized in these buildings will happen in the not-too-distant future, how are we going to get to the fully integrated and smart building?

CURRENT SENSORS

Going back to fundamentals, at the most basic level, only one building sensor is necessary: a thermostat that controls HVAC equipment. The size of the HVAC equipment is based on the maximum expected temperature difference between the interior and the exterior and the ability of the envelope to retard the flow of energy to and from the conditioned environment. Unfortunately, though, due to the typical integration of multiple cladding systems, thermal bridges occur and moisture management becomes an issue.

Hopefully, the building design minimizes thermal bridging and keeps the condensation temperature outside of the air/vapor barrier. However, due to extreme temperatures at certain times of the year, preventing condensation from occurring is often unavoidable. So what is being done to monitor and assess moisture issues in assemblies?

For wall assemblies, hard-wired temperature, humidity, and moisture sensors are typically installed at the time of construction. These are costly to install and provide a potential moisture intrusion point due to the penetration of wires through the air/vapor barrier.

Leave-in-place electronic leak detection systems to monitor roofs also are limited to hard-wired sensor lines that must be tied into a powered computer to collect data (*Photo 2*). In a conventional roof, sensing lines detect moisture through the reduction of resistance in an open-ended circuit, and are only installed on the dry side of the membrane and powered from the interior.

In an inverted roof system, the lines are on the exterior face of the membrane and are monitored for leaks by applying a

Photo 1 – The Iowa Utilities Board and Office of Consumer Advocate building in Des Moines, Iowa (BNIM website). Copyright by Assassi, courtesy of BNIM.

Photo 2 – Wiring and scanning device utilized during construction of a leave-in-place electronic leak detection system.

voltage to the lines and sensing current flow through breaches to the deck. Analysis of the sense lines shows which area is affected and, therefore, the location of the leak. Power for system components can come from a hard line run from the interior or solar panels.

Moisture monitoring can also be installed under stud tracks or around pipes/drains to determine if condensation forms on such components during certain conditions.

Other sensors such as window or door position switches, occupancy sensors, lighting controls, and air-monitoring sensors remain within the building envelope and are therefore easier to integrate; however, their widespread utilization will be essential in order to optimize building enclosure performance.

SENSOR LIMITATIONS

The largest limitation to sensor integration is cost. These systems need to make financial sense and will not be incorporated until the payback period is acceptable to the owner, their integration can prevent costly future repairs, governmental regulations necessitate their integration, or manufacturers require them in order to meet warranty conditions.

Current sensor devices tend to be hardwired for power and data (*Photo 3*), accessible for recharging or replacement of batteries, or are typically abandoned when their power source is depleted. This leads to increased upfront construction costs to install cabling (which can be challenging when dealing with a retrofit), ongoing maintenance costs through battery management of wireless devices, or loss of the sensor entirely when utilized in an inaccessible location and power is exhausted. It is generally agreed that while wireless sensors yield upfront cost savings and have progressed to the point where reliability and security are not of concern, battery longevity is still a major issue. In order to minimize power usage, devices are programmed to duty-cycle or run at specified intervals in order to extend service life; however, this only provides marginal gains. The next leap in technology to ultra-low power devices should provide the means to make sensors run for perpetuity.

SENSOR DEVICE EVOLUTION

Texas Instruments, Intel, and Qualcomm are all working on ultra-low power chips to be incorporated into devices that require much less energy to function, and PsiKick, a Virginia company, is setting itself apart with its approach. Its system-on-chip (SoC) design incorporates sub-threshold circuits (i.e., circuits are able to run with less than the minimum voltage required to run the circuit during normal operation) and integrates power management on the chip to limit power consumption (current flow) while idling to the microampere (μA) range. With such operating specifications, chips can run perpetually in devices from harvested energy generated by thermoelectric or piezoelectric elements and recharge batteries or capacitors to store surplus power if partnered with the correct data transmission system.

In order to produce such devices, manufacturers will reduce the wireless transmission power consumption through utilization of slower transmission rates on a lower frequency. The typical 2.4-GHz wireless protocols, utilized in home and office environments, require a relatively large amount of energy and provide transmission rates from 54 Mbit/s to 600 Mbit/s; whereas, in the sub-GHz range (where current and proposed low-power wireless standards occur), data transmission rates are of the magnitude of about 0.1 Mbit/s. So while transmission rates will not be sufficient for a video signal, they will be adequate for sampling of sensor devices. Sub-GHz transmissions also have the added benefits of a larger signal range due to longer wavelengths being able to penetrate assemblies more easily and of less interference due to the frequencies being relatively unused.

A large step that enabled device manufacturers to integrate with the largest and most widely utilized building management communications protocol, BACnet[1], happened in 2011 when a profile for commercial building automation utilizing the wireless platform ZigBee was finalized (Nardone & Schader, 2011). Essentially, the profile allows the ZigBee wireless network architecture to be utilized for transmissions, and a gateway then translates the ZigBee protocol to BACnet through a wired connection. Currently, ZigBee is the only protocol that supports sub-GHz and 2.4-GHz transmissions, which is why integration with ultra-low power devices is almost mandatory. However, the Institute of Electrical and Electronics Engineers (IEEE) is scheduled to finalize a sub-GHz standard (Standard P802.11ah) by March 2016 (McCann & Ashley, 2015). At that time, BACnet will be directly integrated through building wireless networks, which integrate 802.11ah; how-

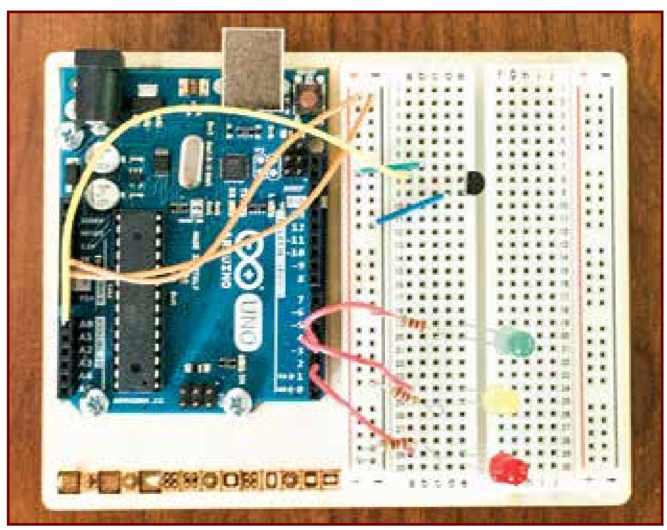

Photo 3 – A low-power Arduino computer and sensors configured and programmed as a temperature threshold alarm.

ever, until then, ZigBee is the only solution that allows for the largest device functionality range that can be utilized to best meet the goals and limitations of device integration.

ZigBee has the added benefit that, unlike traditional networks, it is a personal area network (PAN). Devices send out transmissions, and all devices within its range receive and rebroadcast the transmission to devices within their range. This happens for as many hops as necessary until the transmission reaches its final destination. Therefore, should one device fail, the transmission can circumvent the failed node and still reach its destination through other operable devices within its range. While not as efficient with network traffic due to the redundancy of transmissions, devices are easier to install and implement on networks; and, due to the rebroadcasting of signals, this reduces the number of repeaters (i.e., devices used solely to retransmit data) needed for adequate signal coverage.

There are some drawbacks that prevent widespread utilization of ZigBee and fragment the sensor market. Zigbee requires a yearly Alliance Adopter fee to utilize the ZigBee brand (name, logos, interoperability icons) and for access to its certification program. For smaller boutique sensor manufacturers, it is not feasible to incorporate the technology unless a project specifically necessitates or provides the financial means to do so.

Another drawback is that a translation gateway is required. While home networking wireless access points such as Google's OnHub have begun integrating ZigBee, it will be a few years before enterprise hardware incorporates the ZigBee or 802.11ah standard. This increases network hardware costs and complexity. Unfortunately, for the foreseeable future, ZigBee will be the only available integration solution for BACnet, due to lack of interest in the wireless working group to pursue additional wireless capabilities (WN Working Group, 2015).

DATA REPORTING AND ANALYSIS

Select cities have begun taking steps towards enabling architects to take an analytical approach to design. Manual data collection, enacted through ordinances, requires utility usage reporting. For example, the Minneapolis Climate Action Plan has outlined a goal to reduce greenhouse gas emissions by 30% from a 2006 baseline by 2025 (*Table 1*). As a result, public reporting of utility usage for commercial buildings is underway and required for governmental buildings larger than 25,000 square feet. This is currently submitted through the Environmental Protection Agency's (EPA's) portfolio manager, where data from month-

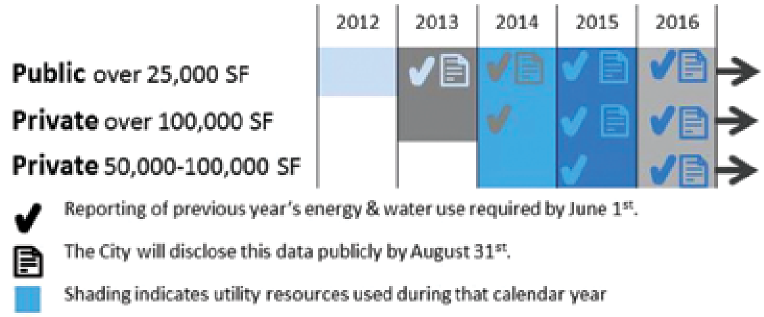

Table 1 – Benchmarking timeline intensity (from City of Minneapolis 2013 Energy Benchmarking Report).

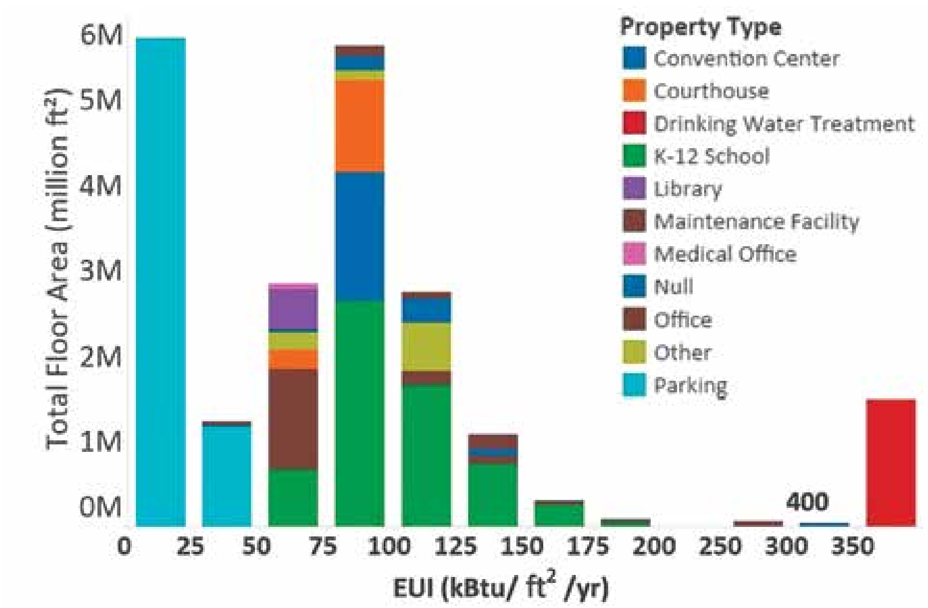

Table 2 – Cumulative public building property type area by energy usage intensity (in thousands of BTUs/sq. ft./year). From Minneapolis 2013 Energy Benchmarking Report.

ly bills are manually uploaded (Schmitt, 2015); however, it could be automated through integration with utility billing platforms and, eventually, through building management systems.

Minneapolis is also taking the next logical step and issuing Energy Benchmarking Reports based on the data (*Table 2*). The bulk of the report draws conclusions based on analysis of the data, and the raw data is provided as an appendix. Breakdowns by building type have identified trends and underperforming outliers, which can be targeted for the largest return on investment.

For the first time, this year's report contained data on private buildings. While utility utilization is typically provided to tenants prior to sale or lease, this will provide further transparency. In addition, it will also provide architects/building owners with a marketing tool to differentiate their property/designs from those of their peers.

Other data sets could also be added to the reporting requirements in order to push building design even further. For example:

- Roof assemblies could be correlated with site temperature and radiation information to accurately model dynamic heat island effects and shape city planning policy.
- Occupancy polling information could be utilized in order to evolve ASHRAE design parameters as HVAC and lighting designs evolve.
- Air barrier data could be analyzed across larger data sets.
- WUFI modeling could be refined with real-world moisture migration data through assemblies.

CONCLUSION

At the heart of the building will be sensor devices and platforms optimizing designs to make envelope-pushing building practices of today the industry standards of tomorrow. Device hardware has evolved to the point where sensor integration is not limited by power and communications limitations. This allows designers the freedom to incorporate sensors into new applications that supplement building performance requirements, occupancy comfort, and building maintenance.

While evolving enclosure building codes will push sensor integration, some select cities have begun requiring submission of utility utilization through manual uploading of billing data. Over time, this can be automated through sensor integration and expanded to include real-time, real-world building data sets.

Analysis of such data will aid in refining design model accuracy, help develop governmental policy, and shape the evolution of enclosure design.

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FOOTNOTE

1. BACnet is an ASHRAE, ANSI, and ISO 16484-5 standard communications protocol.

Ryan Krug

Ryan Krug is a project manager at Pie Consulting & Engineering in Minneapolis, MN. His expertise is in coordination and detailing of building enclosure systems and ensuring compliance of installed components in the field with the design and performance intent. He provides building enclosure consulting and commissioning (BECx) services; technical plan/specification peer review; and quality assurance observations and building envelope performance testing, including fenestrations, curtain walls, and claddings for both commercial and government sectors.