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Data-driven Insights: Improving Indoor Environment Quality and Sustainability with Room Sensor Technology

White Paper 523

Version 1

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Executive summary

Digitalization is driving every aspect of the building industry, including the adoption of room sensing technology. But there are differences in room ventilation options and they're not all created equally. This paper reviews the values of real-time data captured by room sensors, specifically its effect when paired with room ventilation technologies such as constant air volume (CAV) and demand-controlled ventilation (DCV) systems. It discusses the value of data driven decision making and identifies low hanging fruit for energy efficient operation via scalable analytics dashboards. It explores the idea of people counting as an accurate way of maximizing energy savings, space optimization, and occupant comfort. It concludes with key considerations for choosing a partner for holistic building management plus room-level sensing functions for faster time to market (TTM) and better returns on investment (ROI).

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Introduction

As one of the largest sources of carbon emissions, commercial building owners are under pressure to reduce its adverse environmental impact. Buildings account for 75% of electricity use in the US[1] and 40% of energy consumption globally. They account for 33% of GHG emissions[2]. Instead of remaining a cause of concern, smart building technologies, like room sensors and controllers fuel data-driven building automation. A data-driven approach can be a significant part of the solution to combat the building sector's negative environmental effects.

Along with the pressing need for decarbonization, the onset of the pandemic has accelerated the demand for healthy building-related technologies. The focus on occupant comfort and well-being requires addressing indoor air quality that is largely driven by the Heating, Ventilation, and Air-conditioning (HVAC) equipment and associated air exchange systems. Simulations for designing innovative approaches to building operation show occupant comfort and energy efficiency to be tradeoffs. Thus, a pressing question within the smart building industry is solving the need for maintaining energy conservation measures (ECMs) while equally prioritizing occupant comfort.

Traditional approaches to HVAC control often fall into the category of "constant air volume" (CAV), where air is continuously provided to a space or zone. In relatively newer buildings, this is based on a defined schedule or triggered using presence detection sensors. As building owners and regulators alike move towards optimizing energy use as a part of sustainable building operation or "net-zero" efforts in commercial properties, there is a need to move from a static air flow operation model to dynamic air flow. This dynamic air flow model using the concept of "demand-controlled ventilation" (DCV), relies on real-time data such as CO_2, occupancy, or people count to enable control decisions and efficiently run the HVAC system.

This paper explores applications and effects of using newer room sensing technologies combined with data-enabled ventilation controls keeping in mind, both demand-controlled ventilation (DCV) and constant air volume (CAV) systems. It will demonstrate scope for energy savings and ensuring occupant comfort through improving overall indoor air quality.

Potential for smart room sensor technology in buildings of the future

Building energy programs (such as the Building Electrification[3] mandates) and energy optimization trends (such as using occupancy-based building controls), have increased the need for zoning beyond the floor level. Decisions based on real-time data collected from the space can impact variables such as energy consumption. Implementing zone-level control and establishing a connected layer of sensors that deliver data points of these individual spaces provide granular access to room or space monitoring and controls. This is an efficient step towards building energy and comfort monitoring, and optimization. Examples of useful datapoints in this context include people count data, temperature, humidity, particulate matter, air flow rates, CO_2 levels, etc. The alternative uses generalized occupancy patterns and normalized estimations of heat load profiles that creates uncertainty in predicted energy usage and costs.

[1] https://www.energy.gov/sites/prod/files/2017/03/f34/qtr-2015-chapter5.pdf

[2] https://www.weforum.org/agenda/2021/02/why-the-buildings-of-the-future-are-key-to-an-efficient-energy-ecosystem/#:~:text=Buildings%20are%20responsible%20for%2040,33%25%20of%20greenhouse%20gas%20emissions.

[3] https://www.usgbc.org/articles/building-electrification-why-it-matters

In larger buildings, sensor data is captured and logged onsite or in the cloud. These datapoints once analyzed, provide insights that improve as historical databases grow. A cloud integration or on-premises data warehouse provides the opportunity to engage machine learning algorithms and related technologies for advanced automation and other applications in the future. Some examples of AI based applications are occupancy-based energy load forecasting, space utilization tracking, and resource allocation. The following bullets explain how room sensor data can be used to drive improvements:

- Sensor data can be used to train AI models that support automation and decision-making towards several functions including those directly relating to cost, energy, and emissions reduction. For example, thermostat temperature logs correlated with energy (load) consumption sourced from energy meters can be used to create an overall thermal signature for the building. This signature can be leveraged to run a forecasting model. The datapoints combined with building occupancy predictors (developed from occupancy data history) helps generate AI models for making decisions such as determining if an HVAC system needs to run all day or if it can be allowed to turn off for some periods to save energy.[4]
- Even without the use of AI on these data points, raw room sensor data logs can be used by facility operators to visualize occupancy across the building and optimize space usage and building facilities accordingly.
- Data storage and analytics aside, sensors just by themselves can support building automation by using, for example, motion detection to trigger lighting controls.

Historical data tracking and analysis also supports requirements for popular energy and well-being certifications.

Efficient HVAC operation: proactive vs reactive technologies

One of the biggest smart building industry challenges at the room level is maintaining occupant comfort while balancing EMCs as stated above. Some examples of simple energy conservation techniques are running lighting controls using timers or occupancy sensors, using variable speed drives, and making upgrades to HVAC equipment by adding dampers, actuators, and associated control sequences. With digitalization[5], these straight-forward modes of operation are achieving higher levels of efficiency KPI's. This is attributed to using room sensor data points for dynamic, real-time HVAC load management, where decision points are based on several factors like occupancy levels, participation in peak shaving and load shedding grid services, and working with onsite solar or battery systems, etc. While these strategies are highly effective in energy optimization and add towards building decarbonization, occupant comfort has been an unfortunate trade-off since the first area trimmed for energy savings is often in heating and cooling.

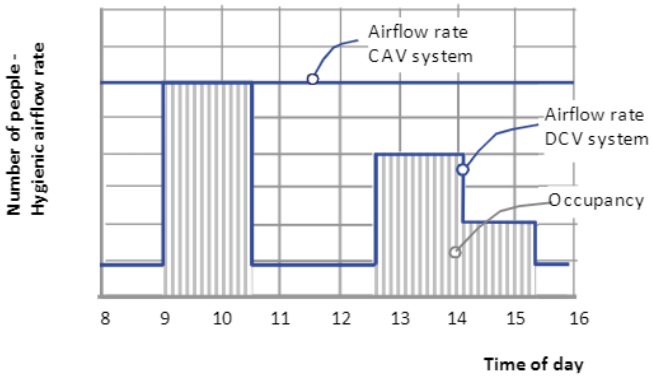
However, demand-controlled ventilation-based HVAC systems are an effective solution to balance comfort and energy spend.

[4] Refer: WP 508 describes the integration of an AI tool with a BMS and results from existing deployment; WP 502 describes fundamentals of AI specific for HVAC optimization

[5] By digitalization we mean putting devices on a network for data collection, monitoring and control

Figure 1

Comparison of a DCV system with a CAV system in applications for room air quality control



DCV is highly reliant on input variables that indicate occupancy or the need for ventilation in some form. Traditionally, DCV controls are triggered when CO_2 levels in the space rise above a set threshold. Between receiving a high CO_2 reading and waiting for a series of mechanical equipment to recycle air in the space, the occupant has already become uncomfortable before the ventilation change occurs. The problem is, HVAC systems end up over-cooling or over-heating a space if they are triggered based on simple occupied or unoccupied statuses as opposed to operating based on data that is conveying insights such as 'there is just one person in this conference room with a capacity of 20'.

People count data can be used to determine the time, amount, and rate of required ventilation, whereas binary data points on room conditions (i.e., temp, CO_2 levels, occupied/unoccupied) can only suggest ventilation at the room's design setting. **That is, a room without people sensing data will only ever be comfortable for the exact number of people it was designed to hold, whereas a room with people count data can be more finely tuned to the exact number of occupants.** This is a realistic approach at ensuring occupant-centric operation without compromising on judicious energy use.

The response times for occupancy-based DCV favors occupant well-being better than CO_2-based DCV.

When implementing an effective DCV strategy, HVAC system equipment for a given space cannot be expected to perform instantaneously. These systems are relatively slow to create an indoor environment quality impact. Hence the need for proactive HVAC operation (i.e., occupancy-based DCV) that guarantees a faster response time as opposed to traditional reactive ways of heating or cooling spaces.

With DCV, airflow rates, cooling capacity, and other factors are constantly in line with the real-time load. The need for extra HVAC capacity in unoccupied areas may be reduced or even eliminated when compared to a traditional schedule-based constant air ventilation system.

In addition, lighting control systems based on occupancy and using light sensors can be integrated with the ventilation system as a data point. In cooling seasons, about 76% of sunlight that falls on standard double pane windows enters to become heat.[6] A light sensor's data can be used as a feed into the DCV, blind control, and lighting system's algorithms.

[6] https://www.energy.gov/energysaver/energy-efficient-window-coverings

Optimized demand-controlled ventilation (DCV) relies on real-time people occupancy data to use the HVAC system just when needed. The key benefits of DCV driven by room sensors for occupants are largely around indoor air quality:

- Fewer indoor allergen, improved IAQ
- More productive, healthy occupants
- Optimal comfort and satisfaction

For owners and facility managers, benefits also include:

- Compliance with standards, such as ASHRAE 62.1, 62.2 and ISO ICS 91.140.31
- Significant energy savings as energy is only used to run HVAC by room usage levels

Currently available solutions for creating a DCV system in commercial buildings often rely on the use of camera-based technologies. Because of growing concerns over privacy and compliance with regulations such as General Data Protection Regulations (GDPR), this is increasingly becoming a problematic approach. To achieve DCV, the sensing technology should rely on non-camera-based people counting technology. DCV's potential is not entirely realized by using a traditional passive infrared sensor (PIR), which can only detect the presence of people in binary terms.

Field study – sensors for sustainability

A controlled room experiment was carried out at one of Schneider Electric's offices to show the benefits of simple and raw data captured from a room sensor. Data gathered via the installation of a SpaceLogic™ Insight-Sensor in this room shows clear trends for percentage of time occupied, time of use, and frequency of use. Working with occupant data can support occupancy-based ventilation sequences as described in the previous section. This approach delivers greater sustainability achievements as opposed to work week schedules (e.g.: 7 am – 6 pm) that are still considered demand-controlled ventilation methodologies.

Benefits of multi-sensor technologies:

- Improved accuracy for demand-controlled ventilation
- Insightful space utilization
- Understanding of impacts to spaces based on variables
- Lesser inputs to the controllers
- Reduced number of sensors on the walls
- Harmonious sensors data database

Figure 2

Floor plan with Occupancy data

In the experiment, a ceiling mount sensor was installed centrally in the small space categorized as the 'team room'. The dimensions of the room are approximately 17 sq. ft. Figure 2 is a screenshot of the floor plan that shows the room's location and occupancy status. Notice how a single desk in the lab is occupied while the entire space is constantly being heated or always cooled.

This sensor was configured to deliver data for six features in one-minute intervals. The datapoints are being stored in a Postgres Database to handle the heavy load of data required for this ongoing study. In a general installation, data logging (data trending) can be configured for user defined intervals of every minute, hour, day, or week; aggregated any way desired (averaged, sum, delta, min or max). The room controllers and associated servers can handle lower frequencies of datalogging via built in memory modules and the need for added storage depends on the installation use-case.

This sensor can be operated purely by displaying data points on a real-time basis using dashboards and without logging trend data. The advantage of trend data is highlighted as we move forward in the paper. For our case, the following dashboard (Figure 3) is displayed at all times on a tablet or monitor by the room. Simple dashboarding services are usually hosted out of a BMS server. There are ways to interface with third-party dashboarding services when needed.

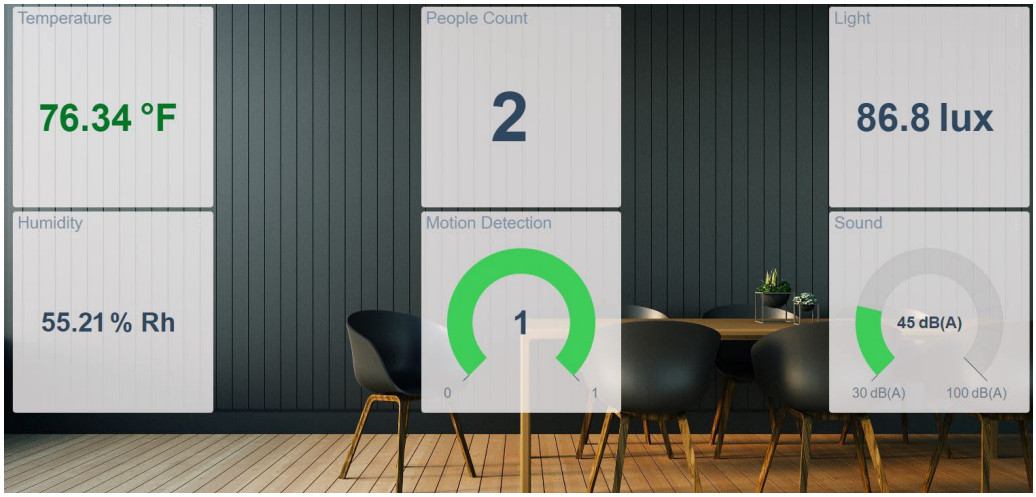


Figure 3

A simple customizable dashboard informs facility manages of room settings, such as this one from the SpaceLogic Insight-Sensor

A quick look at a completely customizable dashboard on a display tablet allows building occupants to identify the following about a closed office, conference, or team room:

- Is the space occupied or unoccupied, and what is the occupancy frequency?
- Is this space now too hot, too cold, or too humid?
- Have we left the lights on for too long without an occupant?
- Are the occupants maintaining a healthy noise level?

Circling back to the discussion on occupancy-based ventilation control techniques, here is a graph that shows occupancy levels for the room in discussion. Having run some basic analyses on several months' worth of data using the sensor, it is evident that

  - The room is being used for an average of 65% on Tuesdays, 86% on Wednesdays, and 95% on Thursdays

- The room is being used for an average of 47% on Mondays
- The room was barely used on Fridays, and never used on Saturdays, and Sundays.
- Overall, the room was 'occupied' for less than 65% of the building's operational time of 7 am – 7 pm (M-F)

The room is currently being ventilated and on a heating or cooling cycle during the building's entire operation time, irrespective of occupancy.

Figure 4

Weekday time of use mapping based on occupant count for 4 weeks of monitoring

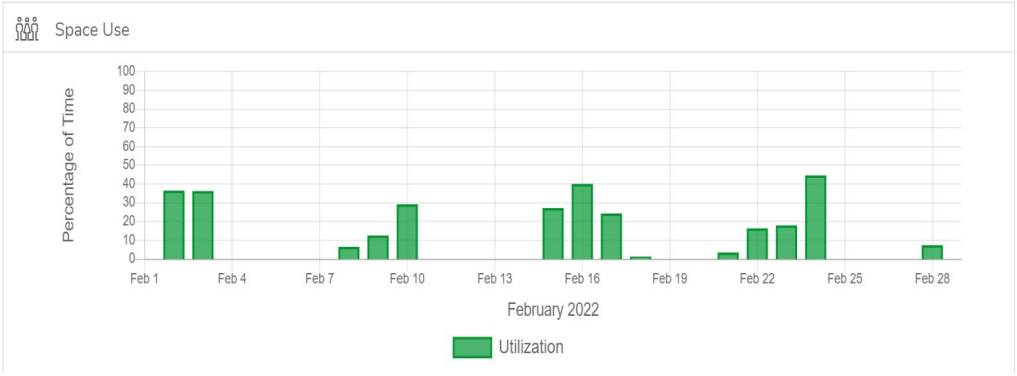
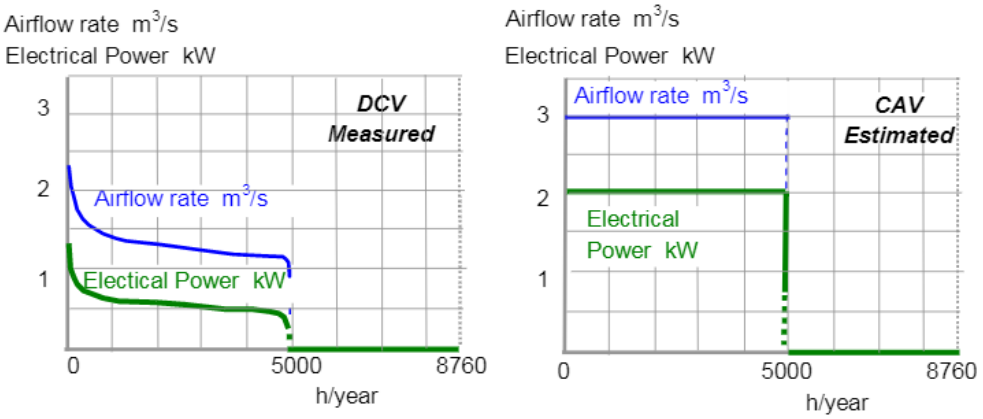


Figure 5 & 6

Measured supply airflow rate and supply air fan electrical power.



According to an analysis in the REHVA guidebook[7], in a 2500 square meter office space, a DCV-operated system worked with less than 45% of the design airflow rate during 80% of its scheduled operating hours[8]. This savings is attributed to there being a lower room occupancy which enabled the reduced airflow pattern.
Energy is often wasted in conditioning spaces for people who are not there, and significant savings can be made by resetting the fresh air level from design level to the actual level needed based on accurate occupancy insight.

The above is an example of quickly derived insights on space utilization and associated ideas on energy conservation methods. Working with the sensor also helped identify key use cases leveraged at the site. They are detailed below:

Optimal Space & Resource Utilization

Applications for people counting is immense and of prime need in smart buildings and their drive to move towards sustainability and mindful energy use.

[7] https://www.rehva.eu/hvac-guidebook-repository

[8] https://swegonnorthamerica.com/wp-content/uploads/DCV-Systems-in-Commercial-Bldg-Maripuu.pdf

1. Space Optimization

In commercial buildings with large conference spaces, occupancy detection and people counting can identify if an exceptionally large space is used by a small group or a single individual for longer durations. The room facilities contribute to energy waste if used in excess by a group size much smaller than the room's intended capacity. People count data can help identify these values. It can help in decision making towards:

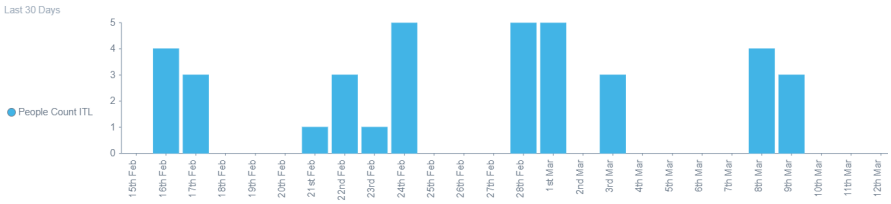
- Splitting a room with a false wall
- Engaging zoning for lights so only the corner with the occupant is well lit
- Disabling room facilities unless it has been booked

2. Maintenance Scheduling

The sensor relays people count data every two minutes. If a space is being used only every alternate day, it might not warrant the need to be cleaned everyday by the facility staff.

Figure 7

This data represents daily occupancy with the number of people that were in the space that day.

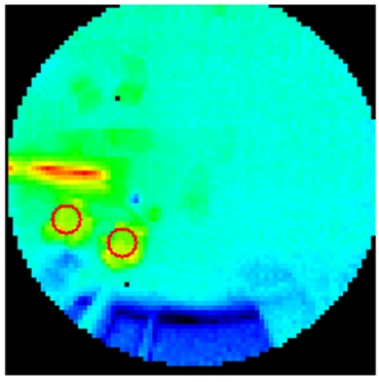


Occupancy Detection

Passive Infrared (PIR) is technology most widely used in occupancy detection. Occupant sensors use infrared technology to deliver cost effective solutions but falls short when an application requires an occupancy level.

Figure 8

Thermal Image of a space under the sensor demonstrating anonymous people counting functionality.



- Thus, the PIR function when paired with thermal imaging boosts accuracy and availability of headcounts. A hot laptop and a human are both thermal blobs, the PIR is sensitive to tiny movements and can work with the thermal imaging system to differentiate a human from a stationary hot object.

- PIR helps with instantaneous occupancy detection, to trigger room facilities, preferably only if the room is reserved.

The device in our experiment has a people counting feature enabled by an integrated thermal imaging sensor. The thermal images are captured and processed within the sensor. The image never leaves the sensor, and the on-board processor takes care of delivering a headcount every two minutes. It is understandable that rooms may have devices, objects or equipment with a high thermal signature that can be mistaken for a human. To tackle this, there is a masking feature that is used to create boundaries within the space and leave out a section(s) every time an image is captured.

Occupancy sensors that contribute to reducing or turning of lighting systems can save between 10% - 90% lighting energy use depending on the space.[9] For several years, these sensors have been promising in a way of reducing energy consumption. According to the Department of Energy, lighting can account for up to 11% of energy use in a commercial building.[10] **According to an EPA study, occupancy sensors can reduce energy waste by as much as 68% and increase energy savings by almost 60%[11].**

Indoor Environment Quality & Occupant Well-being

The lux sensor is highly sensitive to bleeding light and variation in ambient light levels are captured instantaneously. Coupled with data from the occupancy sensor, and access to lighting controls, the lux indicator datapoints can be used as an efficient energy trim metric.

- The room facilities can be scheduled to activate when an occupant enters the space.
- Lighting can be dimmed or turned all the way down based on the amount of sunlight the room receives.

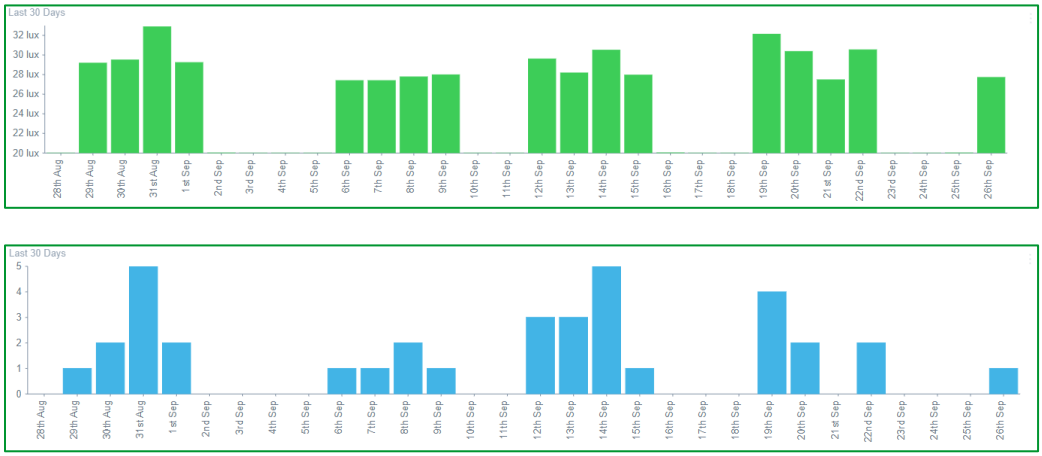


Figure 9 & 10

The graph shows light and occupancy data for the test room across a 4-week period. Light levels are above 0 lux usually only when an occupant is occupying the space.

There are periods of outliers that can be attributed to movement detection as opposed to occupant presence. The lux values in this space are not constant and display a range because of ambient light fluctuations from surrounding areas.

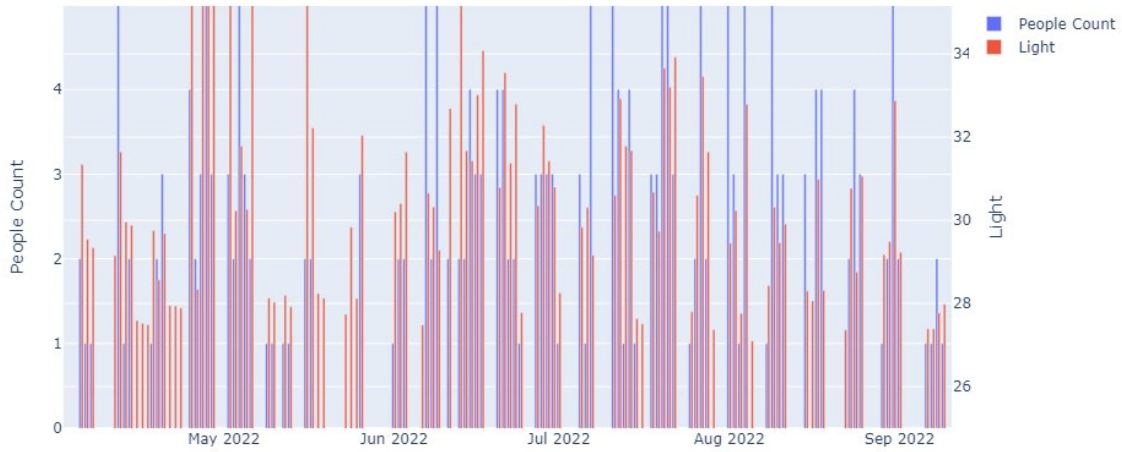
[9] https://www.energy.gov/eere/femp/downloads/wireless-occupancy-sensors-lighting-controls-applications-guide-federal-facility

[10] https://www.energy.gov/sites/prod/files/2017/03/f34/qtr-2015-chapter5.pdf

[11] https://www.nema.org/standards/view/demand-reduction-and-energy-savings-using-occupancy-sensors

Figure 11

The graph shows light and occupancy data align. Trend charts like this help visually spot periods in the month of May where the room lighting system was constantly turned on in the absence of an occupant. Identifying this error and correcting it has helped with energy savings (minimal for one room but can be impactful for whole buildings).



According to the WELL building standards, "Built environments can harbor sounds that are distracting and disruptive to work or relaxation. Employee surveys show that acoustic problems are a leading source of dissatisfaction within the environmental conditions of an office." The WELL standards also highlight 'Light' under one of its seven primary features with a direct impact on productivity, health, circadian rhythms and impacts of sunlight vs artificial lighting. For addressing most of these concerns, ambient light sensors can be made useful.

- Poor lighting and digital eye strain - Ambient light sensors can be used to optimize and maintain desirable lux levels. In a room that allows natural light, the lux sensor can detect natural illumination and trigger turning down or dimming lighting systems as needed. Daylight harvesting helps the indoor environment and supports the conservation of energy.

- Comfortable & Healthy- Data from sensors can be weighted and added to monitor periodic comfort scores to ensure occupant well-being.

- Occupant Preferences & Productivity - Along with effective space and resource utilization, every occupant might have different needs and preferences based on their requirement of the room. A small tablet displaying dashboards equipped with historical data from the space can be insightful. If an occupant wants to find an extremely quiet space to work, they only need to look at trend data that shows average and expected decibel values in the vicinity.

The same goes for light levels and identifying spots in the building that might be warmer, colder, or just right. On average, 86 minutes per employee per day are wasted due to noise distractions.[12]

[12] https://hbr.org/2015/03/stop-noise-from-ruining-your-open-office

Figure 12

People Count indicator

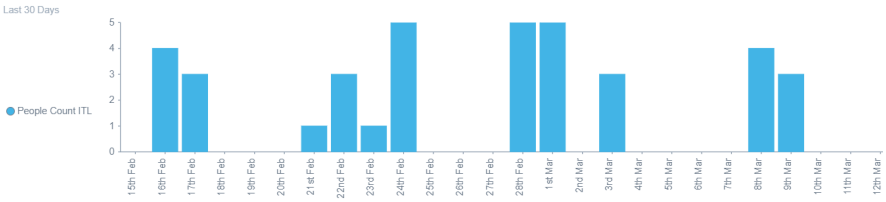
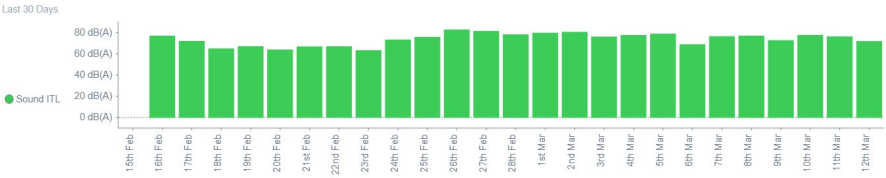


Figure 13

dB indicator displaying ambient sound: The space was almost equally as noisy when occupied and unoccupied; upon investigation the team identified that this room was experiencing noise disturbances from HVAC equipment feeding this space.



Temperature and humidity are essential elements to indoor environment quality monitoring. Trend data helps create building thermal signature tools, identify correlations between energy usage and temperature, and most importantly help with decision making about applications such as load shifting, peak shaving and HVAC system coasting.

Sensors further support energy and wellness goals by qualifying for points within common building certifications, such as LEED and WELL. The ability to control temperature, monitor light, detect noise and humidity plays a significant part in those points.

Five things to consider when choosing a room sensor solution

Sensors provide dynamic building flexibility and carry the potential for significant energy consumption reduction. There is massive potential for data-driven insights, reporting, decision-making and building of reliable applications and use-cases. This type of sensing has previously been expensive, in early stages, and with a lack of cybersecurity and scalability.

The first steps to identify the right room sensors are an evaluation of applicable use cases, goals, and business objectives. Some important questions to think about might include:

- Are we analyzing meeting room energy efficiency?
- Are we focused on occupant well-being metrics such as circadian lighting, ambient noise control and/or indoor air quality monitoring with temperature, humidity, and particulate matter count?
- Is the application focused on studying space utilization trends?
- Are there potential risks to keep in mind such as privacy or cybersecurity concerns?

Once a clear vision for building sensor functions is identified, the following five-step checklist can help in choosing the right feature set for a positive ROI.

1. Room sensing requirements and mounting alternatives

It is easy to get lost within the large market of sensor offers. Identifying the right set of functions to targeted goals will help narrow down the scope of search. Some examples are:

- Wellness and Comfort metrics: Sensors that monitor ambient light, sound, humidity, occupancy, people flow, and people counting
- Air Quality metrics: Sensors that monitor Carbon di-oxide (CO_2), Volatile Organic Compounds (VOC), Particulate Matter (PM) (PM1, PM 2.5, PM 4, PM 10), Radon, etc.

There are several technologies that support each of these functions, for example, occupancy detection can be done using Passive Infrared (PIR), Ultrasonic (US), Image recognition and thermal imaging technologies. Each of these have unique benefits and can be weighed against one another to decide for each targeted application.

Data reliability and availability is a key aspect to choosing sensors. Some products provide access to historical data based on a subscription rate and others allow a direct BMS-sensor connection without a third-party interface for data transfer. It might use standard protocols such as TCP/IP or Modbus versus communicate via a REST API interface for example.

These room sensors are typically wall or ceiling mounted. Depending on the function and type (single feature vs multi-sensors) the customer might like to have flexibility in reducing the number of devices on the wall.

2. Purpose and coverage

Not all sensors are created equally. A room-level people counting sensor cannot be placed in a hallway and be expected to deliver accurate results. Some sensors have the capability to connect multiple devices and work in conjunction with each other, others are stand alone and work within defined floor dimension. This can be based on mounting height (wall/ceiling). Paying attention to these specifications helps while picking out the right sensors for each space type.

Power delivery to the sensors is another factor. Battery powered sensors carry a disadvantage if the sensor has a short battery life span. They might be acceptable for short-term analytics or applications where data transfer intervals are longer. Alternate options include power over ethernet (PoE) or USB power delivery – these options may include a longer installation time, but might be ideal for energy intensive, long-term installations.

3. Privacy and cybersecurity

Sensors in large commercial spaces are usually installed in swarms. If they are wireless sensors that tap into the corporate network, the customer will largely benefit from ensuring that the product features a cyber secure, end-to-end connection. Privacy is a major connection especially in camera-based occupancy or people counting devices. Image recognition technology, if needed, should be limited to on-device processing; eliminating the need or ability to extract and store captured images.

4. Occupant centricity and building standards compliance

While gaining the ability to extract real-time data points for decision making, indoor environment data can also be used on display screens across the building space to highlight features. For example, values for temperature, humidity, IAQ, sound and light levels help develop human-building interactions and facilitates a healthy work environment. With just improved air quality, there is a 5-10% increase in occupant performance and productivity.[13] Occupants can also be made aware of energy efficiency measures and targets achieved in sustainability and net-zero efforts based on decisions enabled by the sensor ecosystems. This helps in facilitating conservative and considerate use of building facilities. Further, most data points can be directly translated to achieve pre-requisites or check off compliance for building standards certification bodies, such as LEED, WELL, Fitwel and others.

Studies have also shown 26% higher values in cognitive test scores in high performing green certified buildings.[14]

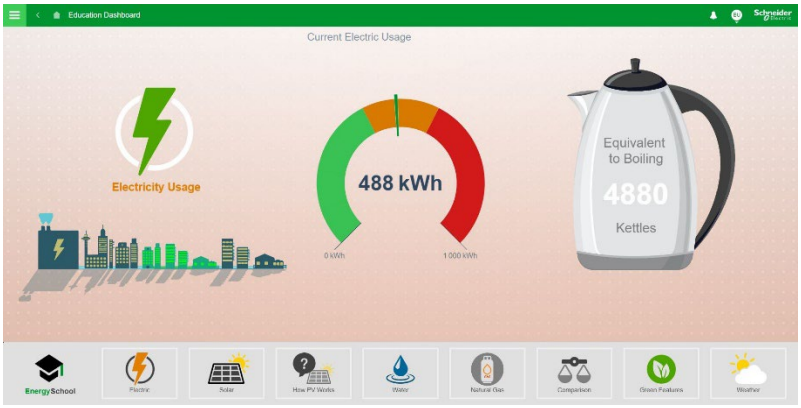


Figure 14

Human-building interactive dashboards can engage occupants in sustainability initiatives

5. Installation, maintenance, and value extraction

One of the most basic and powerful benefits of IoT and digitalized building technologies is its ability to integrate with building facilities and management systems. Scalability is key, especially in larger commercial spaces. Sensor vendors should be able to connect, communicate, work with, and seamlessly integrate to existing building management systems (BMS) and analytics platforms. This will help ensure continuous use of data points and prepare for potential applications in predictive analytics and automated controls as required. This is where buildings owners/operators benefit from working with trusted partners and experienced solution providers.

Conclusion

Several studies, including the experimental set-up mentioned earlier in this paper, highlight the massive potential that multisensor technologies embedded in everyday spaces can provide. Demand-controlled ventilation is an established and effective energy conservation strategy that is fully enabled with the onboarding of data resources such as occupancy sensors. Innovation in this technology space helps create new strategies for sustainable and comfortable workplaces. Such science-based design processes that focus on work patterns, building operations and

[13] *International Centre for Indoor Environment and Energy, Technical University of Denmark*

[14] *https://www.sciencedirect.com/science/article/pii/S0360132316304723*

adaptive technologies are leading the way towards a new generation of user centric, decarbonized, resilient and optimized workspaces.

About the author

Anubama Chinnakannan is an Application Engineer in the CTO Office of Digital Buildings at Schneider Electric. She is an Electrical and Electronics Engineer with a master's in Energy Systems Engineering from Northeastern University, USA. She is a WELL Accredited Professional and CESAM Associate. She actively works on technical experimentation and thought leadership on Artificial Intelligence and Grid-interactive buildings, multi-technologies research and innovation, and evaluations of startups in the buildings domain.

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