Best design practice: Lighting installation and beyond – IoT structure

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with the coordination of the BS Division

The Internet of Things (IoT) technology is transforming the building services industries by improving efficiency, reducing costs, and enhancing users' experience. With the increasing engagements of IoT technology in the building services sectors, it not only brings forth our goals in reaching carbon neutrality but also enhances well-being for occupants and environments within safe and secured envelopes.

This paper illustrates how structures of low-power local-area IoT wireless network could further shape the performance of predesigned operation modes of lighting installations by programming sensors to collect data and to execute responses continuously and in real time, under the ultimate authority of the master programme. The wide footprint coverage of the lighting installation readily serves as the platform for other building services provisions to repeat the same. It is also envisaged by collating individual raw data and performance levels across each and every branch of building services, that edge computing will be used to rationalise and coordinate due and needed executions – on the spot, and not after scrutiny of periodical reports.

Electrical power circuitry

For fixed electrical wiring, a switch controls the power supply to equipment connected in and along the same circuit, in continuous modes of either ON or OFF. A pulse switch can also control electronic devices to operate in a series of repetitive ONs and OFFs. The path of command is linear along the electrical circuit.

The conventional wisdom of designing electrical fixed wiring installations is isolating the power for safety, maintenance, convenience and emergency. Some of the isolations are automatic dependent on the status of the supply side, as contactors; some are 'irreversible', as the spring-released solenoid, or firm physical contacts as toggle switches. For added safety, positive reversal is required before closing a circuit as emergency stops. For normal operation and convenience, manual switches are used to connect the power supply but due awareness is needed to terminate the power for energy-saving purposes.

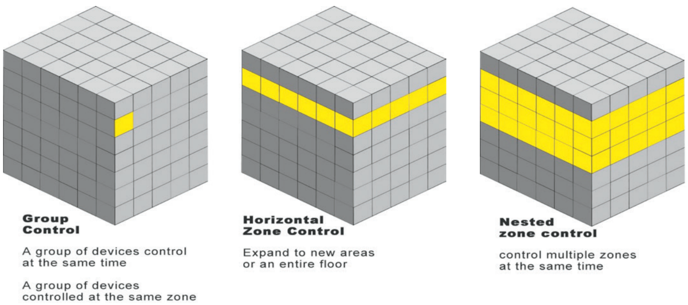
The fixed wiring installation is primarily based on inputs from the supply side, including devices like thermostats, inputs from which are actually feedbacks of consequential data. Any change in operational status and extent is confined to along the same dimension of the wiring path.

IoT control zoning

The system of Internet of Thing, IoT, provides an alternate method by switching signals within and among a matrix of devices, or Zone.

Internet of Things[1] has been considered a misnomer because devices do not need to be connected to the public internet; they only need to be connected to a network, and be individually addressable.

The 'switching' activates a device to relay bursts of signals. With equipment in connection and each identified or being assigned with an address, signals transmission can be restricted to selected devices either by switching instantly ON/ OFF or by sliding gradients or steps. The signals coverage is called Zone in various configurations:



A wireless system could be switched OFF either by manually disconnecting its power supply or by switching to initiate operation or onto standby mode by signals.

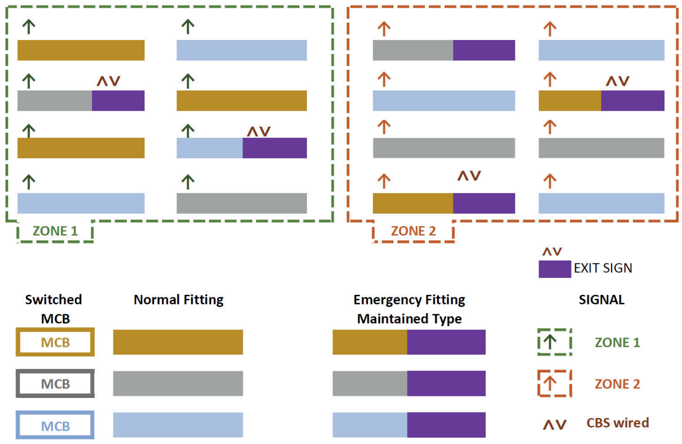
The IoT approach allows feedback from outputs to formulate and modify subsequent and successive commands to devices for close-loop refinements at any point chosen at design stage or amended on site during operation.

In a control system, a feedback loop is an important tool, the feedback loop will consider the system output and this will help the system to alter its operation in order to get the required output.[2]

If the feedback from output data is instantly adopted, it is called automation; if the feedback is different from the expected performance, it is an abnormality; if records of operational trends or abnormality are examined to formulate prompt responses in anticipation, it is a learned solution; if the learning process to deduce solutions is passed onto the software programme, it is Artificial Intelligence (AI).

Linear control vs zoning coverage

Below are two typical power supply circuits for general lighting and maintained type of emergency lighting installations, with paths of circuits running for the former and wireless signals zone coverage for the latter. The fixed wiring circuits and signals path covering both normal and emergency lighting fittings require the understanding of signals confine and its path for conversion of a fixed installation to IoT network.



Hard wirings arrangement vis-à-vis signals coverage

The alternating current (AC) power supply to the lighting fittings is spread across three circuits of Brown, Grey and Blue phases of the utilities supply controlled by respective Miniature Circuit Breakers (MCBs). The circuit of AC power supply is unidirectional and single-dimensional. Once the AC power supply is activated, all fittings along the circuit will be either switched ON or OFF. During power failure and in testing mode, only the emergency lighting fittings are in operation. To ensure even illuminous distribution during power failures, the emergency lighting fittings must be strategically located across the footprint of the Brown, Grey and Blue circuits.

Signals transmission switches IoT devices between different operation statuses through a wireless communication device, Node, to form part of the software system. In between operations, the IoT equipment retires to standby or sleeping mode, reawaken by fresh signals to resume operation for energy saving. Similarly, the whole IoT network system can be switched to a standby status, reawaken by defined inputs. The energy consumed for the Node in standby mode is minimal, typically about 3.3 V/12 μA in sleeping mode.

Nodes can be programmed to exchange information with others within range. The path of a wireless signal is multi-directional and multi-dimensional. A coordinating device, Gateway, facilitates signal transmissions to and from the master programme. In theory, Nodes connected in a truly mesh configuration do not require a Gateway to communicate with the master programme. In practice, signals exchanged among Nodes are confined within a particular zone under the remit of the particular Gateway in managing signal traffic.

Limitation of manual switching

Local switches are installed for manual switching to control the lighting ON/ OFF along the same electrical circuit, typically for the first occupant's entry to and the last occupant's departure from the premises, or to turn off the power supply for ease of maintenance services and energy saving. The switch must be installed at convenient locations or in proximity to the circuitry it controls. The tendency is to specify an abundance of local switches. Using a two-way switch enhances the need of convenient and timely control, but conversion of circuitry to two-way switching after installation might not be practical.

Isolated daylight and motion sensors used for centralised control

Daylight and motion sensors are usually specified to centrally control a group of lighting fittings along the same electrical circuit. Typically, the daylight sensor is of a dimmable type with illuminance level memory and installed in a perimeter zone, along areas with external light sources and at areas in proximity to light sources. The motion sensor is usually of a single ON/ delayed OFF type controlling lighting fittings in both the perimeter and inner zones, to override the daylight sensor in the perimeter zone with ultimate authority in OFF instruction.

Under the traditional lighting circuitry arrangement, if the lighting fittings and the sensors were controlled by the same AC power supply switch, both would be turned either ON or OFF. One solution is to specify adequate numbers of bypass switches for emergency and routine maintenance of the sensors used for centralised control or by limiting the number of lighting fittings that a particular sensor uses for centralised controls. On occasion, another ON/OFF switch is installed to bypass the control of a centralised sensor's in order to keep the lighting fittings in operation during maintenance work.

Because a centralised sensor transmits the same instruction to all lighting fittings within its remit, all lighting fittings respond at the same and aligned level of performance. The common practice is to increase the number of centralised daylight sensors along the perimeter zone to prevent all lighting fittings from dimming down to the same illuminance level instructed by a lone and obscured centralised daylight sensor located elsewhere. For the inner zone, the tendency is to install more units of centralised motion sensor to prevent a large number of lighting fittings from either lighting up or turning OFF at the same time in a large footprint area. Substantial effort of trial and error is needed in finding the locations and the number of centralised sensors required for optimal performance. Conflicts in authorities between daylight and motion sensors are largely handled by minimising the number of lighting fittings connected under joint control from both sensors.

On completion of maintenance and servicing of the centralised sensor controlling a group of lighting fittings, cross verification of the performance of each lighting fitting is required. But if the same lighting fitting group is controlled under both daylight and motion sensors, each at different levels of authority, the 'fault' could be located between or within the two sensors.

The burdens caused by a single failure of a sensor controlling a group of lighting fittings are well-recognised. Typical measures taken to minimise the unwanted nuisance caused by group control arrangements are by specifying high-end products, identifying optimal installation locations, limiting the quantities of control points and, failing that, manual override.

Electricity power circuitries and IoT network signals paths do not have to be mutually and physically confined to the same group of lighting fittings cum sensors. In IoT networks, sensors could be deactivated by signals for maintenance and reactivated upon completion of work. Or, the sensor input to one particular lighting fitting could be 'switched' off to avoid the situation of penalising all other functional lighting fittings whilst working only on a single faulty one sans the sensor control. Whether the motion sensor is switched OFF from its power supply or switched to standby mode by signals, the lighting fittings remain functioning at status quo. The network programme can select those sensors and lighting fittings desirable for any particular purpose. If an individual built-in sensor is installed in each of the lighting fittings as an integral part, a bypass switch to isolate a sole and faulty centralised controlling sensor for maintenance work is not needed because the lighting fitting cum built-in sensor is merely another lighting fitting that could be isolated on its own without turning OFF the whole circuit; the built-in sensor is just another component like the driver that needs to be examined. The result of the work is instantly verified.

Luminaire integrated with built-in sensor

The essence of IoT is to have every device connected to everything to share data and information among all so connected – in a wireless manner.

The Internet of Things (IoT) describes physical objects (or groups of such objects) with sensors, processing ability, software and other technologies that connect and exchange data with other devices and systems over the Internet or other communications networks.[1]

The growing trend is to install both daylight and motion sensors as a built-in and integral component of the lighting fitting to collect more finite and accurate inputs to form a network covering the full spectrum to maximise and optimise the management programme with precise control of a wide footprint network.

The detection area of the built-in sensor is confined to the work plane or any chosen area directly beneath the lighting fitting. With coverage only on a small area, a more focused cone or narrower beam angle design suffices for detection of lux measurement and fine and continual movements over its designated territory without the need to employ more expensive models of motion sensors. The burden involving diligent effort in finding the best location to install a sensor for centralised control is not necessary. As a result, the site involvement in testing, commissioning, verification and future configuration changes are simply a process of assigning and programming a matrix of the lighting fittings - a matter of adjustments on a tablet.

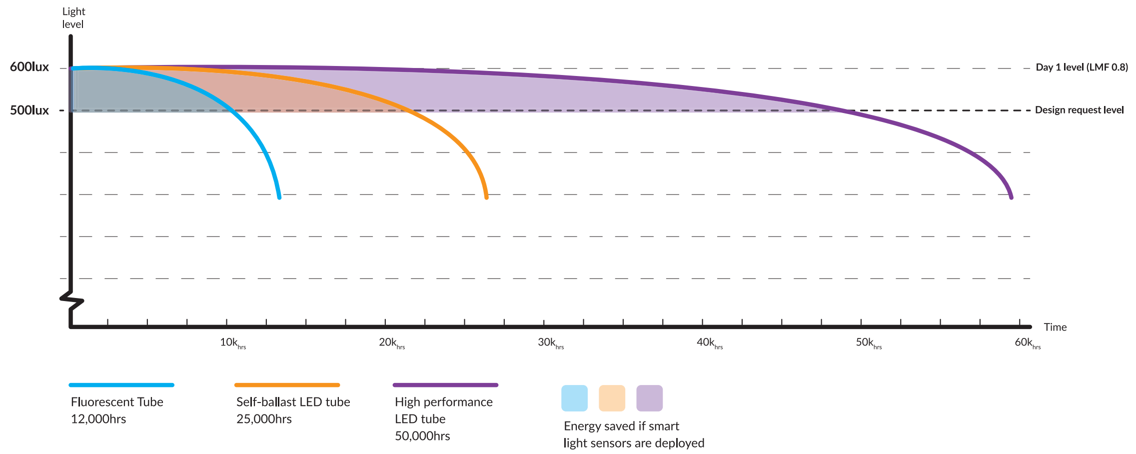
Combined synergy to integrate inputs from sensors

Each daylight and motion sensor can be programmed with preset memory and by integrating the inputs from both sensors installed in the same fitting with the controlling programme. The sensor combinations can execute in-situ the reconciled and desirable level of performance without conflict in priority. Each integrated sensor combination can also be programmed to communicate with other designated lighting fittings, including those not in the same physical boundary and out of the line of sight.

Redefining maintenance factor

Maintenance factor is a textbook parameter for over-designing the illuminance output during the initial and longer portion of the lamp lifespan to offset degraded performance during the latter portion. In operation, only a fractional of the lifetime duration is of the designed optimal lux level and most of the times it is either too bright, wasting energy, or too dim towards the latter lifespan.

The performance curve below illustrates how the lamp could be dimmed to save energy during the longer duration of initial operation. The daylight sensor ensures the performance of each lighting fitting in keeping the recommended illuminance level constant over almost the entire lifespan of the lamps, not only for energy saving but also to enhance the ambience and wellbeing of occupants. Sensors used for centralising a group of lighting fittings cannot handle individual lamp adjustments. The Building Energy Code (BEC) should provide factors in calculating power consumption assessment with the maintenance factor adjusted dimming provision.



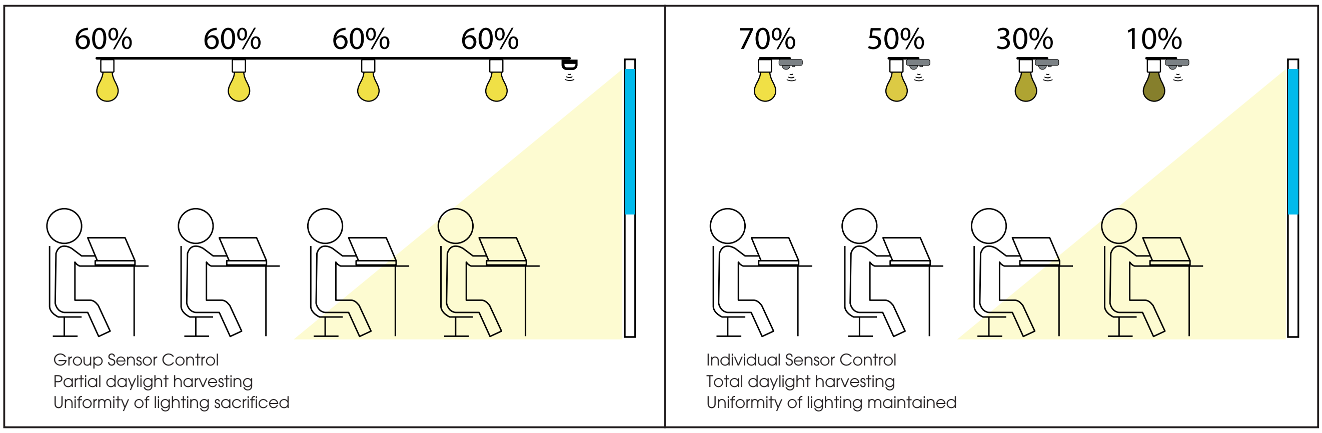
On-going adjustments enable energy saving and maintain better uniformity (1)
(Note: The portion of the curve above design level of 500 lux represents the energy saved of different LED fluorescent lamp types.)

Daylight harvesting

The presence of daylight does not stop at the window perimeter; it goes beyond abutting rows. The territory that the built-in daylight sensor needs to cover is again immediately below the lighting fitting. The Illuminance level measured becomes proprietary and free from distortion by one measured at a distance away. With a preset lux level, the built-in sensor maximises the daylighting savings in each and every fitting whilst at the same time maintaining uniformity of illumination across the whole area. The odd situation of isolated spots around a lone sunlight pipe or next to an obstacle affecting a particular lighting fitting is no longer an issue, nor is there the need to assign different circuits for the perimeter and inner areas. Additional credit should be given to installations with lux control dimming across the whole area in green building assessment.

during lunch hours, beyond the duration of normal office hours, for holidays and festive events with provisions overriding for routine, periodical and emergency off-hour cleaning, testing and maintenance work.

To allow entries to premises outside normal working days and working hours, a manual pass-by switch is usually installed to override the time-scheduled control and to initiate the operation by turning on the lighting fitting installation outside normal hours. Unfortunately, counting on the last departing occupant to initiate the bypass switch to restore the management programme is never reliable, while working outside normal days and hours is rather common for certain trading sectors.



On-going adjustments enable energy saving and maintain better uniformity (2)

A motion component detected behind a closed door can light up the upper and lower landings before the occupant steps out onto the Back of House (BOH) staircase, and the sensors at each landing communicates with other succeeding ones in a continual manner either along the accenting or descending path as taken by the occupant for safe passage. A daylight component spotting strong ambient light together with motion detected can partially light up the entrance light in a closed room for occupants' safe entry.

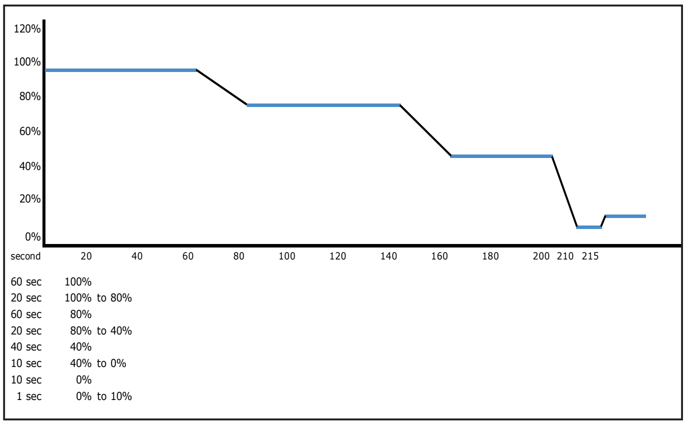
Time scheduling and scene control

In essence, time-scheduling control preset by a software is used to reflect different activities that are needed or expected during different calendar days and different times of each of the calendar days. Some of the typical arrangements are scheduled turning off or dimming down of the lighting fittings

Safety precaution

In order to provide added safety to occupants working off-hours and respond to the uncertainty of isolated motion sensors installed for centralised control in scanning, motion detection cum sweeping cycles are repeated to delay turning OFF the lighting fittings to avoid leaving a residing and undetected occupant in total darkness. Typical tender specification prescribes delayed durations of two to three hours to confirm the absence of occupancies.

An integrated combination of built-in sensors installed in each and every lighting fitting above and across the whole area narrows down the territory that each sensing component needs to cover. Detection of fine movements is more reliable and erratic ON/ OFF disturbance is limited. The motion component can be programmed in multiple steps, adjusting rates of fading time and duration to initiate actions. Below is a chart to illustrate that even with condensed durations to turn off all the lightings, the occupants could be promptly alerted - repeatedly - but still not being startled on an impending shutdown within 216 seconds, that is, about 3.5 minutes instead of the usual two to three hours:



Scene programming allows energy saving and safety
(Note: Any motion detected during different and successive cycles will reset the clock to the first. The staged dimming down cycles provides adequate alert to an occupant. The final setting of 10% reassembles the situation that a minimum illumination level is required at certain locations after the lighting fitting was turned 'OFF'.)

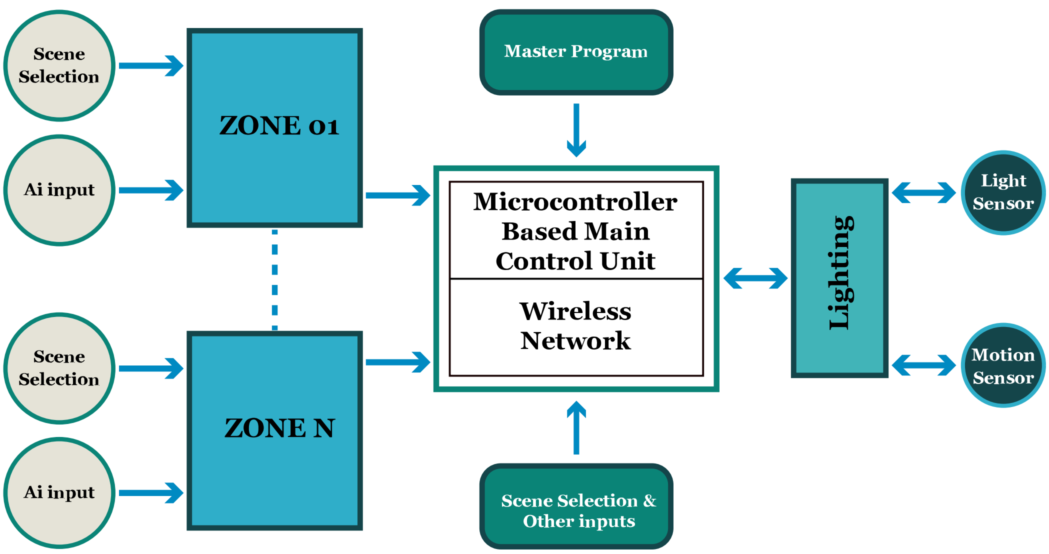
Energy consumption vis-à-vis wellbeing

In terms of energy consumption, a typical IEEE 802.15.4 compliance ZigBee Node operates at about 3.3 V/12 μA in sleeping mode. For 1,000 Nodes operating in sleeping mode at 24 hours a day, 365 days a year, the power consumption is about 0.35 kWh. Ten 16 W LED tubes with a loss of 2 W running for two hours would consume about 0.36 kWh.

The wellbeing of occupants is one of the crucial factors in devising an intelligent programme. Motion denotes presence of occupants. The motion component can be programmed in master-and-slave configuration with abutting and integrated sensor combinations so that movement detected by one would be transmitted and cause others to function. In the case of tenants working on premises outside the normal hours, the area lit up by a single detection is not only confined to the area under its host lighting fitting. A cluster of integrated sensor combinations in proximity could be programmed as master-slave mode to 'light up' the surrounding lighting fittings and around a lone typist, to keep the balance between ambient wellbeing and energy consumption. In due time, with a lone occupant, only the area around the activity will be lit, while the rest will be dimmed down or switched to OFF under a lack of movement detections. With several occupants stationed at different locations, a larger area would remain lit as it should be.

Interface & beyond

But before the question is raised on how IoT technology could be utilised for other building services provisions, it is conducive to look at the combined working nature of different sensors in the lighting installation to understand how lighting performances could be shaped at the locality front. The daylight sensor is working continuously to adhere to its preset memory or lux level, by lighting up or dimming down. The motion sensor's operation is interactive but governed by a timer and assigned responding parameters or percentages of performance. When the motion sensor is assigned a 0% performance or prompted to turn off the lighting, it would be a de facto response; the motion sensor does not override the control of the daylight sensor. The master management programme schedule holds the prioritised authority. The lighting installation is part of the total building intelligent system:

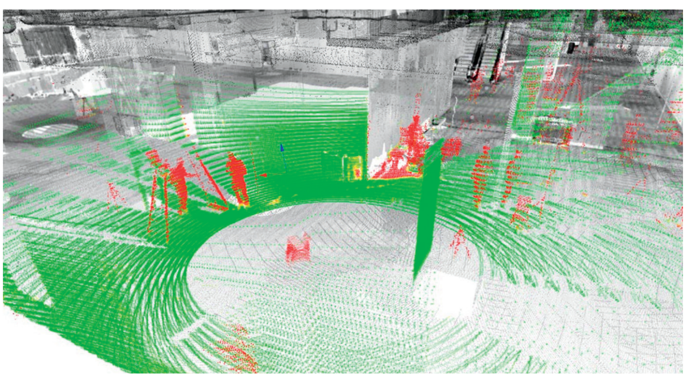


Signals paths – Lighting installation (Source: IoDeeds, November 2022)

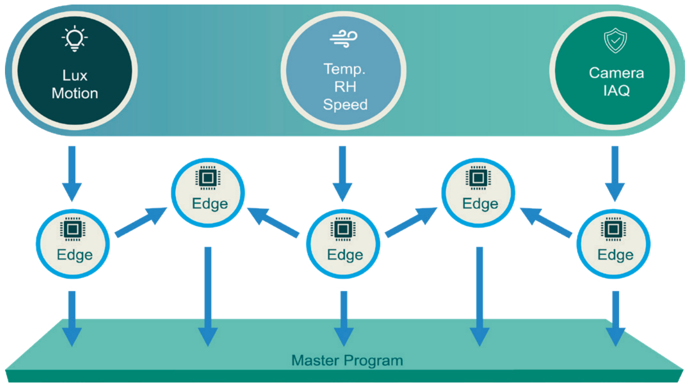
The usage of wireless connection to secure data and control responses is gaining momentum in centralised air ventilating systems. Equally for Heating, Ventilation, and Air Conditioning (HVAC) systems, a temperature sensor prescribed with a 'fixed' memory functions like the daylight sensor, using humidity and CO^2 to count occupancy in a more static manner, and the speedometer to measure and adjust the final performance. The performance matrix among air speed, humidity, temperature is an extension of the amalgamated logic of daylight and motion sensors. Air movement control is an analogy of uniformity in lighting. Both CO^2 and radon sensors are supplementary and complementary to the motion sensor.

Without more accurate counts of occupant presence, the practice of either reducing the output of or turning off the HVAC system by time scheduling during lunch hours or outside normal working hours impedes the wellbeing and productivity of occupants working overtime. Interfacing with lighting installations, HVAC systems operating outside normal hours could be turned OFF within minutes, instead of abiding by the outdated prescription of two-to-three-hour sweeping cycles. Wireless interface devices that allow users to connect an installed room-cooler with remote control in concert with a motion sensor either for local control or to master management programme are already available on the market.

Interfacing HVAC with other building services provisions is already a common arrangement. A large crowd influx signaled by lift-landing destination algorithms or by camera counting estimated numbers of passengers at a lift lobby not only is useful for lift operations, but can also provide real-time input to the HVAC system to commence operation other than following prescheduled forecast. Sometimes, infrared cameras are used to count movements of occupants and scan the interior layout inside office on each floor. In this regard, a report of the estimated numbers of occupants and movements on the floor, with fire alarms with interval counts at the minute, one minute after, two minutes after…and so



(Source: Winning entry, Indoor Localization Competition 2015, Seattle Joint Research Centre, European Commission)



Interfacing Extension – Edge Computing
(Source: IoDeeds, November 2022)

forth until the cameras were blocked by smoke and heat after a fire alarm was activated, would be paramount for firefighting.

The boundary of the algorithm coverage of an IoT network rests with the innovation of the designers. Interfacings among various services are numerous, and opportunities to shape combined performance by edge computing are real-time and almost endless.

Under the principal IoT requiring each and every lighting fitting is to be installed with a wireless module in mesh connection, the lighting installation becomes a system of flexible and integrated matrix at optimal locations of a large footprint serving as an infrastructure to interface with all other services and as an operating platform to gather data - as input sources and to relay and execute commands either to a single device or a group of interfaced services within an overall zone - as the receiving ends.

With sensors of different natures connected to the wireless modules installed in lighting fittings for onward communication with the master controlling programme, an intelligent lighting installation becomes the backbone for other intelligent provisions of performance.

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References

1. See the Wikipedia page at https://en.wikipedia.org/wiki/Internet_of_things.
2. Learn more about feedback control system at https://automationforum.co/what-is-a-feedback-control-system-and-what-are-its-types/.