MEBS6005 Building Automation Systems

http://ibse.hk/MEBS6005/

Lighting Controls

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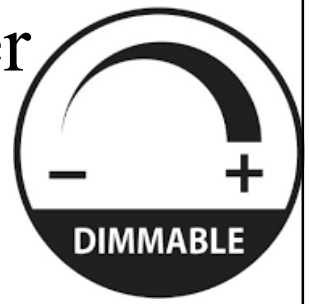
- Basic principles
- Lighting control techniques
- Design considerations
- Wired & wireless systems
- Smart lighting

Basic principles

- A good lighting system design includes a good lighting controls design to enable users manually or automatically to:
  - Turn the lights ON & OFF using a switch; and/or
  - Adjust light output up & down using a dimmer
- Benefits for the owner:
  - Flexibility to satisfy user visual needs
  - Automation to reduce energy costs (on electricity use & demand) & improve sustainability



Benefits of good lighting controls

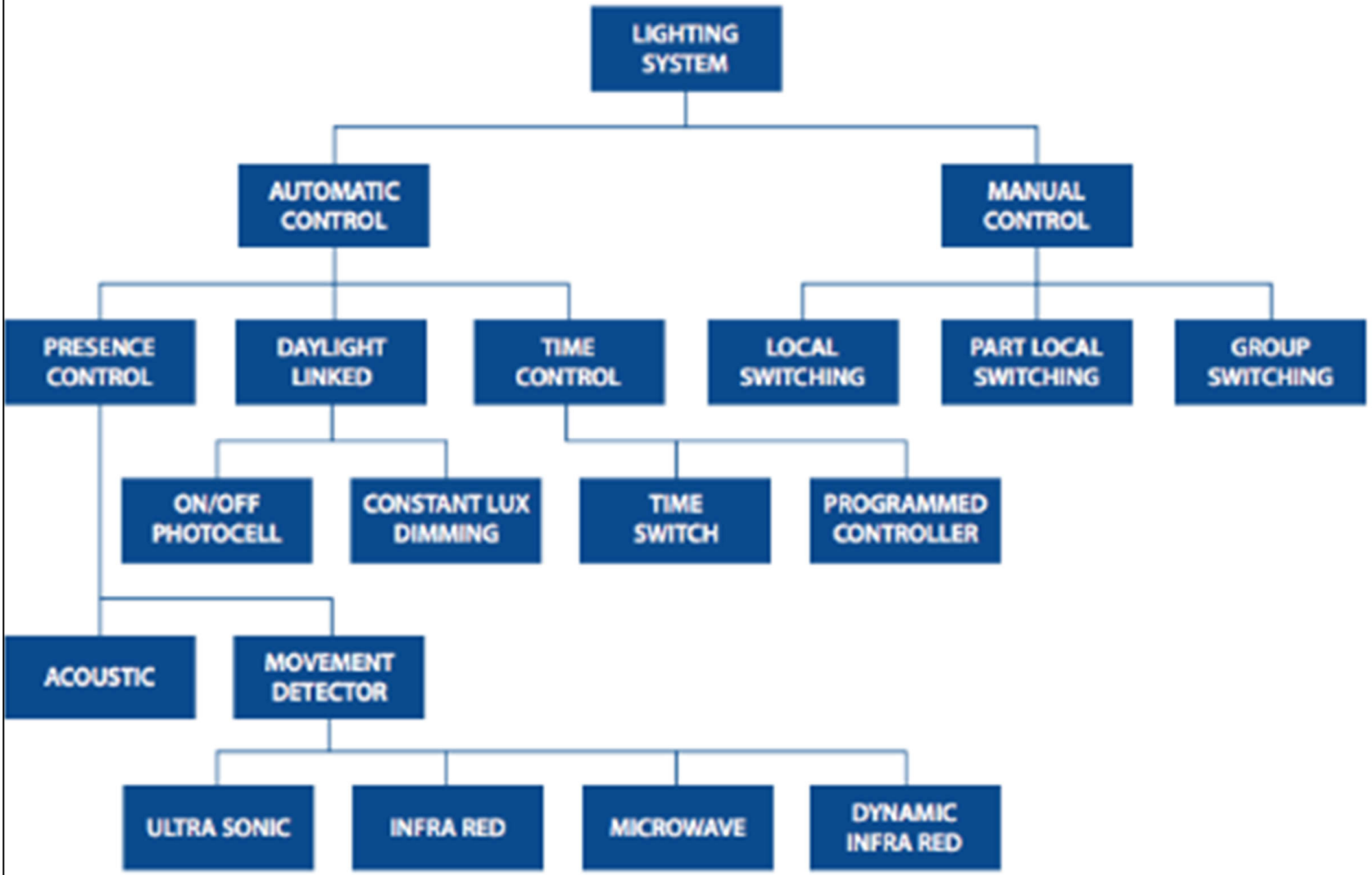
Visual Needs	Energy Management & Sustainability
• Change space appearance • Facilitate different functions of the space • Alter atmosphere & mood • Reduce glare & visual discomfort conditions • Increase user satisfaction by providing users the ability to control their lighting	• Reduce both energy demand & energy consumption • Reduces building operating costs • Comply with building energy codes • Facilitate more efficient building operation & maintenance • Provide data & information for building optimization

(Source: https://lightingcontrolsassociation.org/2017/07/21/introduction-to-lighting-controls/)

Basic principles

- The aim of lighting controls is to encourage the maximum use of daylight & to avoid the unnecessary use of lighting when spaces are unoccupied
- Benefit of a good lighting control system:
  - Occupant satisfaction & productivity
  - Planning flexibility (suit work layouts & patterns)
  - Better facility management information (e.g. for security & maintenance)

Overview of lighting control methods



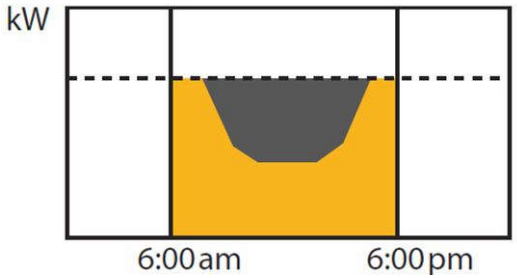
(Source: https://www.controlco.com.au/blog/2015/7/16/lighting-control-methods)

Basic principles

- Five basic methods of lighting control:
  - 1. Localised manual controls
    - Using local switches & dimmers, remote control
  - 2. Time switches
    - For buildings with fixed occupancy times
  - 3. Occupancy detection
    - Using occupancy or presence sensors
  - 4. Lighting level (e.g. to integrate daylight)
  - 5. Scene set control (different lighting schemes)

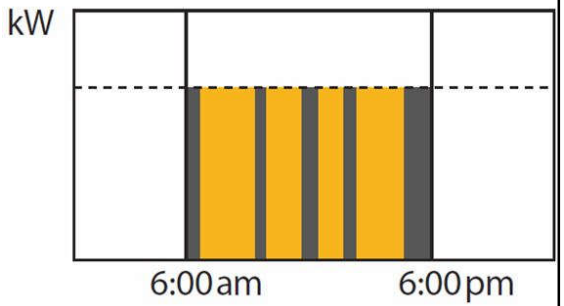
Basic principles

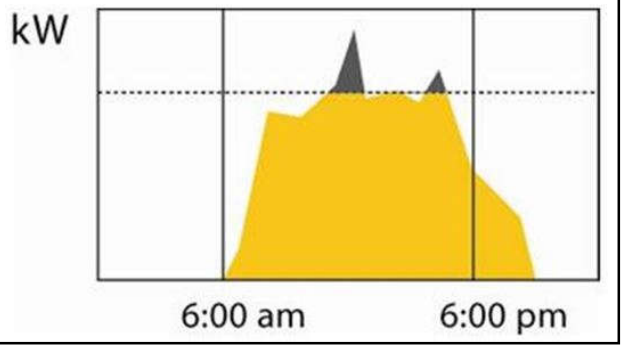
- Integrate lighting controls with BAS
  - Lighting can be turned on, off, or dimmed with a building automation or lighting control system based on time of day, or on occupancy sensor, photo sensors & timers
- Common lighting control functions:
  - 1. Occupancy control, 2. Time scheduling
  - 3. Daylight control, 4. Task control
  - 5. Personal control, 6. Variable power shedding



Basic principles

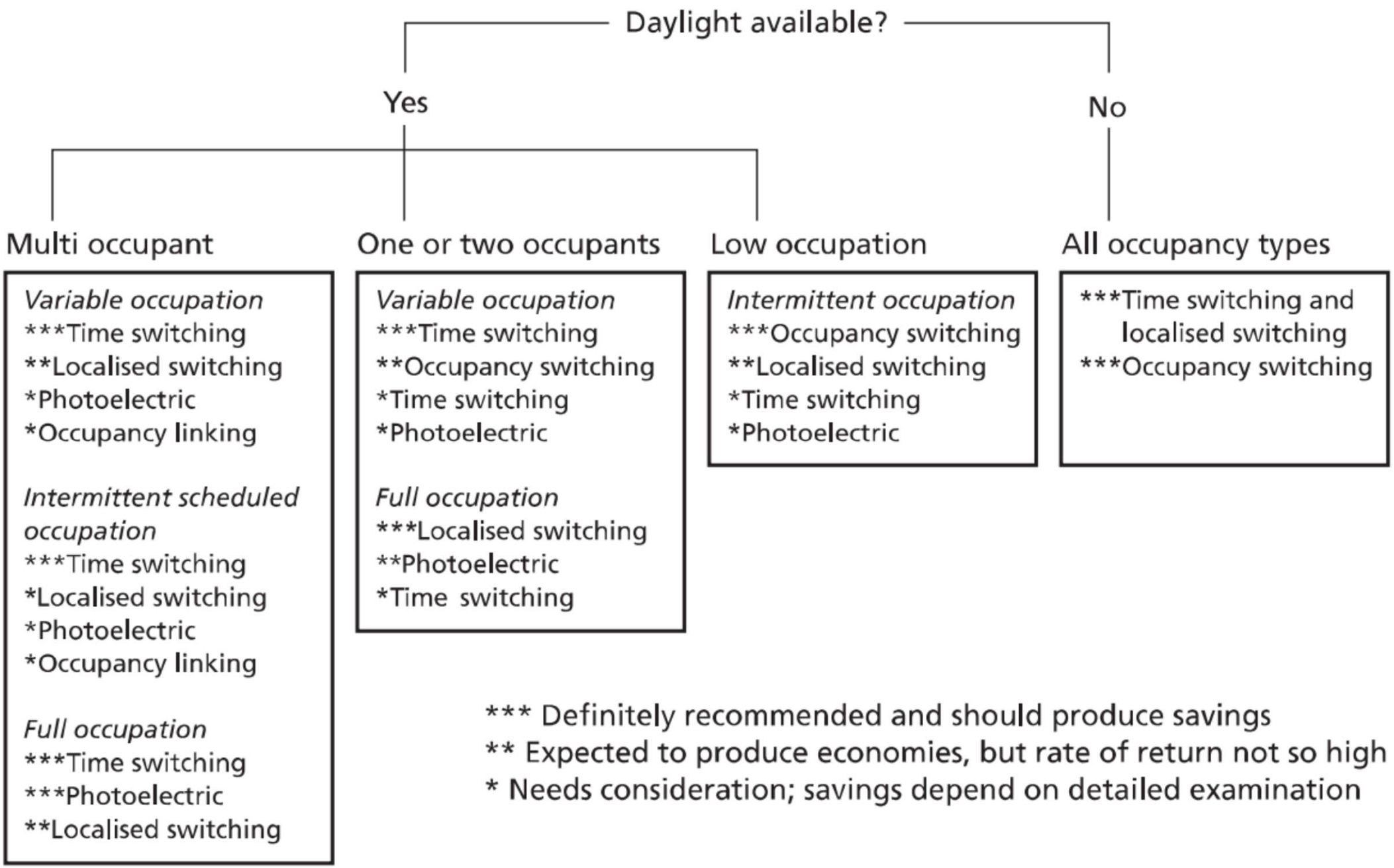
- Typical control strategies:
  - Manual control (local/group)
  - Time scheduling (time-based control)
  - Occupancy sensing (vacancy sensing)
  - Daylight response (to reduce electric lights)
  - Institutional task tuning (user preference, scene)
  - Colour tuning (various effects)
  - Data generation (intelligence)
  - Demand response (↓demand costs)





(Source: https://lightingcontrolsassociation.org/2017/07/21/introduction-to-lighting-controls/)

Selection of lighting control strategy



[Source: CIBSE, 2008. *Building Control Systems*, CIBSE Guide H, 2nd ed.]

Basic principles

- In recent years, lighting controls have evolved two additional capabilities:
  - Adjust light source colour, including shade of white light (using LED light source)
  - Generate data via measuring and/or monitoring
- Basic functions of lighting controls
  - Switching (ON/OFF)
  - Dimming & adjusting light intensity
  - Colour & correlated colour temperature (CCT)

Basic & advanced functions of lighting controls

(a) Basic functions:

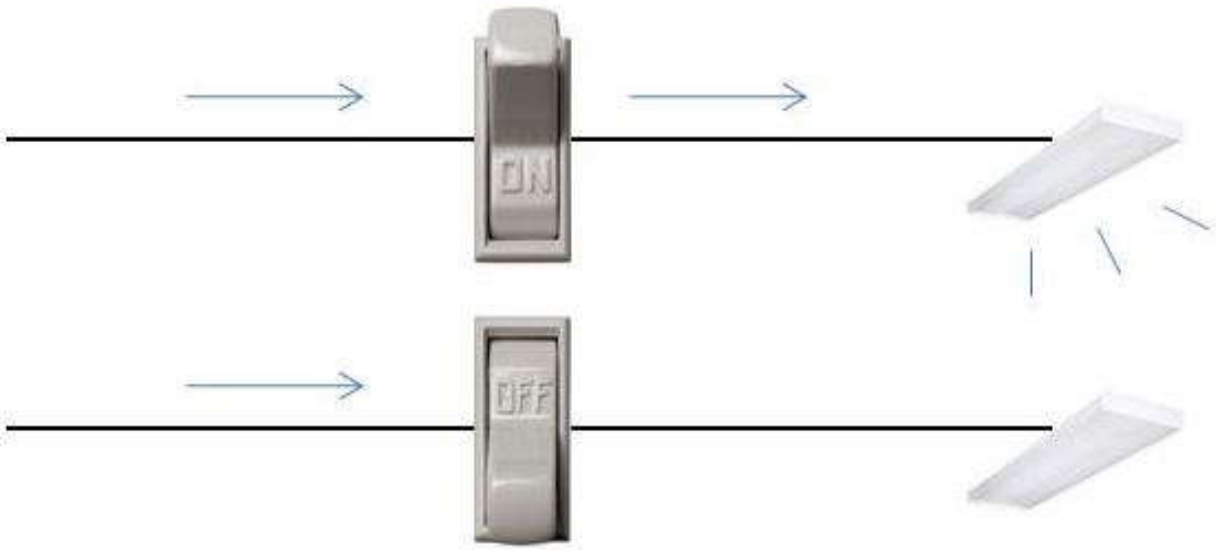
WHAT	HOW
Produce the right amount of light…	Light output (intensity) dimming
…where the light is needed…	Zoning of luminaires to controllers
…and when the light is needed…	Automatically reduce lighting when the space is unoccupied

(a) Advanced functions:

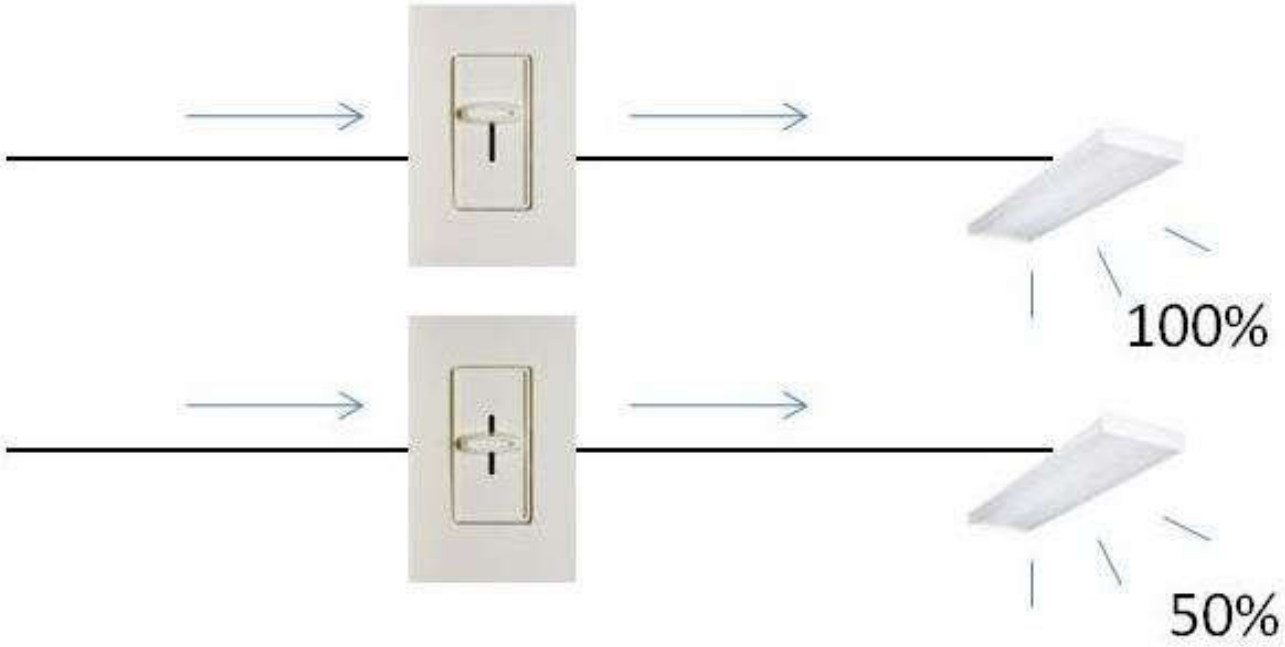
WHAT	HOW
Produce light at the right colour or shade of white light…	Separately dimming arrays of LEDs with different colours or white-light correlated colour temperatures (CCTs)
…allow remote programming and control…	Control systems with programming and lighting management capability
…and tell you how your lights are performing…	Centralized intelligent control systems with measuring and/or monitoring/alarm capability

(Source: https://lightingcontrolsassociation.org/2017/07/21/introduction-to-lighting-controls/)

Switching & dimming lighting controls



(a) Switching (ON/OFF)



(b) Dimming

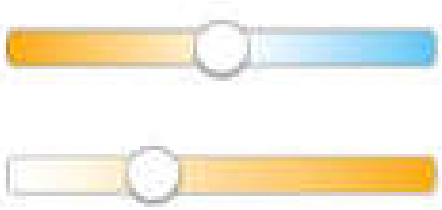
(Source: https://lightingcontrolsassociation.org/2017/07/21/introduction-to-lighting-controls/)

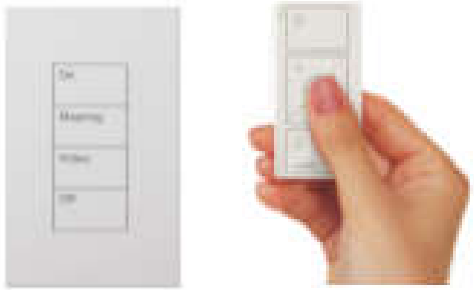
Tunable lighting & lighting controls in a classroom

(Source: https://energyperformancelighting.com/7-ways-a-lighting-upgrade-will-benefit-your-school/)

Basic principles

- By adjusting the intensity of one or more layers of lighting, lighting controls can:
  - Change space appearance
  - Facilitate different functions of the space
  - Alter atmosphere & mood
  - Increase user satisfaction by providing users the ability to control their lighting
  - Reduce glare





Lighting control panel of a lecture theatre

(Source: HKU Learning Environment Services https://its.hku.hk/services/teaching-learning/learning-space/)

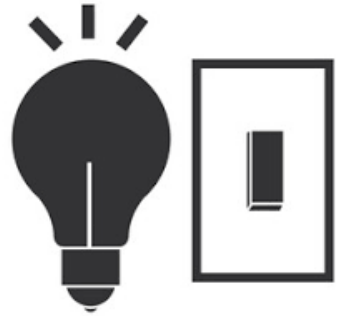
Effects of lighting control in a meeting room

(Source: https://lightingcontrolsassociation.org/2017/07/21/introduction-to-lighting-controls/)

Lighting control of correlated colour temperature (CCT)

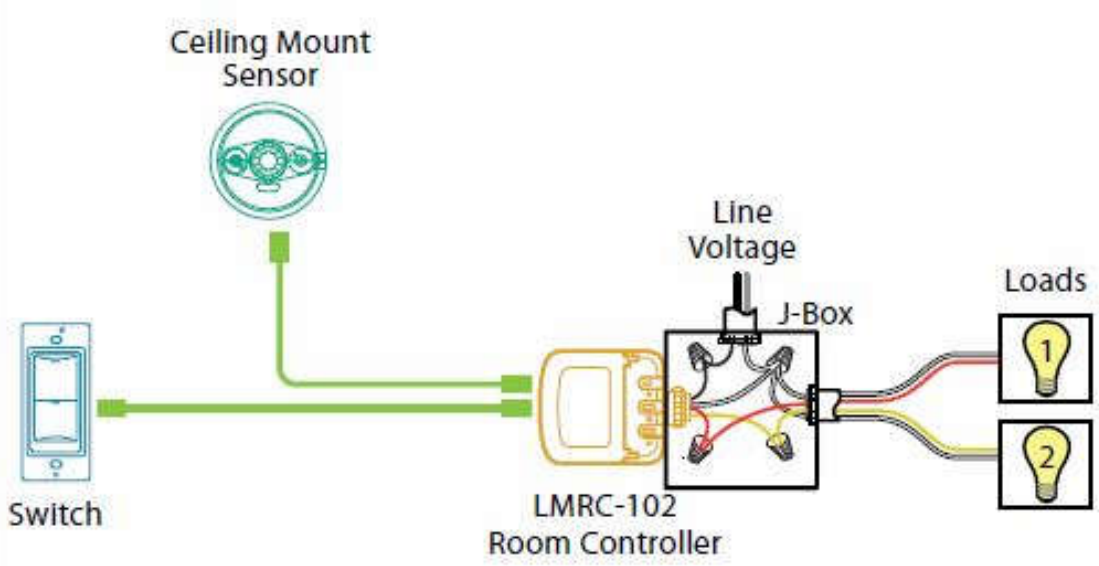
(Source: https://lightingcontrolsassociation.org/2017/07/21/introduction-to-lighting-controls/)

Lighting control techniques



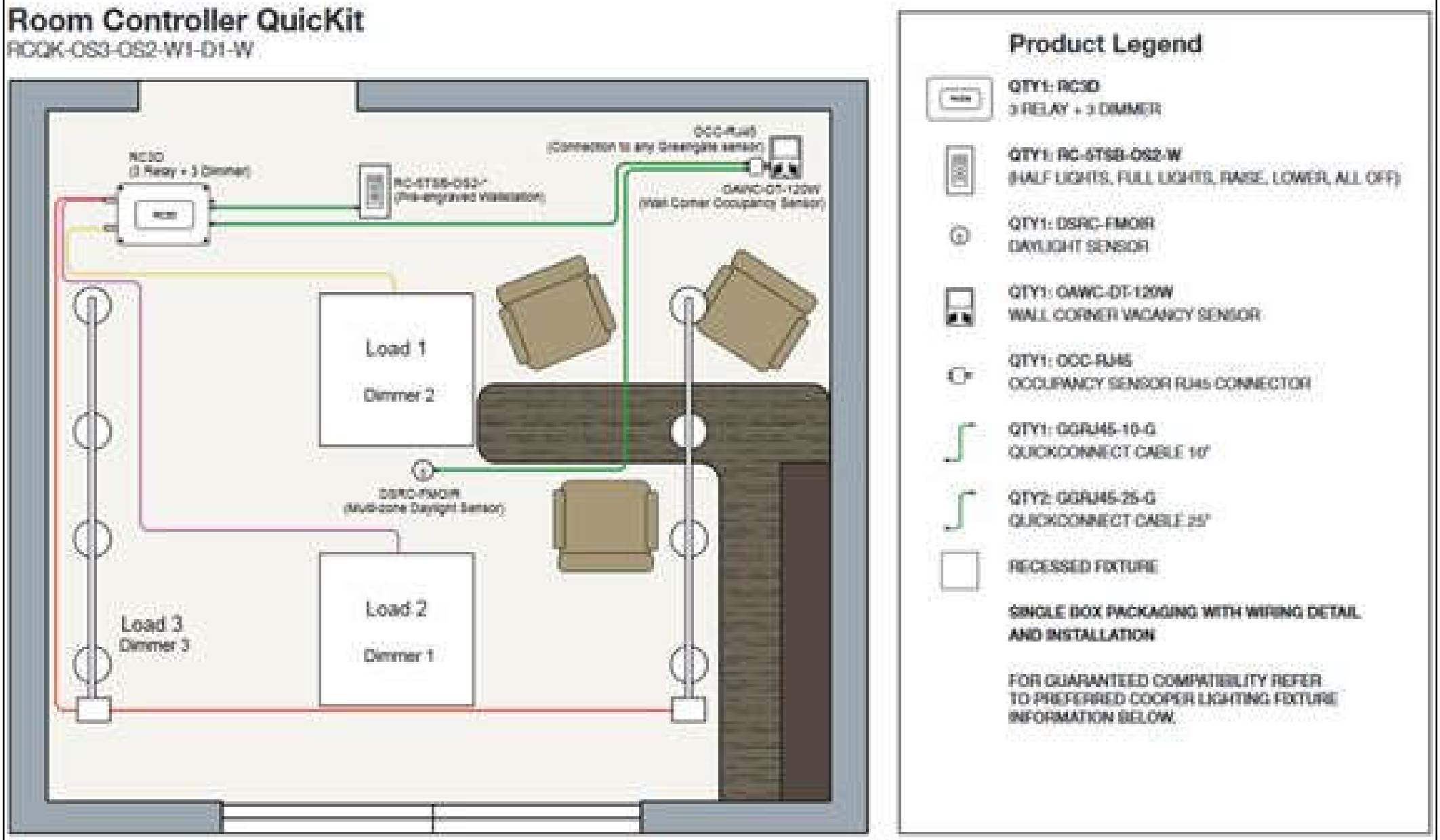
- General types of lighting controls
  - 1. Standalone devices (luminaire-based)
    - Autonomous operation of a lighting load, which may be a luminaire or luminaires installed on a switch leg
    - Standalone embedded sensors
  - 2. Room-based control systems
    - A package of lighting controllers & input devices designed for autonomous room-based operation
  - 3. Centralized building control systems
    - Programmable lighting control for entire floors, buildings or campuses

Standalone lighting control panels & embedded occupancy/light sensors



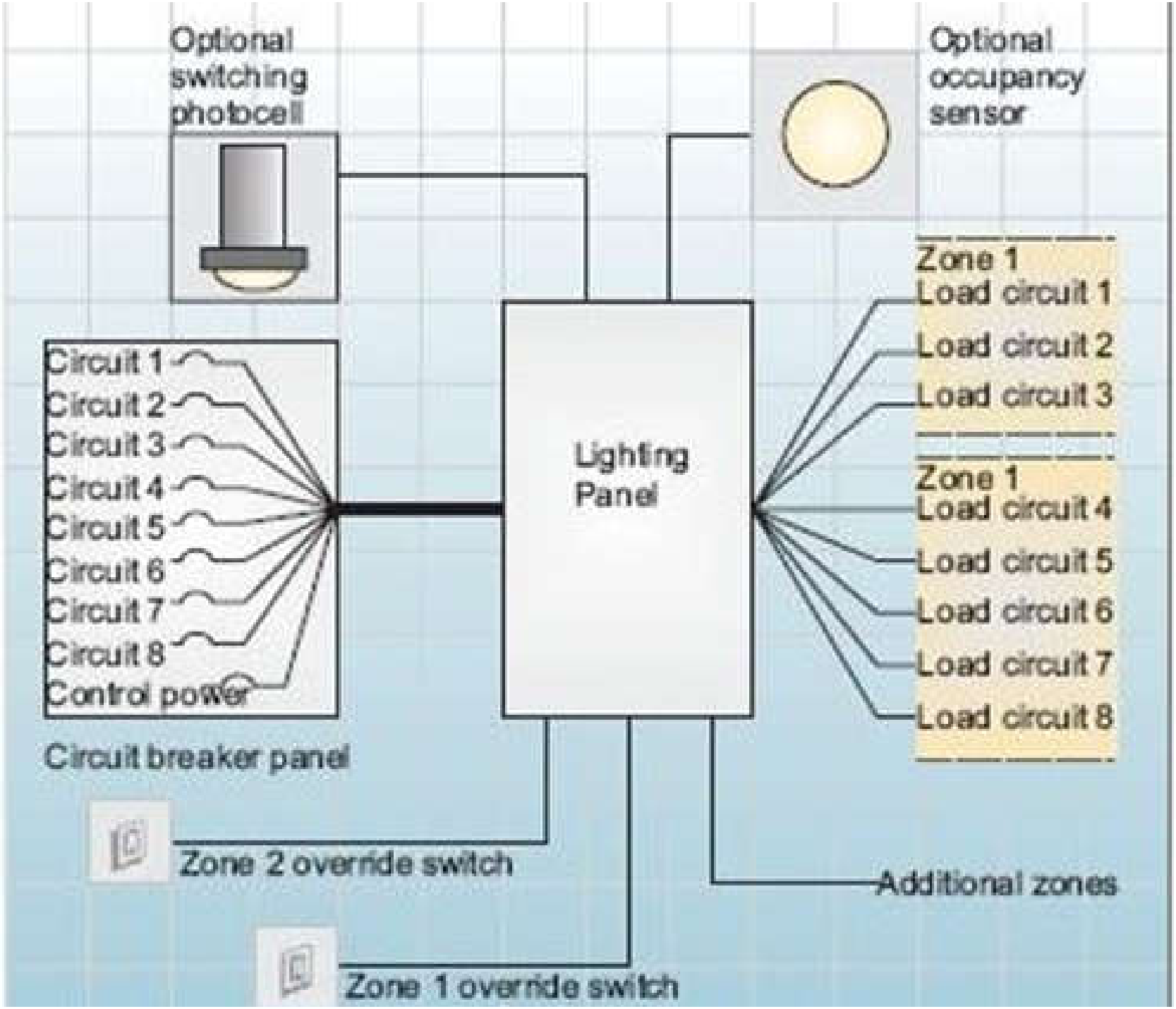
(Source: https://lightingcontrolsassociation.org/2017/07/21/introduction-to-lighting-controls/ & https://www.intelligentenvironments.co.nz/all-latest-trends/standalone-lighting-control/)

A room-based luminaire lighting control in a small office



(Source: https://lightingcontrolsassociation.org/2017/07/21/introduction-to-lighting-controls/)

Centralized intelligent networked lighting control systems

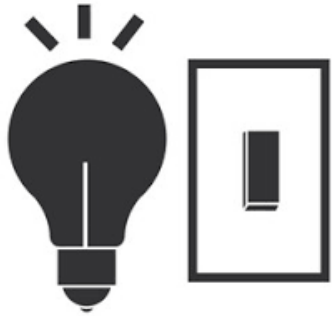


(Source: https://lightingcontrolsassociation.org/2017/07/21/introduction-to-lighting-controls/)

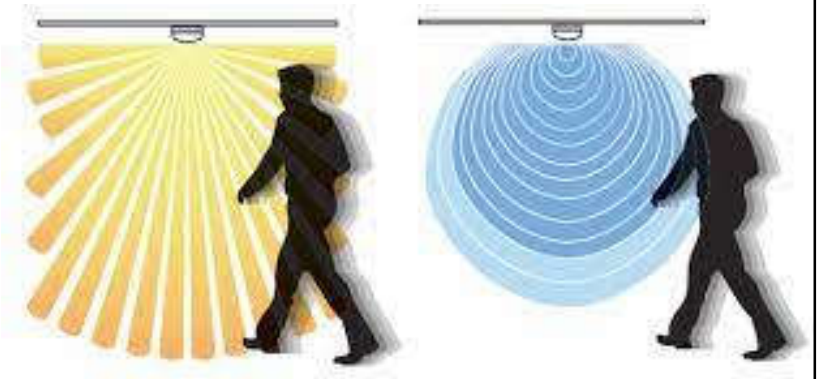
Lighting control techniques

- Typical lighting control techniques & tools
  - Manual control (switches)
  - Timed control (timeclocks)
  - Presence detection
  - Absence detection
  - Photocells
  - Daylight linking
  - Constant illuminance adjustment
  - Dimming & regulation

Lighting control techniques



- Occupancy sensing detection
  - Passive infrared detectors
  - Microwave detectors
  - Ultrasonic detectors



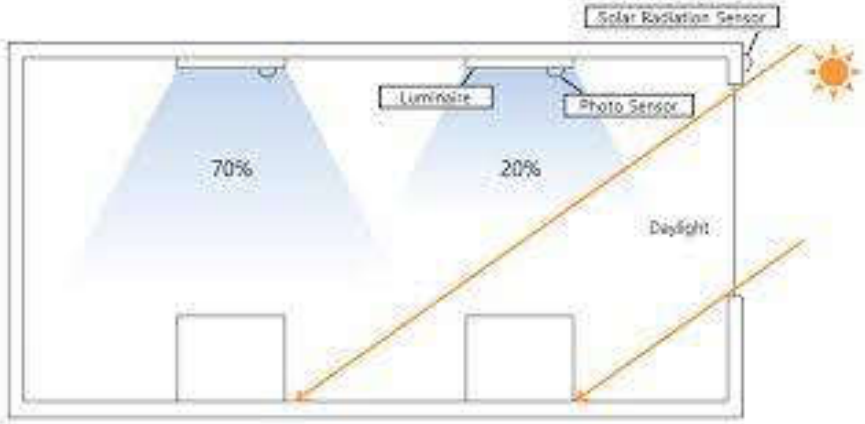
- Photocells & daylight linking
  - Measure available light at a specific location
  - Switch off or dim/regulate the electric lighting
    - Can adjust for constant illuminance at working plane
- Dimming: by supply voltage or electronic

Daylight linking of luminaires from left to right

(Source: SLL, 2016. *Control of Electric Lighting*, Lighting Guide 14, Society of Light and Lighting (SLL), London.)

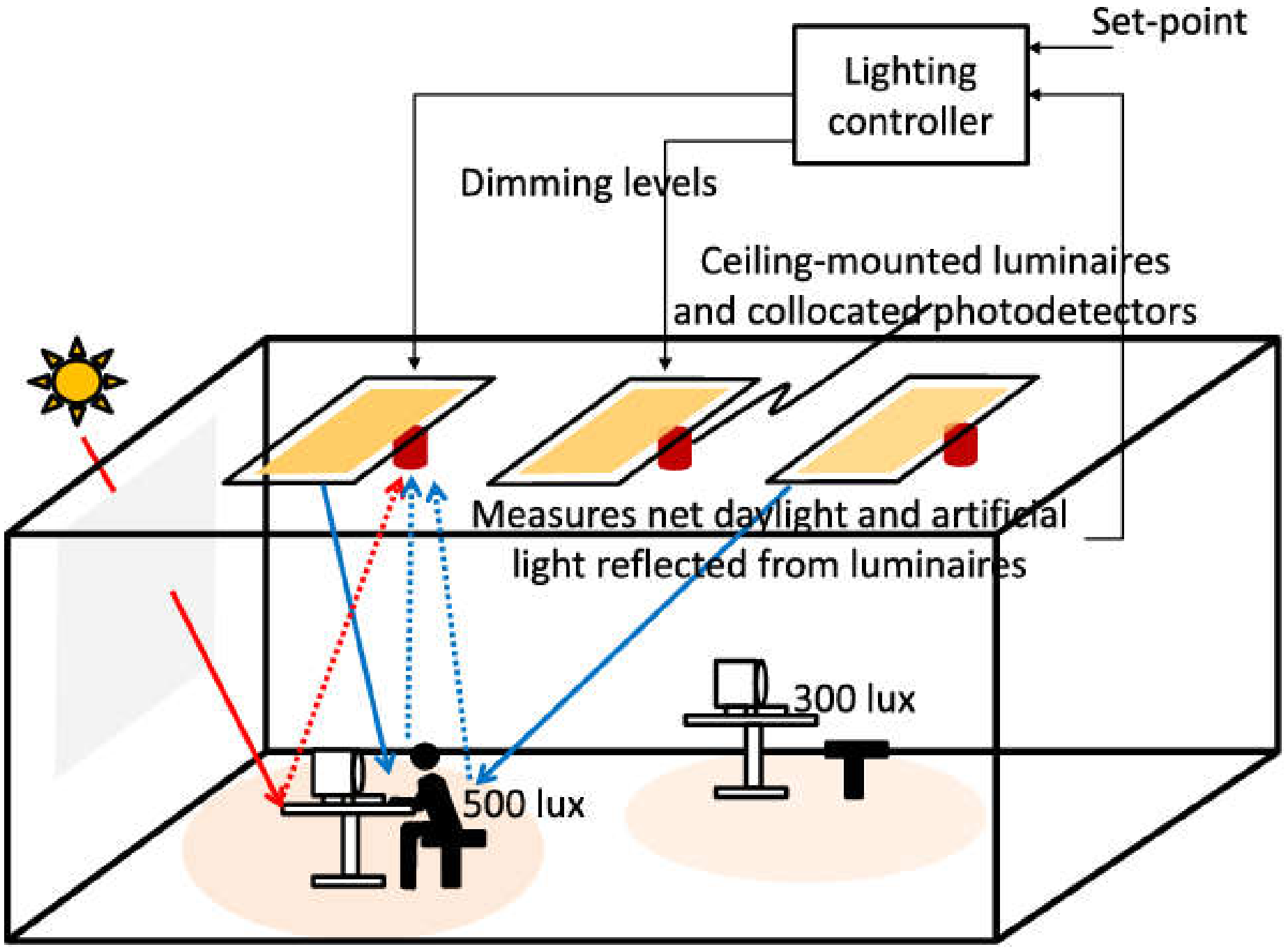
Lighting control techniques

- Daylighting control components
  - Electric light sources
  - Photosensor
  - Dimming or switching units



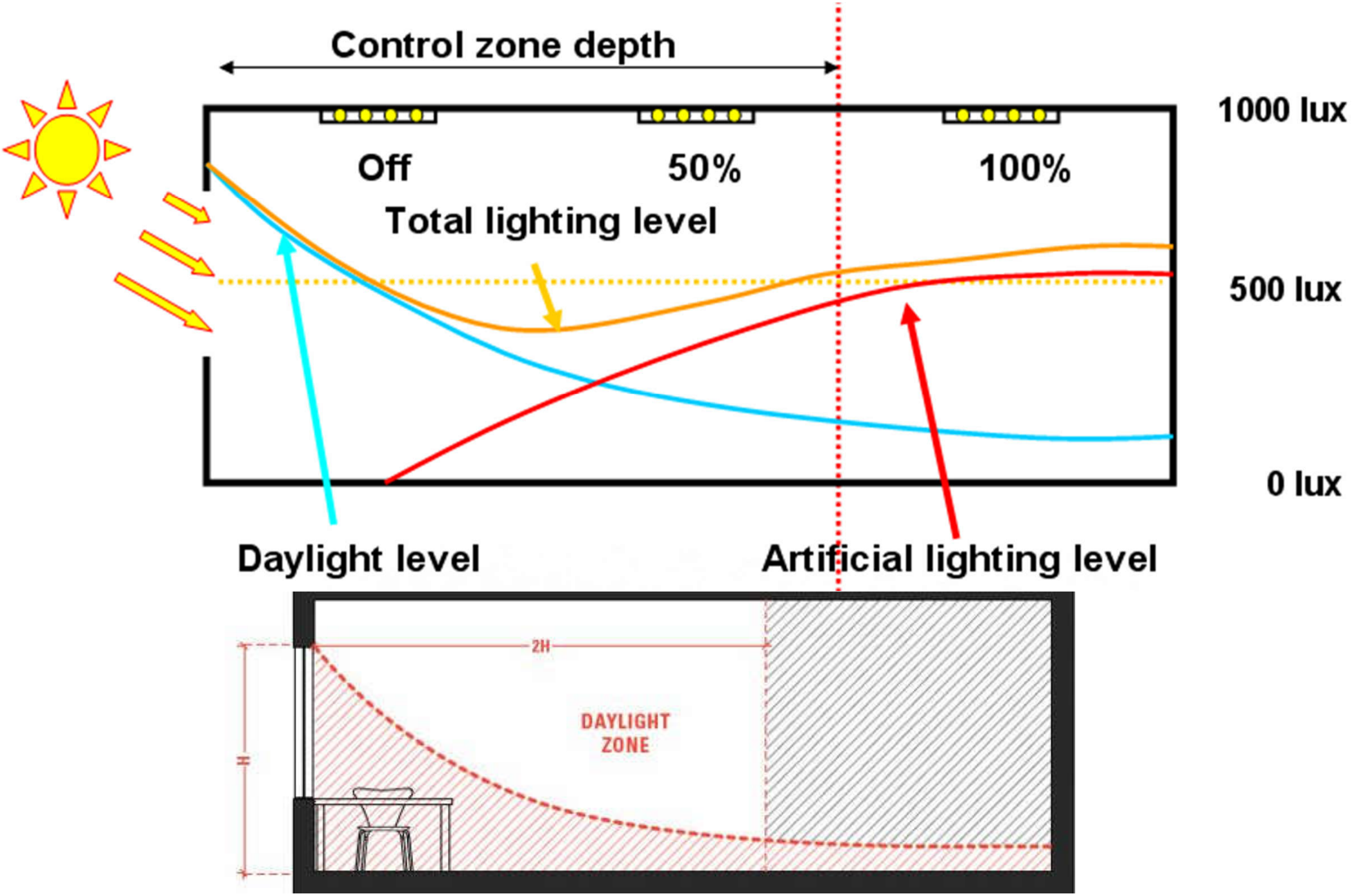
- Placing the photosensor
  - Look directly at a task surface or an interior wall (sense the combination of daylight & electric light)
  - Located on top of a building or view directly out of skylight or window aperture (sense only the available daylight)

Photodetector based lighting control system



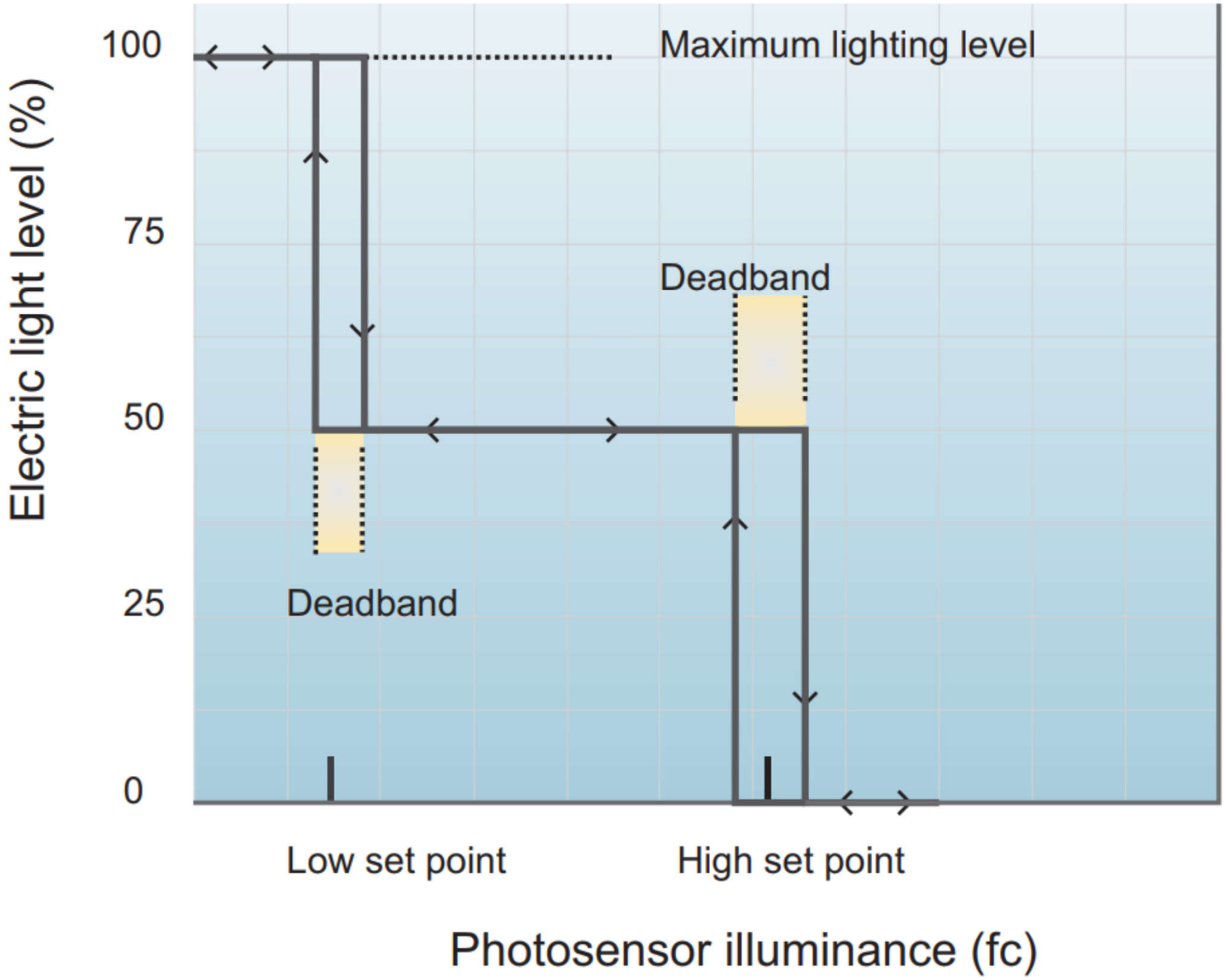
(Source: https://www.semanticscholar.org/paper/Daylight-Sensing-LED-Lighting-System-Li-Pandharipande/)

A room with the profiles of daylight, artificial and total lighting



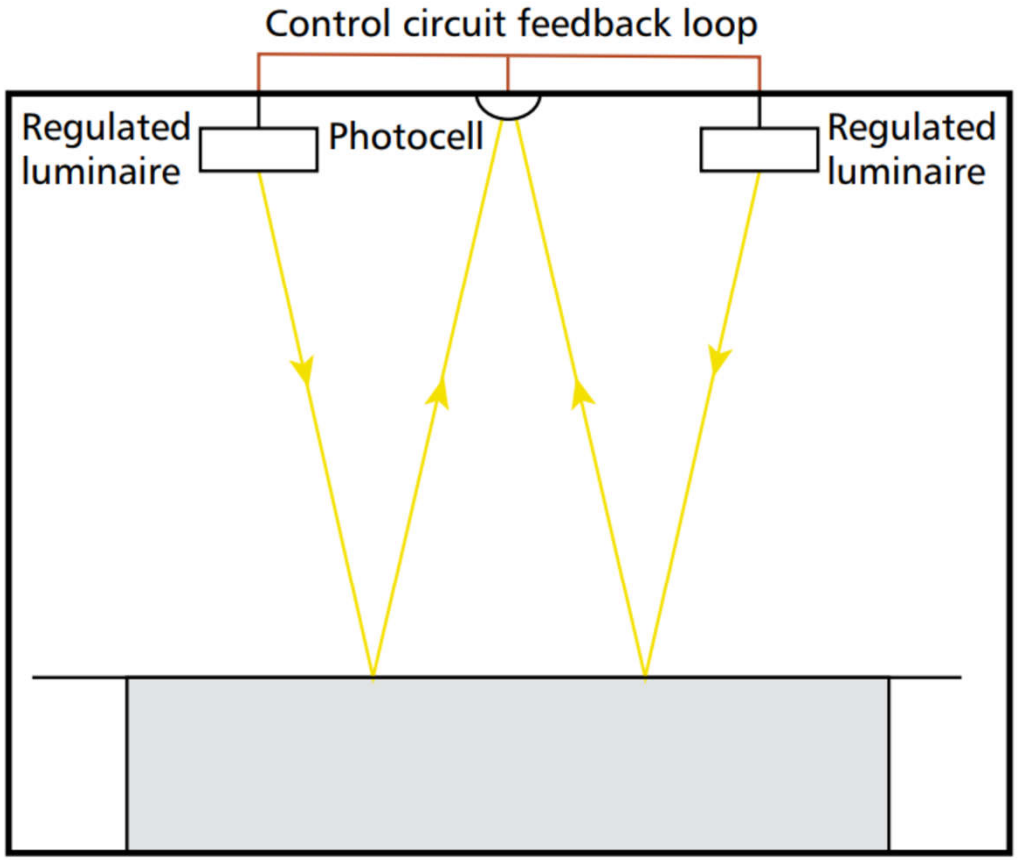
(Source: https://www.researchgate.net/publication/228372427_Reviewing_the_role_of_photosensors_in_lighting_control_systems/)

Switching photosensor illuminance & electric light level with deadbands

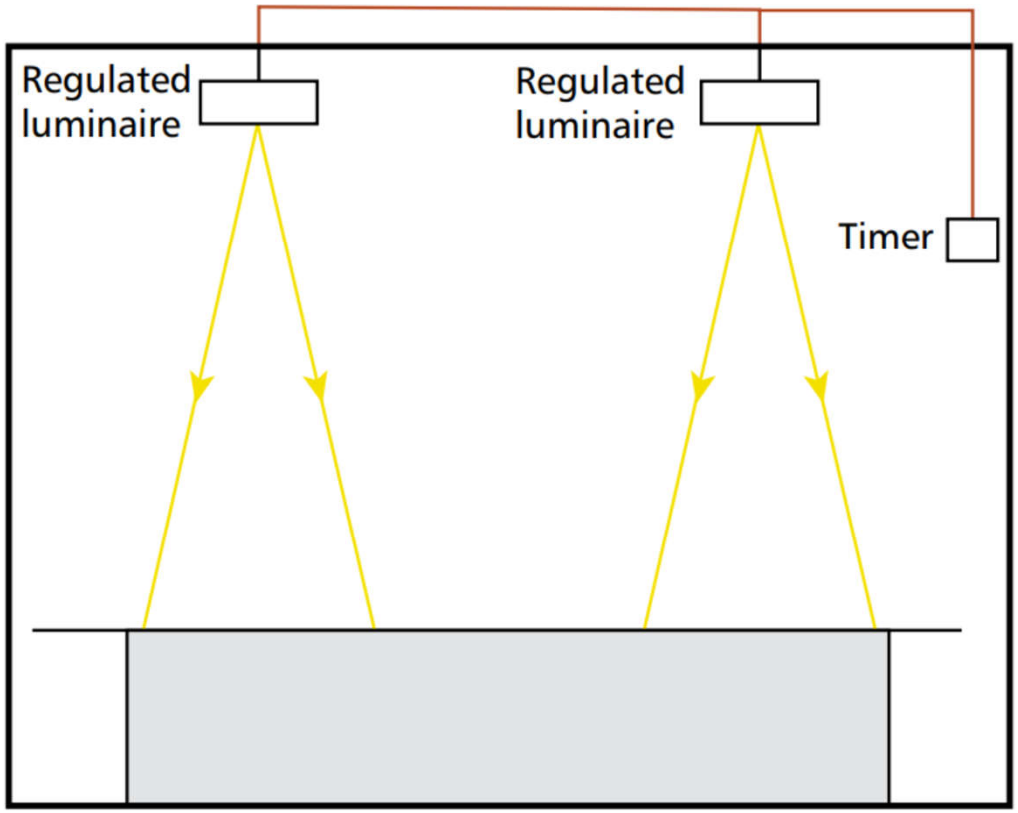


(Source: Advanced Lighting Guidelines 2003)

Lighting control for constant illuminance adjustment



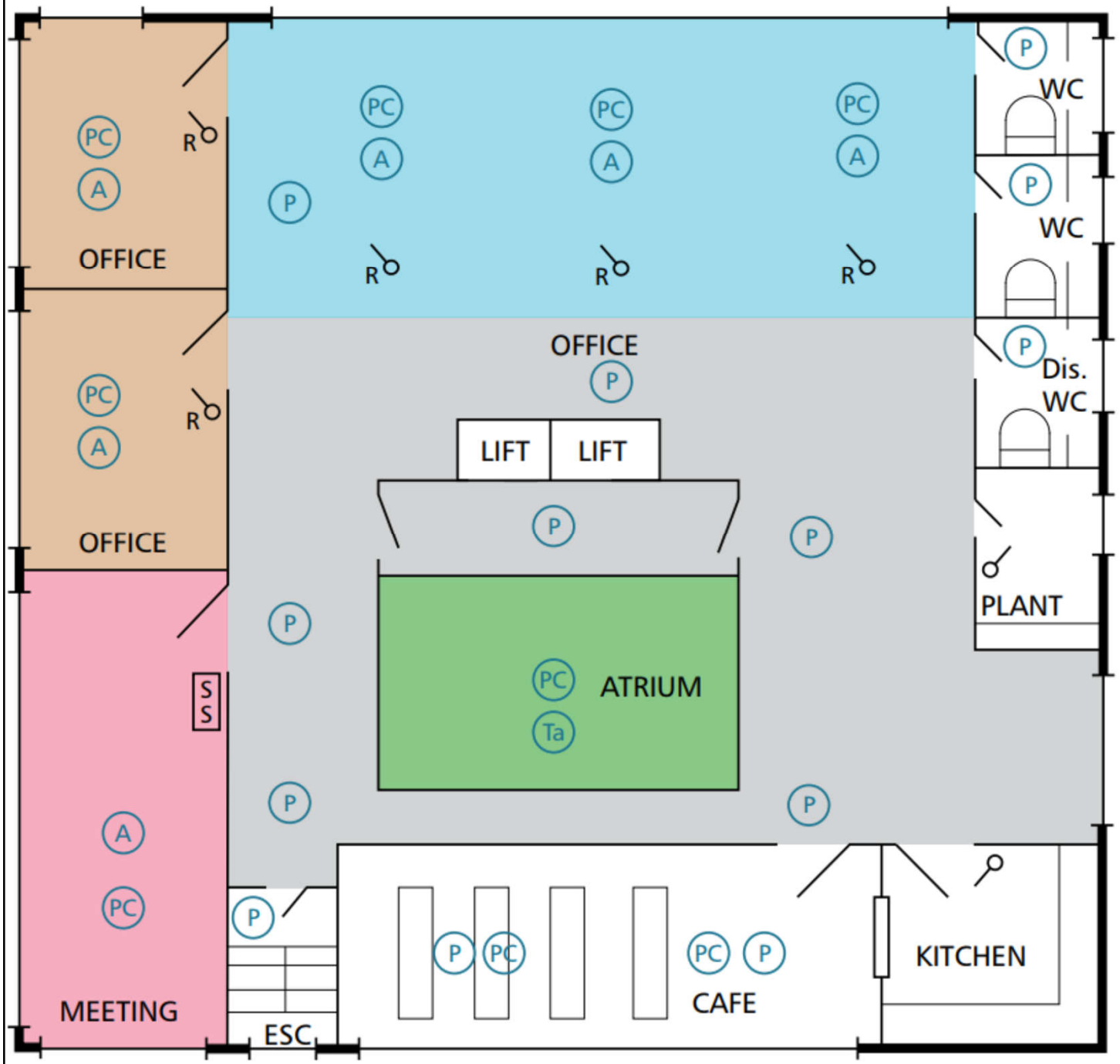
(a) A photocell is used to measure the reflected light from the working plane to adjust the light output to the required output



(b) a timer/data connection is used to regulate the luminaire output at a pre-set level based on 'hours run/maintenance offsets' feedback from the luminaires and manufacturer's data on lamp degradation

(Source: SLL, 2016. *Control of Electric Lighting*, Lighting Guide 14, Society of Light and Lighting (SLL), London.)

Example of lighting control arrangement for a typical office area



P Presence detector

A Absence detector

PC Daylight linking

SS Scene selection and manual dimming

R Retractive switch

Manual switch

Ta Astronomical time clock

Owned space

Managed space

Shared space

Temporarily owned space

Occasionally visited space

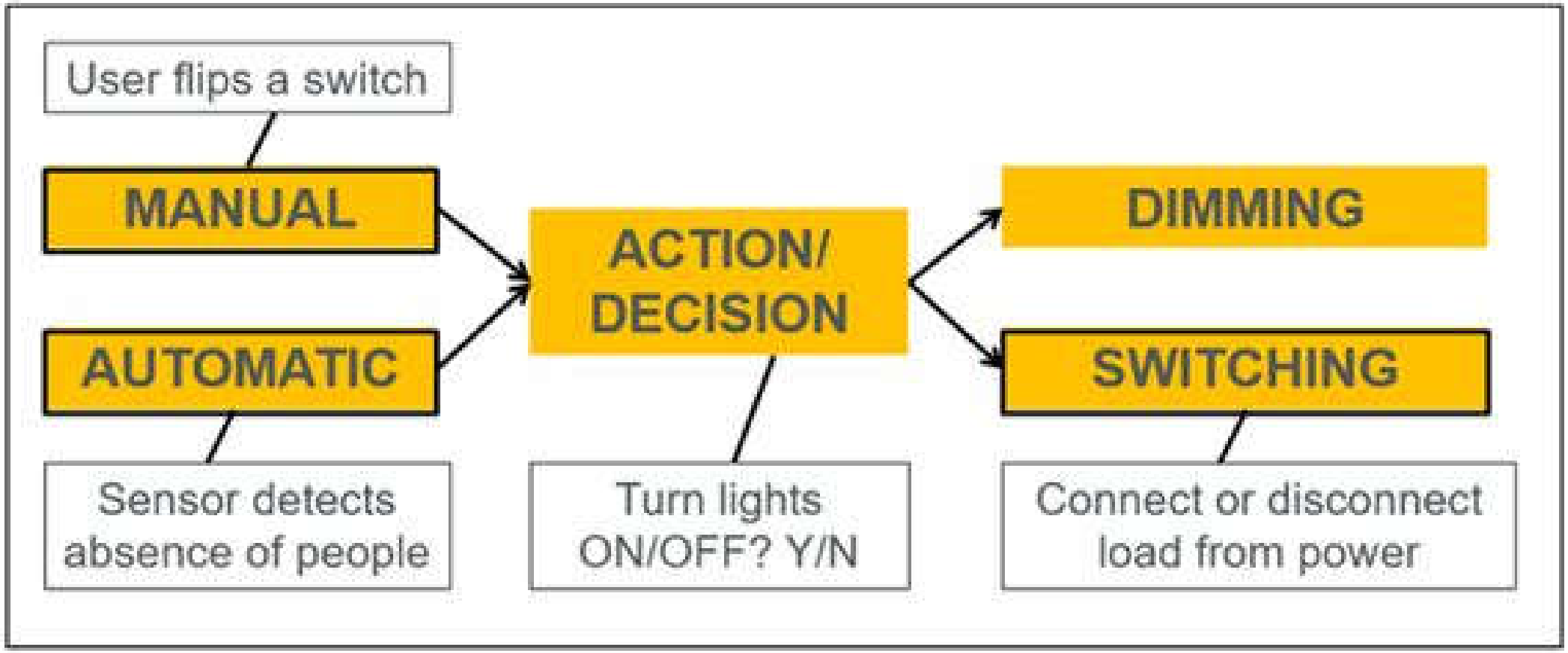
Unowned space

(Source: SLL, 2016. *Control of Electric Lighting*, Lighting Guide 14, Society of Light and Lighting (SLL), London.)

Design considerations

- The input to lighting controls may be manual, automatic or a combination of the two
  - Such as a manual-ON wallbox occupancy sensor
  - The automatic input may be based on time of day, occupancy, light level or some other condition
    - A microprocessor or logic circuit performs this function
- Sensor-based lighting control
  - Occupancy-based
  - Illumination-based

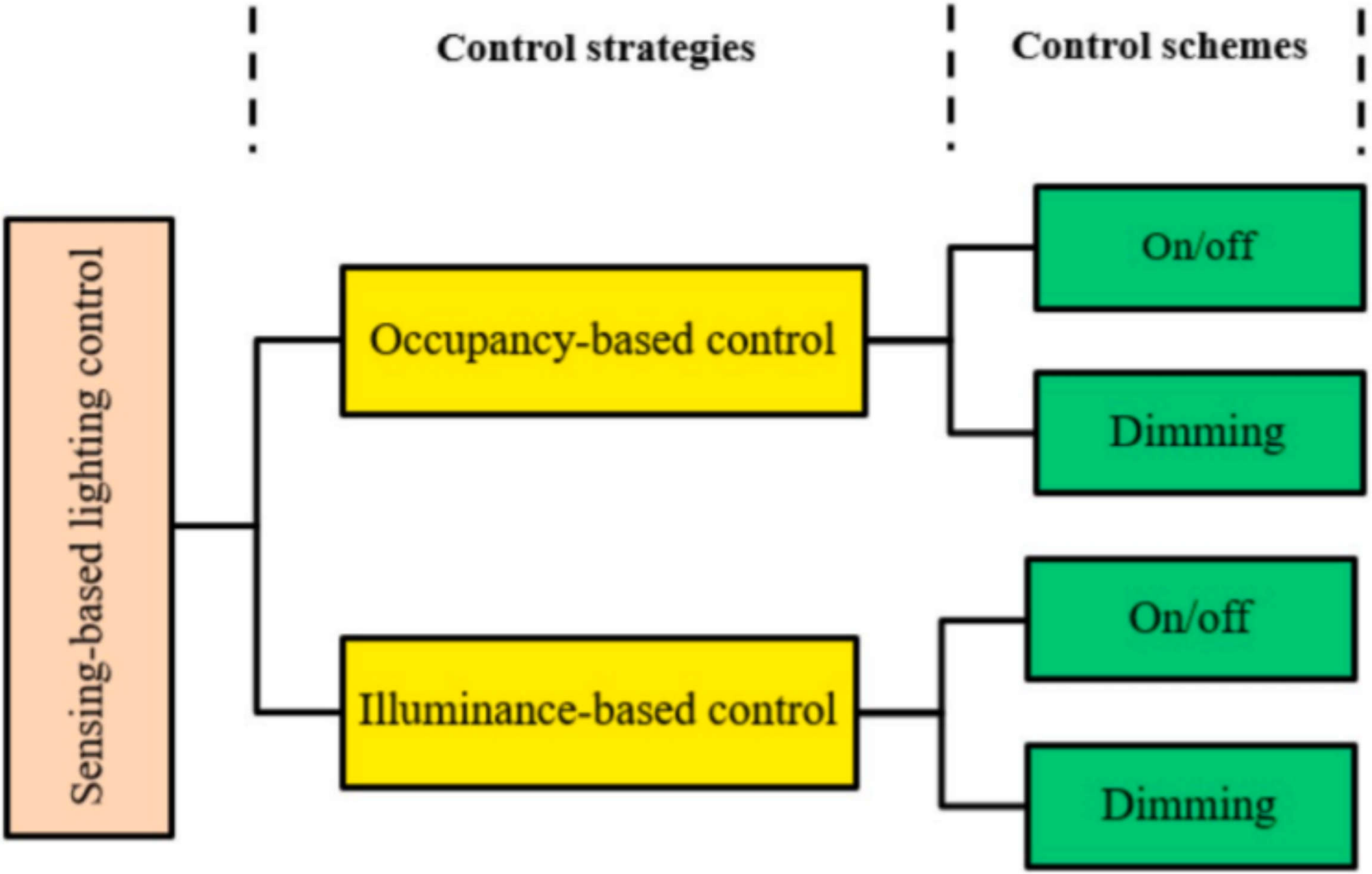
Manual & automatic lighting control strategies (manual-ON wallbox occupancy sensor)



MANUAL-ON OCCUPANCY (VACANCY) SENSOR

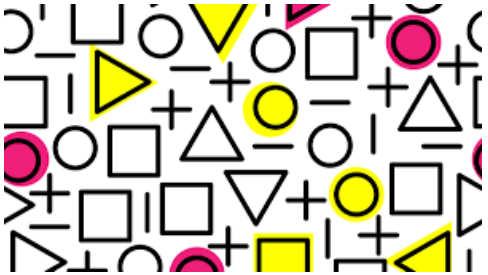
(Source: https://lightingcontrolsassociation.org/2017/07/21/introduction-to-lighting-controls/)

Categories of control strategies and schemes of lighting systems



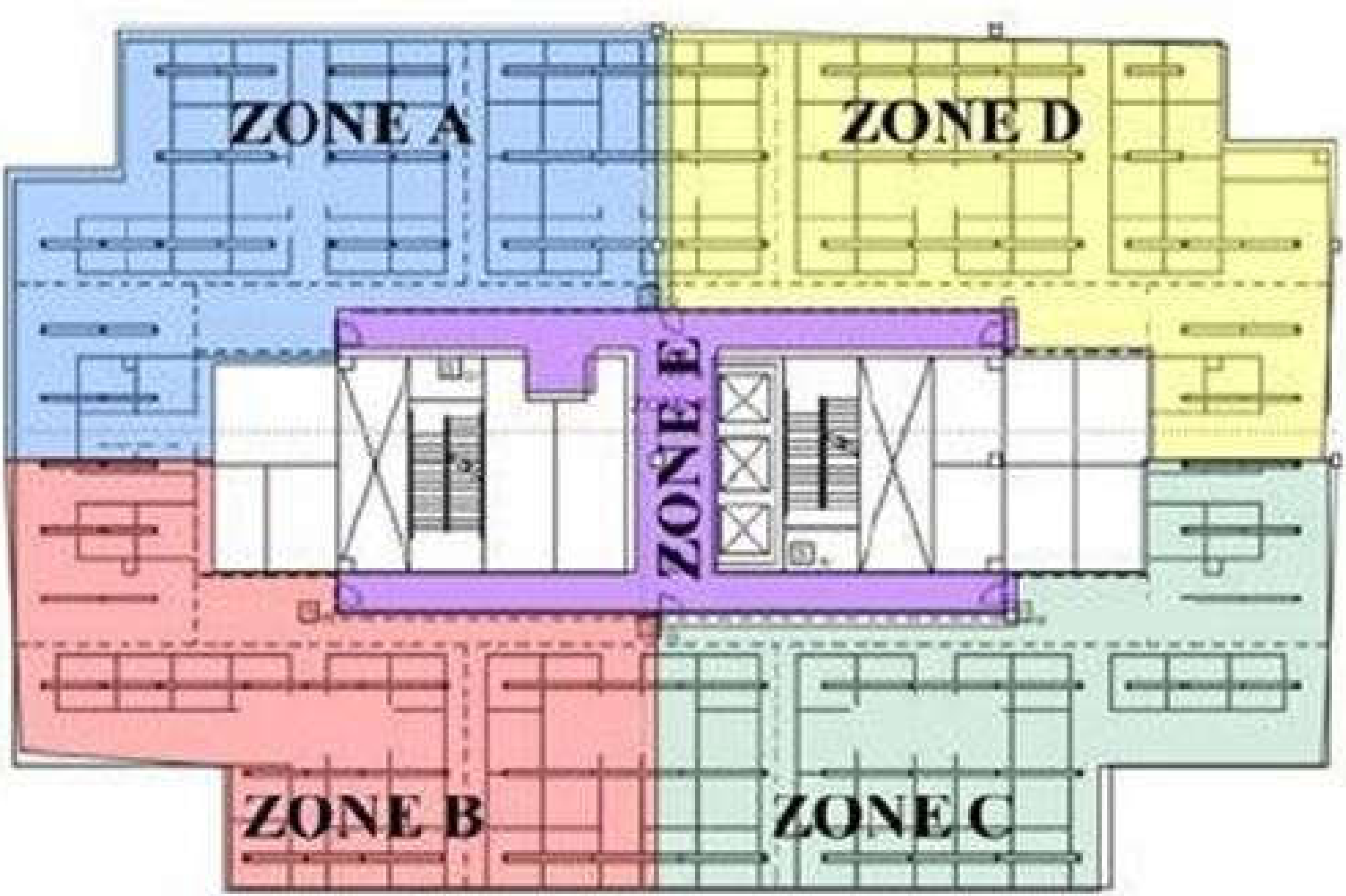
(Source: Wagiman K. R., Abdullah M. N., Hassan M. Y., Radzi N. H. M., Bakar A. H. A. & Kwang T. C., 2020. Lighting system control techniques in commercial buildings: Current trends and future directions, *Journal of Building Engineering*, 31: 101342. https://doi.org/10.1016/j.jobe.2020.101342)

Design considerations



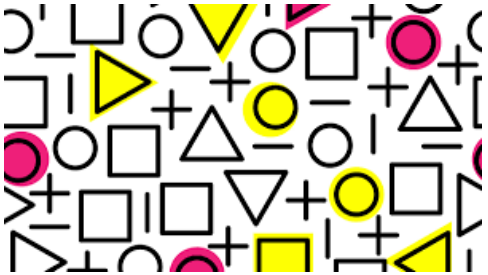
- Lighting control zoning
  - An important aspect of lighting control system design, as zoning is the mechanism through which lighting controls are assigned to lighting loads
  - A control zone is defined as one or more light sources controlled simultaneously by a single control output
  - Smaller control zones (higher granularity of zones in a space or building) introduce greater flexibility & typically higher energy savings

An example of control zoning for lighting control system



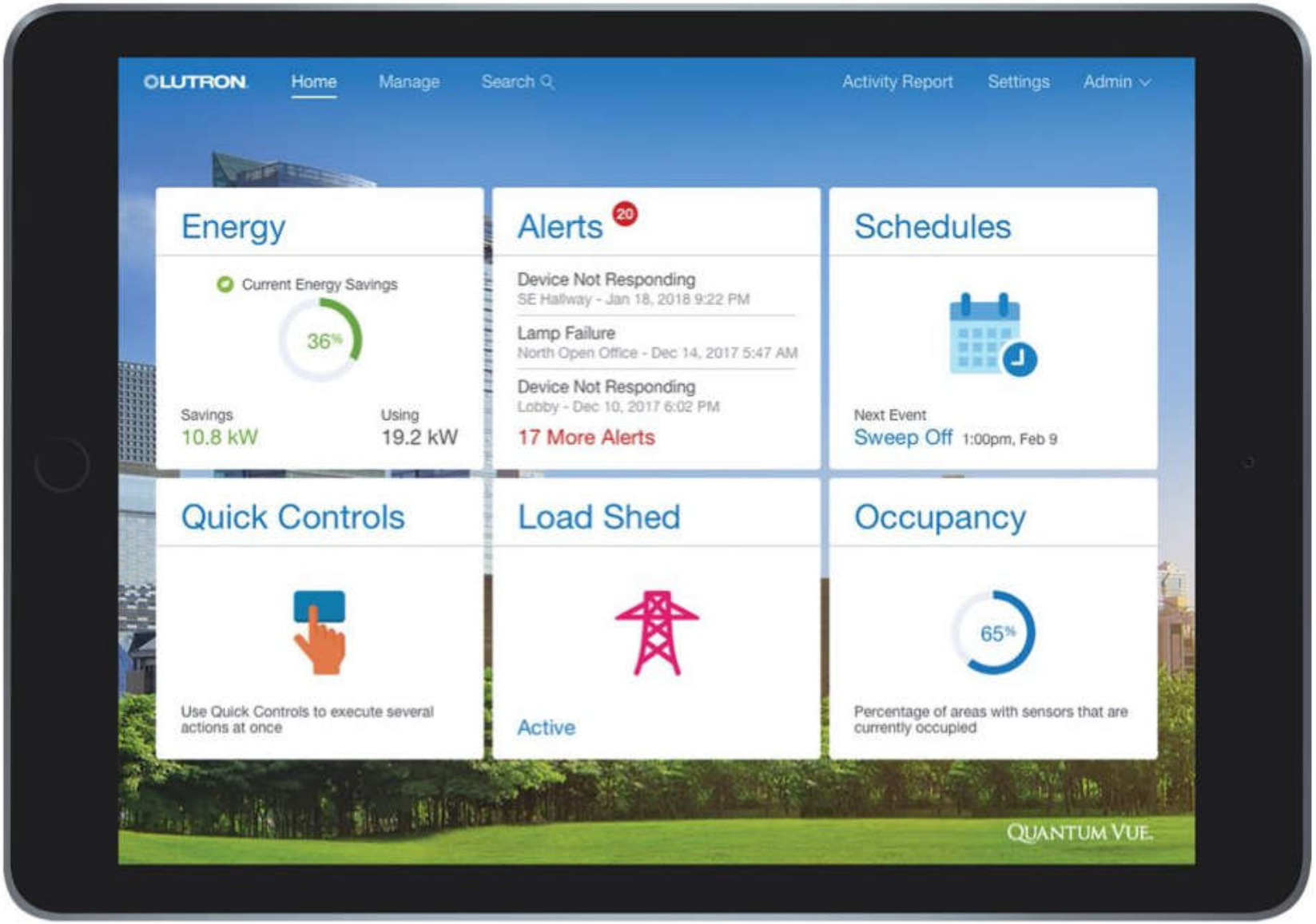
(Source: https://lightingcontrolsassociation.org/2017/07/21/introduction-to-lighting-controls/)

Design considerations



- Lighting control software
  - Various apps & software support implementation
  - The most robust software is available for centralized intelligent networked lighting control systems (on a server or in the cloud)
  - Can provide lighting control, shade control, smart sensor management, advanced programming & energy management from a single platform
  - With advanced conditional logic & customization

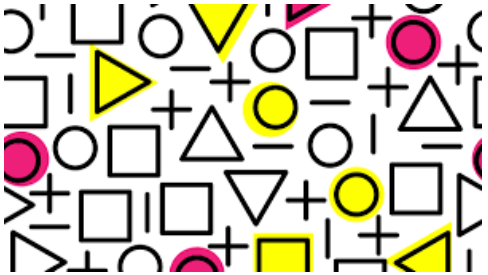
Lighting control software (web-based) with a dashboard management



Video: Quantum Vue – Facility Management Software (1:18)
https://youtu.be/dLNdG6ndLcY

(Source: https://commercial.lutron.com/us/en/whole-building-systems/quantum

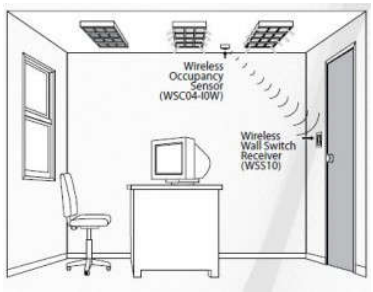
Design considerations



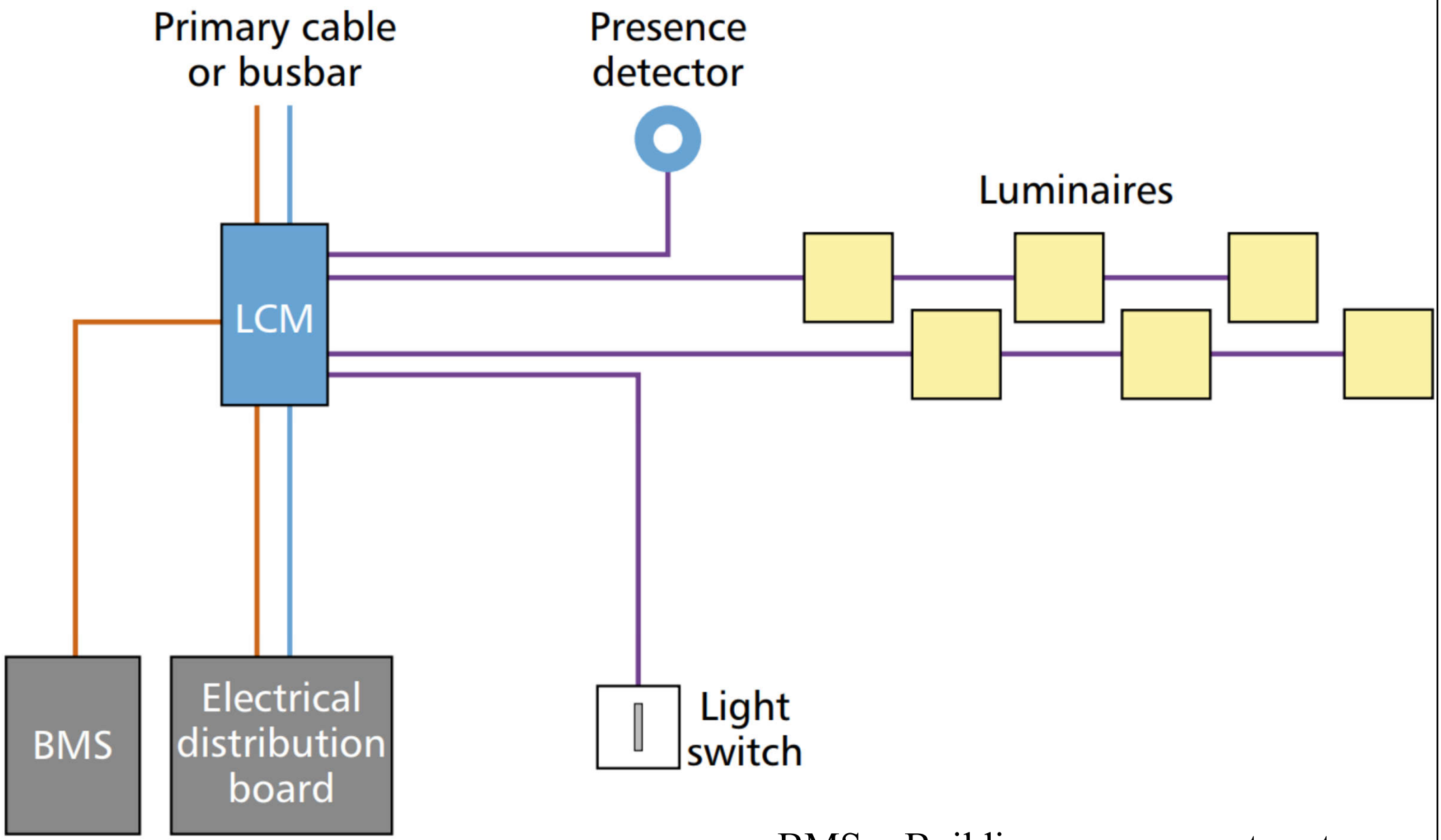
- Typical functions of lighting control software:
  - 1) Discover control points (devices, etc.)
  - 2) Assign control points to zones
  - 3) Program sequences of operation for zones
  - 4) Calibrate sensors
  - 5) Monitor control points & issue service alerts/alarms
  - 6) Record & display energy use and other recorded data
  - 7) Back up data & event logs and create users/access levels

Wired & wireless systems

- Wired systems
  - Line-voltage wiring (powerline communication)
  - Low-voltage wiring (dedicated pathway for control signals, analogue)
  - Digital low-voltage wiring (digital binary signals)
- Wireless systems
  - Eliminate control wiring
  - Control signals from a wireless transmitter to a wireless receiver in a lighting controller



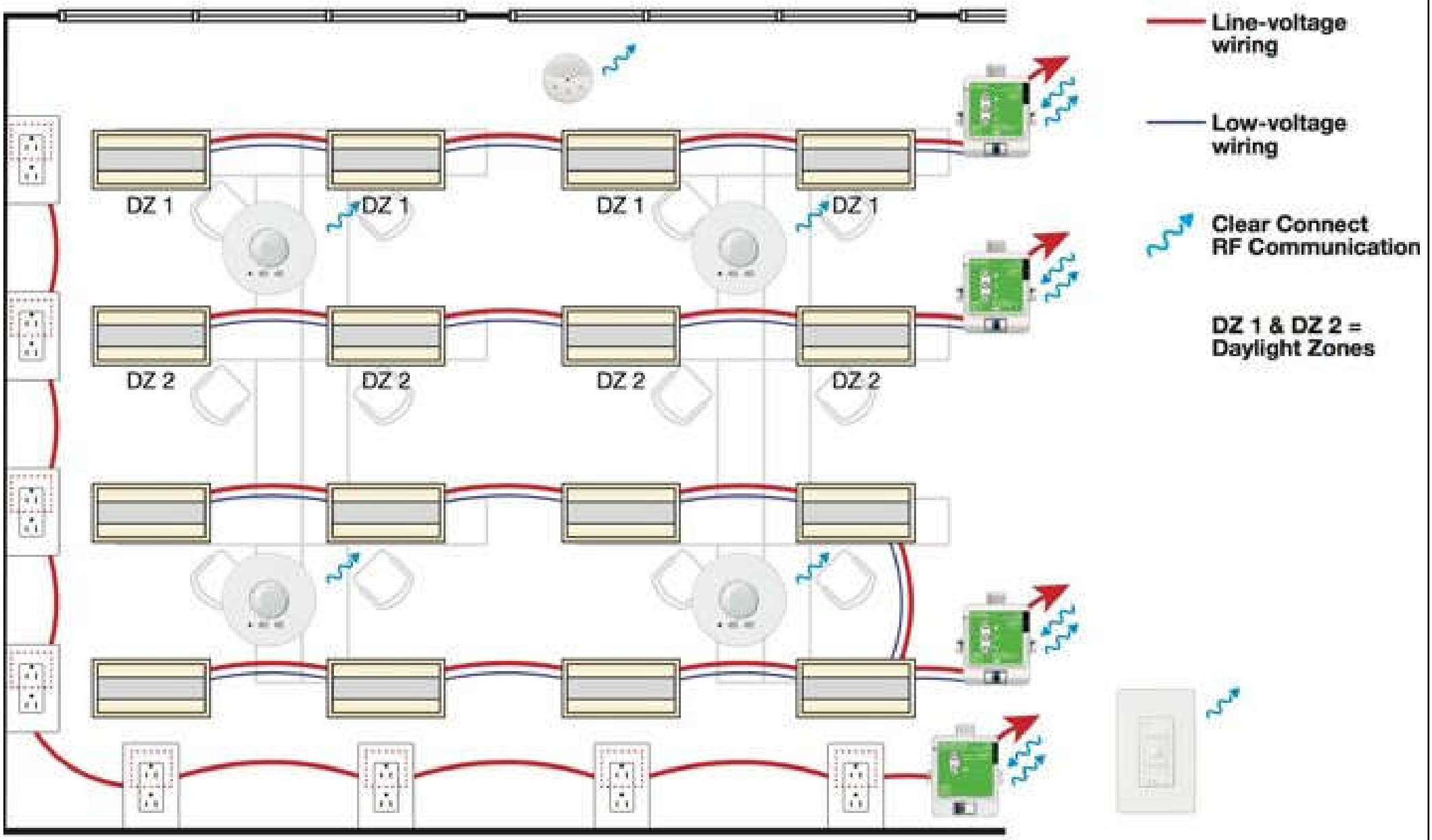
Luminaires connected to a lighting control module (LCM)



BMS = Building management system
LCM = Lighting control module

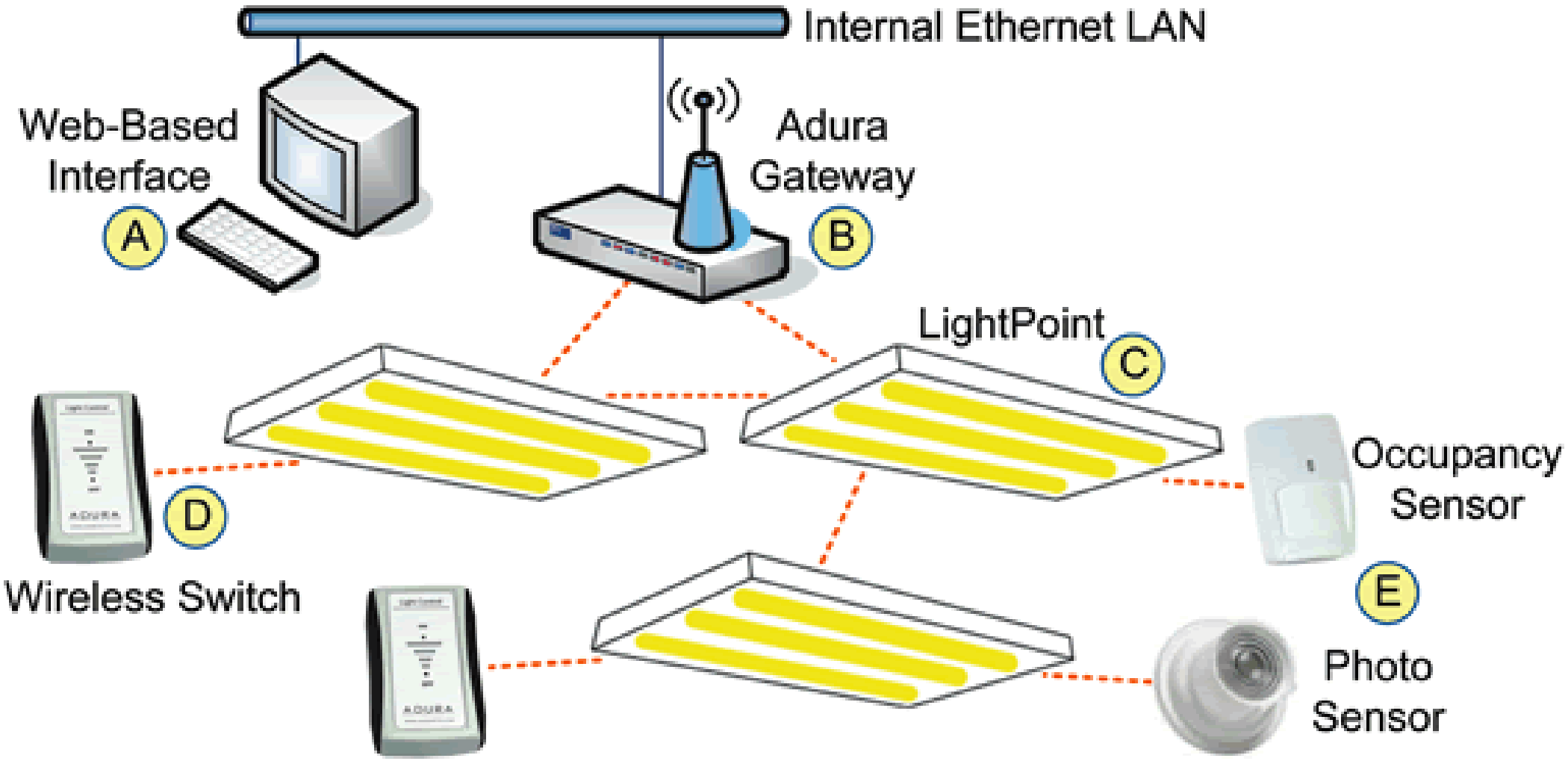
(Source: The SLL Lighting Handbook 2018)

An example of wired & wireless controls for open office layout



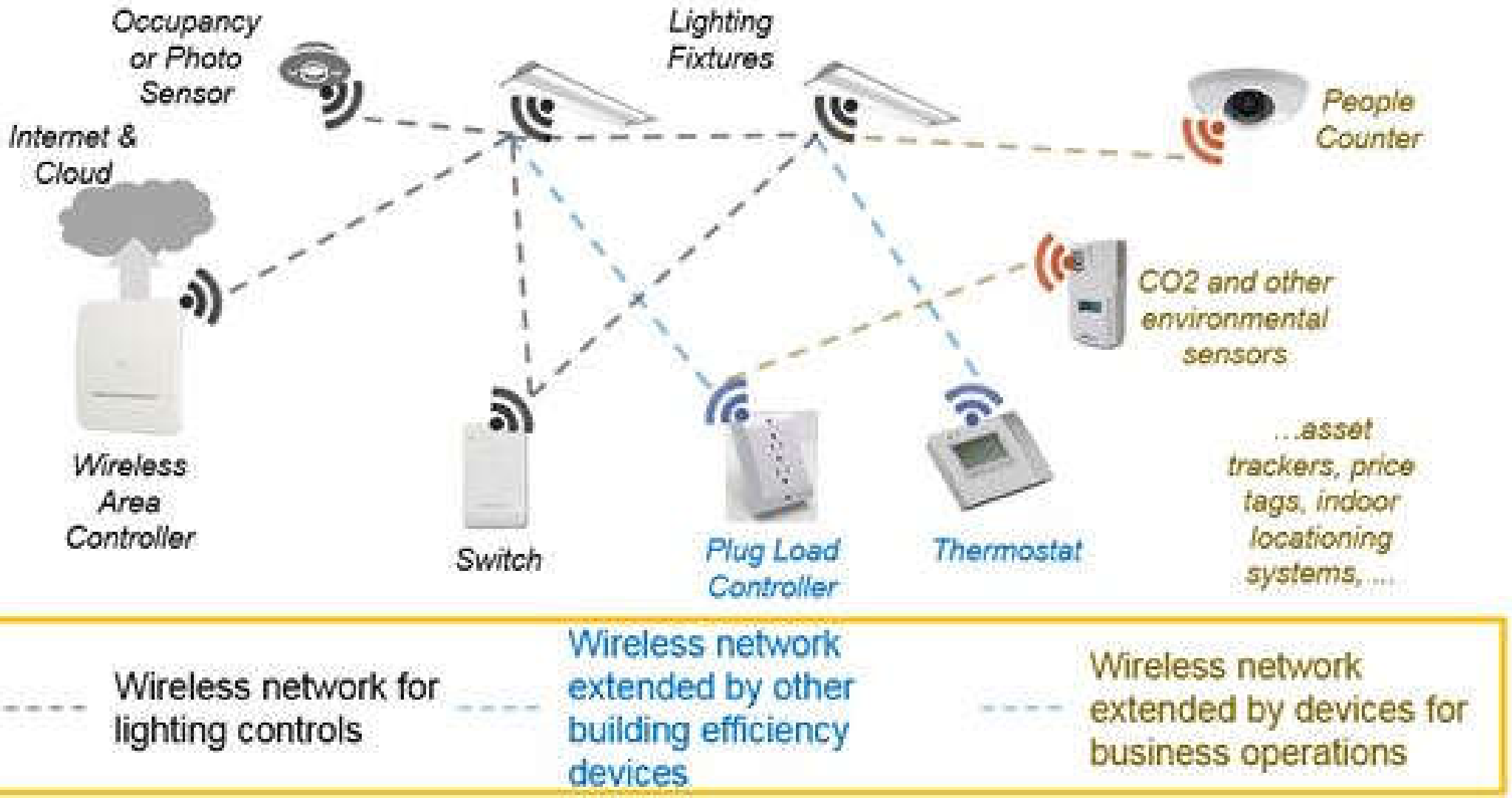
(Source: https://lightingcontrolsassociation.org/2018/03/23/introduction-to-wireless-lighting-controls/)

Wireless lighting control systems



(Source: https://www.buildings.com/articles/34471/where-wireless-lighting-headed)

Wireless control systems for lighting, HVAC & plug loads



(Source: https://lightingcontrolsassociation.org/2017/07/21/introduction-to-lighting-controls/)

Wired & wireless systems

- Digital Addressable Lighting Interface (DALI)
  - A protocol (language) for bi-directional, digital communication between lighting-control devices
  - Technically managed in the open, global standard IEC 62386
  - DALI-2™ is the certification program based on the latest version of the DALI protocol
  - Setting standard for smart lighting control
  - Focused on interoperability

(Source: DALI Alliance (Digital Illumination Interface Alliance, or DiiA) https://www.dali-alliance.org/)

Digital Addressable Lighting Interface (DALI) & IEC 62386 standard

IEC 62386 standard

Purchase standards via the IEC website
More details on IEC 62386: DiiA website

Red text = Parts aligned with DALI-2

Part 101: General requirements – System components

Part 102: General requirements – Control gear

Parts 2xx: Particular requirements for control gear

Published:
Part 201: Fluorescent lamps
Part 202: Self-contained emergency lighting
Part 203: Discharge lamps (excluding fluorescent lamps)
Part 204: Low voltage halogen lamps
Part 205: Supply voltage controller for incandescent lamps
Part 206: Conversion from digital signal into DC voltage
Part 207: LED modules
Part 208: Switching function
Part 209: Colour control

Part 104: General requirements – Wireless and alternative wired systems

Part 105: General requirements – Firmware update **(In progress)**

Published:
Part 216: Load referencing
Part 217: Thermal gear protection
Part 218: Dimming curve selection
Part 220: Centrally-supplied DC emergency operation
Part 221: Load shedding
Part 222: Thermal lamp protection
Part 224: Integrated light source

Part 103: General requirements – Control devices

Parts 3xx: Particular requirements for control / input devices

Published:
Part 301: Push buttons
Part 302: Absolute input devices
Part 303: Occupancy sensors
Part 304: Light sensors
Part 332: Input control devices - Feedback
Part 333: Manual configuration
In progress:
Part 305: Colour sensor

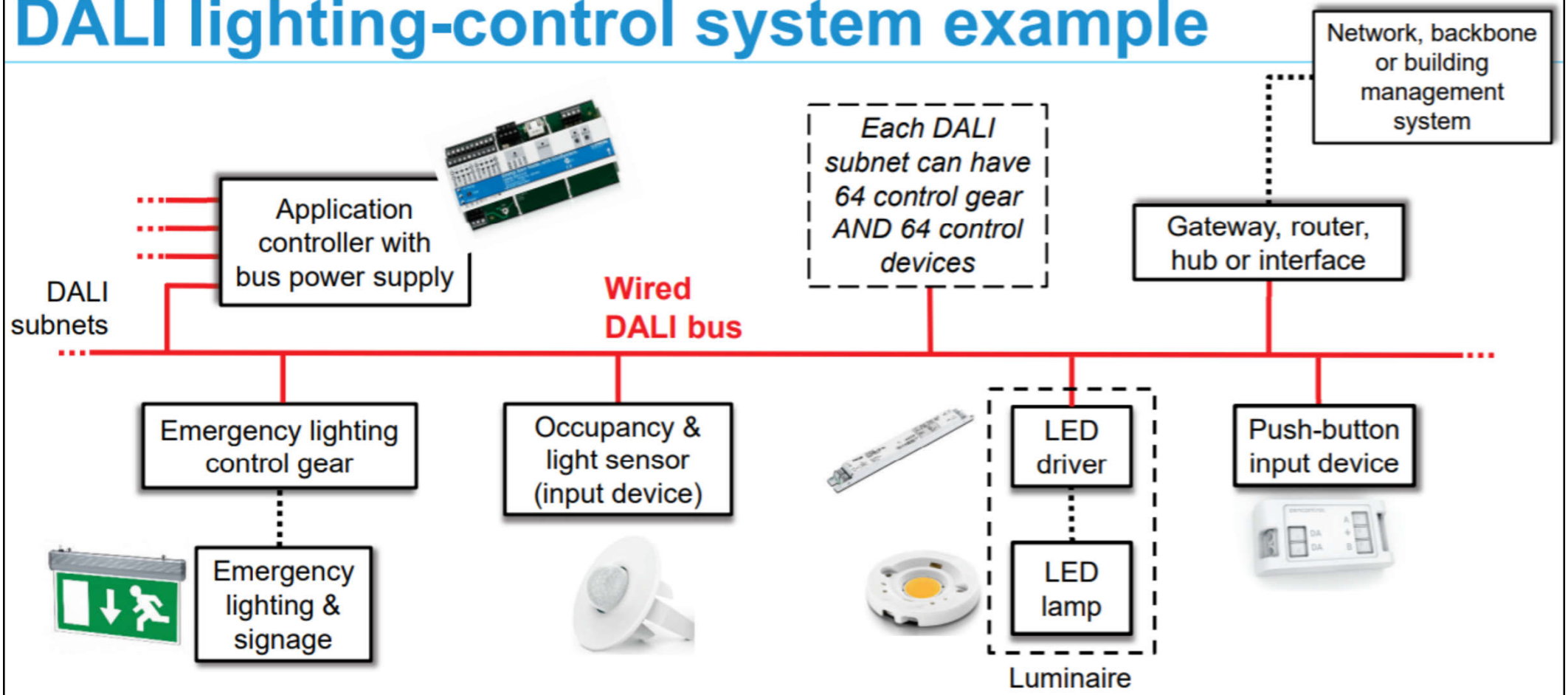
DiiA creates DALI-2 Test Procedure specifications based on these individual Parts of IEC 62386, enabling DALI-2 certification.

(Source: DALI Alliance (Digital Illumination Interface Alliance, or DiiA) https://www.dali-alliance.org/)

Wired & wireless systems

- Digital Addressable Lighting Interface (DALI)
  - A 2-wire bus is used for communication (commands/data) & for power to some devices
    - Commands allow control, configuration & querying of the products
    - Commands can be addressed to individual devices, to a group of devices, or broadcast to all devices
    - Scenes allow fast & efficient recall of light levels across the system
  - DALI devices: bus power supplies, control gear, control devices

DALI lighting-control system example



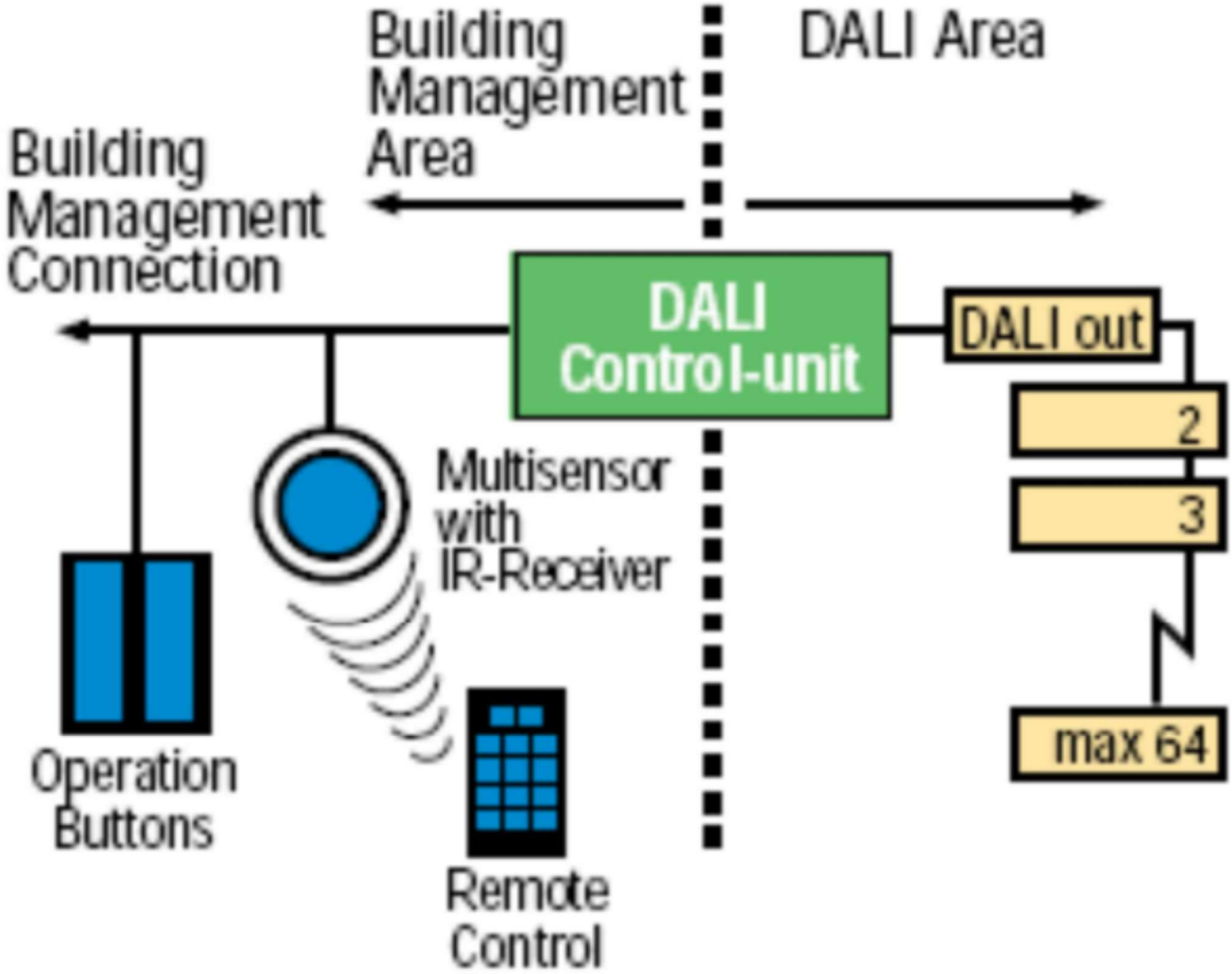
The DALI bus carries DALI power & data on the same pair of wires. Each DALI subnet can have 64 control gear & 64 control devices. Control gear provide power to LEDs & other light sources. Control devices include application controllers (which make decisions & send commands), and input devices such as sensors, switches & push-button devices. A bus power supply is required, providing up to 250 mA and typically 16V to the DALI bus.

(Source: DALI Alliance (Digital Illumination Interface Alliance, or DiiA) https://www.dali-alliance.org/)

Wired & wireless systems

- What can DALI do?
  - Digital control of light with intelligent feedback
    - Precise, repeatable light-output control & standardized dimming curve
    - Occupancy & light-level sensing
    - Luminaire, energy & diagnostics data (for monitoring)
    - Emergency lighting, automated tests (safety)
    - Colour control for human-centric-lighting (well-being)
    - Participate in the Internet of Things (IoT)
    - Connectivity via wireless & IP-based networks

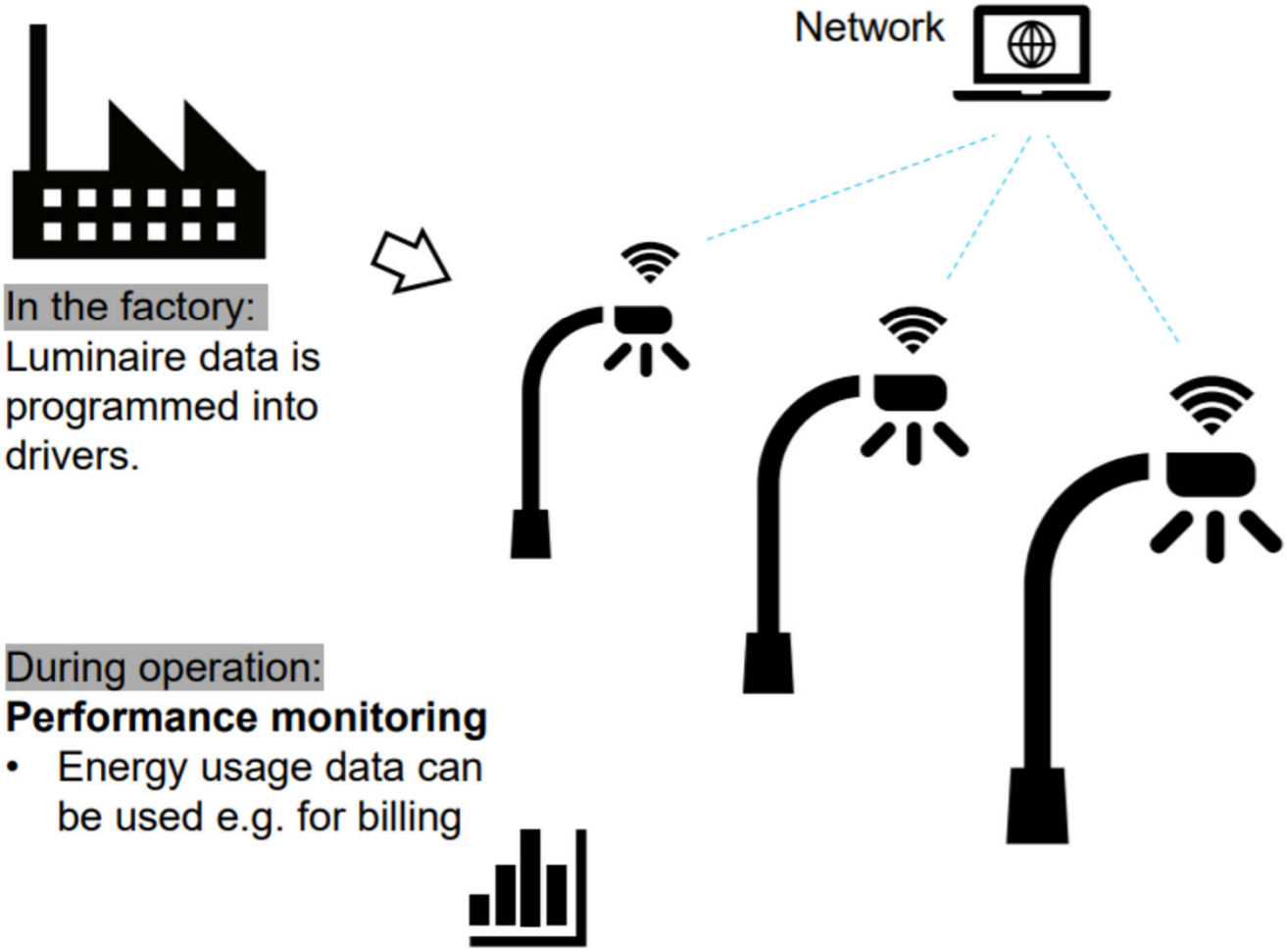
DALI system as a pure subsystem of the BAS/BMS



Wired & wireless systems

- D4i – the DALI standard for intelligent, IoT-ready luminaires
  - DALI-2 power-supply & data specifications
  - D4i LED drivers & sensors provide luminaire, energy & diagnostics data
    - For performance monitoring, asset management, predictive maintenance & many other tasks
  - Enables intra-luminaire DALI (smart connection)
  - Simplify addition of sensors & communication devices to luminaires

DALI data & D4i: An outdoor street lighting example



In the factory:
Luminaire data is programmed into drivers.

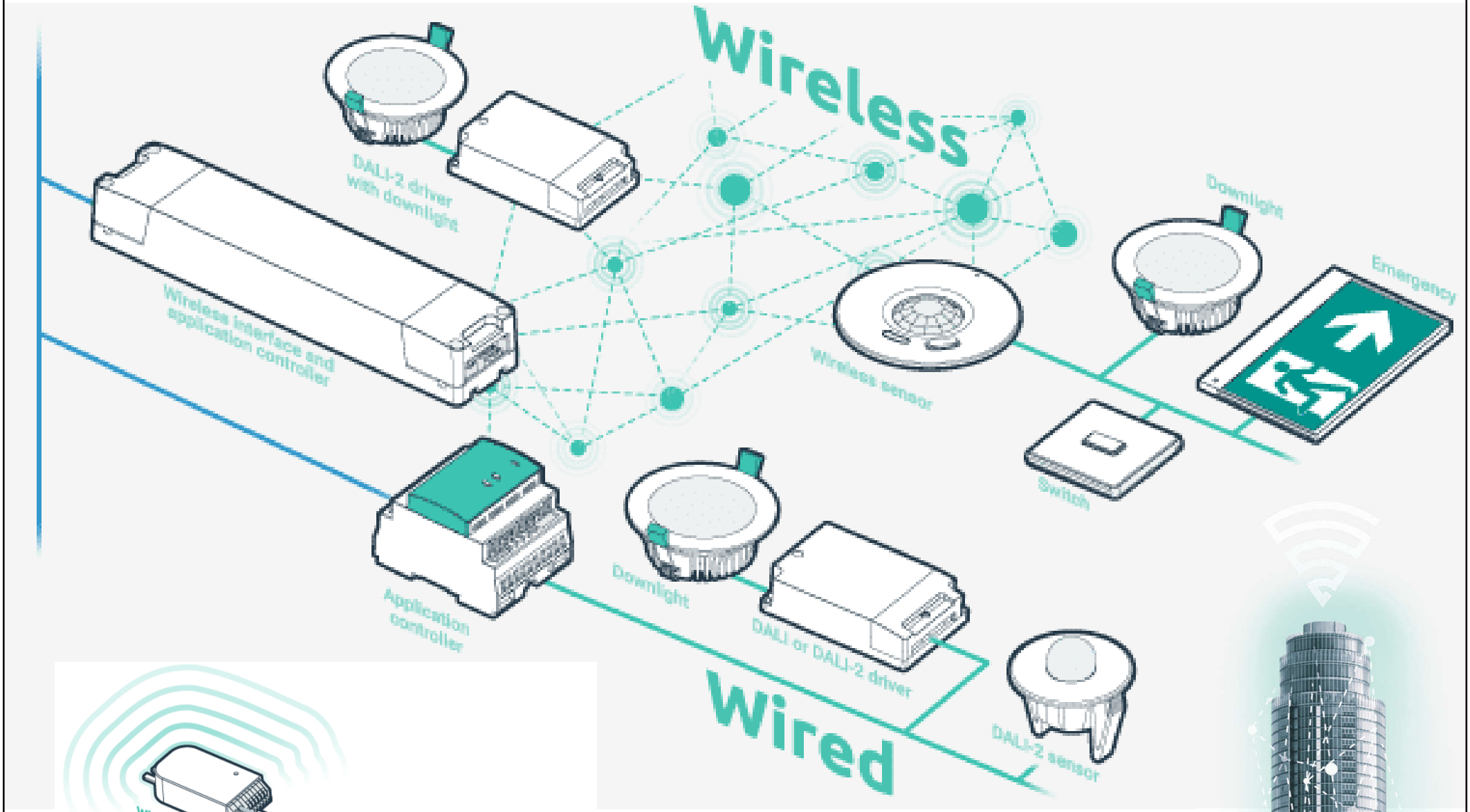
In the field:
Automated commissioning
- When installed, luminaire can automatically transfer data to remote network
- Reduces human error, saves installation time and cost
- Operator has a full map of asset information

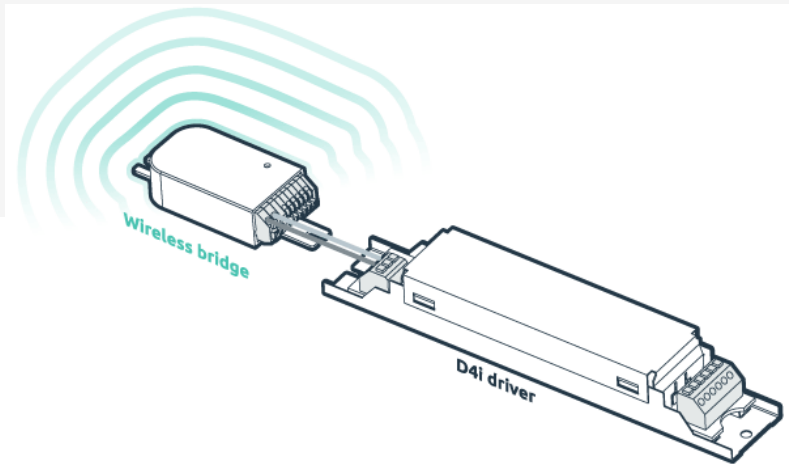
During operation:
Performance monitoring
- Energy usage data can be used e.g. for billing

During operation:
Predictive maintenance
- Diagnostics data allows network operator to anticipate need for maintenance
- Repair team has knowledge of location and type of fixture

(Source: DALI Alliance (Digital Illumination Interface Alliance, or DiiA) https://www.dali-alliance.org/d4i/)

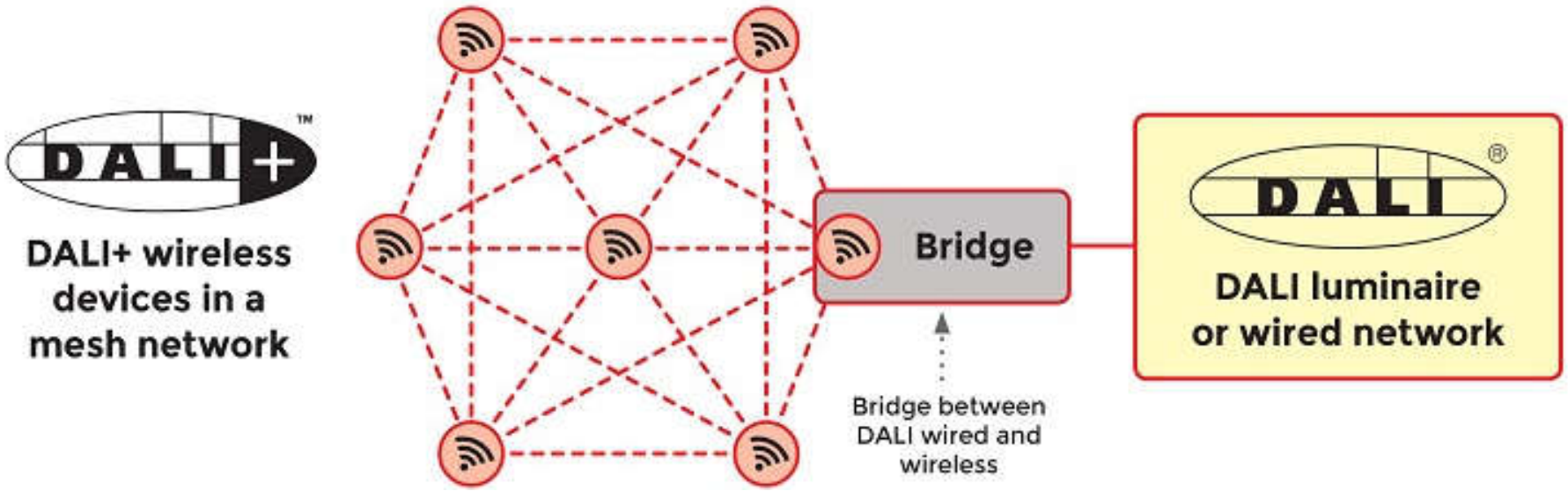
Wired & wireless lighting control





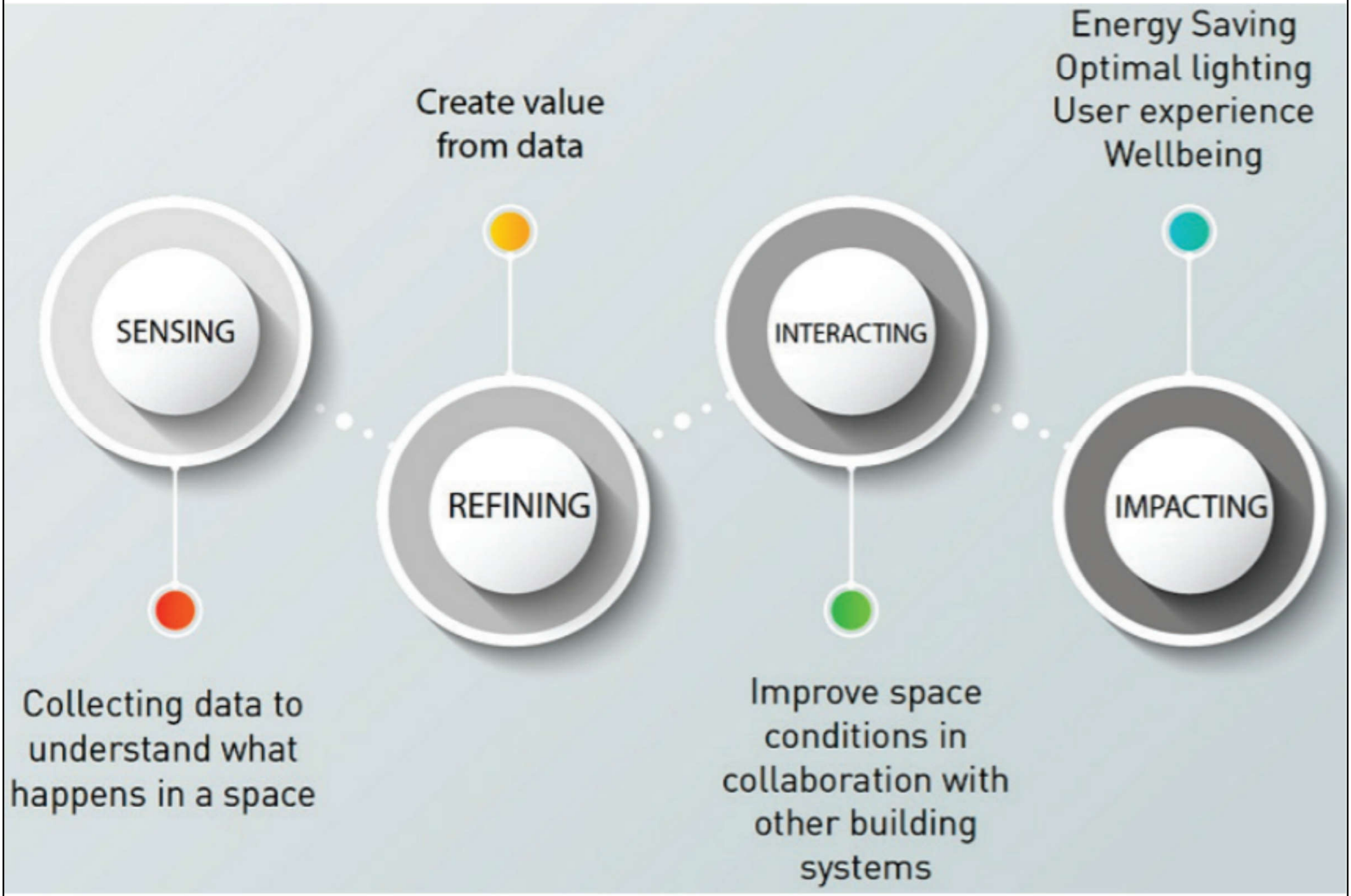
(Source: https://zencontrol.com/wireless-lighting-control/)

DALI lighting control plus wireless & IP-based networking



(Source: DALI Alliance (Digital Illumination Interface Alliance, or DiiA) https://www.dali-alliance.org/)

Elements of lighting intelligence

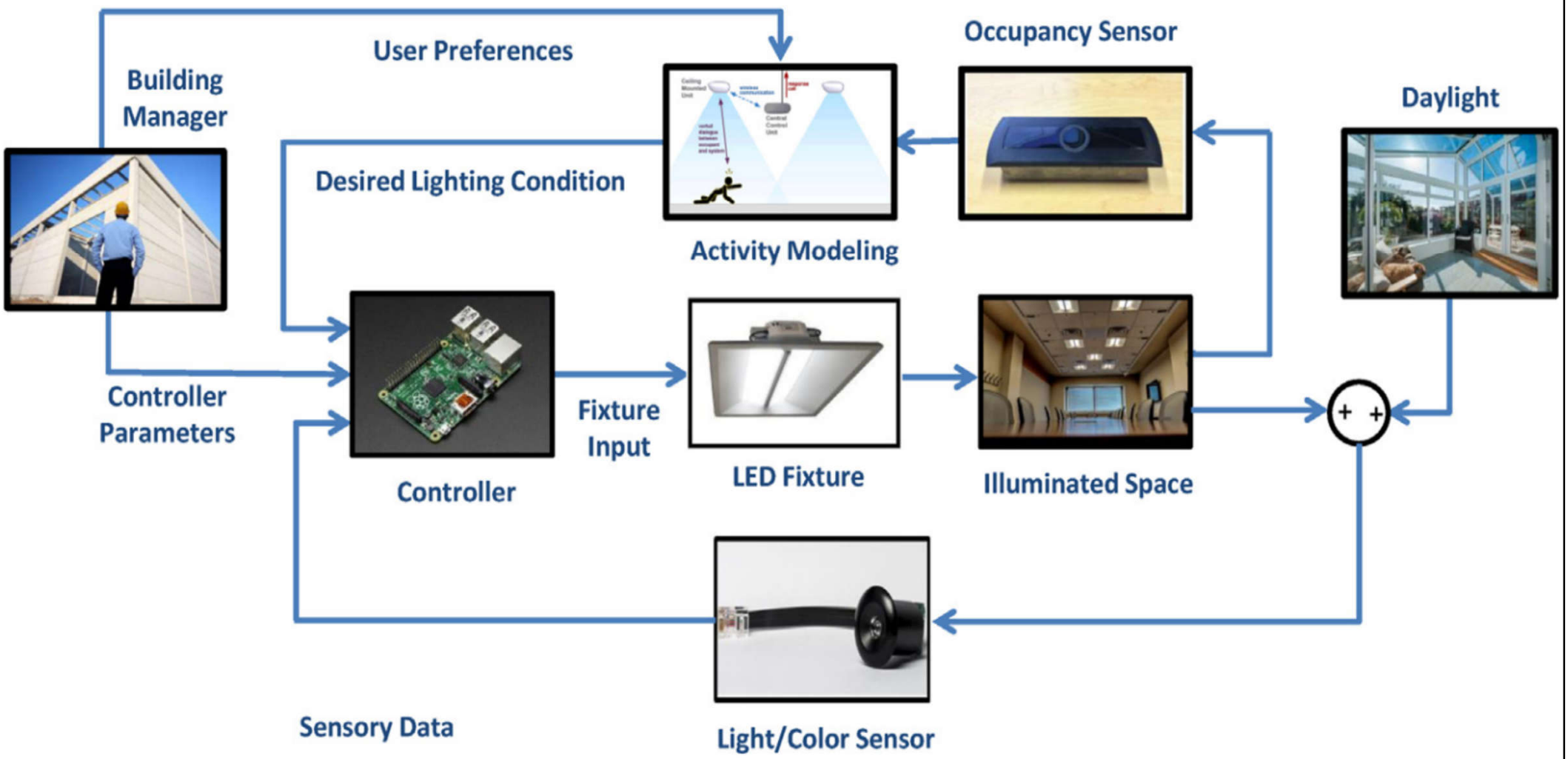


(Source: DALI Alliance (Digital Illumination Interface Alliance, or DiiA) https://www.dali-alliance.org/)

Smart lighting

- Feedback control of lighting systems
  - Logic-based controllers
    - Decision-making techniques are used to infer the correct action for the lighting system in different situations based on measured values from the sensors
  - Regulation-based controllers
    - Aim to achieve closed-loop stability while guaranteeing that the generated illumination tracks a predetermined reference or setpoint value
  - Optimization-based controllers (solve the optimization problem)

Feedback control loop in a smart lighting system

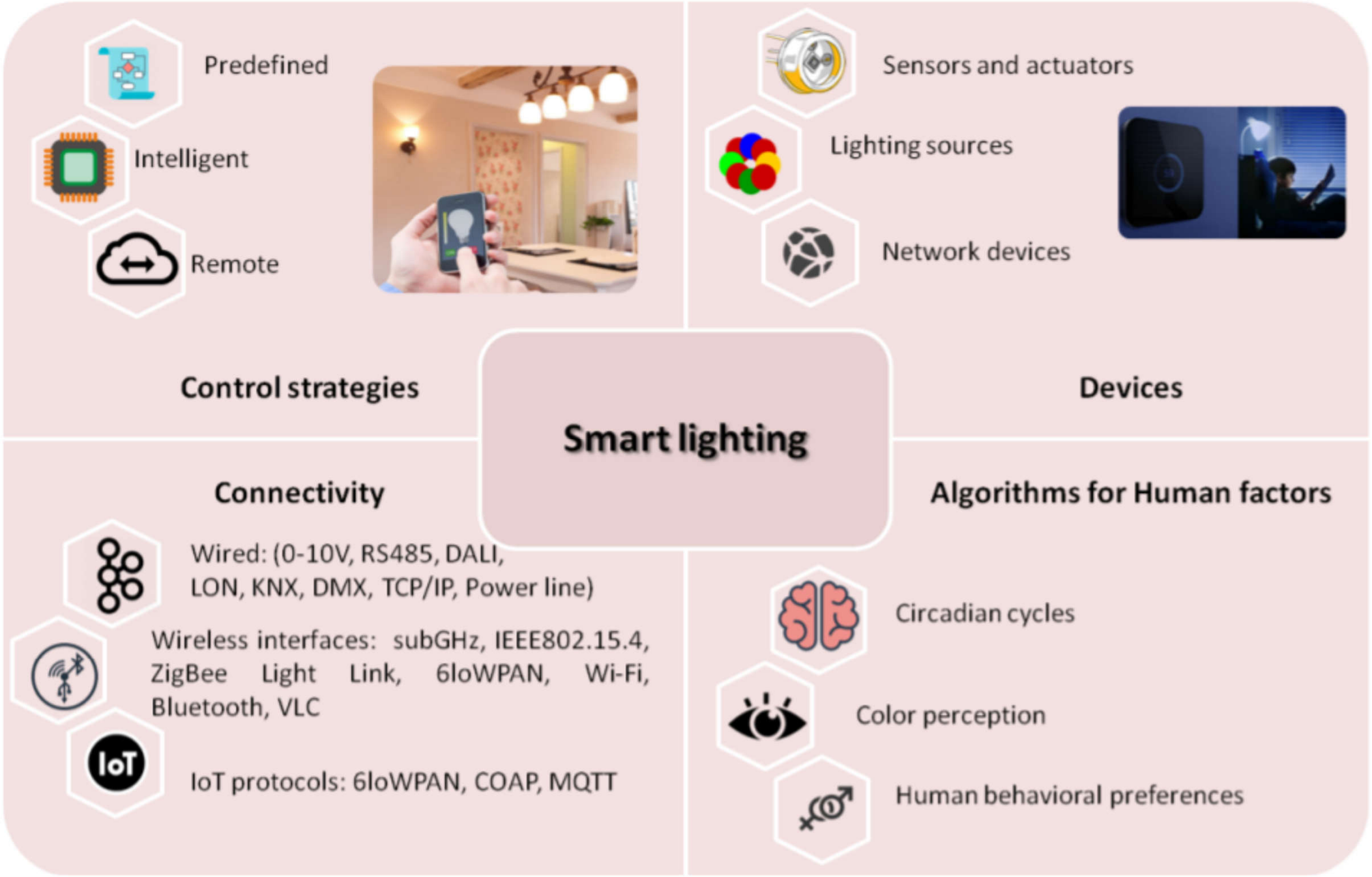


(Source: Imam M. H. T., Afshari S. & Mishra S., 2016. An experimental survey of feedback control methodologies for advanced lighting systems, *Energy and Buildings*, 130: 600-612. http://dx.doi.org/10.1016/j.enbuild.2016.08.088)

Smart lighting

- Connected smart lighting
  - Lighting installations in which the luminaires, with integrated sensors, are interconnected in a wired or wireless network to both control & monitor the lighting
  - Microcontrollers & many sensors, like light, occupancy, temperature, humidity & noise sensors, are small enough to be incorporated in a luminaire
  - In this way, the luminaire becomes both a source of light & information (data)

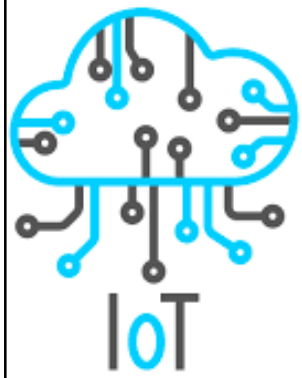
Key elements for smart lighting systems



(Source: https://arxiv.org/ftp/arxiv/papers/1809/1809.00986.pdf

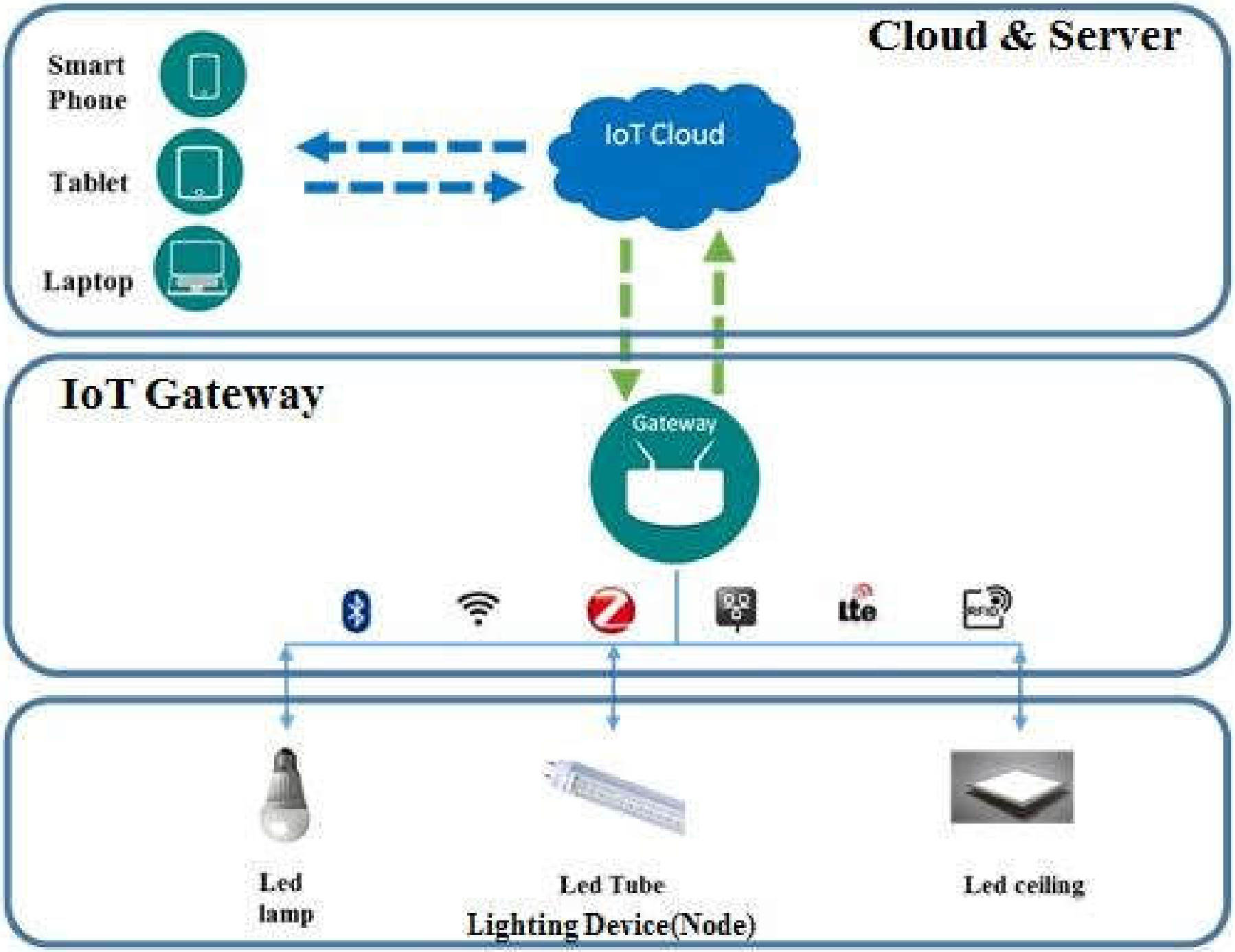
Smart lighting

- Light beyond illumination
  - By connecting a network of LED luminaires with integrated sensors to a network, it becomes the backbone of the Internet of Things (IoT)



    - For smart actions of the connected building services installations (e.g. lighting, HVAC) & facility management (e.g. automated cleaning & maintenance)
  - Light from LED luminaires can be used simultaneously for lighting & wireless data transfer -> Visible Light Communication (VLC)

Internet of Things (IoT) connected lighting system

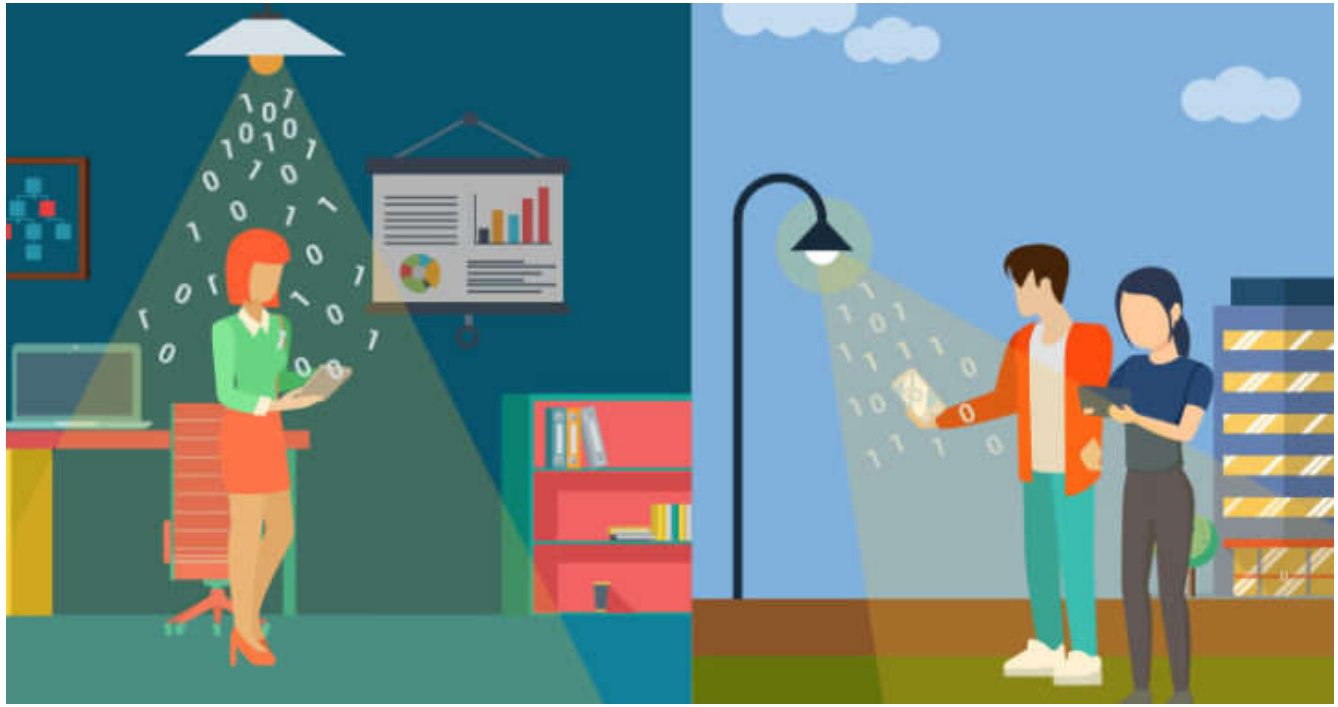


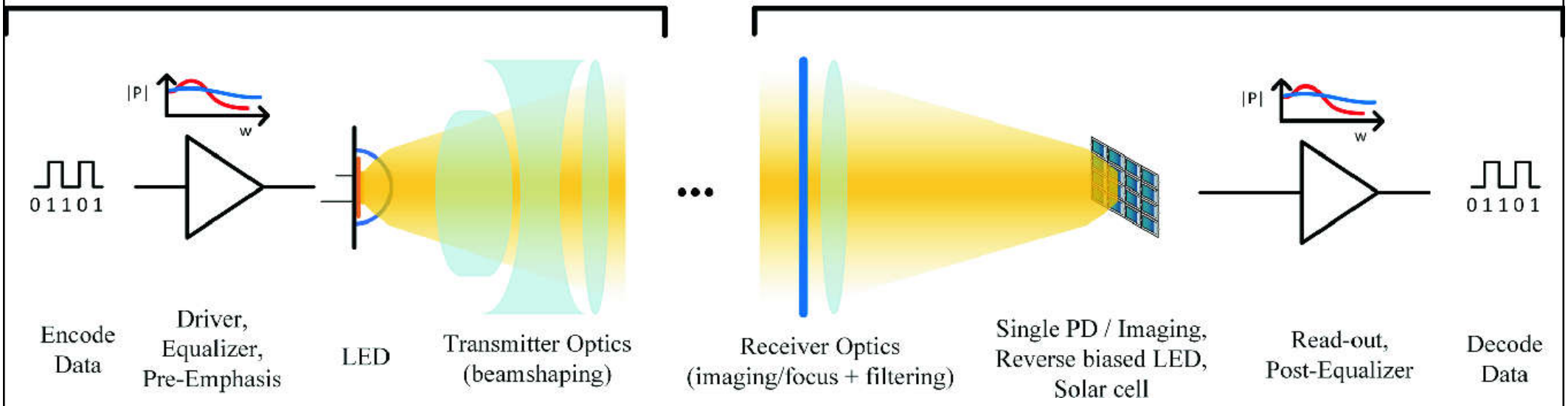
(Source: https://www.researchgate.net/figure/IoT-Connected-Lighting-System_fig1_330159801)

Smart lighting

- Smart lighting & Internet of Things (IoT)
  - Light points can serve as the infrastructure for IoT systems (both indoor & outdoor)
  - Smart sensor networks & connectivity
- Visible Light Communication (VLC)
  - Low power consumption, easy installation, high security, no electromagnetic interference
  - Potential uses: indoor positioning, scanning sensor, light fidelity (Li-Fi) as alternative to WiFi network

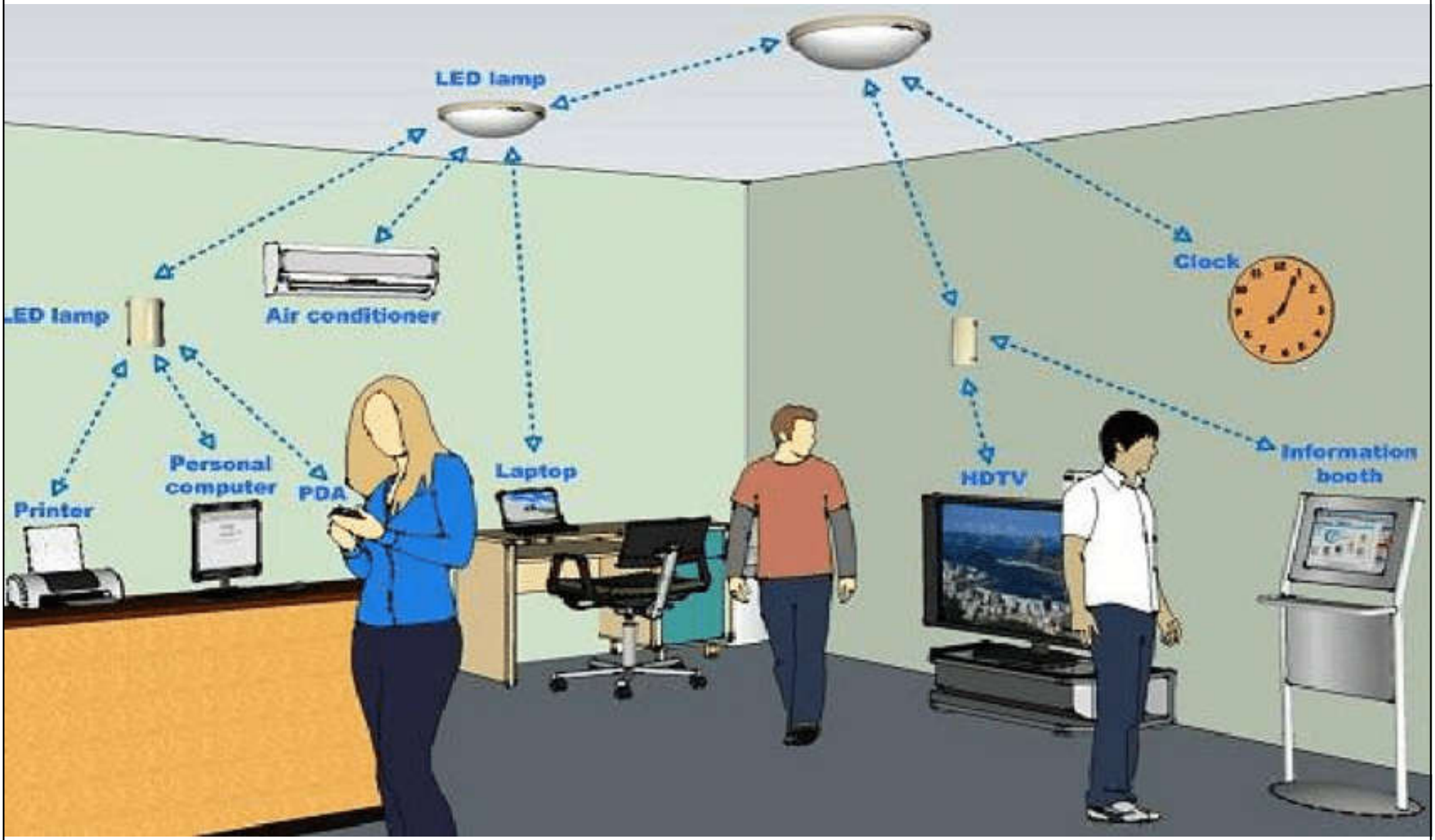
Principles of Visible Light Communication (VLC)





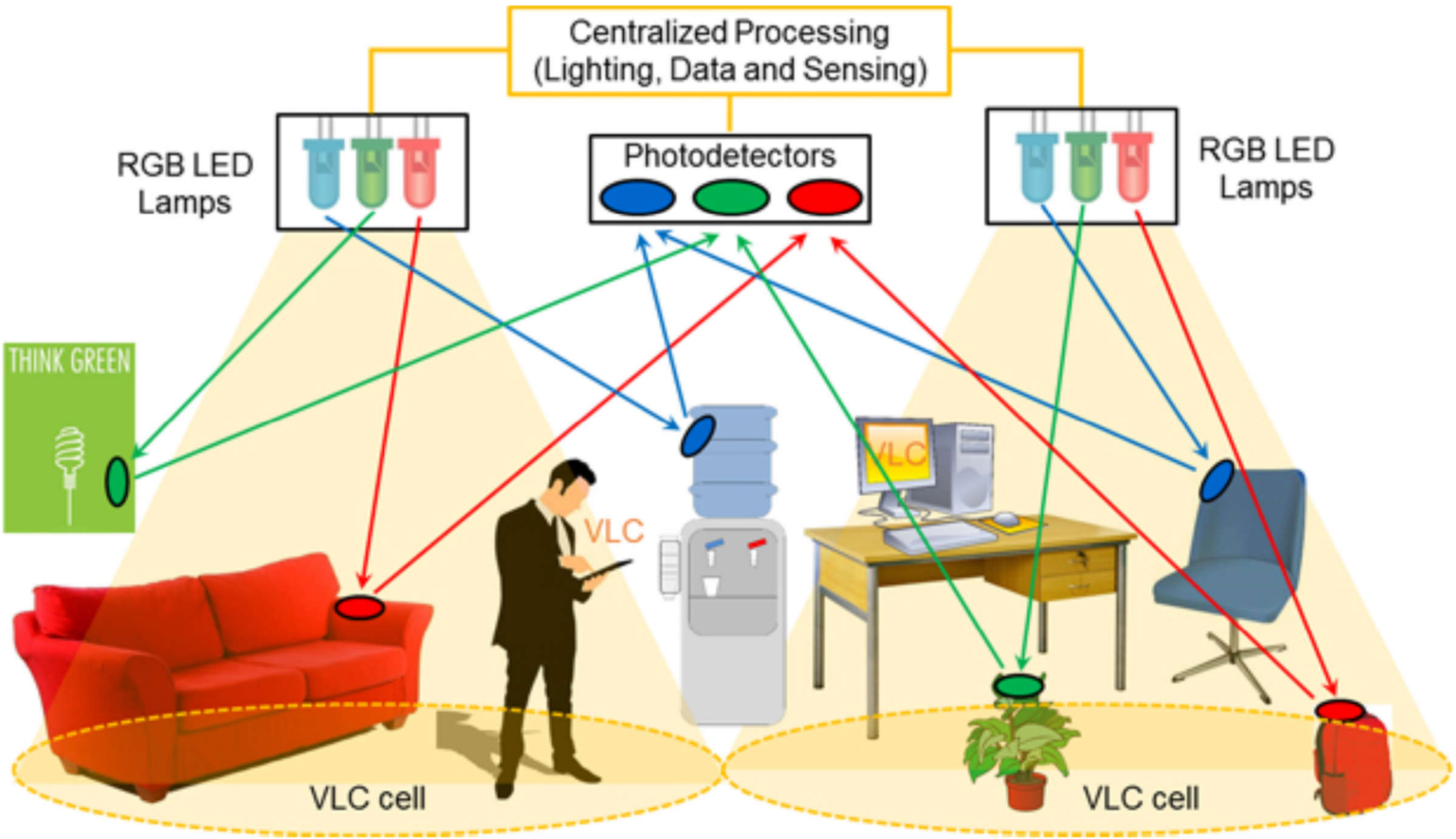
(Source: https://enlightem.eu/a-tutorial-on-visible-light-communication-an-academic-and-industrial-perspective/; https://link.springer.com/chapter/10.1007/978-3-030-24892-5_8)

Visible Light Communication (VLC) environment & data transmission



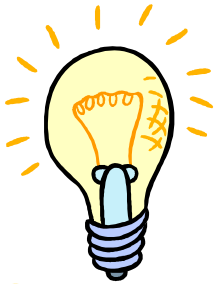
(Source: https://www.researchgate.net/figure/sible-Light-Communication-environment_fig3_308704878)

Visible light communication for indoor monitoring



(Source: https://phase1.attract-eu.com/attract-featured-stories-vladimir/)

Further reading



- Introduction to Lighting Controls https://lightingcontrolsassociation.org/2017/07/21/introduction-to-lighting-controls/
- Introduction to Wireless Lighting Controls https://lightingcontrolsassociation.org/2018/03/23/introduction-to-wireless-lighting-controls/
- Trends in smart lighting for the Internet of Things https://arxiv.org/ftp/arxiv/papers/1809/1809.00986.pdf