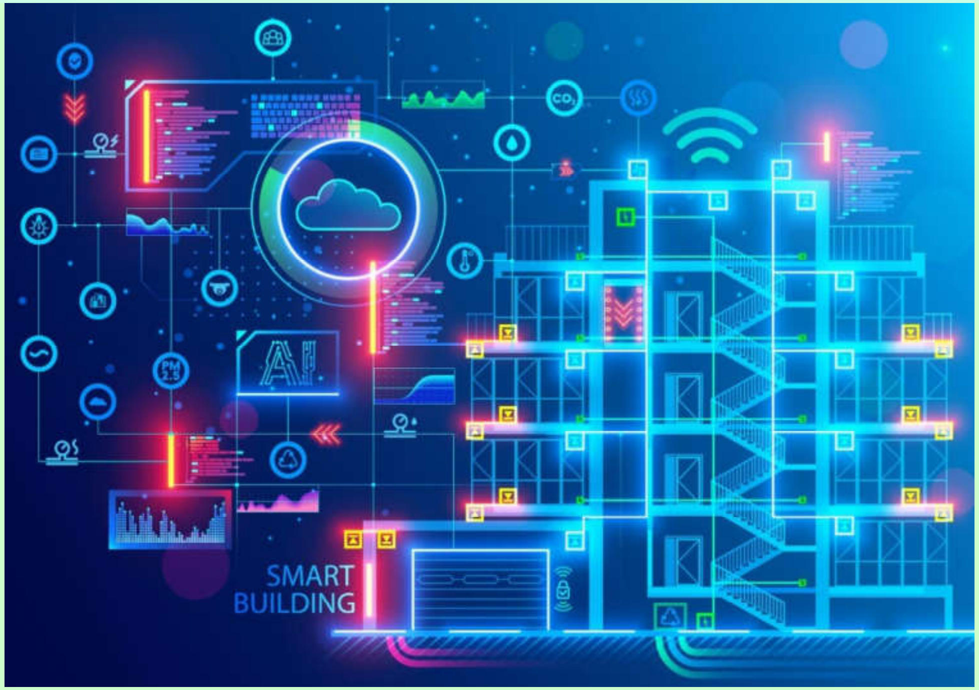

Building Automation

智能大厦科技

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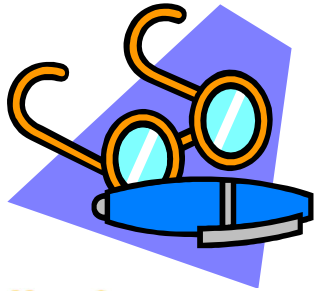
- Basic concepts
- Control fundamentals
- System design
- System components
- Networking

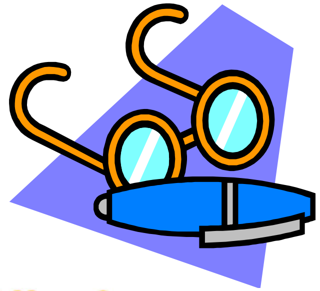
Basic concepts



- Building Automation
  - Use of automation & control systems to monitor and control building-wide systems, e.g. HVAC, lighting, alarms, and security access & cameras
    - Thermostats to control room temperature
    - Occupancy sensors to control lighting
    - Fire & smoke detectors

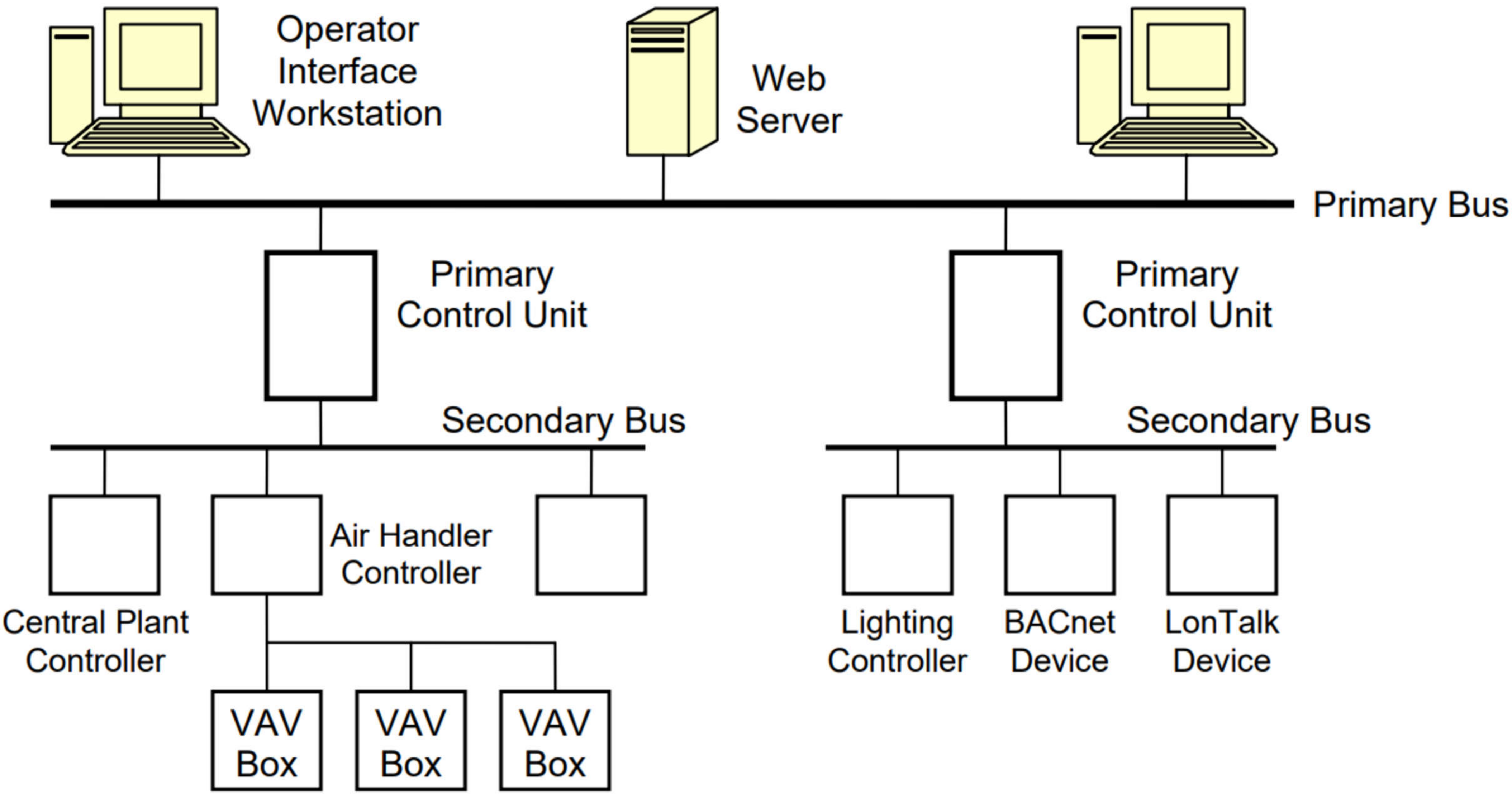
  - Converging these systems into a single information technology (IT)-managed network infrastructure creates a *smart/intelligent building*

Basic concepts



- Building Automation Systems (BAS) are centralized, interlinked, networks of hardware and software, which monitor and control the environment in commercial, industrial, and institutional facilities
- While managing various building systems, the BAS ensures the operational performance of the facility as well as the comfort and safety of building occupants

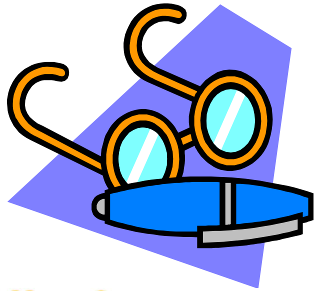
An example layout of a building automation system (BAS)



(VAV = variable air volume)

(Source: Hui S. C. M., 2007. Latest trends in building automation and control systems, In *Proceeding of the CAI Symposium 2007 on Intelligent Facility Management and Intelligent Transport*, 28 March 2007, Hong Kong, 10 p. http://ibse.hk/cmhui/CAI-2007_SamHui.pdf)

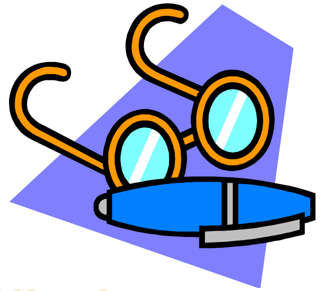
Basic concepts



- Terminology
  - Building automation system (BAS)
  - Building automation & control system (BACS)
  - Building management system (BMS)
  - Building energy management system (BEMS)
  - Energy management system (EMS)
  - Central control and monitoring system (CCMS)
  - Direct digital control (DDC)
  - Intelligent building (IB)

A term coined by HK Govt. depts.

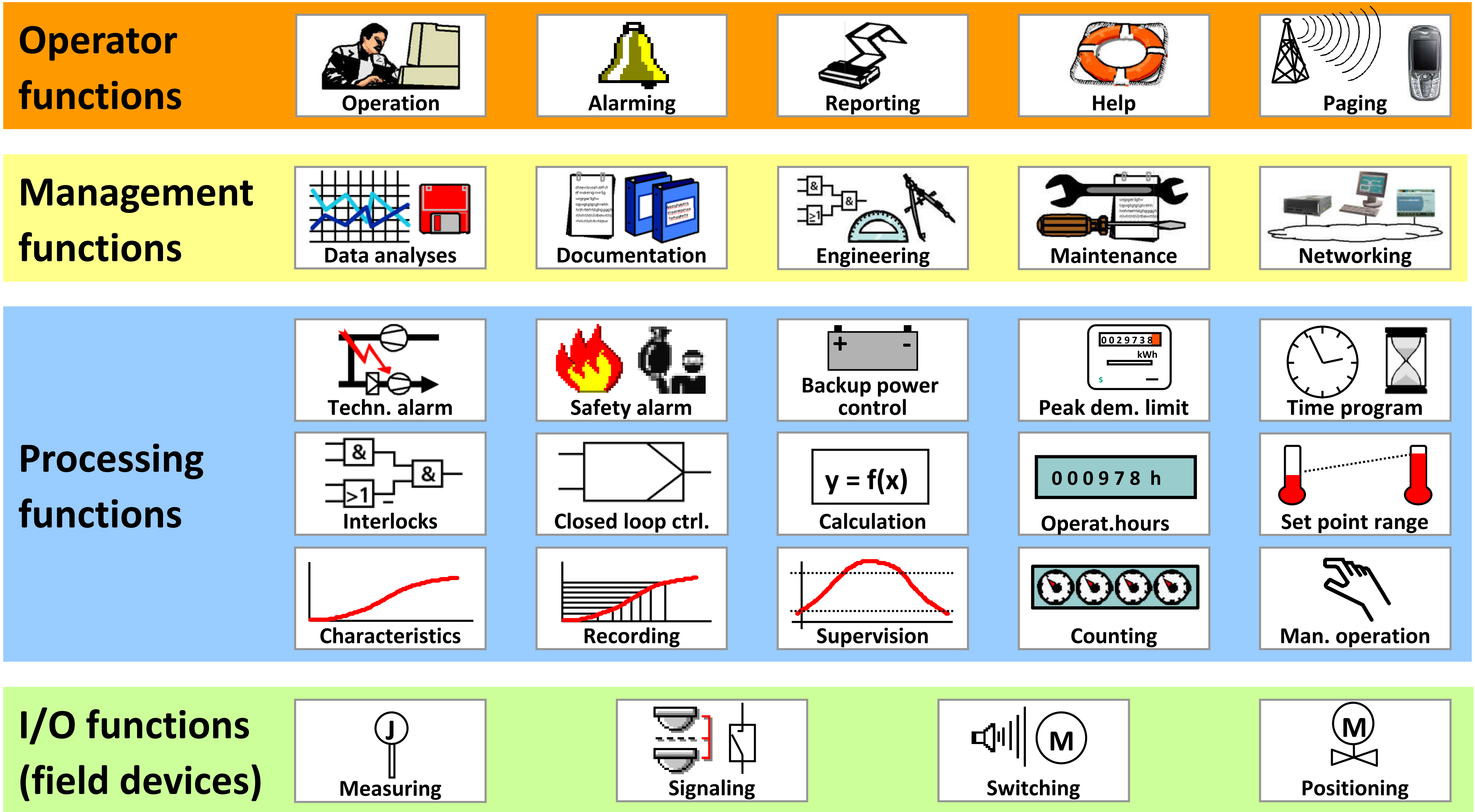
Basic concepts



- Core functions of BAS:
  - Control (e.g. building’s environment & systems)
  - Operation
    - Alert or sound alarms when needed
    - Operate system according occupancy & energy demand
  - Monitoring
    - Monitor & correct system performance

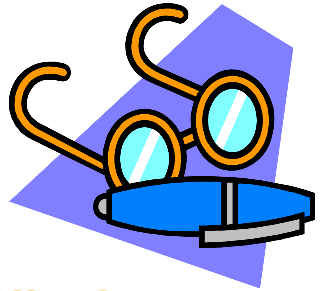
  - Management & analysis
    - Analyze & optimize data collected to provide real time feedback (e.g. trend logs) & documentation

Typical functions of building automation/management system (BAS/BMS)



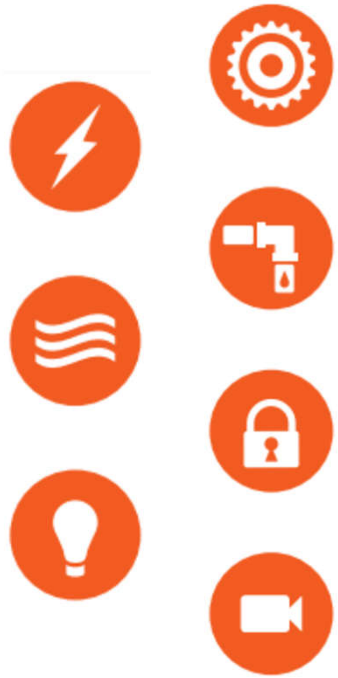
[Source: Honeywell]

Basic concepts



- Building services systems being controlled
  - **HVAC** (heating, ventilation & air-conditioning)
  - Fire services
  - Plumbing & drainage
  - Electrical installations
  - Lighting
  - Lifts & escalators
  - Security & communication
  - Special systems (medical gas, renewable energy)

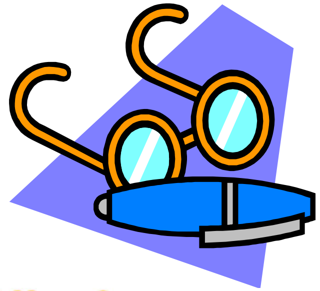
Most important one

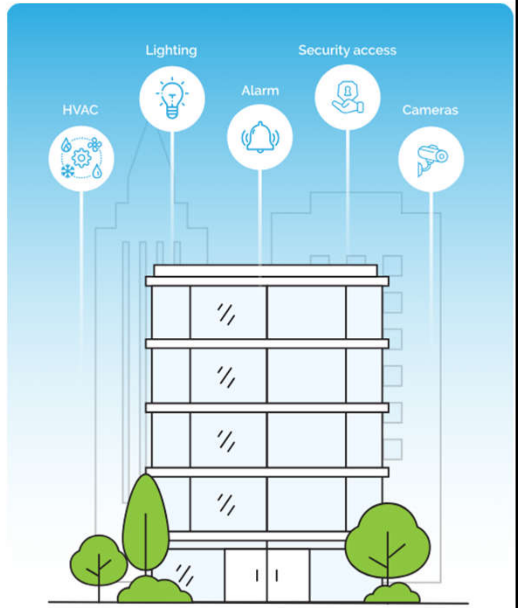


Where building automation system (BAS) are used?

[Source: https://www.sketchbubble.com/en/presentation-building-automation-system.html]

Basic concepts

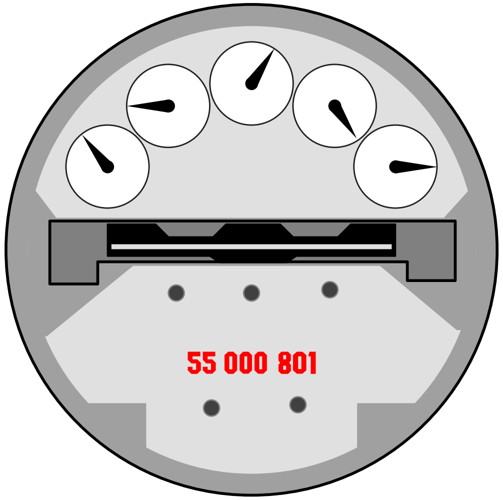




- Why use BAS?
  - Growing complexity of building systems
  - Demand for more efficient building operation
  - Need to save energy & operating costs
  - Need to increase flexibility & reliability
  - Improve indoor environment & productivity
- Connect BAS to major building equipment to
  - Control air conditioning & lighting to save energy
  - Monitor all equipment to improve efficiency of operations personnel & minimise equipment down time

Benefits of Building Automation Systems

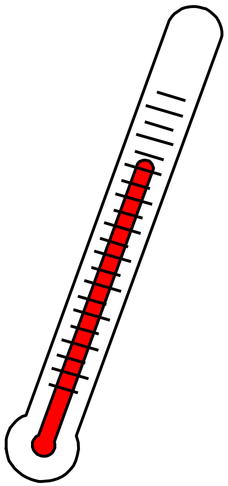
Lower energy cost



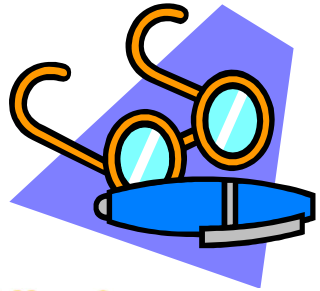
Lower operations cost

Increase flexibility

Ensure quality building environment



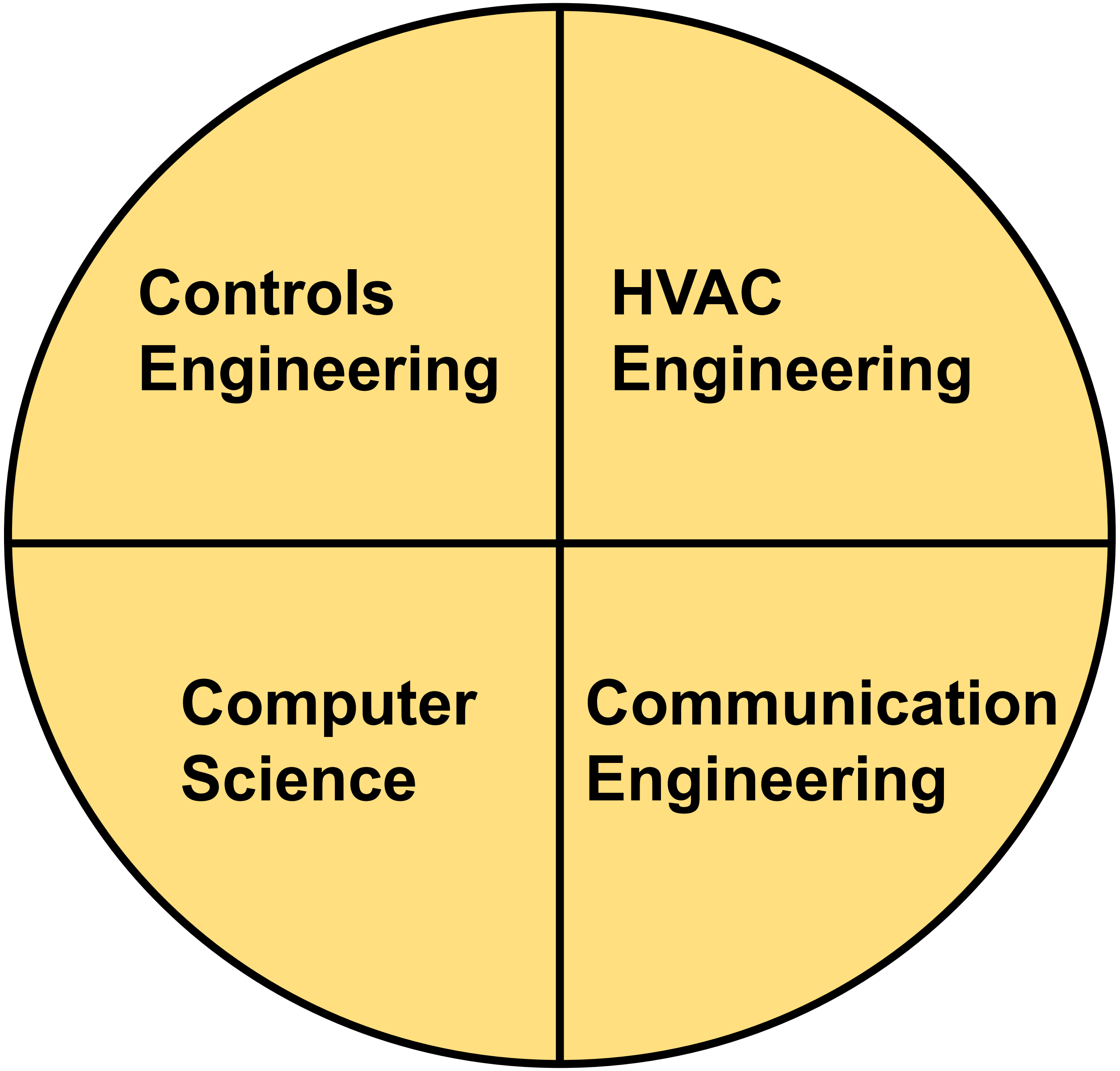
Basic concepts



- Early development history
  - 1st generation (1950's)
    - Remote monitoring panels with sensors & switches (hard wire)
  - 2nd generation (1960's)
    - Electronic low voltage circuits
  - 3rd generation (1960's-1973)
    - Multiplexed systems with minicomputer stations
  - 4rd generation (1983)
    - Microcomputer-based systems
  - 5th generation (1987)
    - Direct digital control (DDC) with microprocessor & software

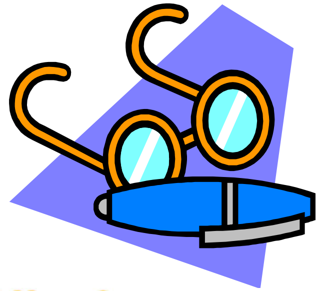
Influenced by computer & information technologies

Nowadays, BAS/BMS involves knowledge of many disciplines.



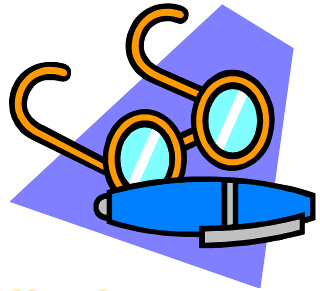
Keyword: "Communicate"

Basic concepts

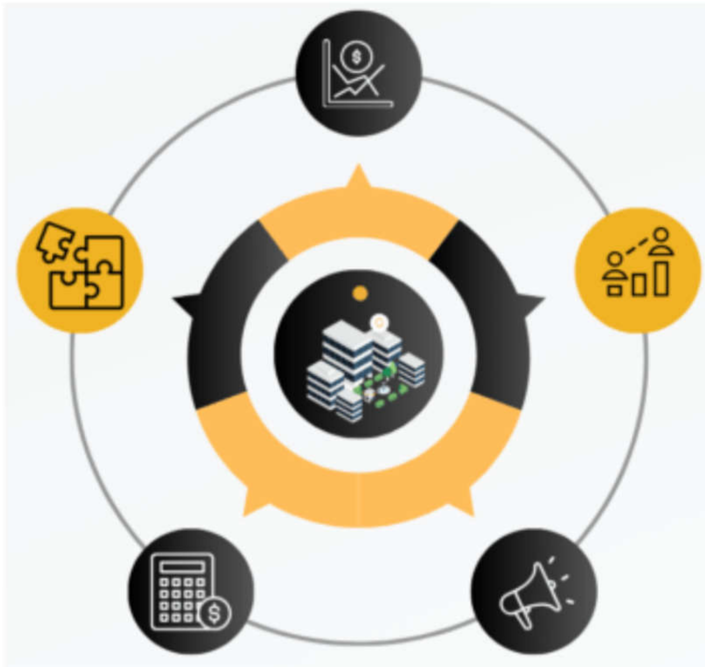


- The future of (smart) building automation systems
  - Internet of Things (IoT) technologies
  - Internet Protocol (IP) based devices + wireless
  - Connectivity + Integration
  - Advanced fault detection & diagnostics
  - Data analytics, machine learning, artificial intelligence
  - Open BAS platforms
  - Software As A Service (SaaS), cloud-hosted solutions
  - Smart grid integration

Basic concepts

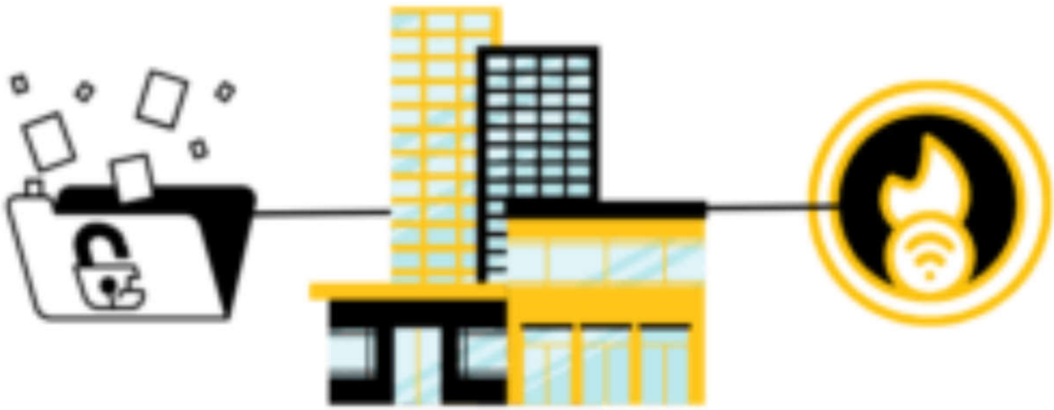


- Benefits of smart building automation
  - Integrated systems
  - Enhanced energy efficiency
  - Employee satisfaction and retention
  - IoT and real-time data collection
  - AI-driven predictive building solutions
  - Remote monitoring
  - Occupant comfort and productivity
  - Advanced security systems
  - Data-driven insights



Basic concepts

- What makes smart building automation successful?
  - Detect: The foundation of smart building automation
  - Diagnose: The analytical bridge to action
  - Improve: The actionable response for optimal performance



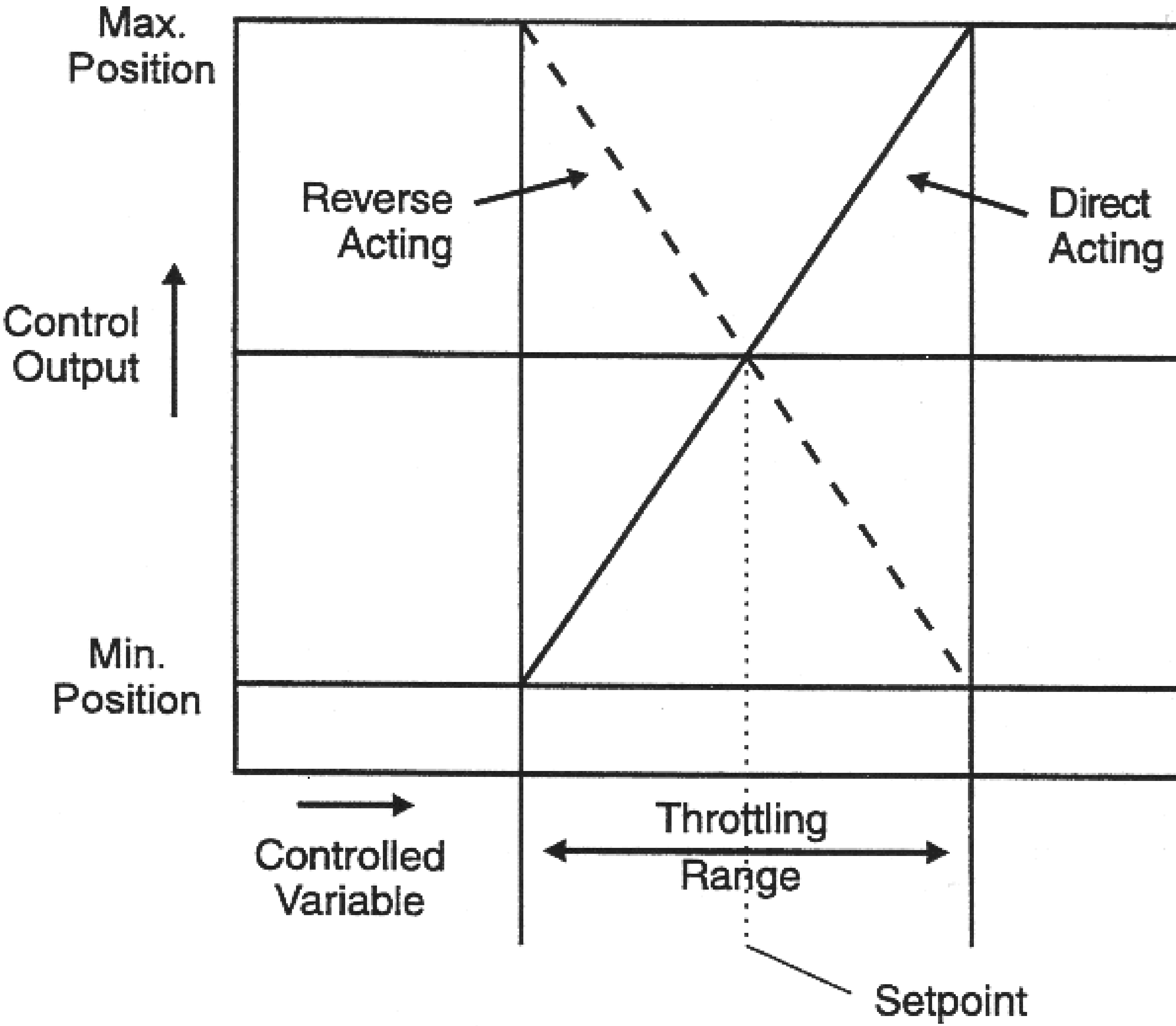
Control fundamentals

- Basic definitions and terms:
  - Analogue:
    - Continuously variable (e.g. a valve controlling water from off to full flow)
  - Digital:
    - A series of on and off pulses arranged to convey information
  - Controlled variable:
    - The quantity or condition that is measured & controlled, e.g. temperature, pressure, relative humidity, and flow

Control fundamentals

- Basic definitions and terms: (cont'd)
  - Setpoint:
    - The value (desired control point) set at the controller
  - Throttling range: (in a proportional controller)
    - The control point range through which the controlled variable must pass to move the final control element through its full operating range
  - Deadband:
    - Range of controlled variable in which no corrective action is taken

Basic concepts and terms of proportional control



[Source: Honeywell, 1997. *Engineering Manual of Automatic Control for Commercial Buildings*]

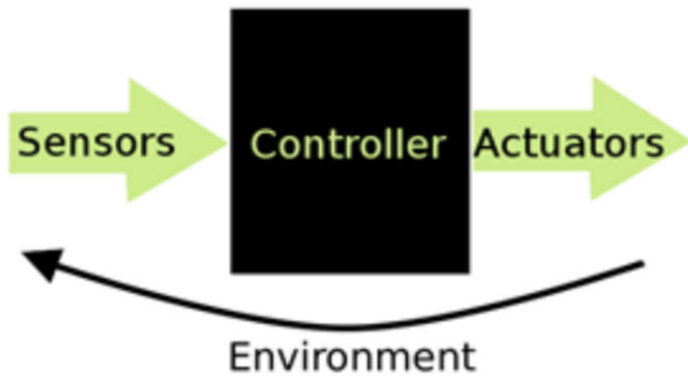
Control fundamentals

- Basic definitions and terms: (cont'd)
  - Controller:
    - A device that senses changes in the controlled variable (or receives input from a remote sensor) and derives the proper correction output
  - Automatic control system:
    - A system that reacts to a change or imbalance in the variable it controls by adjusting other variables to restore the system to the desired balance

Video: Basics of Building Control System Part-1| Building Management System Training | BMS System (11:20) https://youtu.be/hqq3wlhPHXw

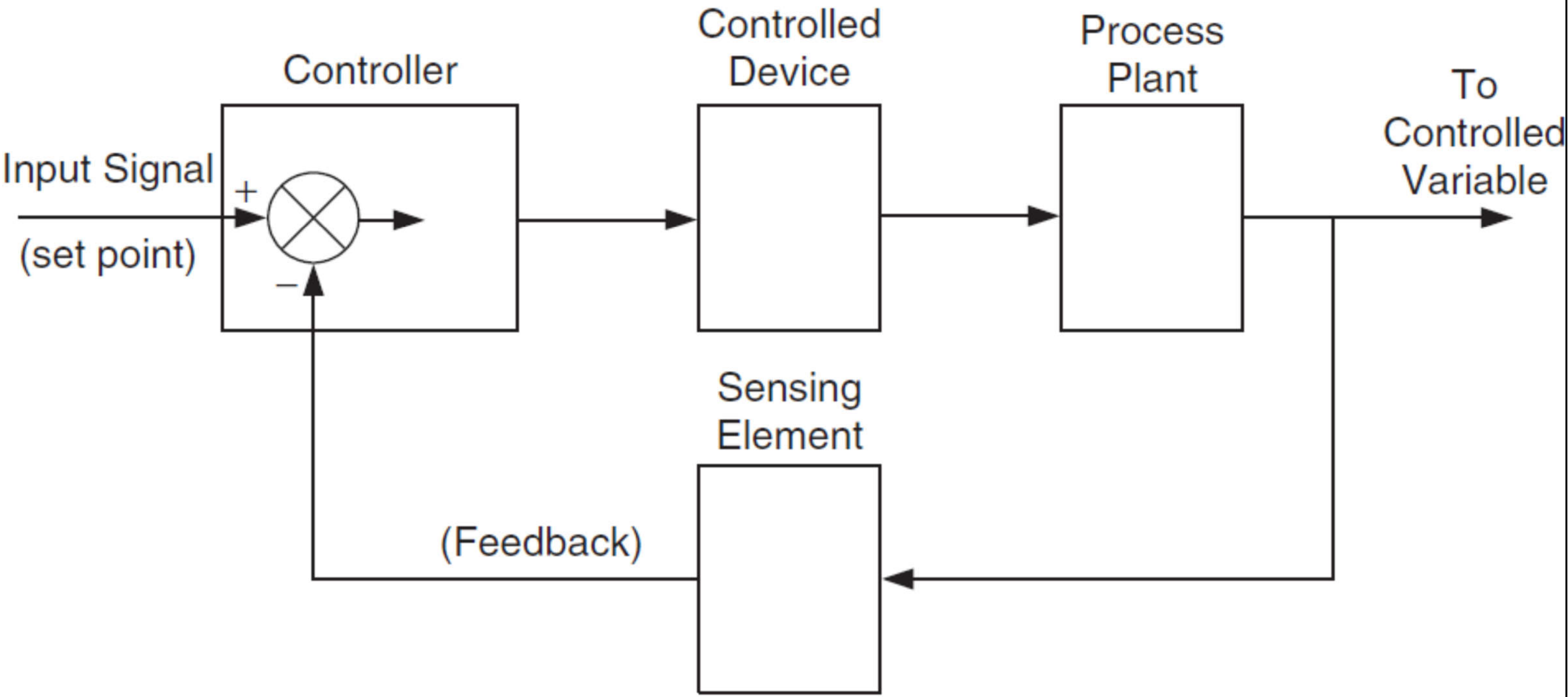
Control fundamentals

- Basic elements
  - Sensor
    - Measure some variables, e.g. temperature
  - Controller
    - Process & compute an output signal
  - Controlled device
    - Act to change the output of the load



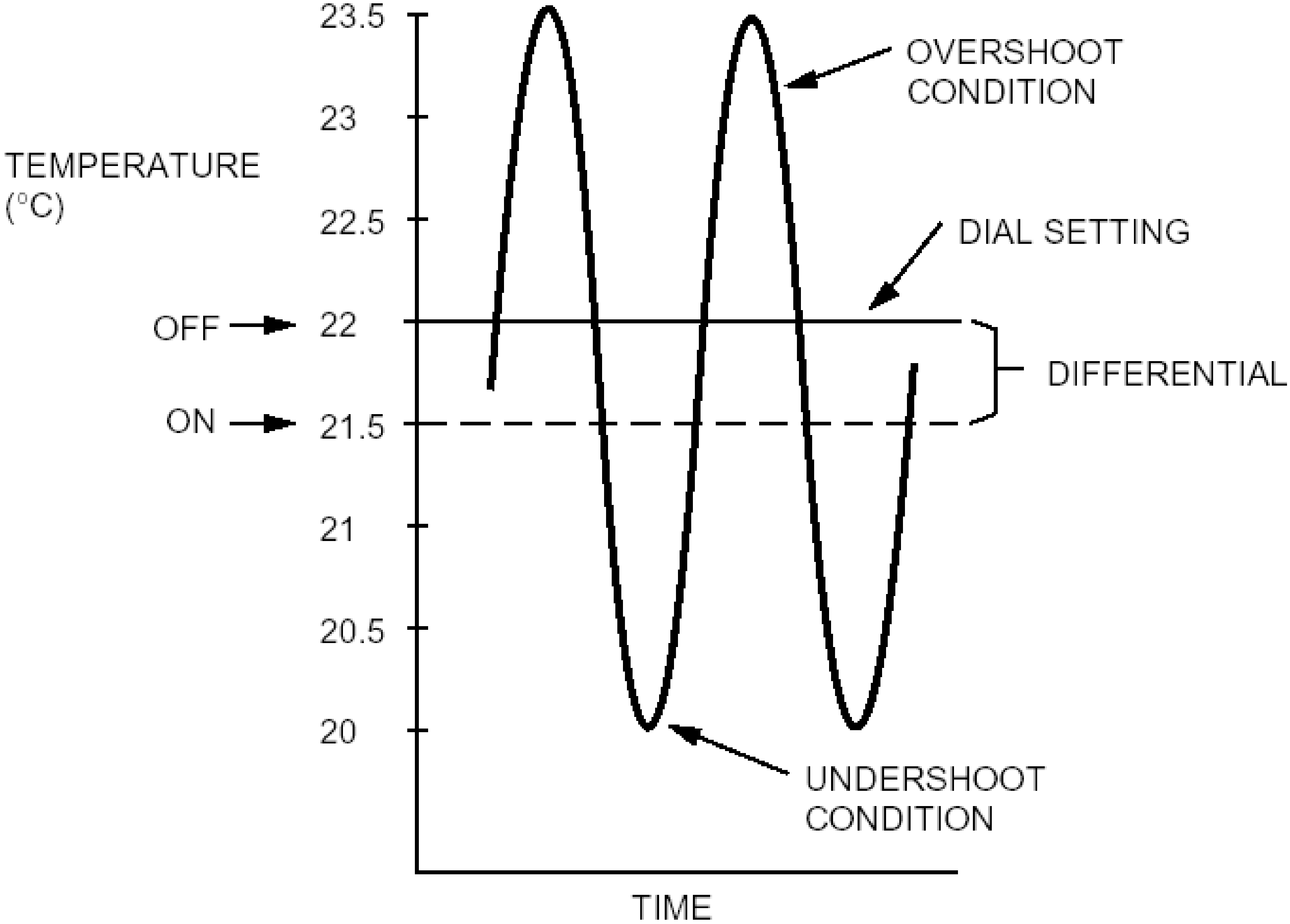
- Typical situation for BAS
  - Close loop systems (w/ feedback loop)

Basic elements of a feedback control loop



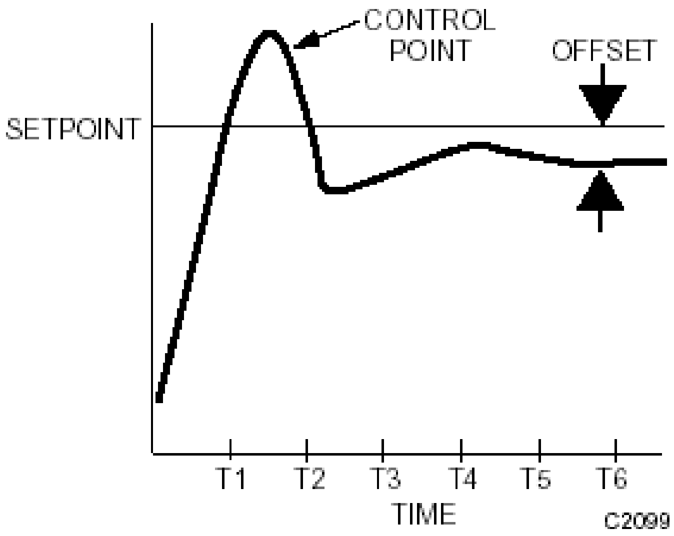
[Source: Montgomery, R. and McDowall, R., 2008. *Fundamentals of HVAC Control Systems*]

Basic two-position (ON/OFF) control

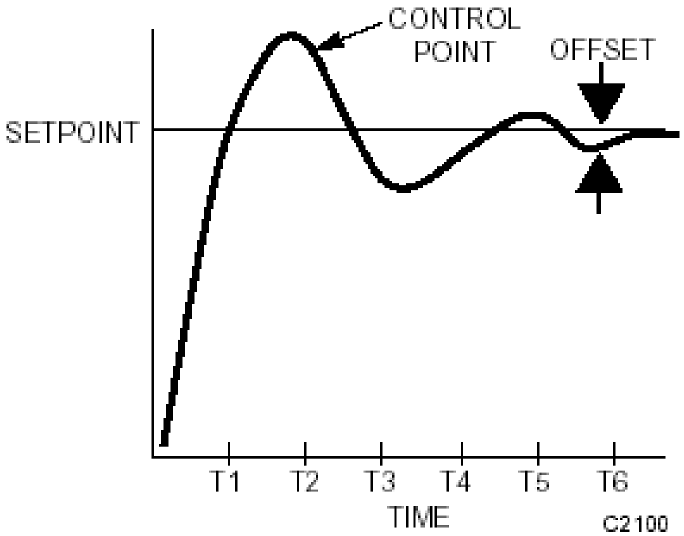


[Source: Honeywell, 1997. *Engineering Manual of Automatic Control for Commercial Buildings*]

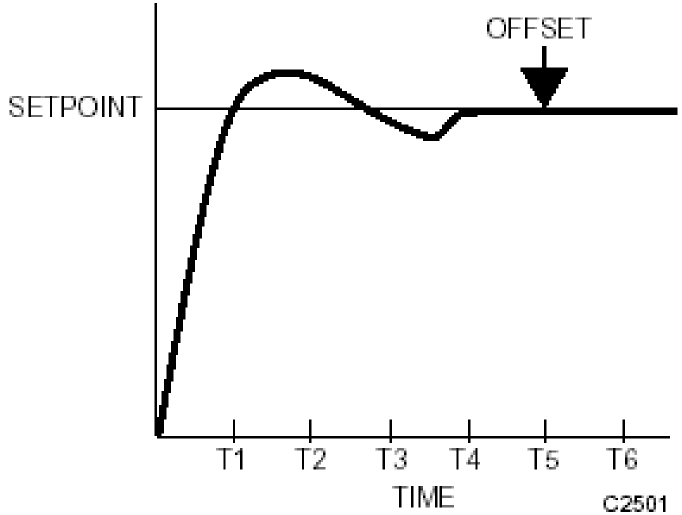
Proportional, integral and derivative (PID) control



Proportional Control



Proportional-Integral (PI) Control



Proportional-Integral-Derivative (PID) Control

$$V = \underbrace{KE}_{\text{Proportional}} + \underbrace{\frac{K}{T_1}\int E\,dt}_{\text{Integral}} + \underbrace{KT_D\frac{dE}{dt}}_{\text{Derivative}} + M$$

[Source: Honeywell, 1997. *Engineering Manual of Automatic Control for Commercial Buildings*]

Control fundamentals

- Pneumatic controls
  - Traditional form of control used in buildings
  - Pneumatic controllers, sensors & actuators
  - Electronic devices may be integrated
- Direct digital control (DDC)
  - Entered the HVAC industry in late 1980's
  - A programmable microprocessor as controller
    - 'Direct' = microprocessor is directly in the control loop
    - 'Digital' = control is accomplished by the digital electronics

Control fundamentals

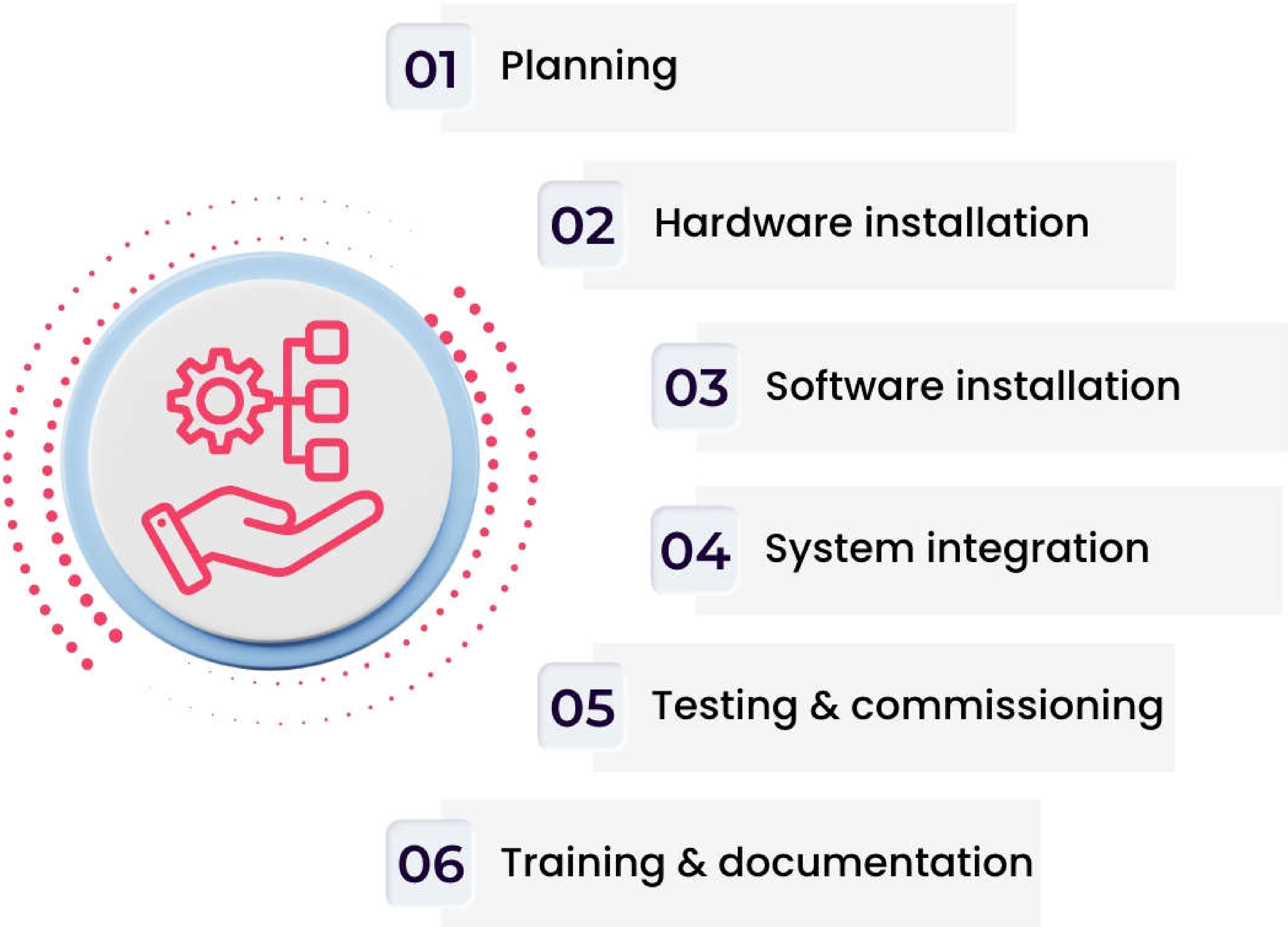
- Common control methods:
- 1) Pneumatic – apply compressed air or pressurized gases to create mechanical control
- 2) Electric – use electrical devices (e.g. relays, time clocks, thermostats, actuators)
- 3) Electronic – use electronic devices
- 4) Direct digital control (DDC) – apply microprocessor-based, network distributed controllers

System design

- Typical procedure for a BAS project
  - Initial concept
  - Information retrieval
  - Candidate buildings & system selection
  - Field survey
  - Technical design
  - Prepare contract documents
  - Contract & tendering
  - Installation, commissioning & training
  - Acceptance, operation & maintenance

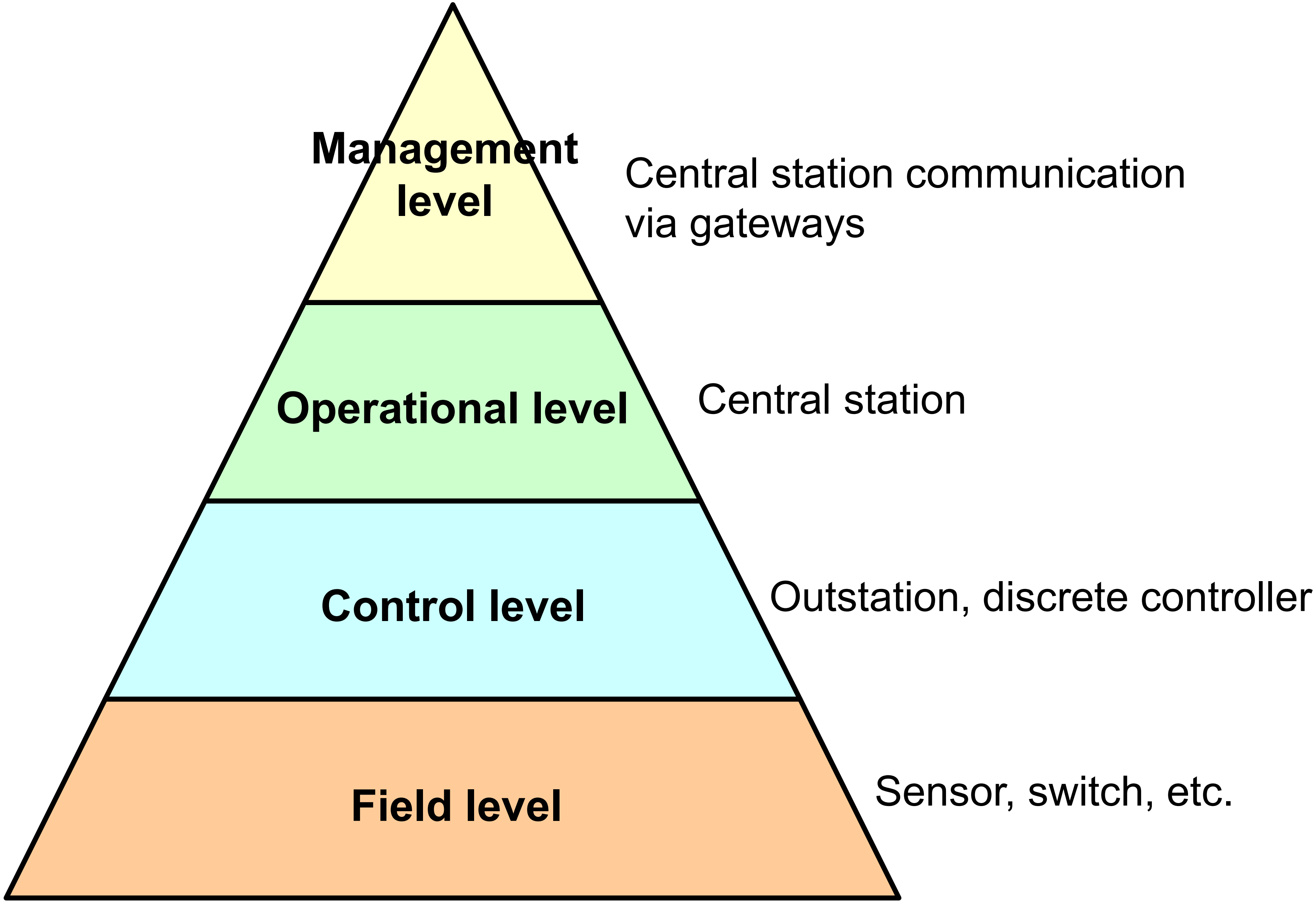
Carried out by consultants, control companies & HVAC contractors

Steps involved in implementing a BAS/BMS



[Source: https://www.zenatix.com/building-management-system-bms/]

Levels of control in building automation system

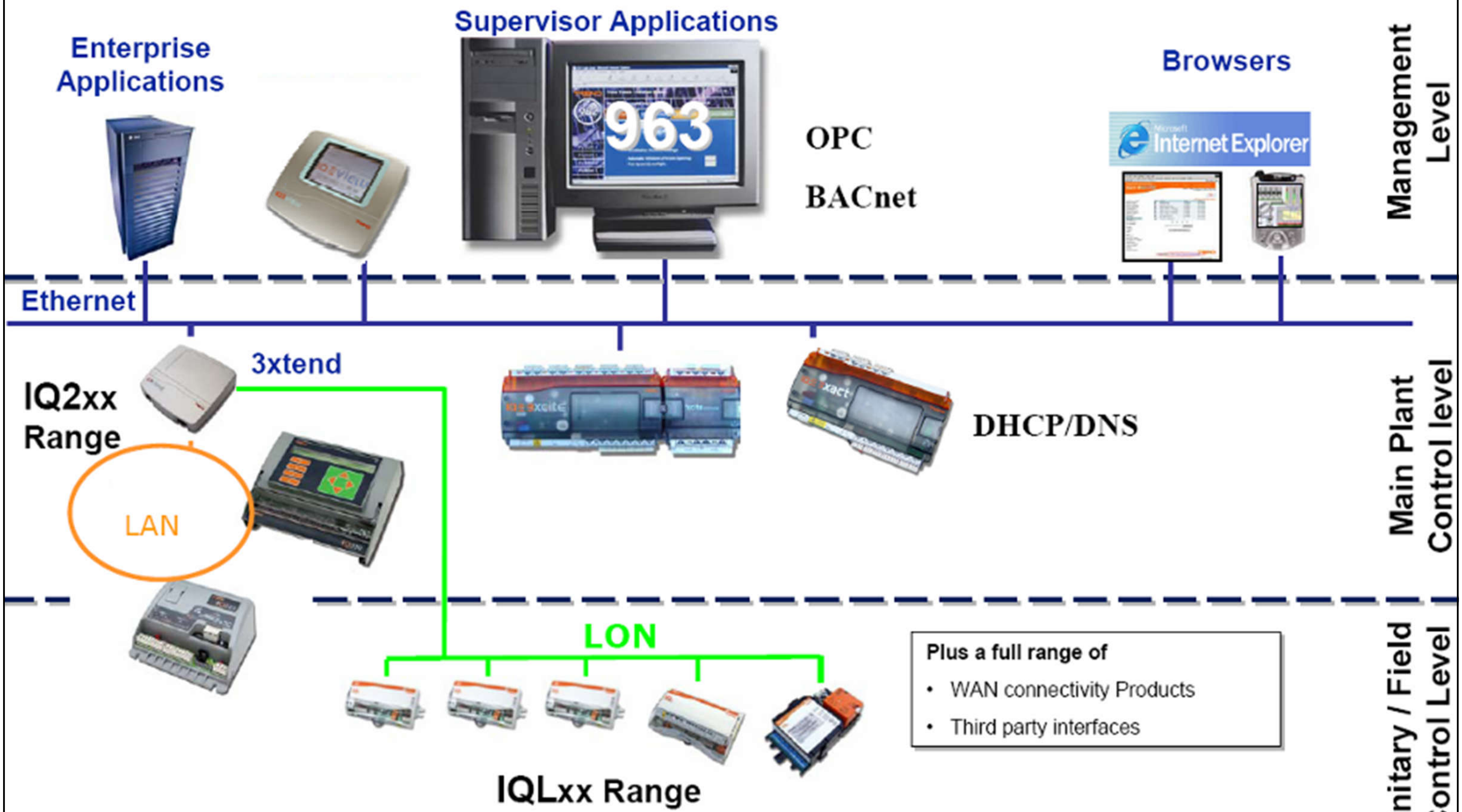


User interaction with BAS/BMS

Level	Operator	Function
Management level	Facilities manager	Reporting
	System administrator	Energy monitoring & targeting; Off-line data analysis
Operations level central supervisor	Non-technical personnel (security, caretaker)	Response to alarm messages and instructions
	System operator	Rescheduling, parameter adjustment, monitoring
	Specialist engineer	Reprogramming, fault finding, expansion
Service tools	Specialist engineer	Monitoring, reconfiguration, fault finding
System level outstation	Non-technical personnel	Some local control of conditions
	Specialist engineer	Parameter adjustment, reprogramming, fault finding
Zone level local control	Occupants	Set point adjustment

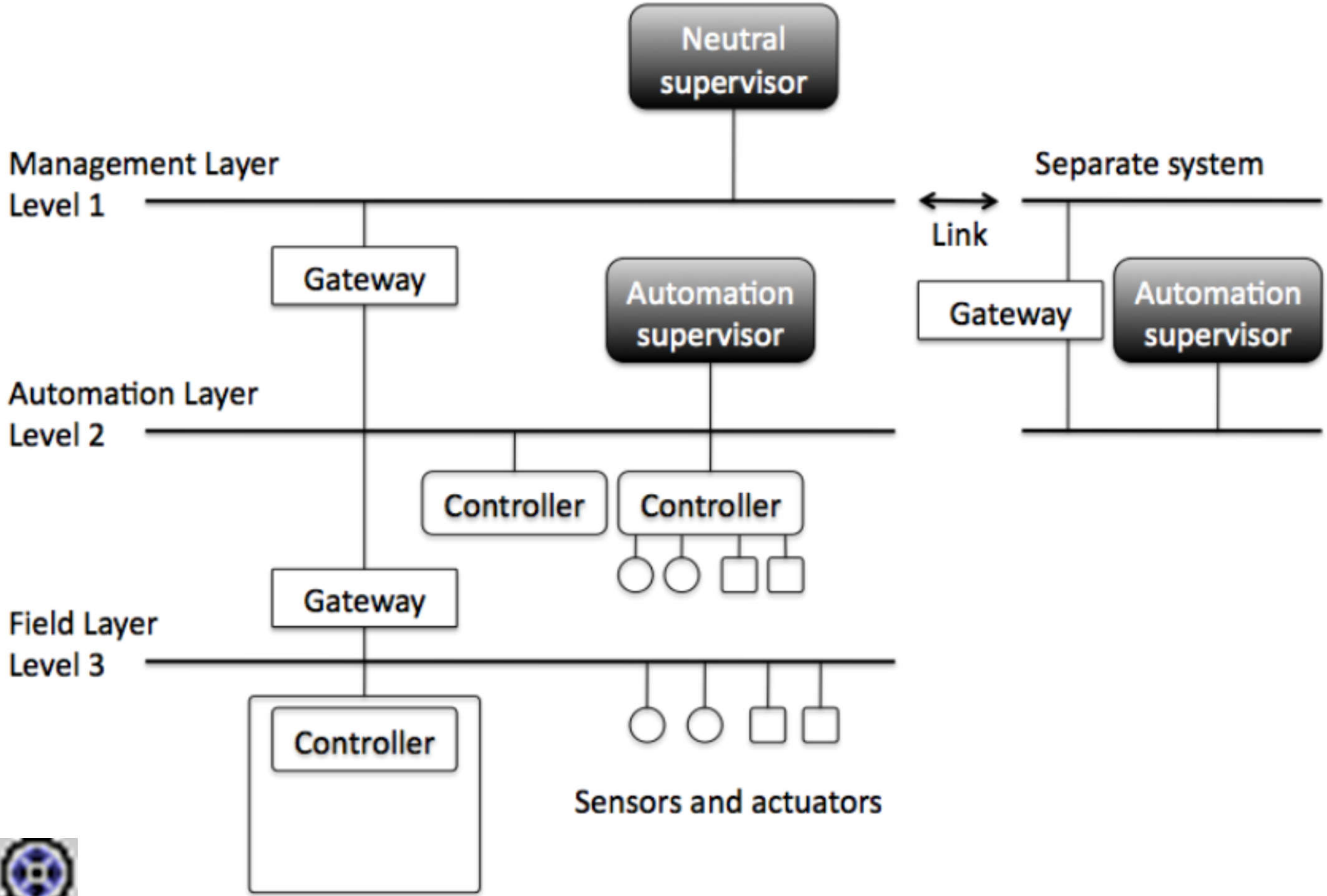
(Source: CIBSE, 2008. *Building Control Systems, CIBSE Guide H*, 2nd edition, Chartered Institution of Building Services Engineers (CIBSE), London.)

Example of system architecture for building management system



[Source: Trend Control Systems]

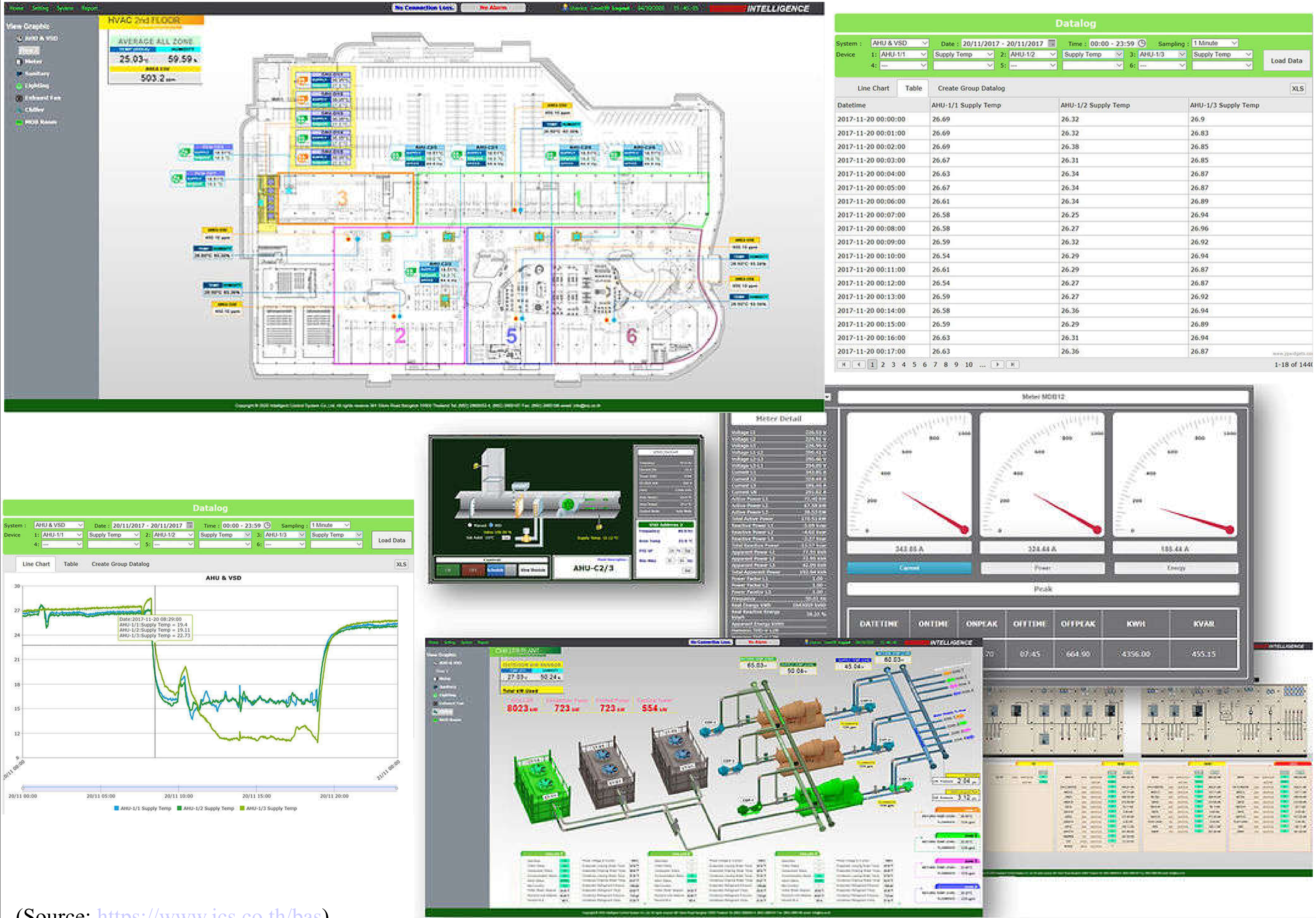
Three-layer building automation system (BAS) architecture



Video: Intro to Building Automation System Architecture (11:26)
https://youtu.be/mQi40A9uIaE

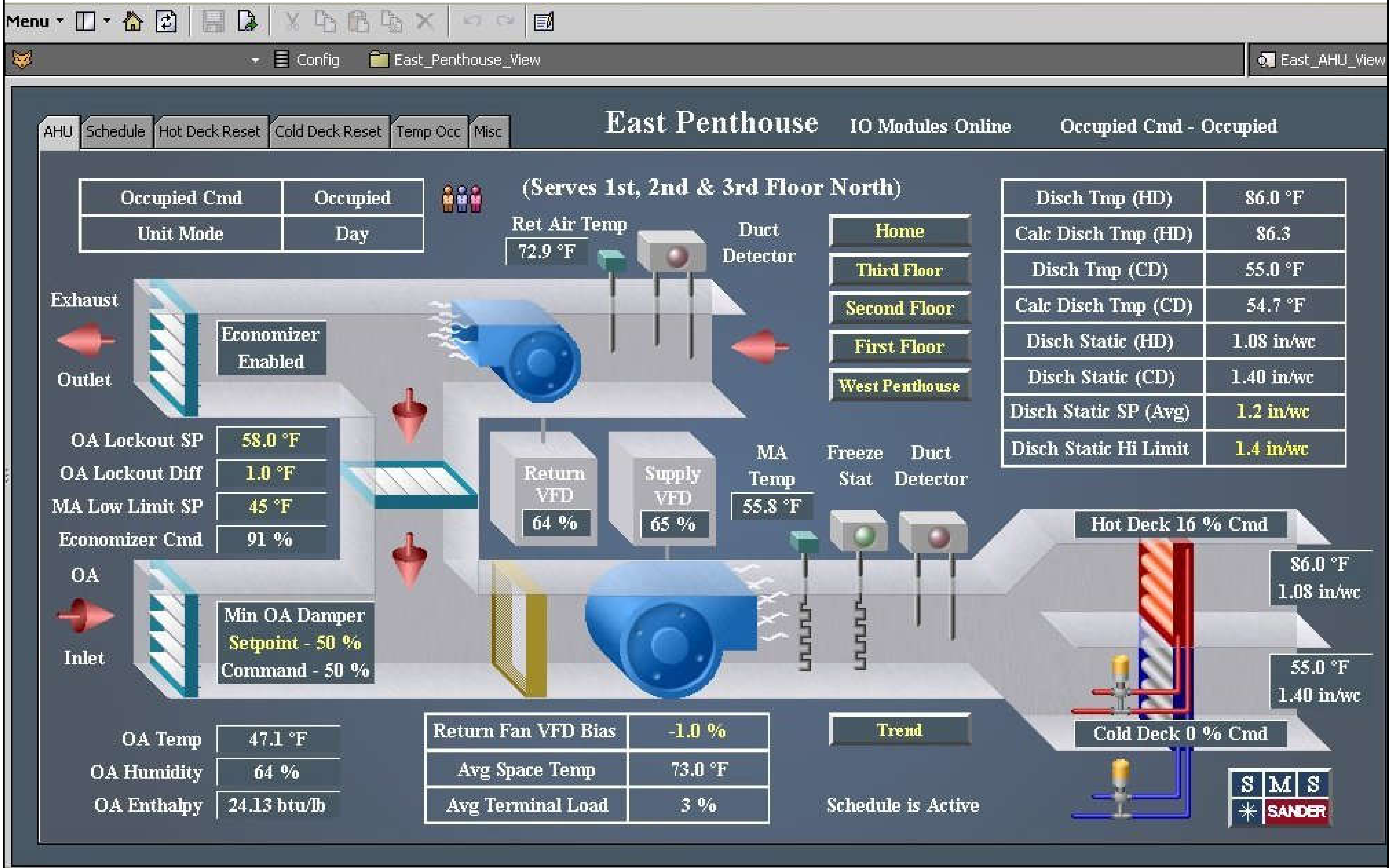
(Source: https://www.securityindustry.org/wp-content/uploads/2018/08/BACS-Report_Final-Intelligent-Building-Management-Systems.pdf)

Examples of virtual control graphic for building automation system



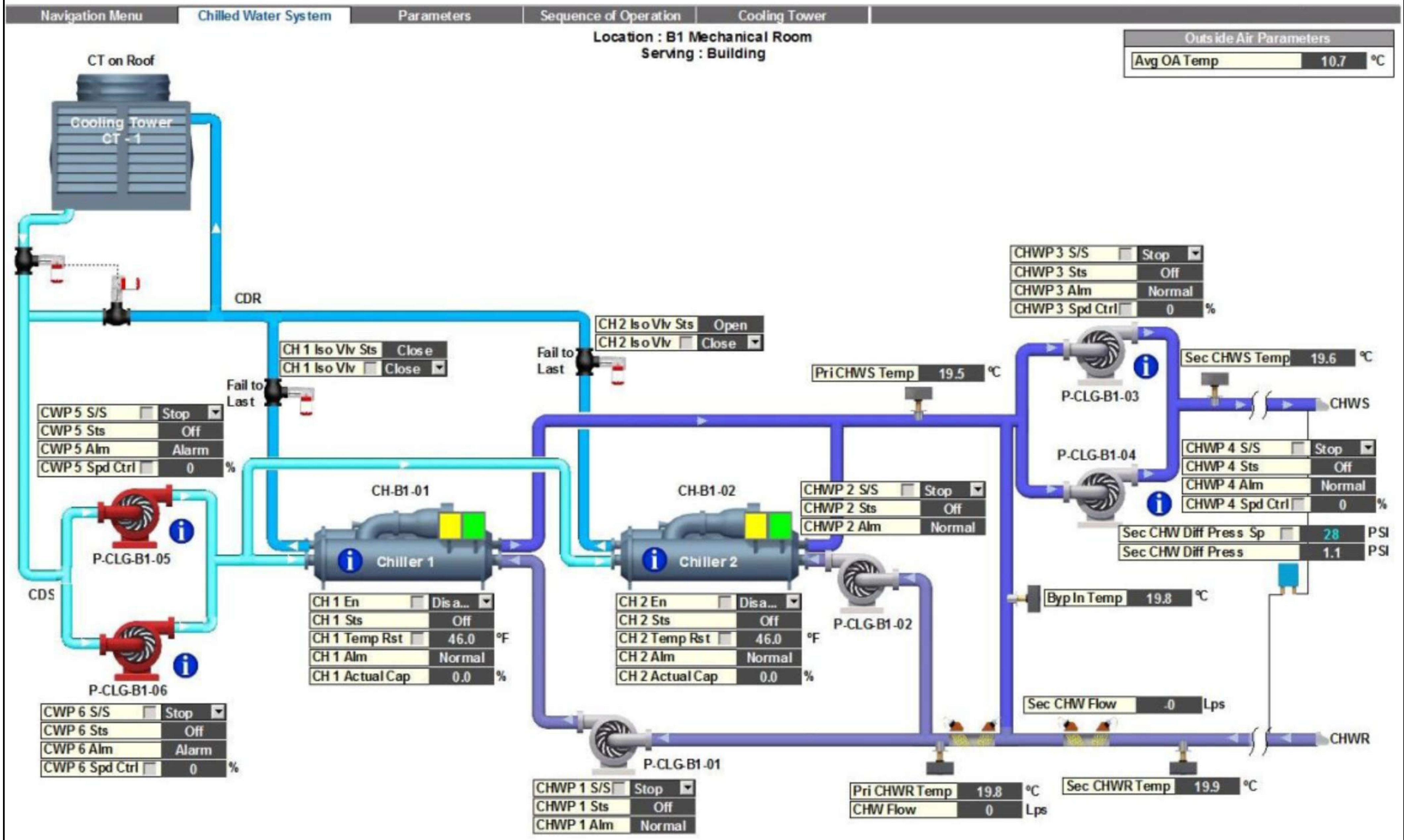
(Source: https://www.ics.co.th/bas)

An example of building automation system (BAS) graphic interface



(Source: https://sandermechanical.com/graphical-user-interface/)

Sample of chilled water loop system graphic



(Source: University of Toronto)

System design

- BAS documentation
  - 1. Functional Description (FD)
    - Details the configuration of the BAS/BMS
    - Overview of the building services systems, sub-systems & other related parts
    - Describes in detail each of the BAS/BMS control strategies & sequences of operation
    - Documents interaction between each part of the system

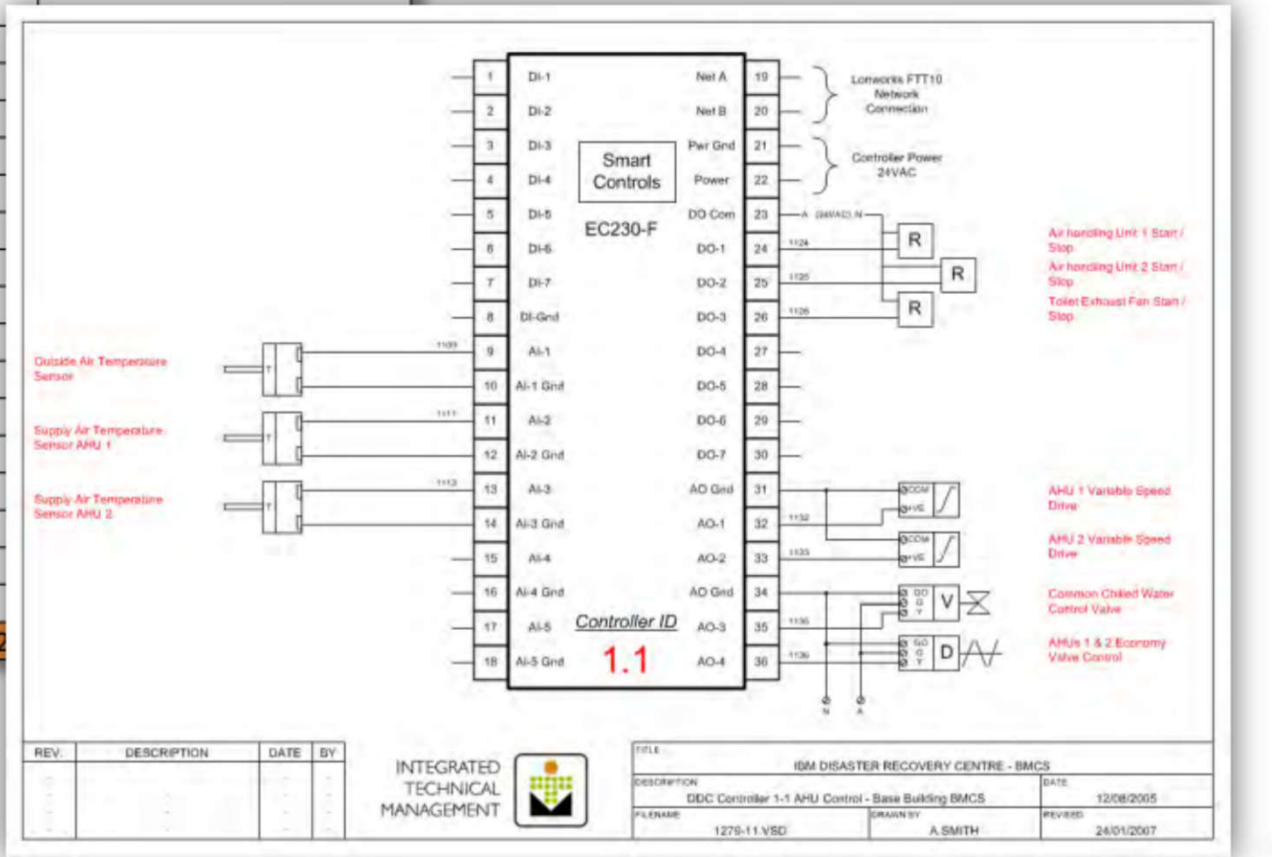
System design

- BAS documentation (cont'd)
  - 2. Point Schedules
    - Detail all connected devices & their point type
    - Critical for planning & system engineering
  - 3. Control System Drawings
    - Should include a network architecture drawing
    - Detail the physical wiring connections to controllers
    - Useful for fault finding & establishing spare capacity

Importance of system documentation

Point Description	DI	DO	AI	AO	HLI	Comments
Chiller HLI					2	Modbus Connection to Chiller
Chiller enable		2				
Chiller run status	2					
Chiller fault status	2					
CHW Pump start / stop		2				At MSSB
CHW Pump run status	2					
CHW Pump speed control				2		Direct to VSDs
CHW Flow temperature			2			
CHW return temperature			1			
CHW system pressure			1			
CHW bypass valve				1		
Tenant Cooling Tower Fans Start / Stop		2				
Tenant Cooling Tower Fans Status	2					
Tenant Cooling Tower Fans Speed				2		
Tenant Cooling Tower Spray Start / Stop		2				
Tenant Cooling Tower Spray Status	2					
Tenant CCW System Pressure			1			
Tenant CCW Pump start / stop		2				
Tenant CCW Pump run status	2					
Tenant CCW Pump speed control				2		
Tenant CCW Flow temperature			1			
Tenant CCW return temperature			1			
Totals	12	10	7	7	2	

- DI – Digital Inputs
- DO – Digital Outputs
- AI – Analogue Input
- AO – Analogue Output
- HLI – High Level Interface



- BMS Drawings show device details and wiring connections

(Source: Andrew Smith, Leader Building Technologies – A.G. Coombs)

System design

- System maintenance
  - The building owner should act as its administrator managing BAS access rights
  - The BAS should be maintained with an appropriate level of servicing
  - As with any software driven system, data & files should be backed up on a regular basis
  - Critical components should be identified & checked at regular intervals

System design

- System maintenance (cont'd)
  - BAS functions e.g. trend data, reports & alarms can be used to perform maintenance by exception
  - Maintenance should be approached as the performance of the controlled system not individual components, i.e. AHU or chiller plant
  - While the BAS equipment vendor should be utilised to maintain the critical components, other suitably qualified technicians can be utilised for field equipment

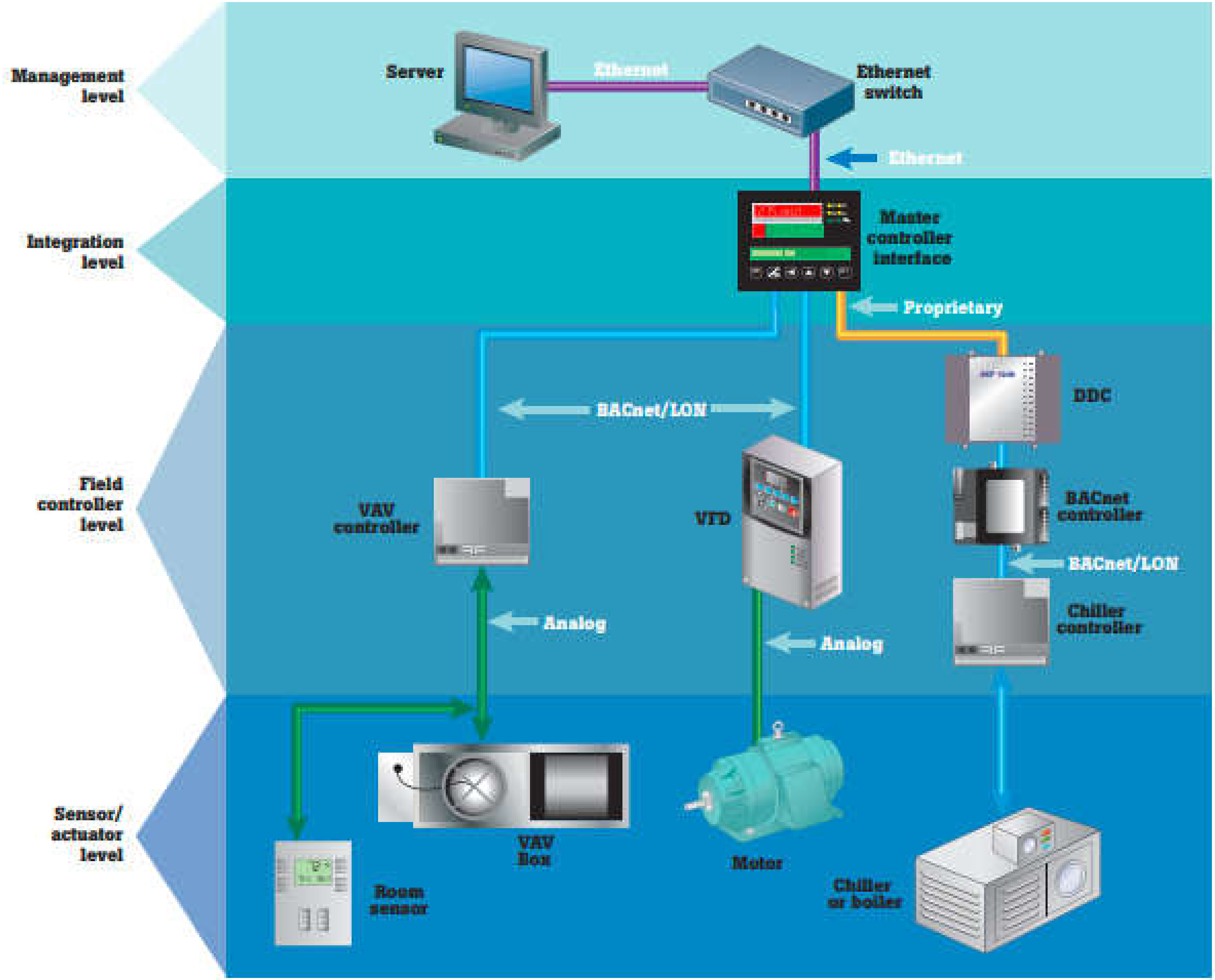
System design

- BAS lifecycle considerations
  - Considerations:
    - Check equipment production cycle status
    - Select hardware with proven record (avoid beta)
    - Check for level of software & hardware support
    - Check for forward compatibility policy
  - Equipment Lifecycle:
    - BAS/BMS field controllers – 15 to 20 years
    - Field devices – 15 to 20 years
    - BAS/BMS computer hardware – 3 to 5 years
    - BAS/BMS software – Major releases 3 to 5 years

System components

- BAS system architecture
  - Define how well the many systems in the building work together
  - Indicate the design or set of relations between the parts of a system
  - A four-layer concept adopted by manufacturers:
    - 1. Application
    - 2. Supervisory
    - 3. Field Controller
    - 4. Input/Output

Four layers of modern building automation system (BAS) architecture

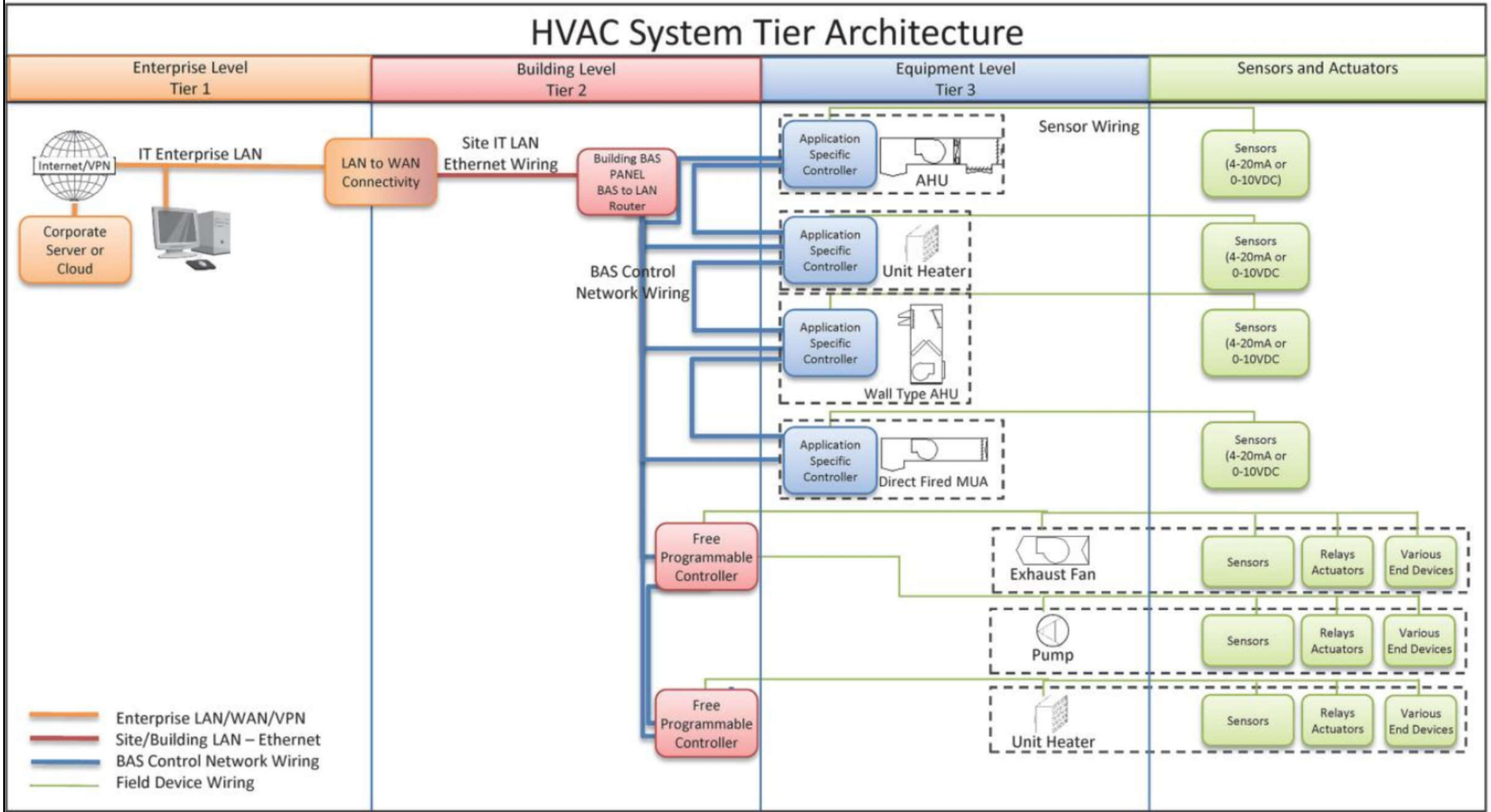


(Source: https://control.com/technical-articles/the-layers-of-modern-building-automation-system-architecture/)

System components

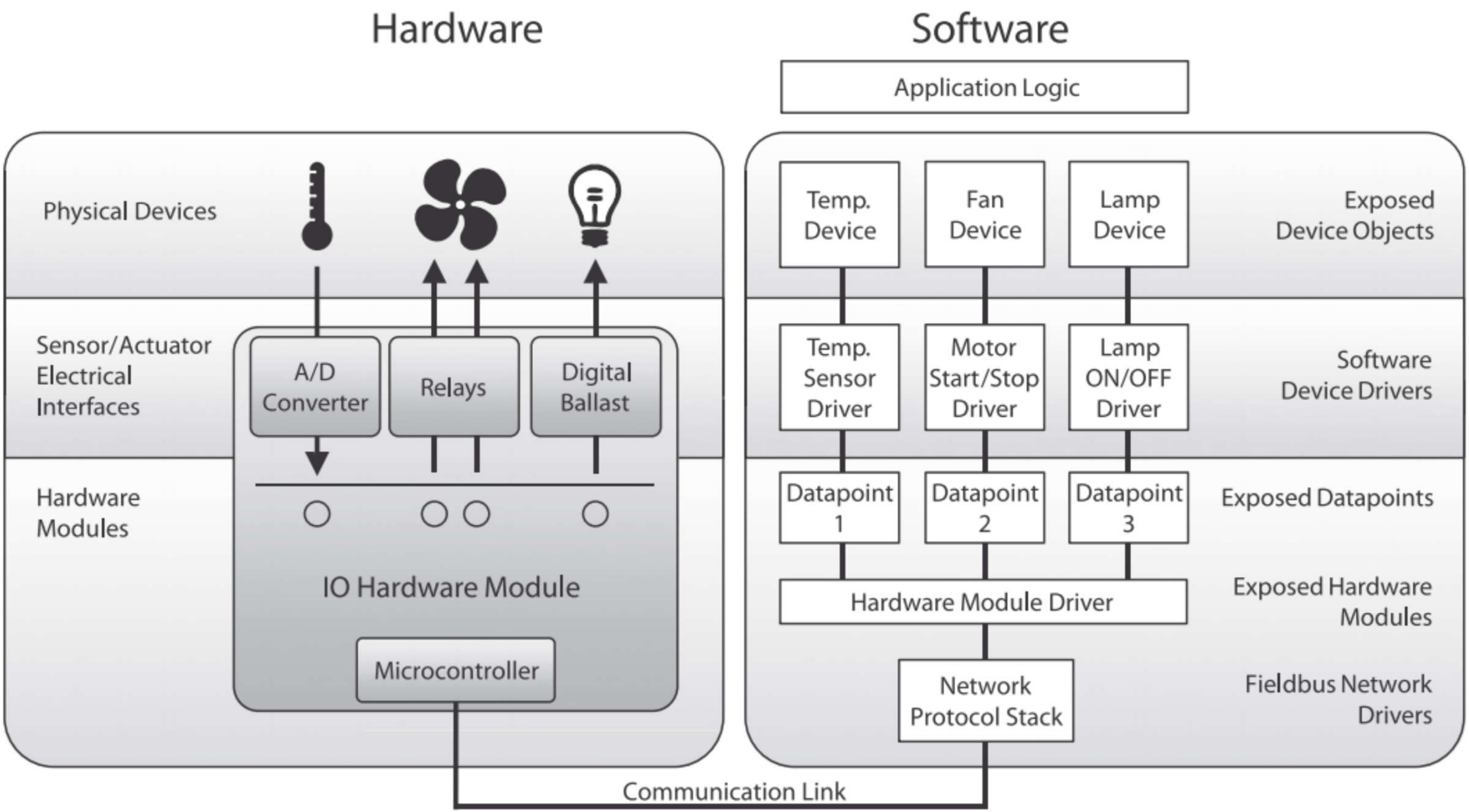
- Four tiers of BAS:
  - Tier 1 Enterprise Level – BAS workstation, control centre
  - Tier 2 Building Level – Building BAS panels & routers
  - Tier 3 Equipment Level – Main equipment of systems
  - Tier 4 Sensors & control devices

Four tiers of building automation system (BAS)



(Source: ASHRAE Guideline 13)

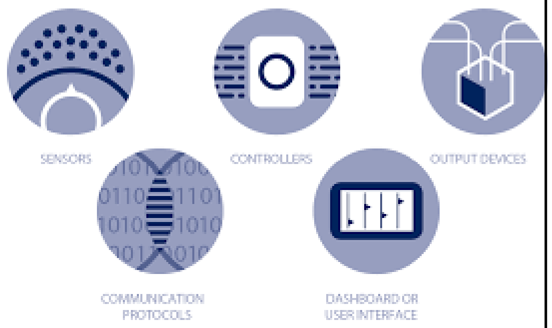
Building automation system hardware and software stack



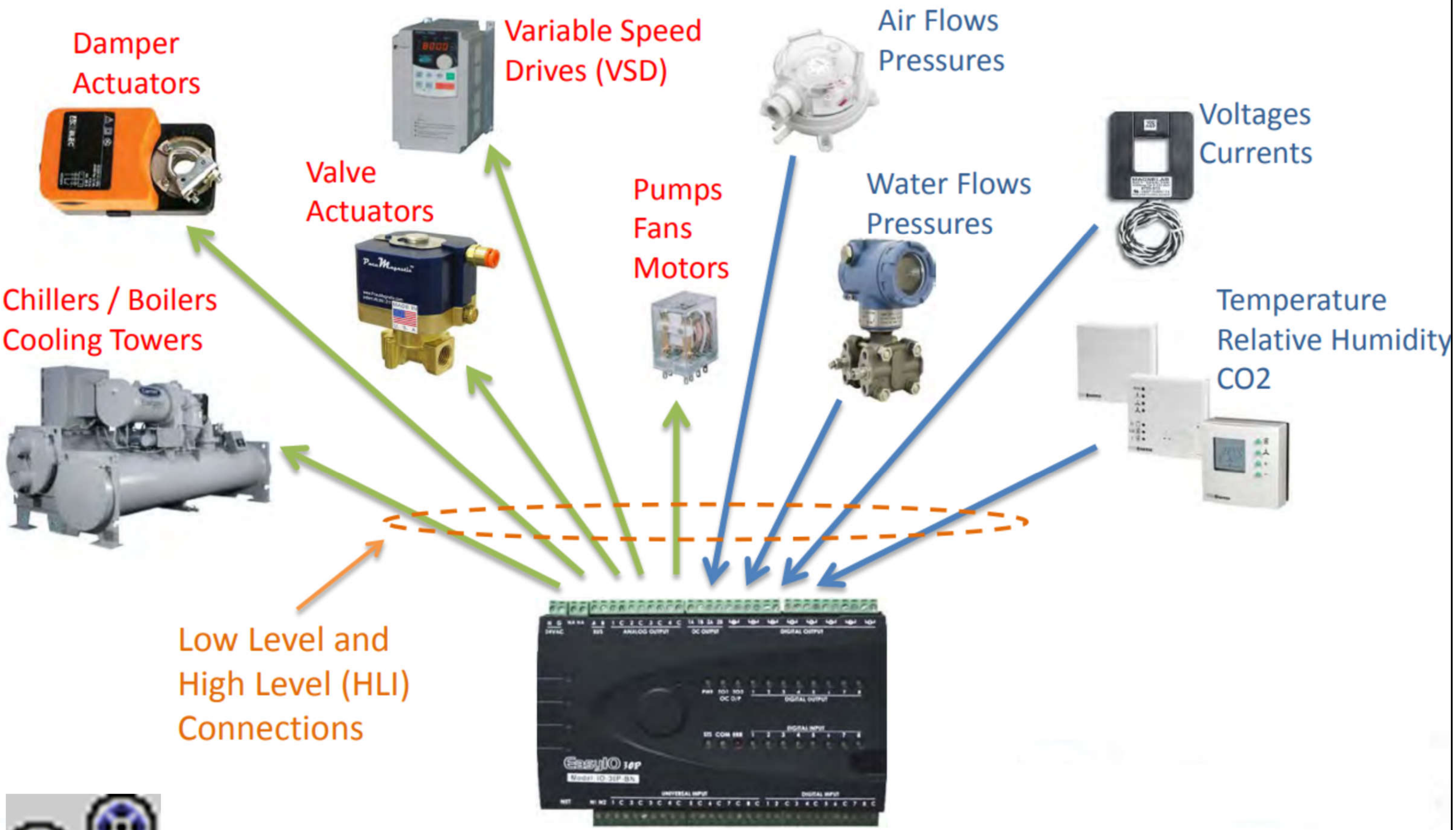
(Source: Domingues P., Carreira P., Vieira R. & Kastner W., 2016. Building automation systems: Concepts and technology review, *Computer Standards and Interfaces*, 45: 1-12. http://dx.doi.org/10.1016/j.csi.2015.11.005)

System components

- Typical components of BAS:
  - Sensors (e.g. temperature, humidity, lighting level)
  - Controllers (the “brain” of BAS)
  - Output devices (e.g. actuators & relays, to carry out commands from controllers)
  - Communication protocols (specific language understood by the system components to modify settings or execute commands)
  - Terminal interface (e.g. user interface, workstations)



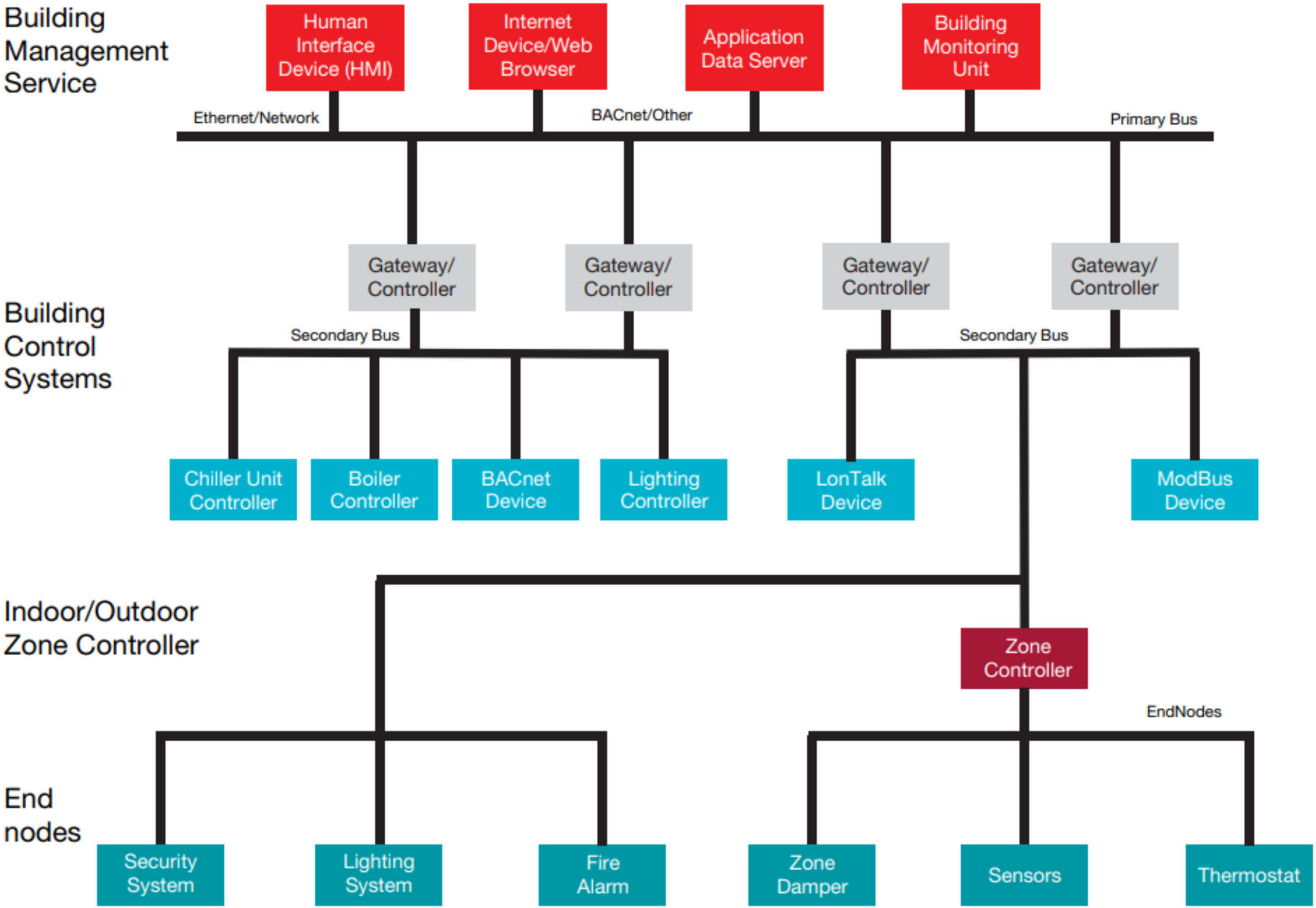
Typical BAS system components – field devices



Video: Building Automation Systems (BAS) Operations (2:06)
https://youtu.be/ByrysZAwoPI

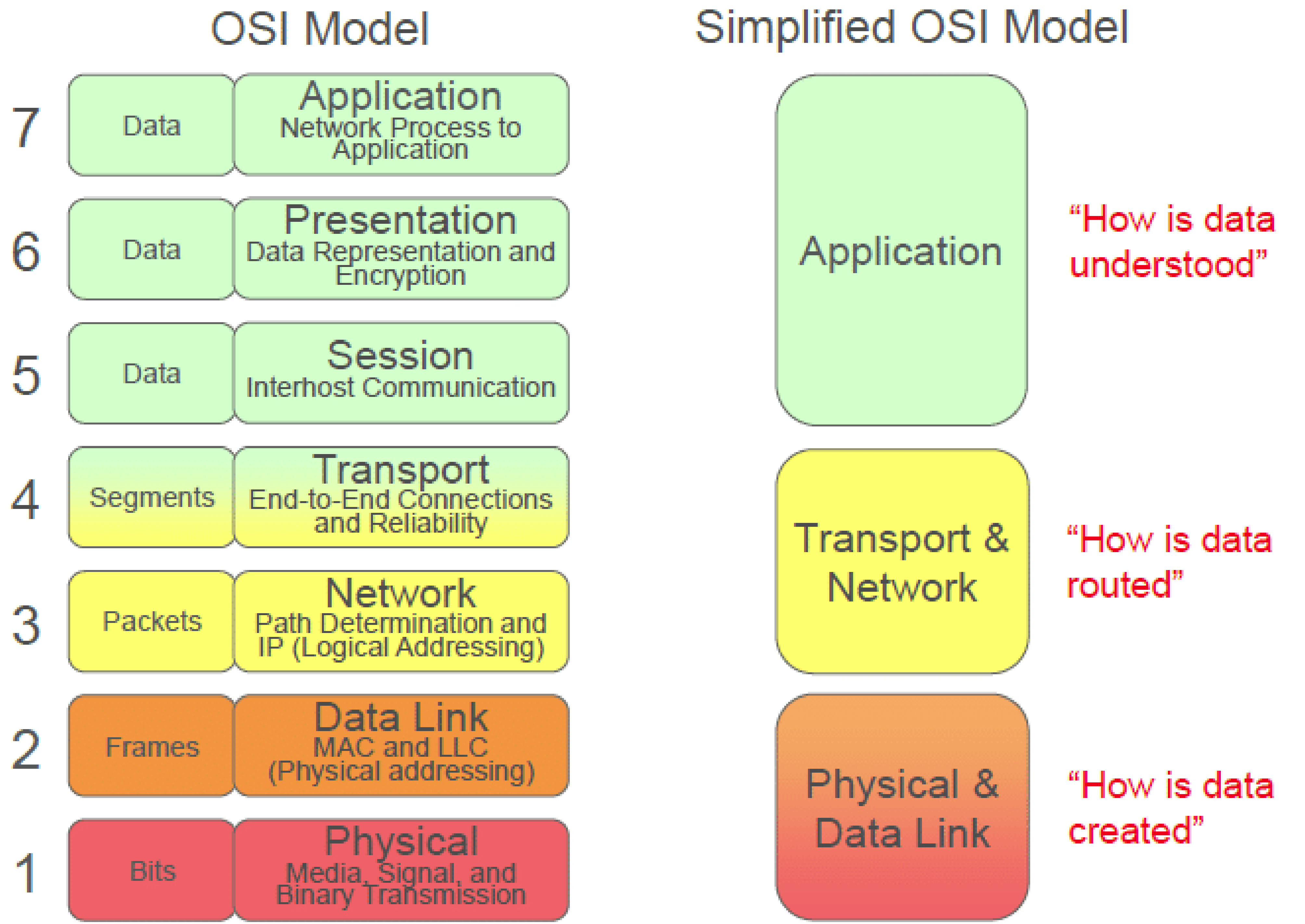
(Source: Andrew Smith, Leader Building Technologies – A.G. Coombs)

Typical building automation system (BAS) topology

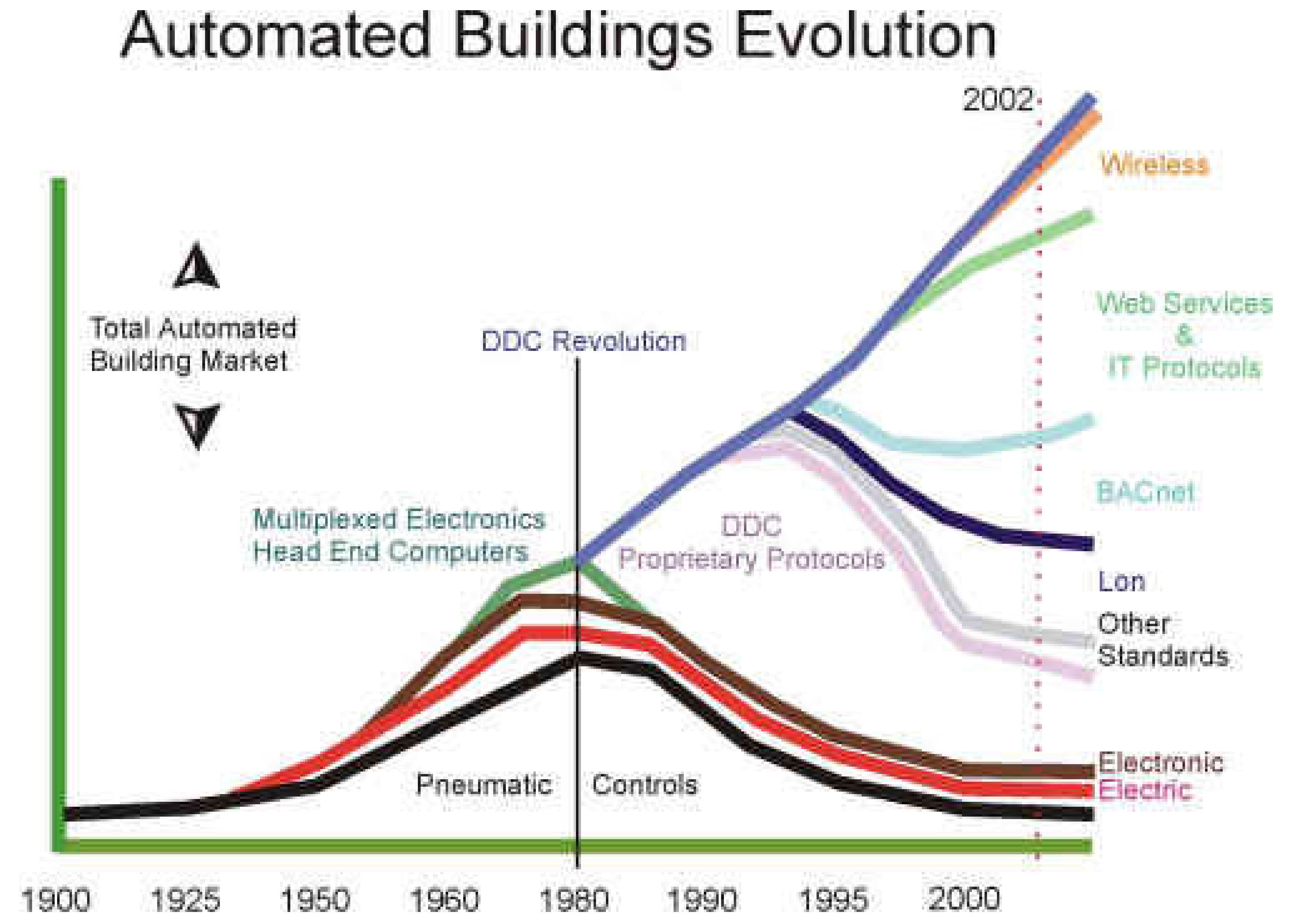


(Source: Texas Instruments https://www.ti.com/lit/wp/spry247a/spry247a.pdf)

Simplified Open Systems Interconnection (OSI) model for BAS



(Source: https://www.researchgate.net/publication/305000013_2016_DOE_SSL_RD_Plan)



(Source: https://www.automatedbuildings.com/news/may01/articles/education/eD.htm)

Networking

- History of building automation (BA)
  - Early 1600s: Invention of the thermostat
  - 1884: Invention of the modern light switch
  - Early 20th century: Homes go electric
  - Around 1925: Invention of the heat regulator
  - 1960s: Networking of buildings
  - 1969: The advent of digital control
  - 1979/1980: BA goes digital DDC, high-speed data transfer
  - 1986: Building information modelling (BIM)
  - 1987 and 1990: The advent of non-proprietary standards
  - 1998/1999: Global networking (The Internet & Wi-Fi)

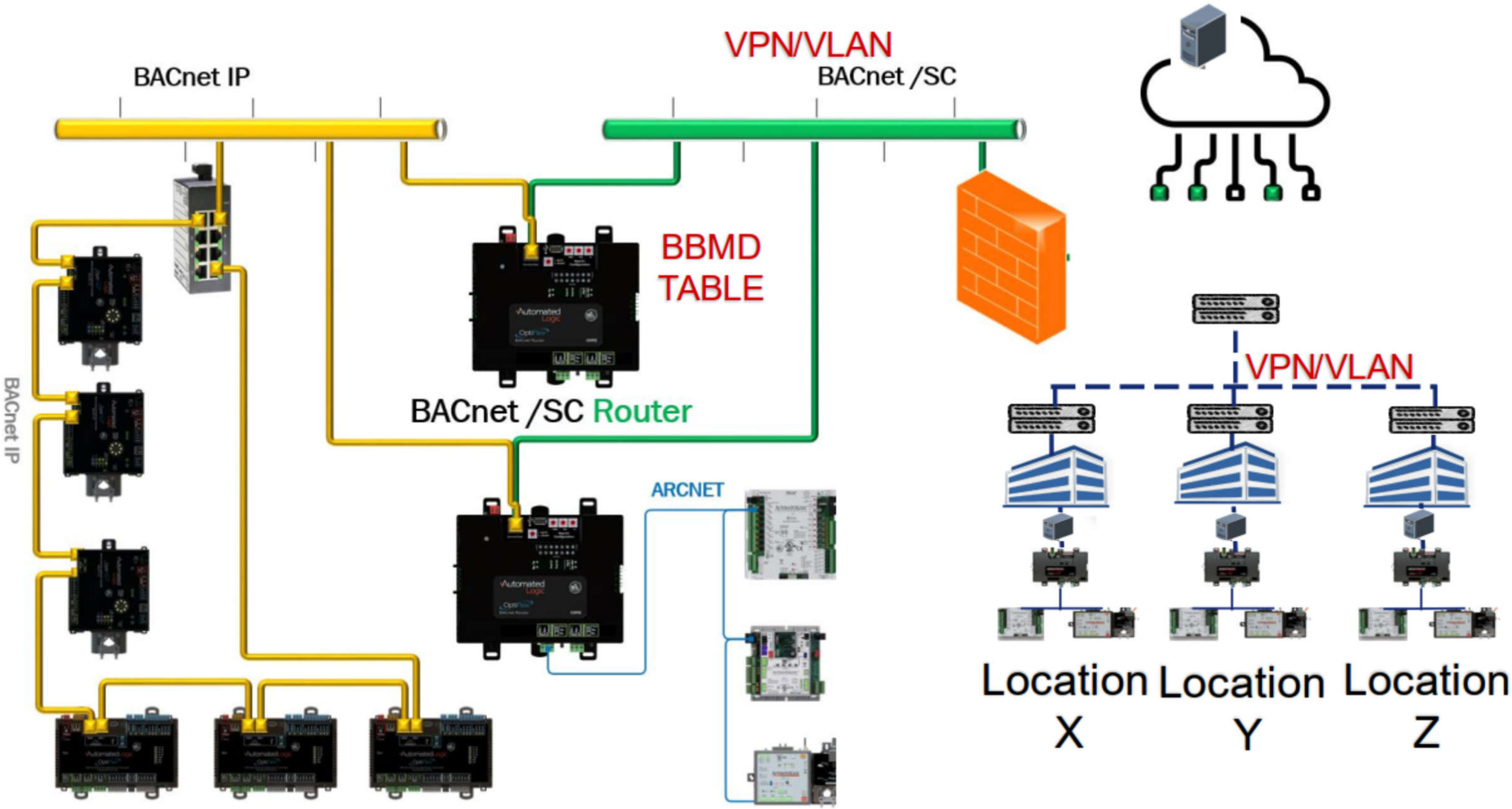
(Source: https://www.boschbuildingsolutions.com/xc/en/news-and-stories/history-of-building-automation/)

Networking

- History of building automation (BA) (cont'd)
  - 2005: Home automation gains momentum in Germany
  - 2007: Smartphones propel a great leap forward
  - 2008: Building automation joins the cloud (cloud-based services)
  - 2009: Wireless control of lighting
  - 2010: Always on the go, always online
  - 2014: Text-to-speech (TTS) technology
  - 2016: The Internet of Things (IoT) networks building technology
  - 2018: A "brain" for buildings
  - 2020: Turnkey artificial intelligence (AI) & intelligent video techno.
  - The near future: A boom in cloud-based services

(Source: https://www.boschbuildingsolutions.com/xc/en/news-and-stories/history-of-building-automation/)

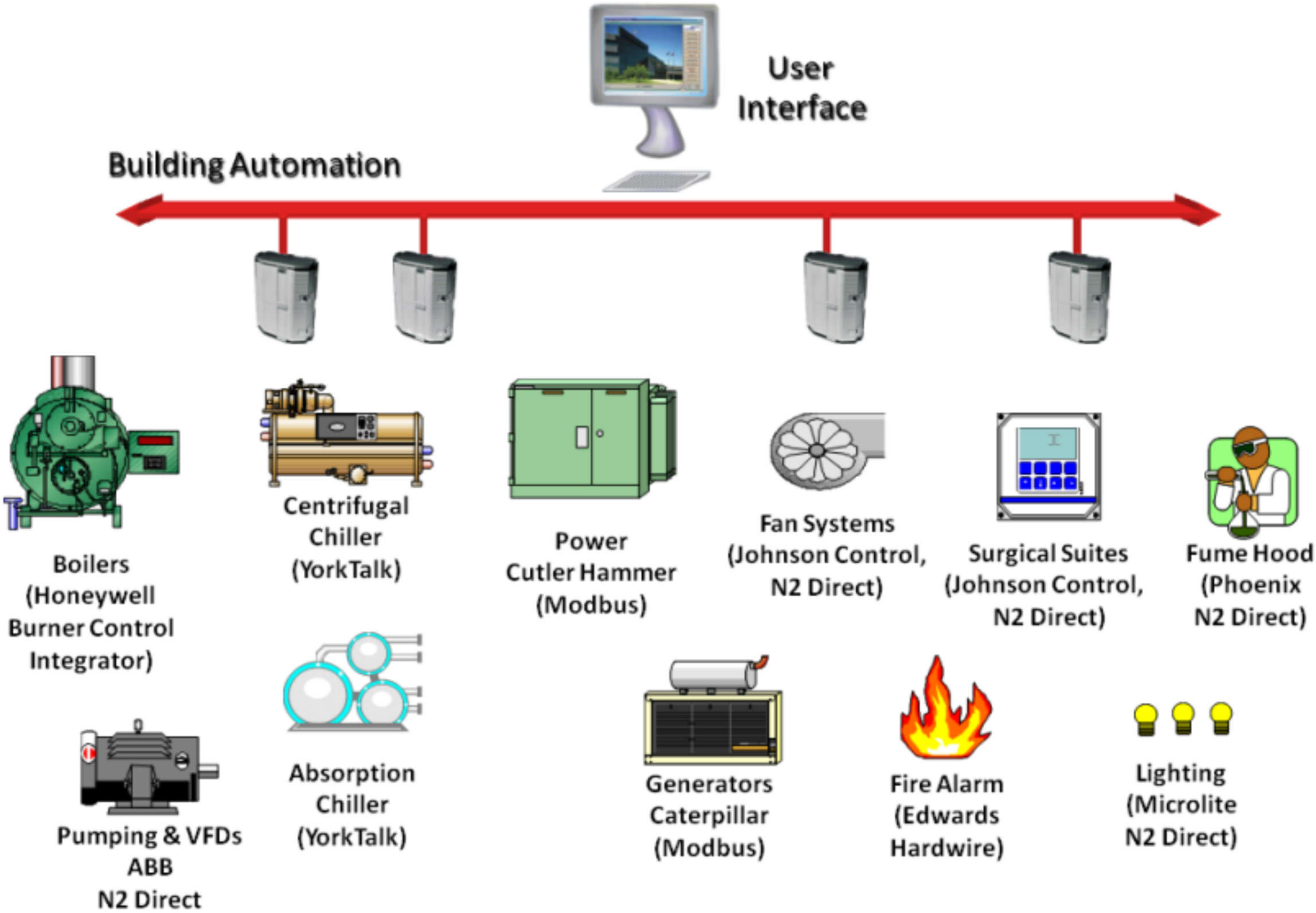
An example of BAS topologies with Cloud



BACnet = Building Automation and Control Networks
IP = Internet Protocol
SC = Secure Connect
VLAN = virtual local area network
VPN = virtual private network

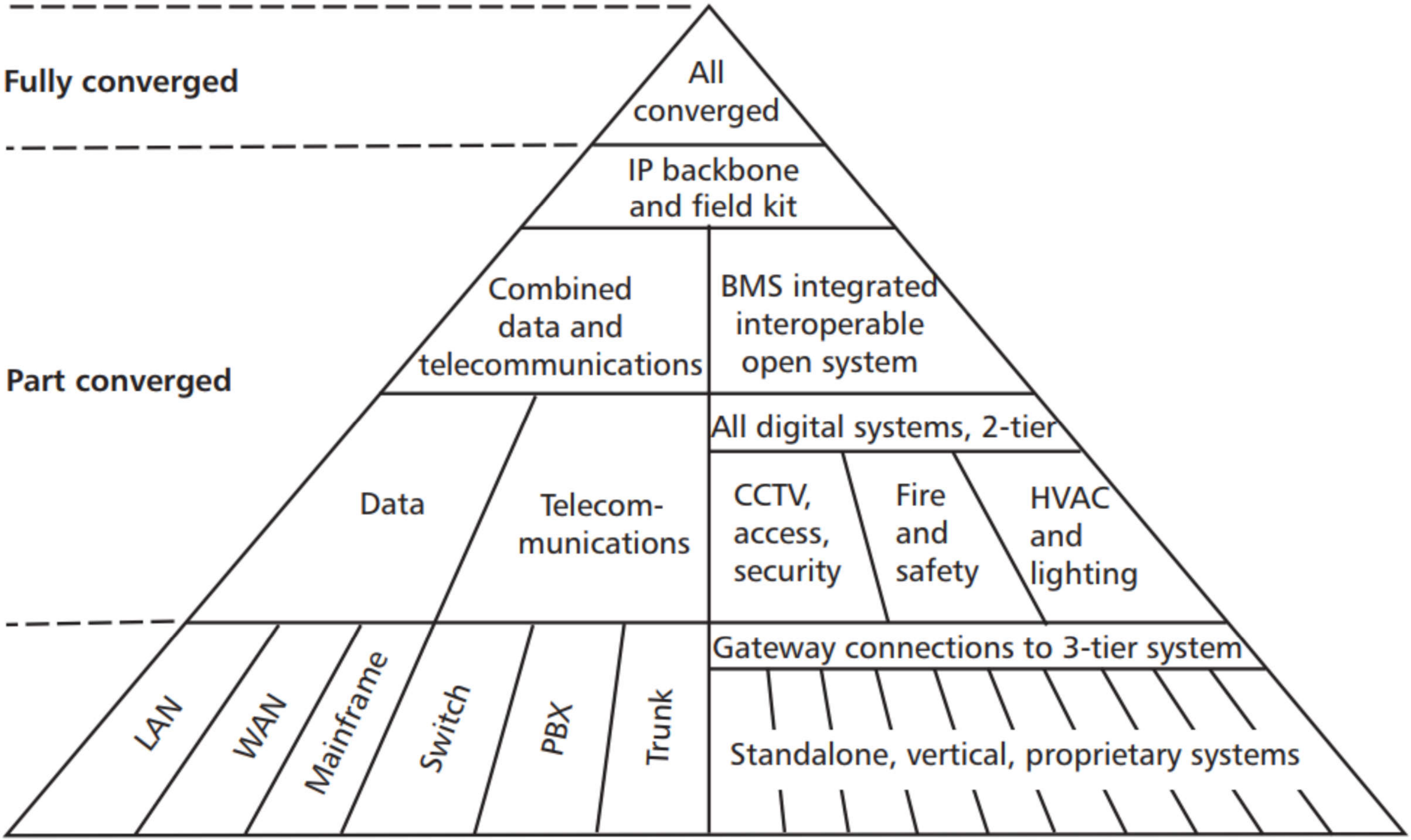
(Source: Carrier and Automated Logic)

The need to integrate different sub-systems of BAS



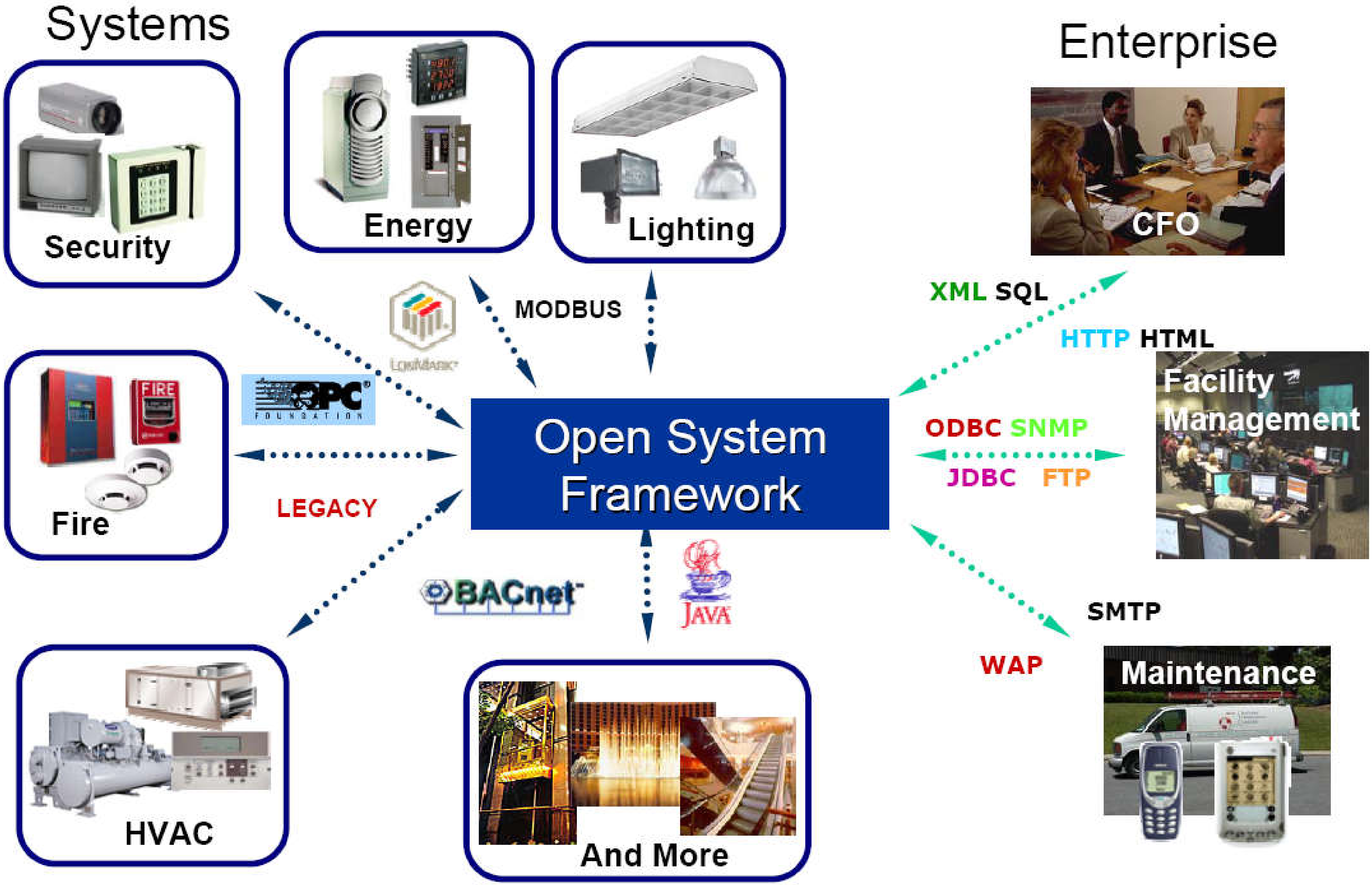
[Source: https://docplayer.net/5893734-Chapter-5-introduction-to-building-automation-system-bas.html]

Controls and information technology (IT) integration hierarchy

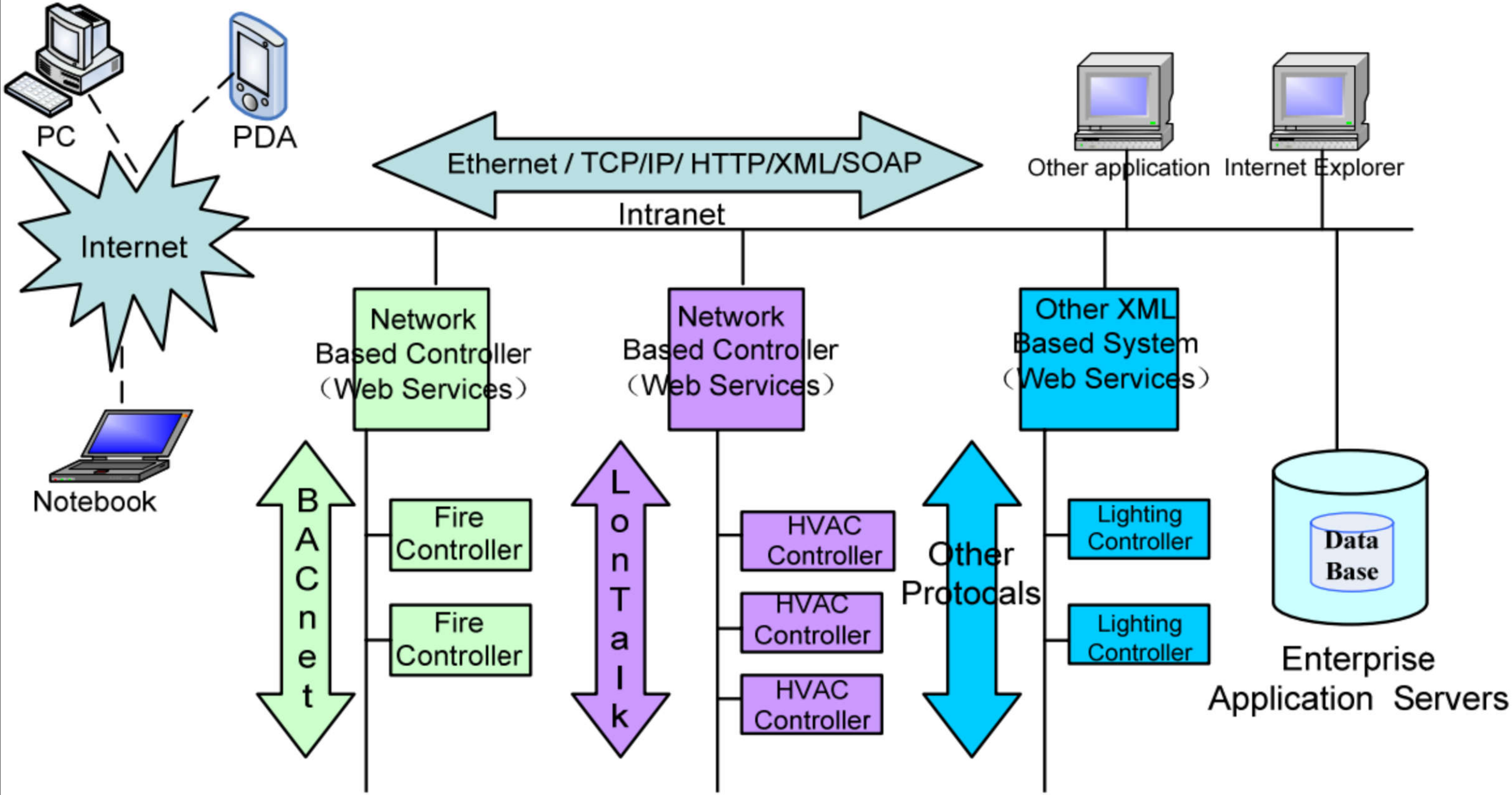


(Source: CIBSE, 2008. *Building Control Systems, CIBSE Guide H*, 2nd edition, Chartered Institution of Building Services Engineers (CIBSE), London.)

Integration of building automation and enterprise information systems



Integration between BASs and enterprise applications based on Web Services

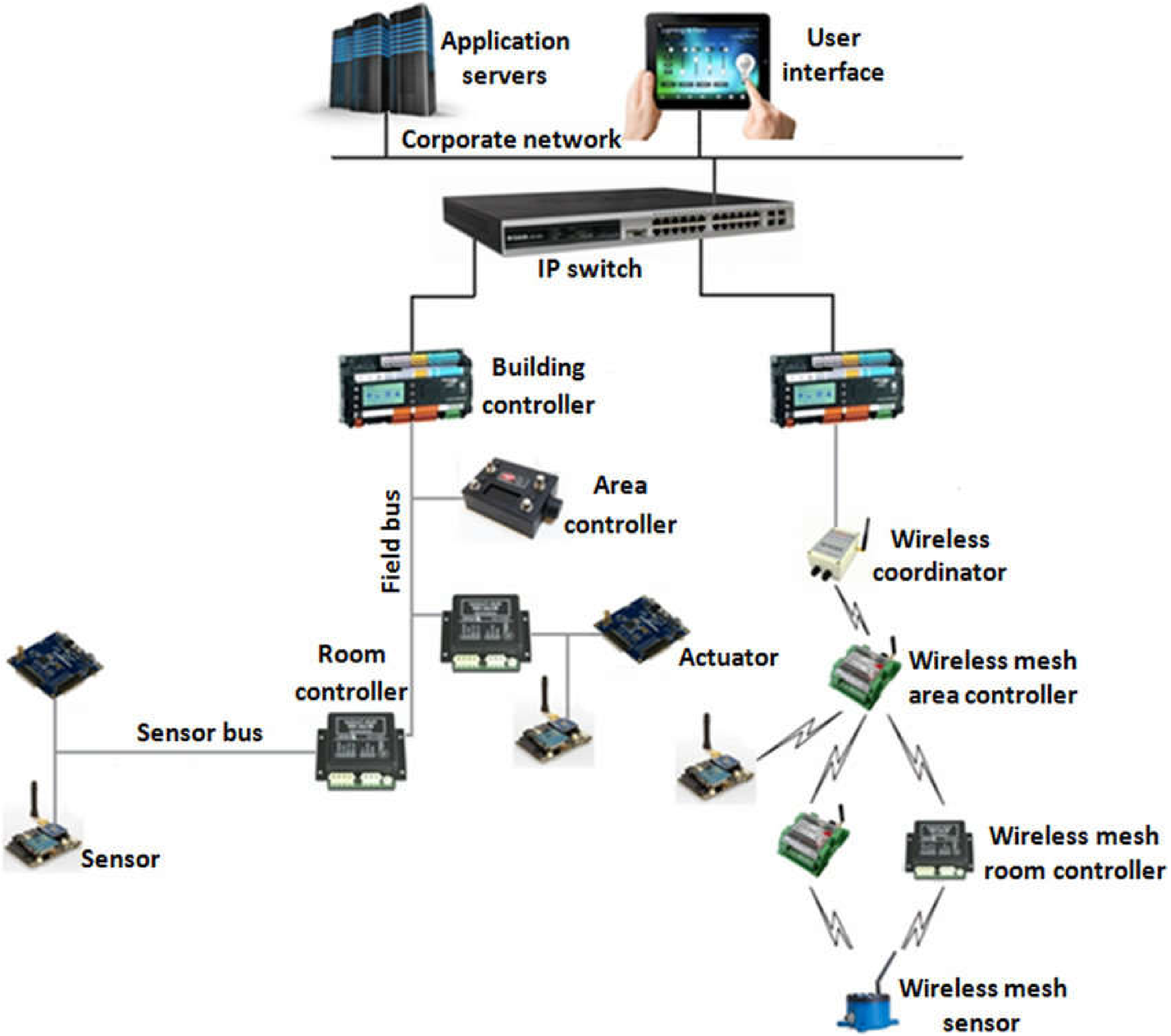


TCP = Transmission Control Protocol
IP = Internet Protocol
HTTP = HyperText Transfer Protocol

XML = Extensible Markup Language
SOAP = Simple Object Access Protocol

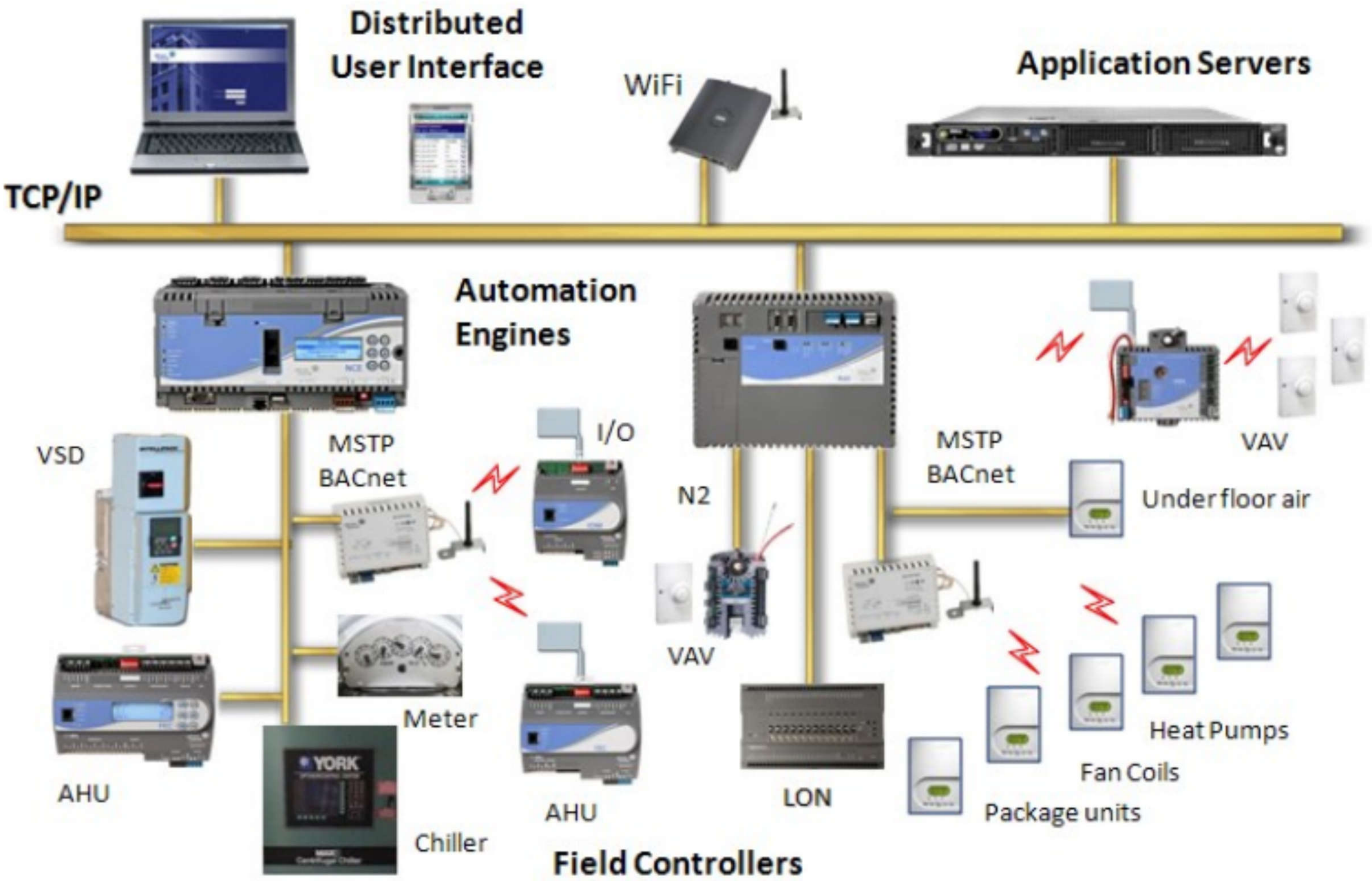
(Source: Bai J., Hao Y. & Miao G., 2011. Integrating Building Automation Systems based on Web Services, *Journal of Software*, 6 (11) 2209-2216. http://dx.doi.org/10.4304/jsw.6.11.2209-2216)

Wired and wireless topological hierarchy of BAS



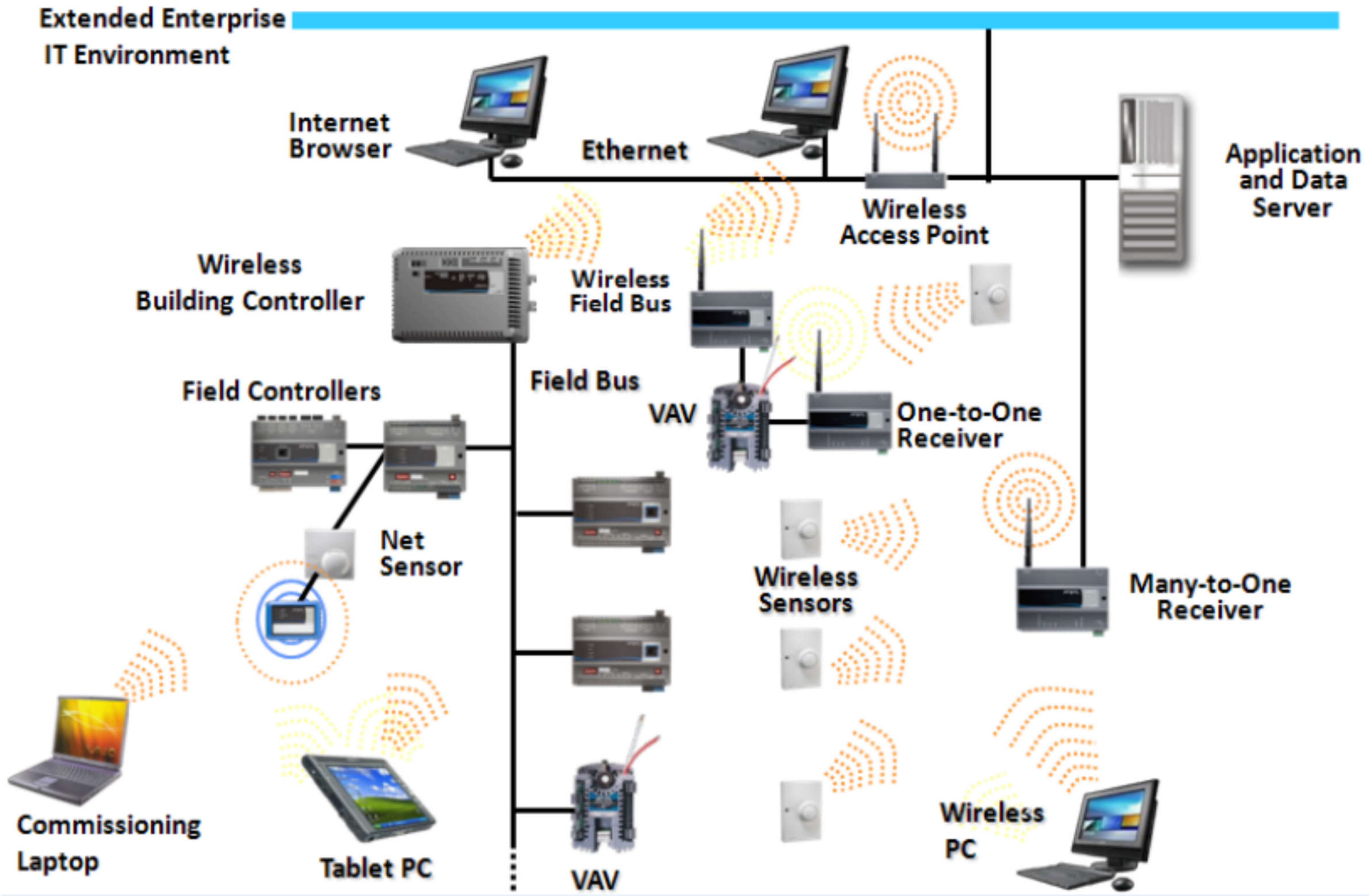
(Source: Maatoug A., Belalem G. & Mahmoudi S., 2019. Fog computing framework for location-based energy management in smart buildings, Multiagent and Grid Systems – An International Journal, 15: 39-56. https://doi.org/10.3233/MGS-190301)

An example of wireless network BAS architecture



[Source: https://docplayer.net/5893734-Chapter-5-introduction-to-building-automation-system-bas.html]

Integration of BAS wireless network and enterprise IT environment

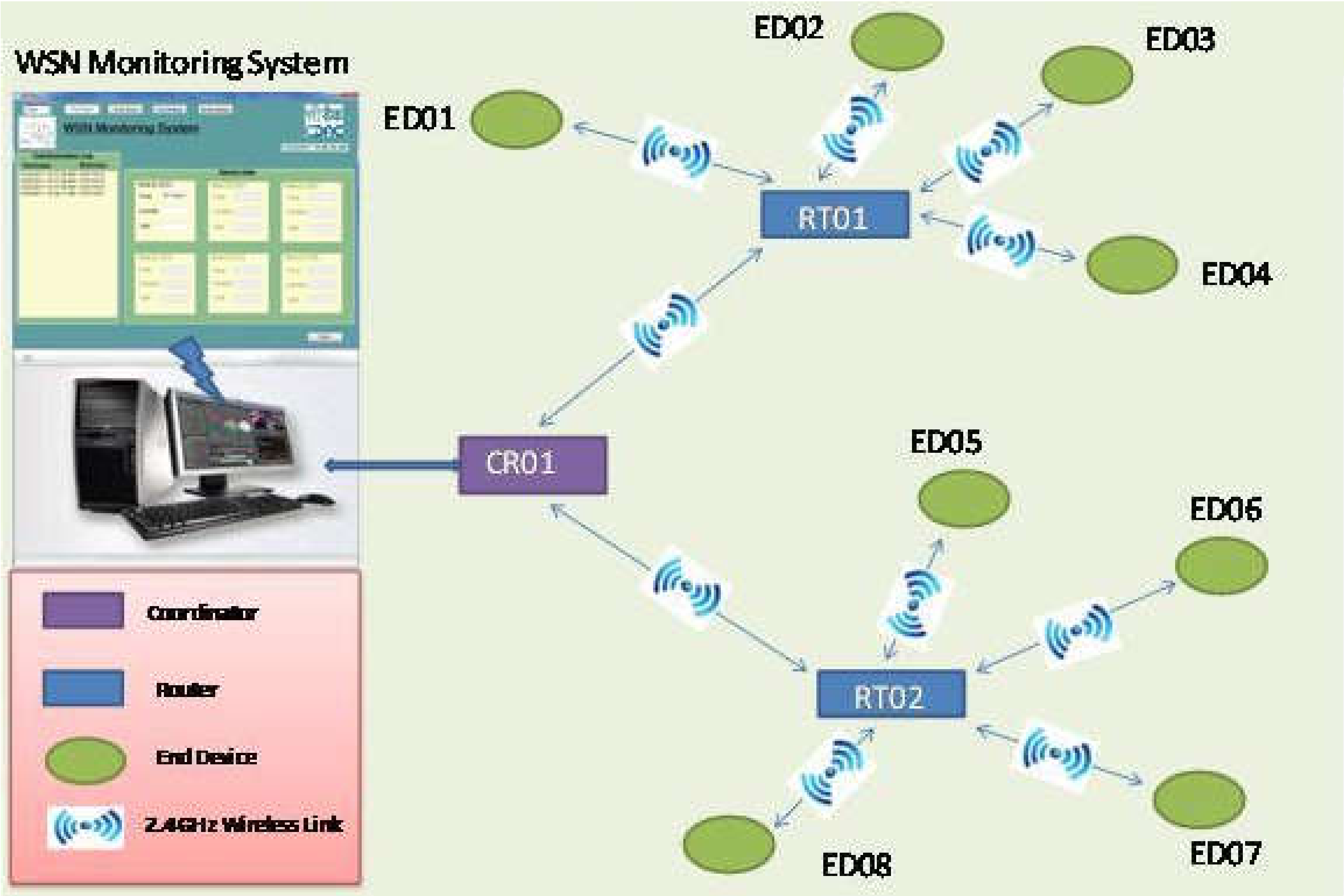


[Source: https://docplayer.net/5893734-Chapter-5-introduction-to-building-automation-system-bas.html]

Networking

- BAS with wireless sensor networks (WSN)
  - Consist of small sensor nodes that sense the environment, perform computations, and communicate with other nodes using the onboard radio module
  - Sensor nodes transport the measured data to a base station using multi-hop communication
  - The size of sensor nodes is close to a matchbox
  - Wiring is avoided and both installation & operational costs significantly reduced

Basic concept of wireless sensor network (WSN)



(Source: https://wirelessmeshsensornetworks.wordpress.com/2014/03/01/introduction-to-wireless-sensor-networks-and-its-applications/)

Networking

- Advantages of wireless networks for BAS
  - Lower installation & maintenance costs
  - Greater flexibility & scalability (no wiring is needed)
  - Easier integration with existing infrastructure
  - Support the deployment of more sensors & actuators, which can provide more granular and accurate data for BAS optimization & automation
  - Enable BAS to communicate and collaborate with other wireless devices (e.g. smartphones, tablets, wearables) to provide personalized and interactive services for building occupants

Further reading

- All about Building Automation System (BAS) https://www.adftech.com.my/wp-content/uploads/2019/08/E-Book-1.-All-About-Building-Automation-System.pdf
- Building automation - Wikipedia https://en.wikipedia.org/wiki/Building_automation
- Domingues P., Carreira P., Vieira R. & Kastner W., 2016. Building automation systems: Concepts and technology review, *Computer Standards and Interfaces*, 45: 1-12. http://dx.doi.org/10.1016/j.csi.2015.11.005
- Ultimate Guide to Smart Building Automation https://www.workero.com/smart-building-automation-guide/