MEBS6005 Building Automation Systems

http://ibse.hk/MEBS6005/

Introduction

建築自動化系統

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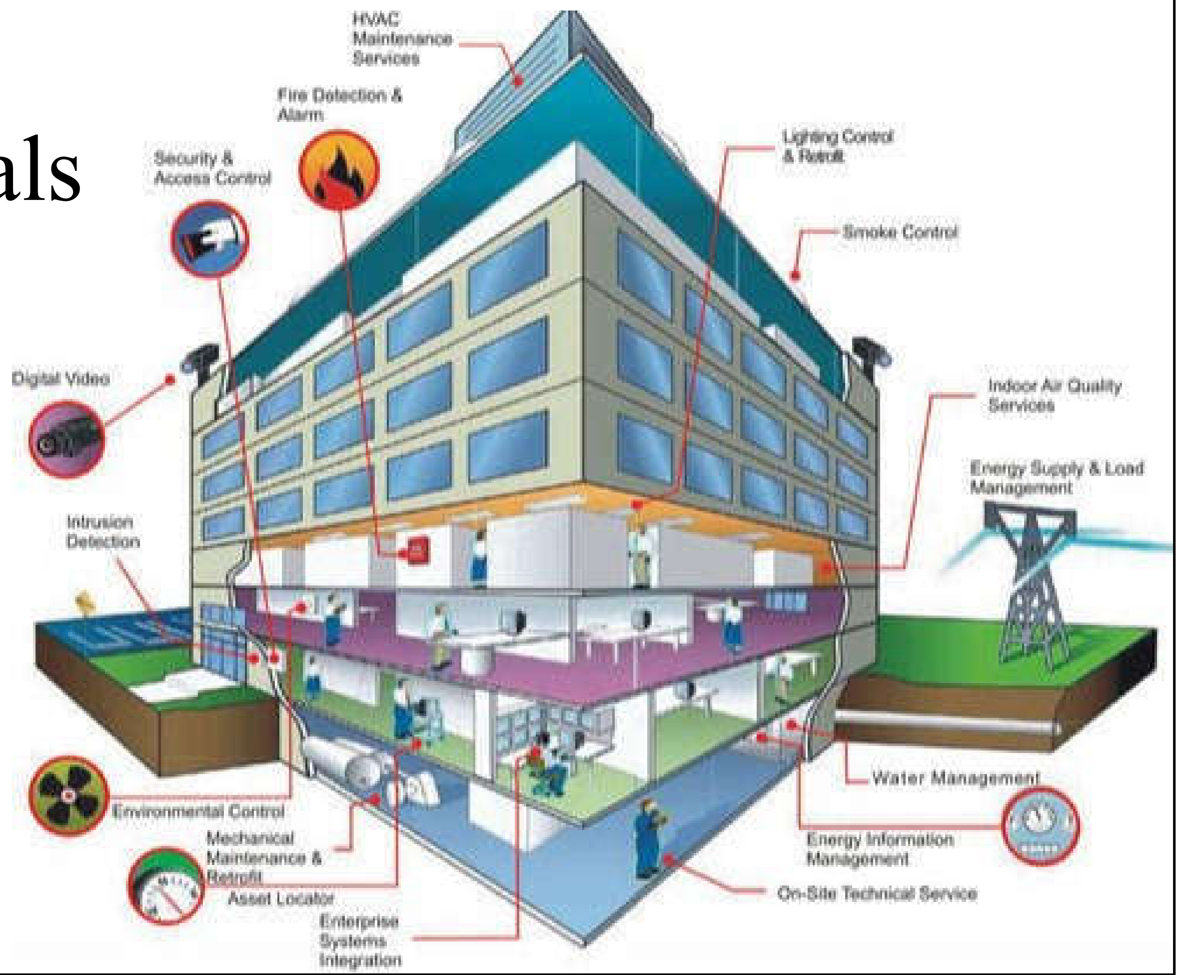
About the Lecturer

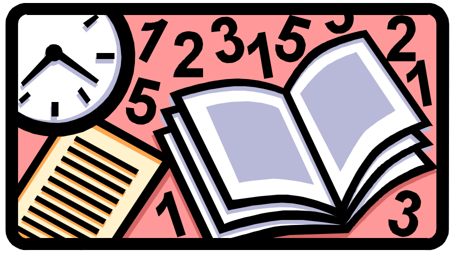
- ***Ir Dr. Sam C. M. Hui*** *許俊民 博士 工程師* http://ibse.hk/cmhui
  - Adjunct Assistant Professor 客席助理教授, HKU Dept of Mech Engg
  - PhD, BEng(Hons), CEng, CEM, BEMP, HBDP, MASHRAE, MCIBSE, MHKIE, MIESNA, LifeMAEE, AssocAIA
    - CEng = Chartered Engineer
    - CEM = Certified Energy Manager
    - BEMP = Building Energy Modeling Professional
    - HBDP = High-performance Building Design Professional
    - LifeMAEE = Life Member, Association of Energy Engineers
    - AssocAIA = Associate Member, American Institute of Architects
  - ASHRAE Distinguished Lecturer (2009-2011)
  - President, ASHRAE Hong Kong Chapter (2006-2007)

Contents

- Course background
- Basic concepts
- Control fundamentals
- Control methods
- System design

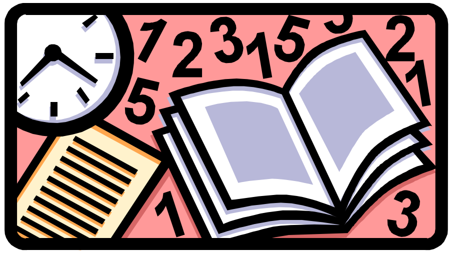


Course background



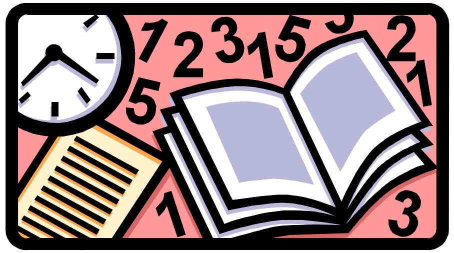
- MEBS6005 Building Automation Systems
  - Educational Objectives:
    - To introduce students to the principles of design and operation of building automation systems for integrated control of building services systems in modern buildings
    - To enable students to configure, specify and select appropriate building automation systems for compliance with specified requirements

Course background

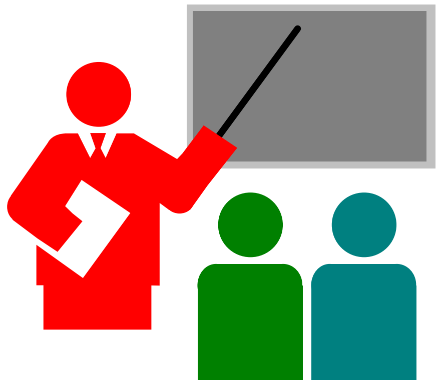


- MEBS6005 Building Automation Systems
  - Learning Outcomes:
    - Describe the basic concepts and principles of building automation systems
    - Apply practical knowledge to design and select appropriate building automation systems for integrated control of building services systems in modern buildings
    - Explain the specified requirements and considerations for design and operation of building automation systems

Course background

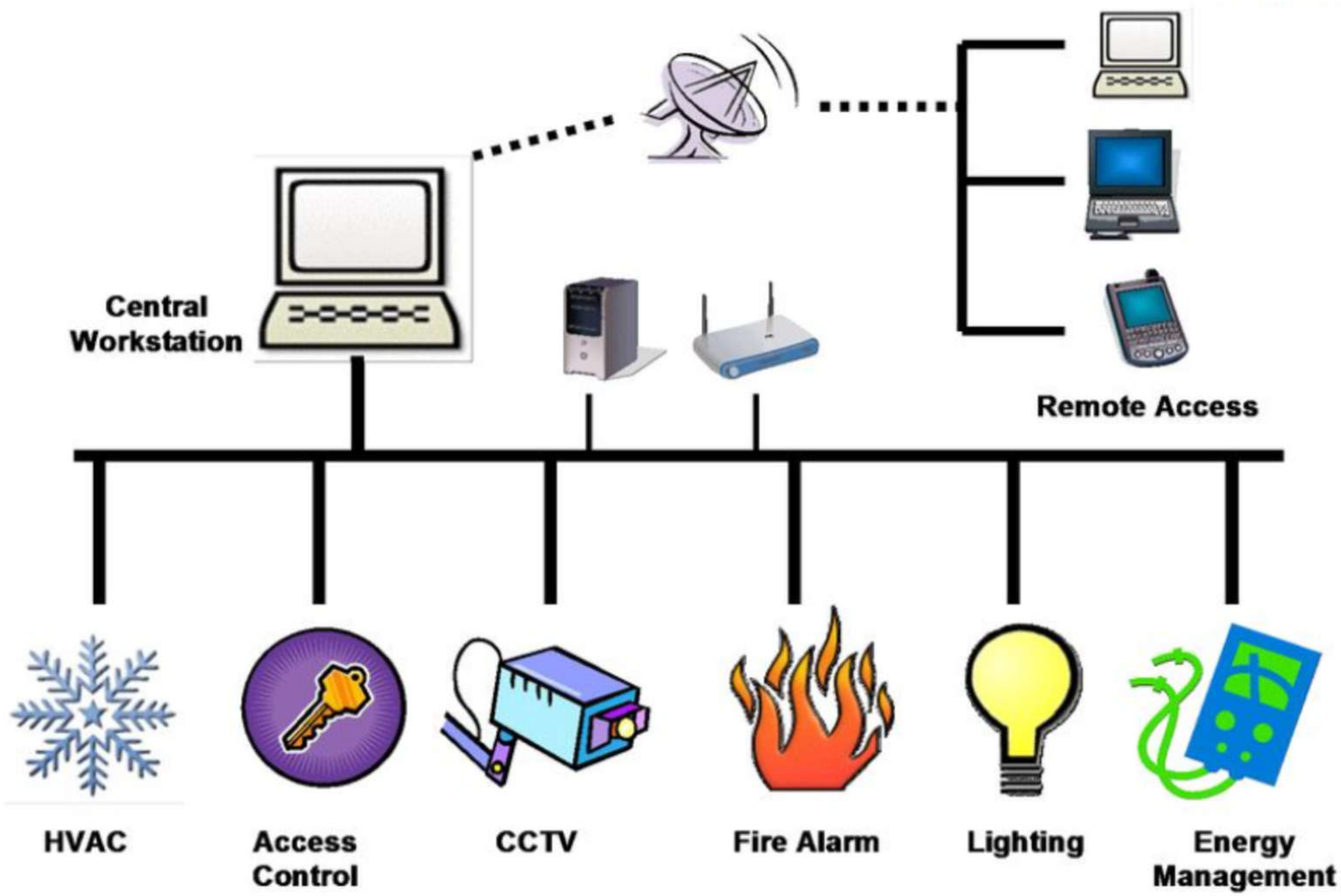


- Prerequisite:
  - Nil.
- Assessment Methods:
  - Examination (60%) – 2 hours written
  - Continuous Assessment (40%) – 2 assignments
- Course Website:
  - http://ibse.hk/MEBS6005/

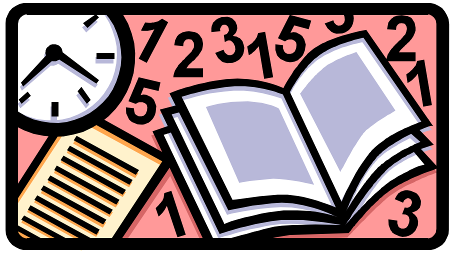


Study topics of MEBS6005 Building Automation Systems

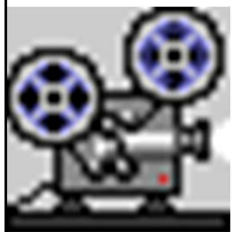
1. Introduction	7. Control of HVAC Systems
2. Hardware Components	8. Lighting Controls
3. System Architecture	9. Fire and Security Systems
4. Networking	10. Building Energy Management
5. Communication Protocols	11. Internet Technologies
6. Control Strategies	12. Intelligent and Smart Buildings



Course background



- Study methods
  - Lectures (core knowledge & discussions)
  - Further Readings (essential study information)
  - Videos (illustration & demonstration)
  - References (useful supporting information)
  - Web Links (related links & resources)
- Assignments
  - Practical skills & applications

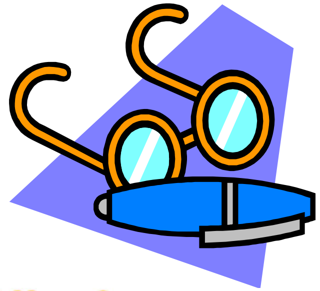


Basic concepts

- 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

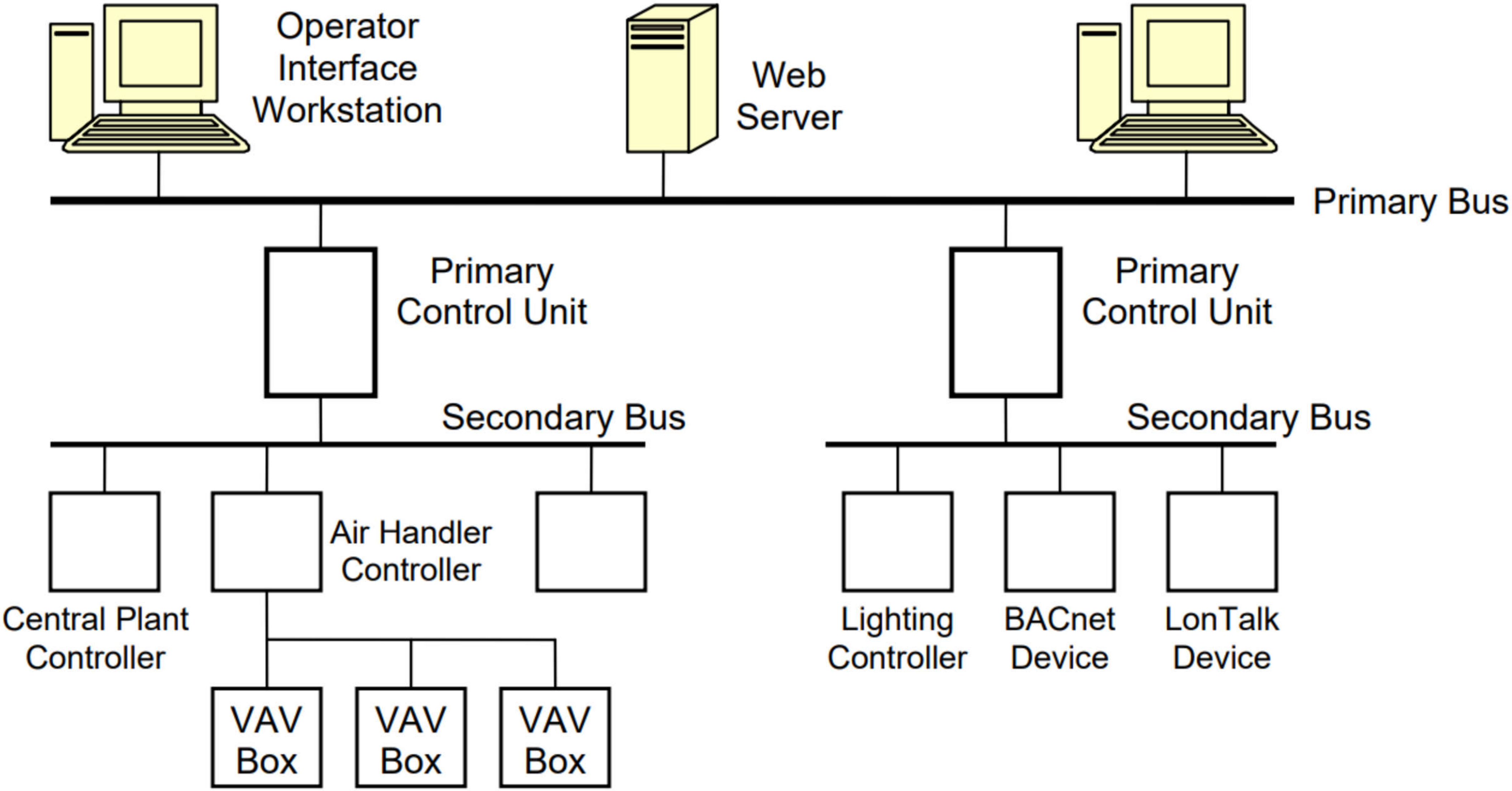
  - Converging these systems into a single information technology (IT)-managed network infrastructure creates a *smart/intelligent building*

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

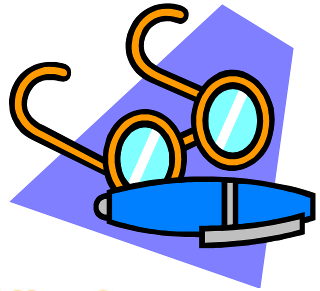
An example layout of a building automation system (BAS)



(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)

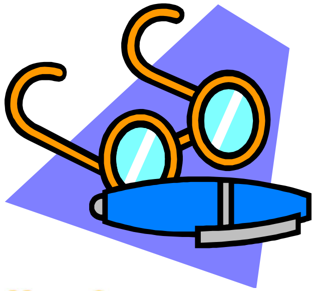
Basic concepts



- 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.

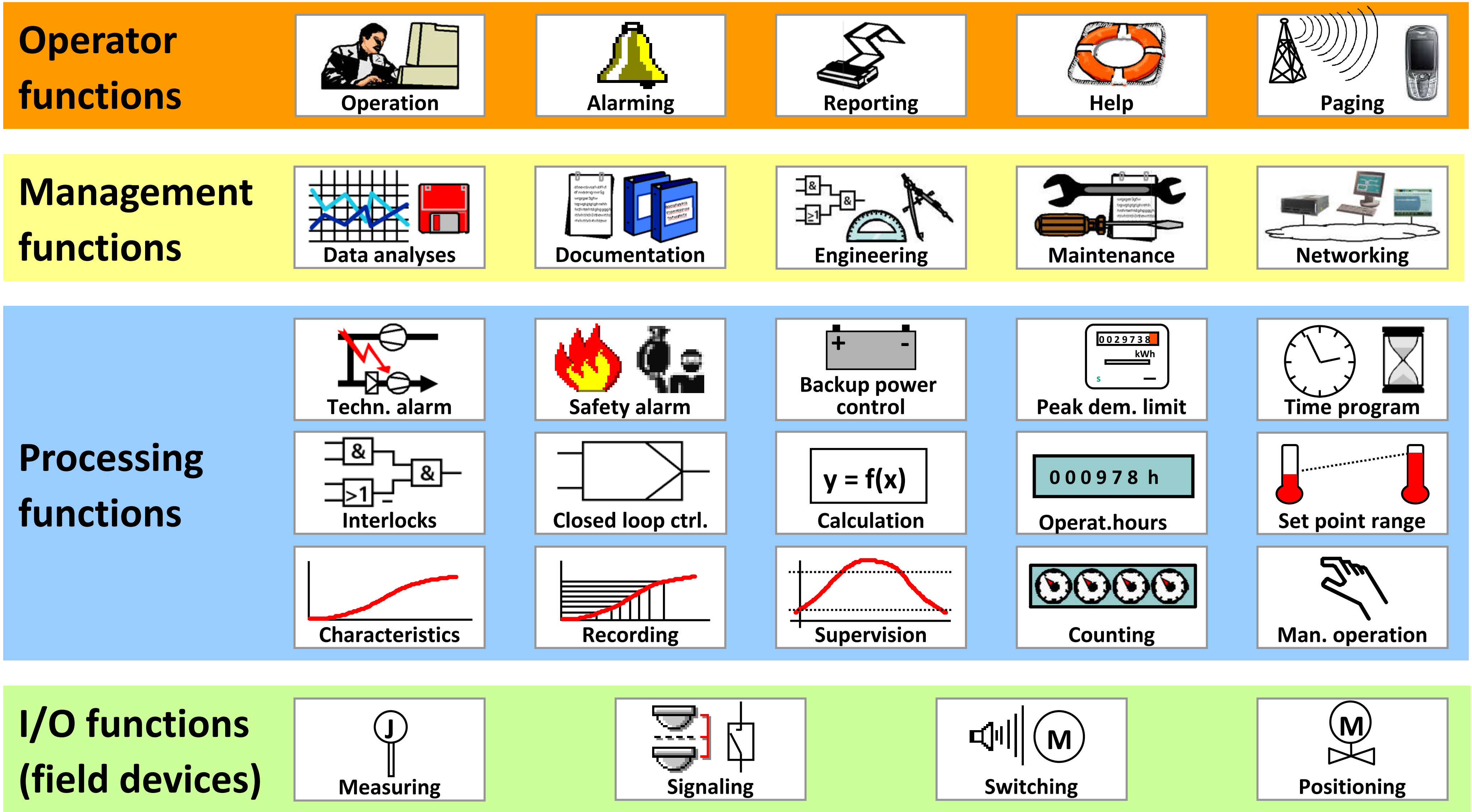
Basic concepts



- 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

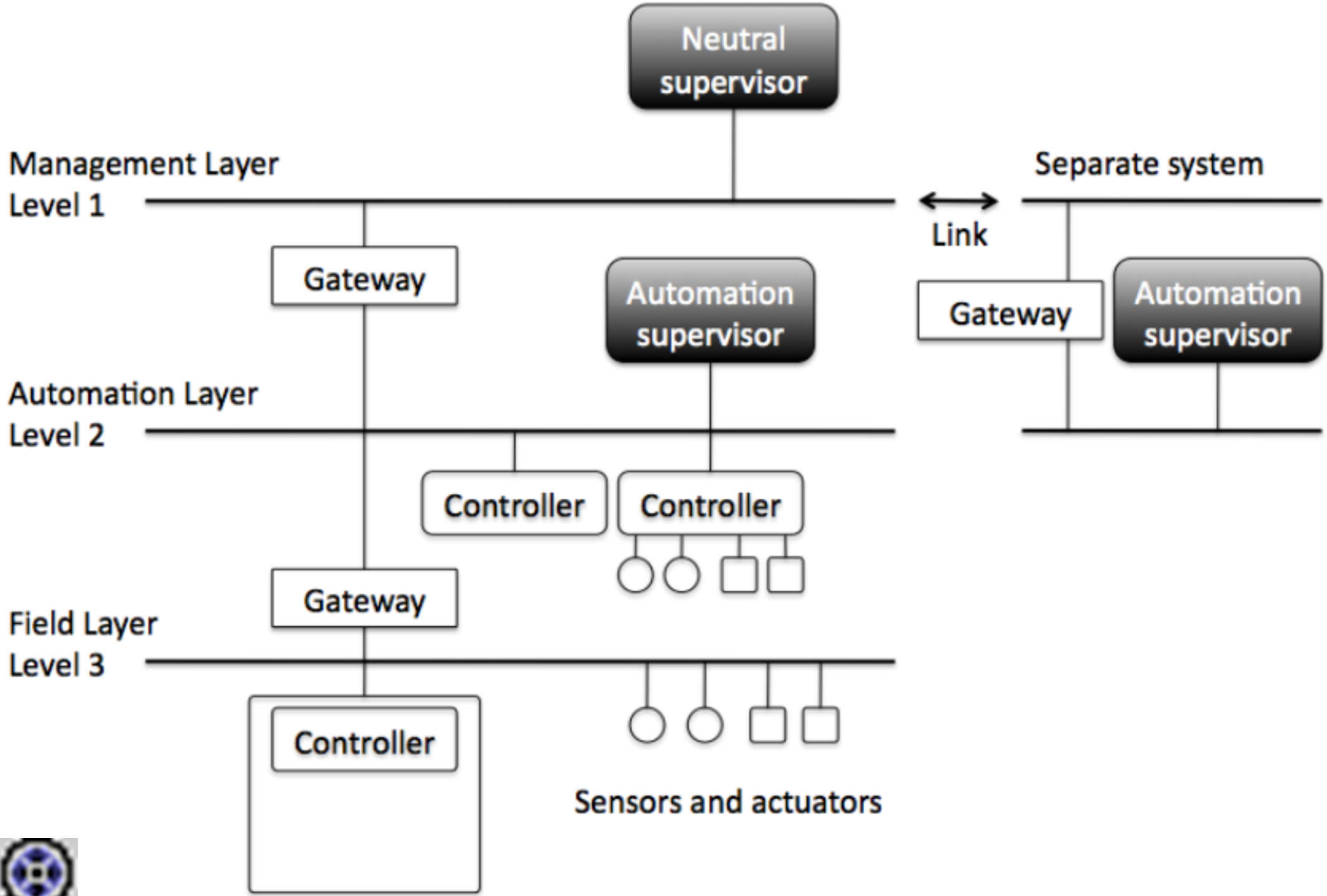
  - Management & analysis
    - Analyze & optimize data collected to provide real time feedback (e.g. trend logs) & documentation

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



[Source: Honeywell]

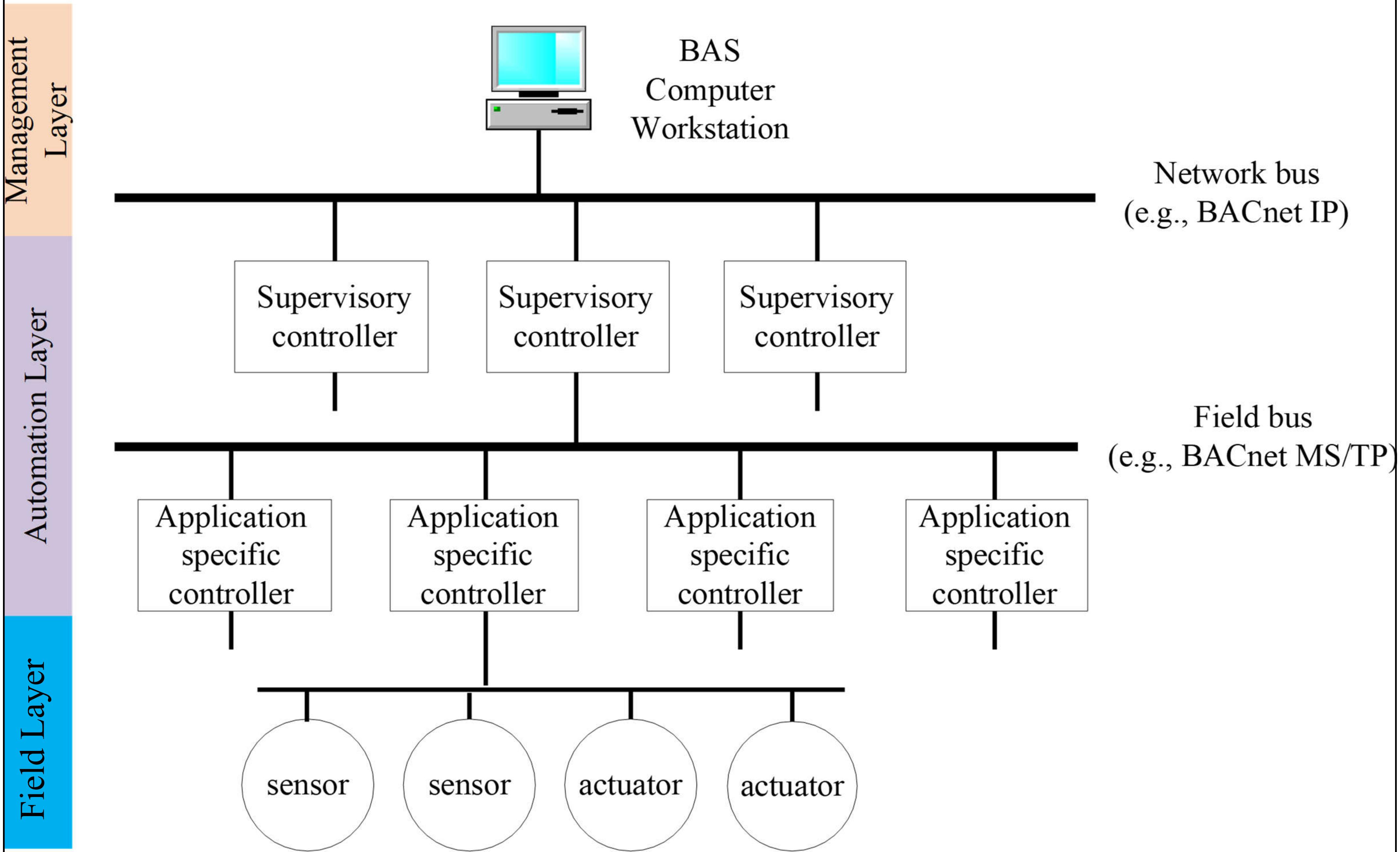
Three-layer building automation system (BAS) architecture



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)

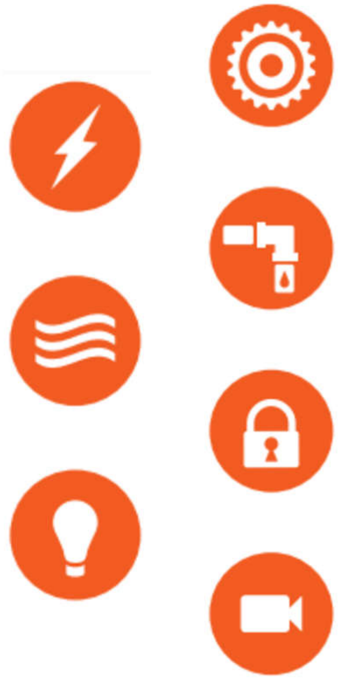
Example of three-layer building automation system (BAS) architecture



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)

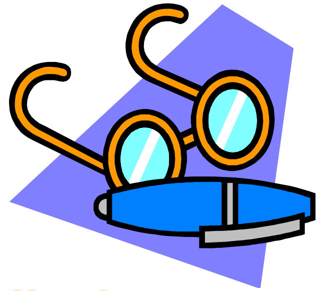
Most important one



Where building automation system (BAS) are used?

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

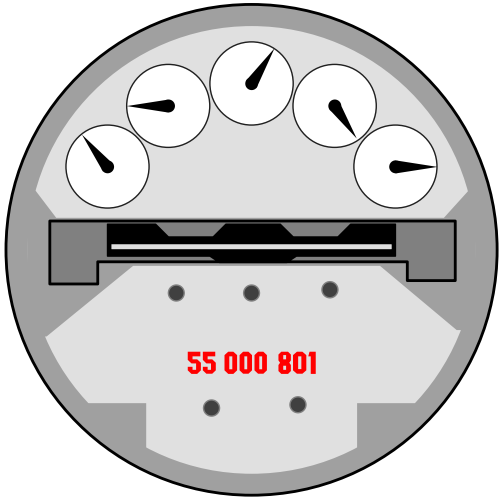
Basic concepts



- 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

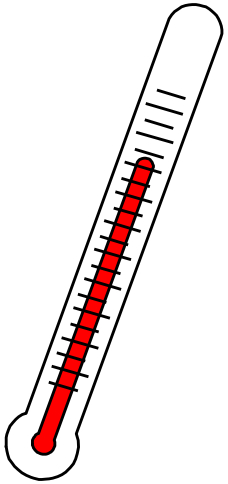
Lower energy cost



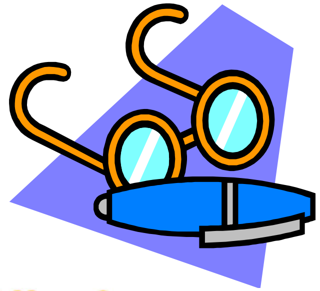
Lower operations cost

Increase flexibility

Ensure quality building environment



Basic concepts

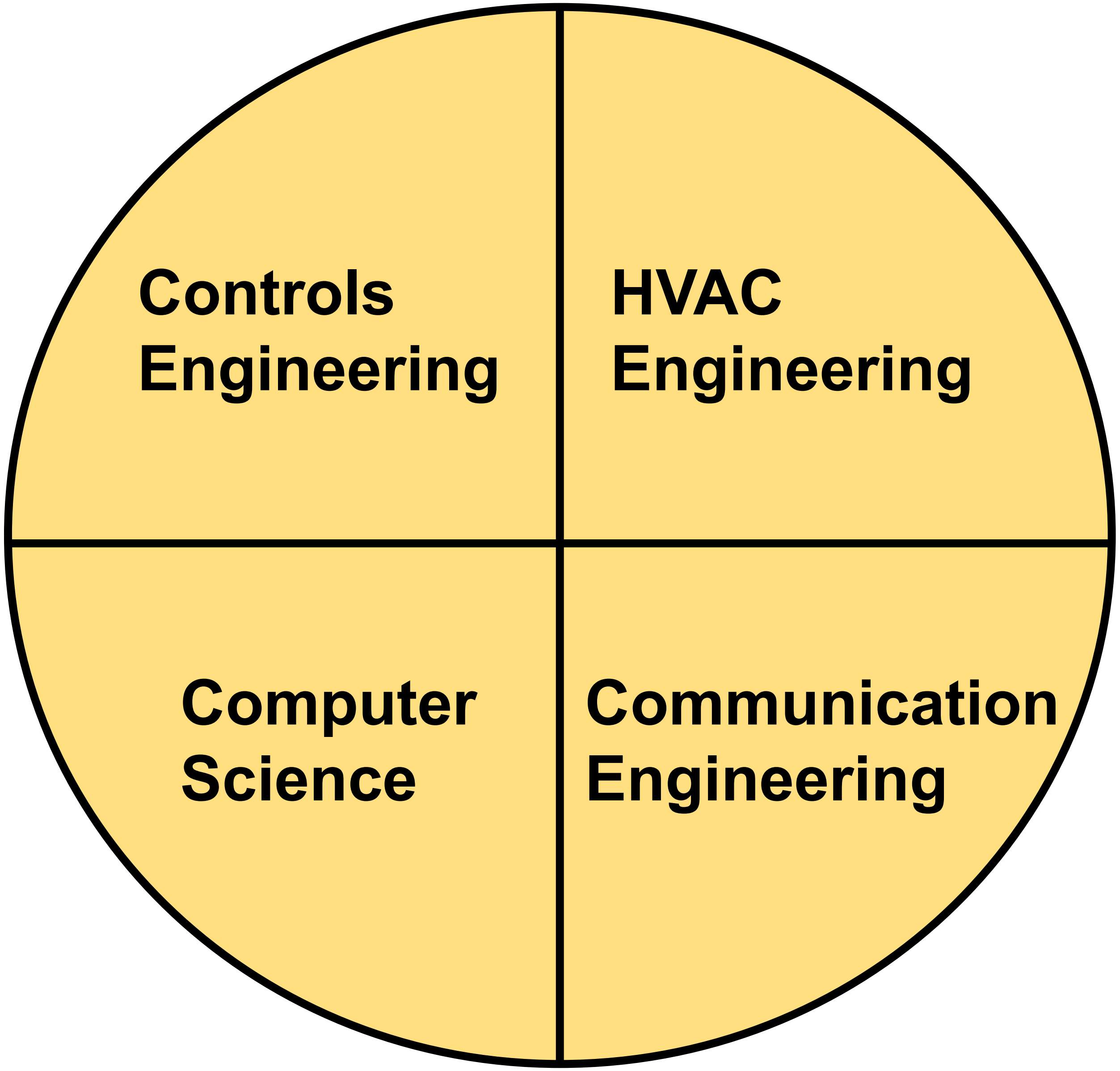


- Early development history

Influenced by computer & information technologies

  - 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

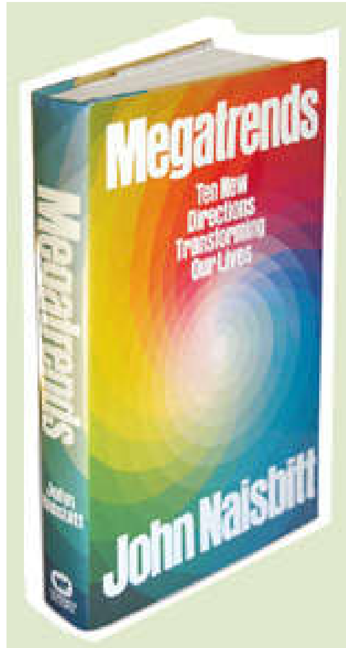
Nowadays, BAS/BMS involves knowledge of many disciplines.



Keyword: "Communicate"

Basic concepts

- "Computer technology is to the information age what mechanization was to the industrial revolution." -- *Megatrends* (1982) by John Naisbitt
- Recent trends of BAS
  - Conventional system (front end based)
    - Central computer + "dumb" field panels
  - Distributed intelligence BAS
    - Central computer + field panels (limited standalone)
  - Fully distributed BAS
    - Multifunction microprocessor close to the equipment (complete standalone)



Basic concepts

- The future of 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

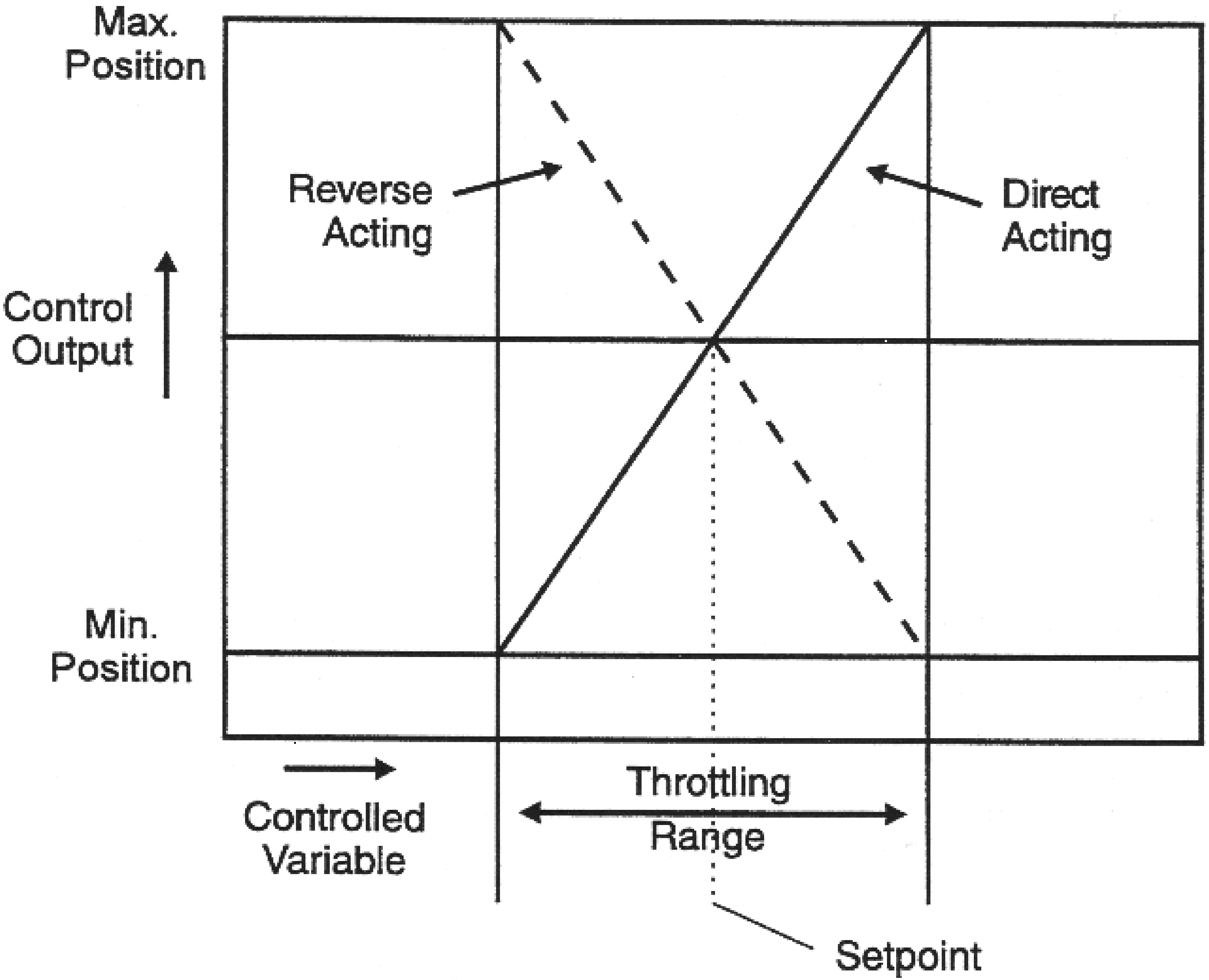
Control fundamentals

- 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*]

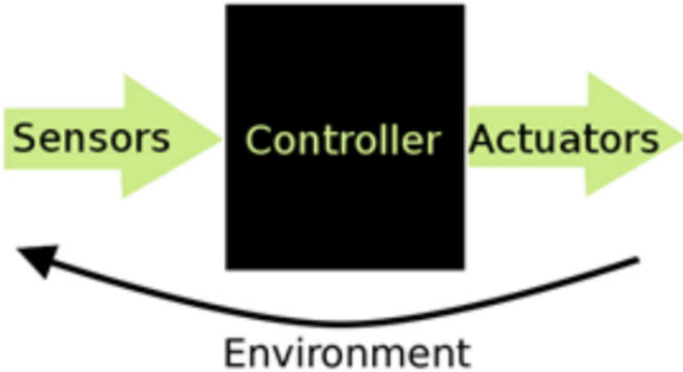
Control fundamentals

- 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

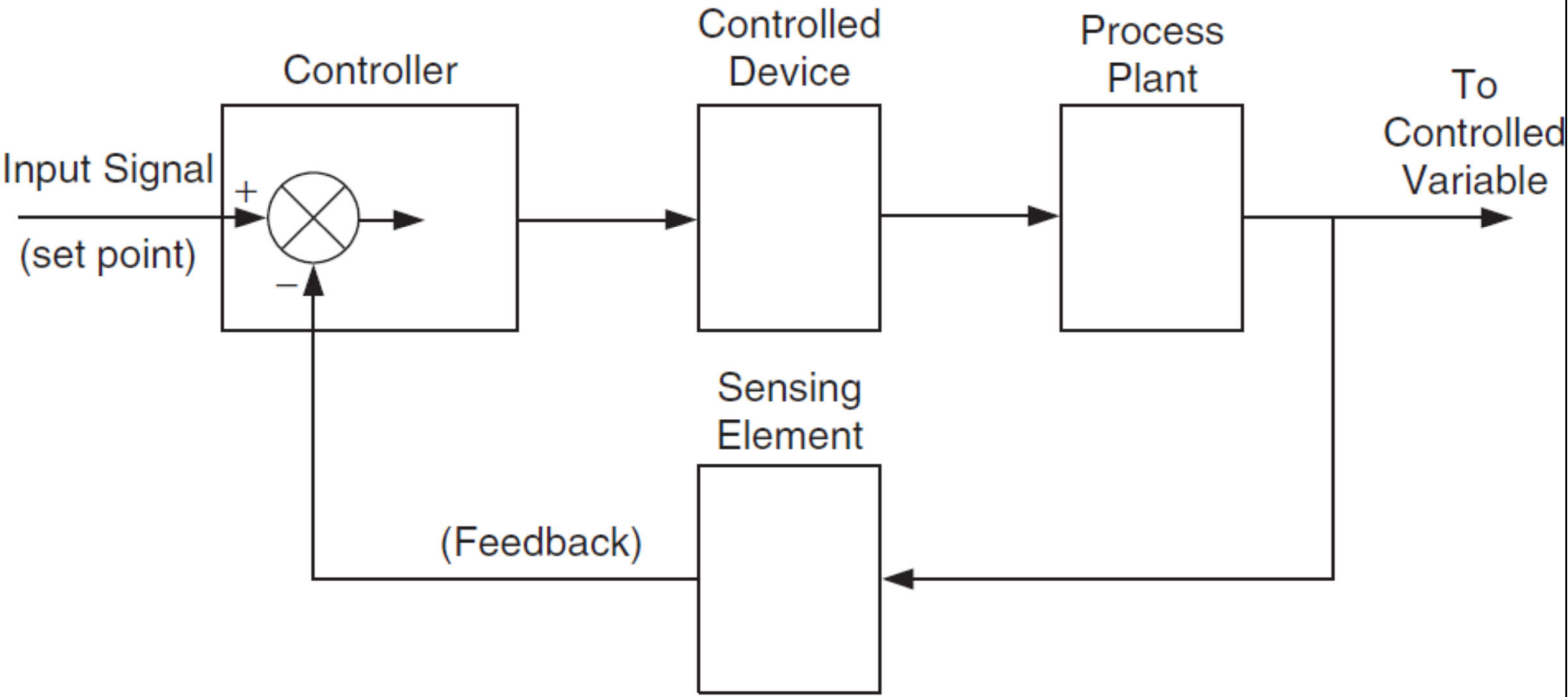
Video: Basics of Building Control System Part-1| Building Management System Training | BMS System (11:20) https://youtu.be/hqq3wlhPHXw

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)

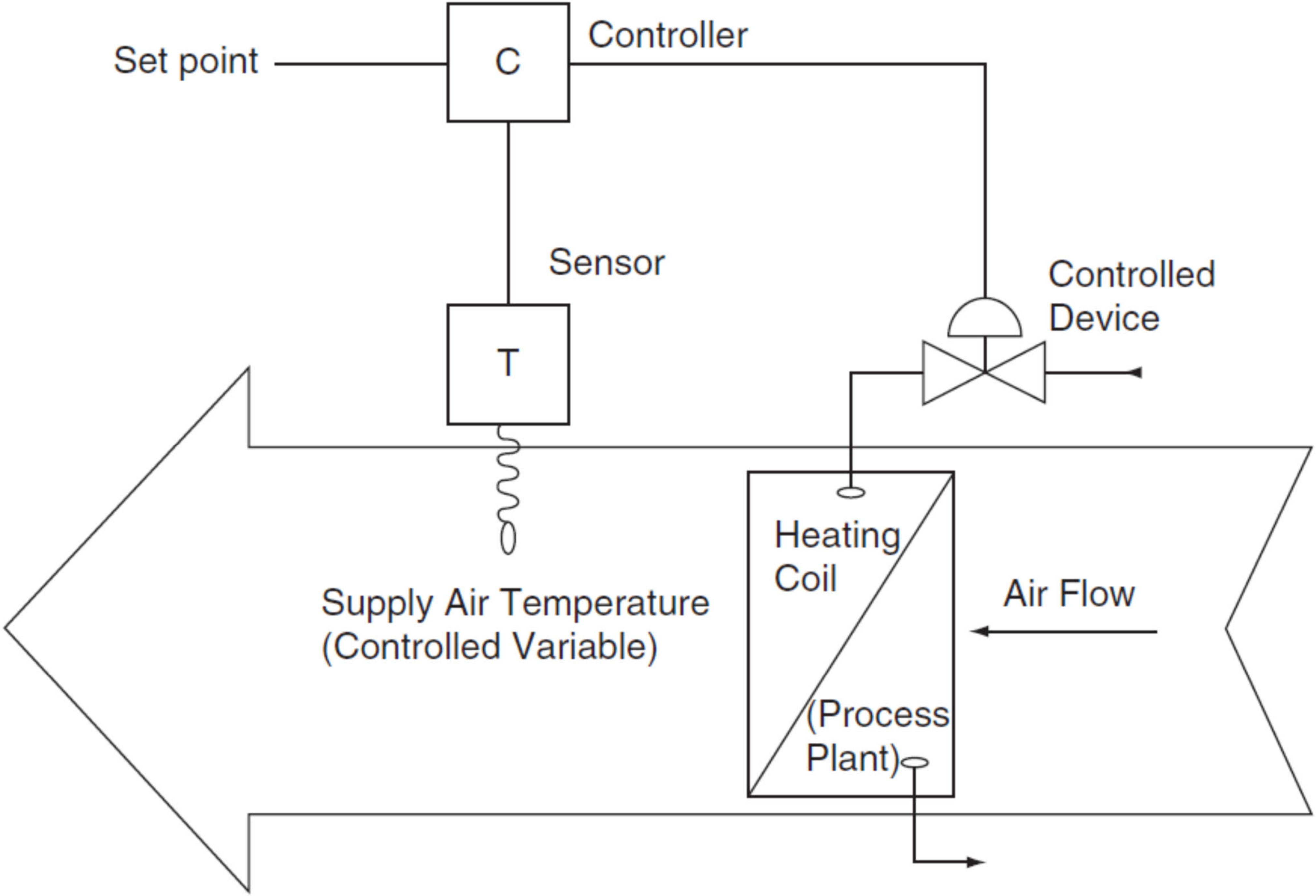


Basic elements of a feedback control loop



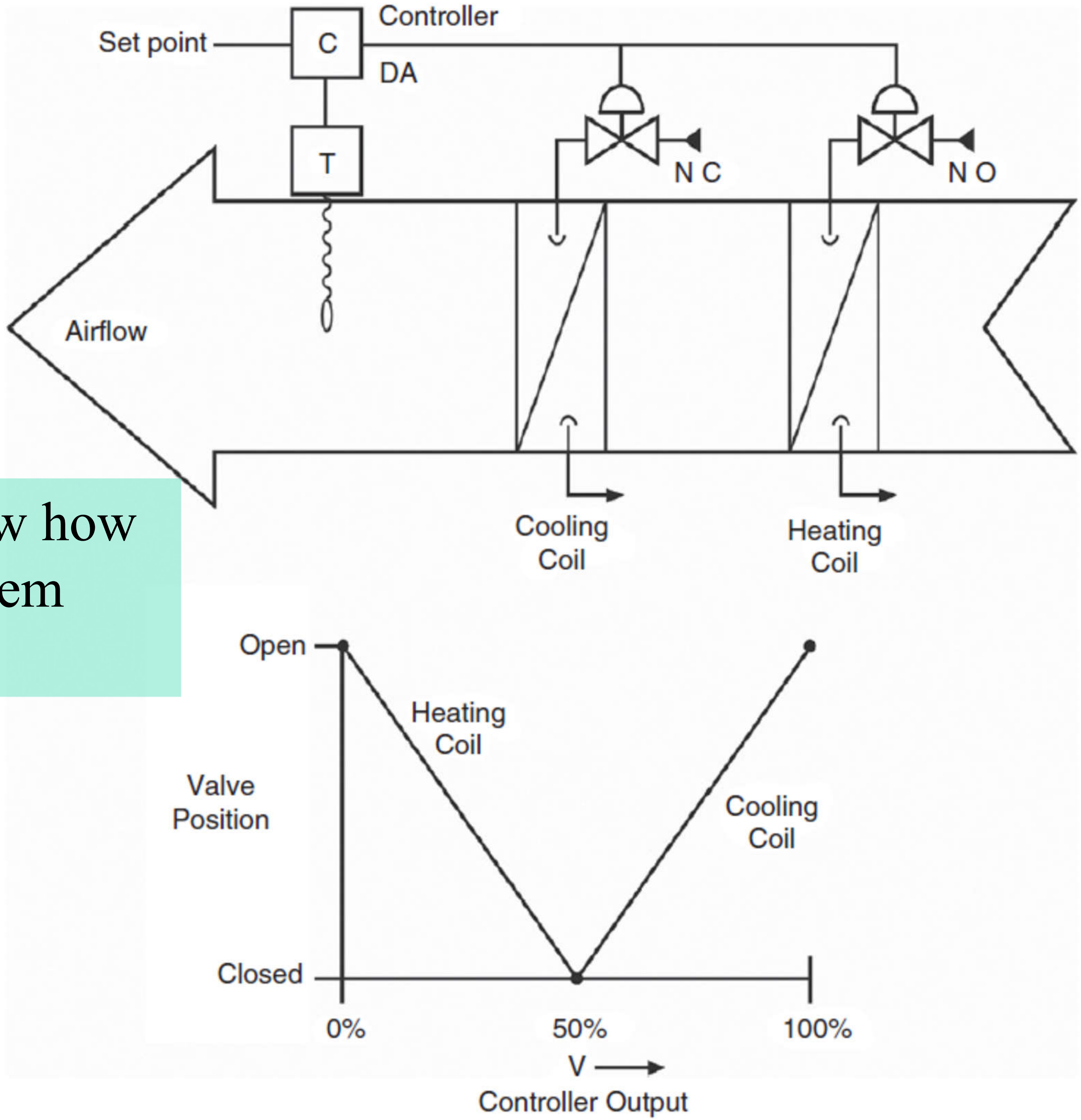
[Source: Montgomery, R. and McDowall, R., 2008. *Fundamentals of HVAC Control Systems*]

Simple heating system



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

Control of cooling and heating coils in HVAC systems



Do you know how to control them over a year?

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

Control system diagram

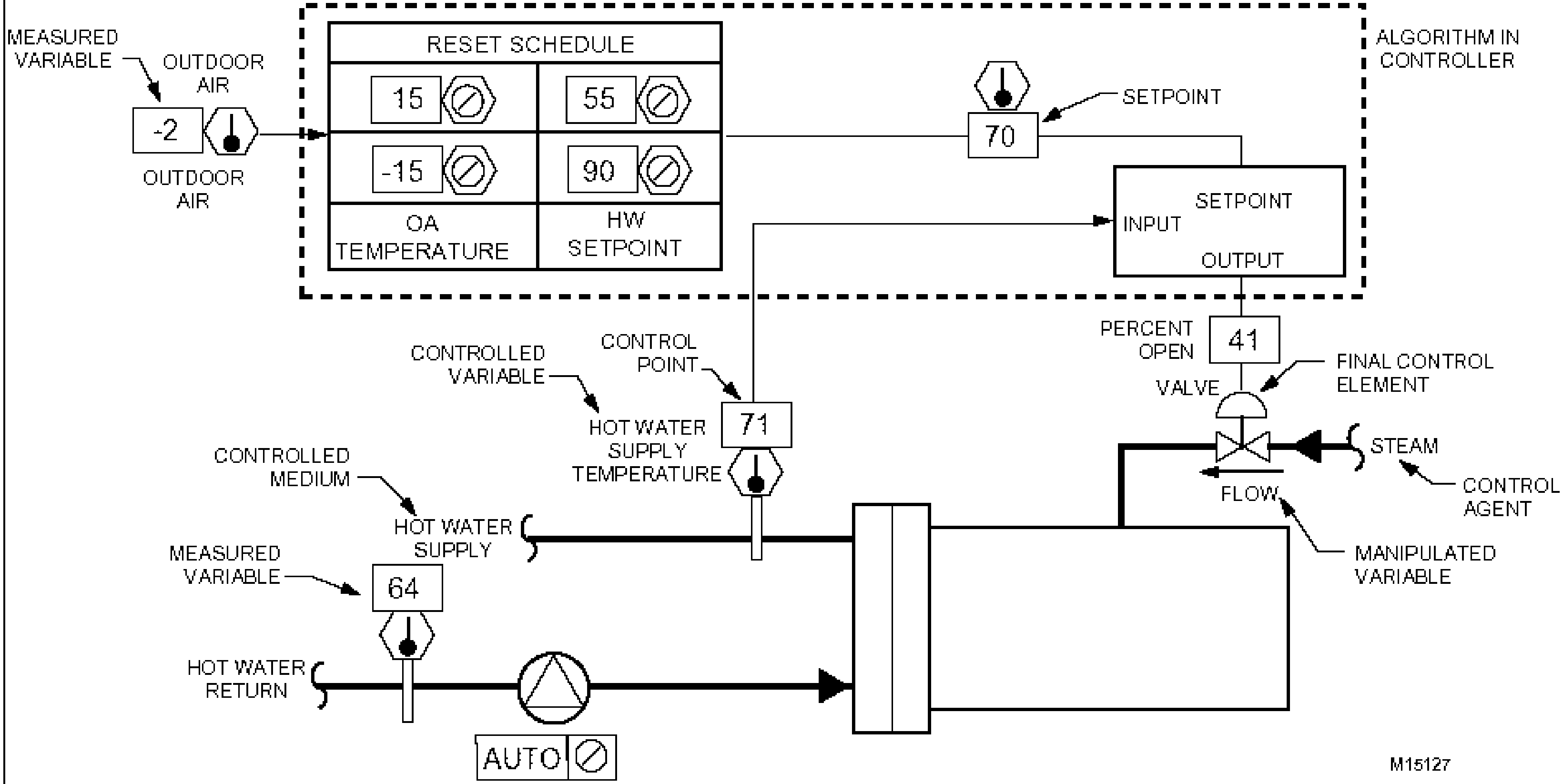


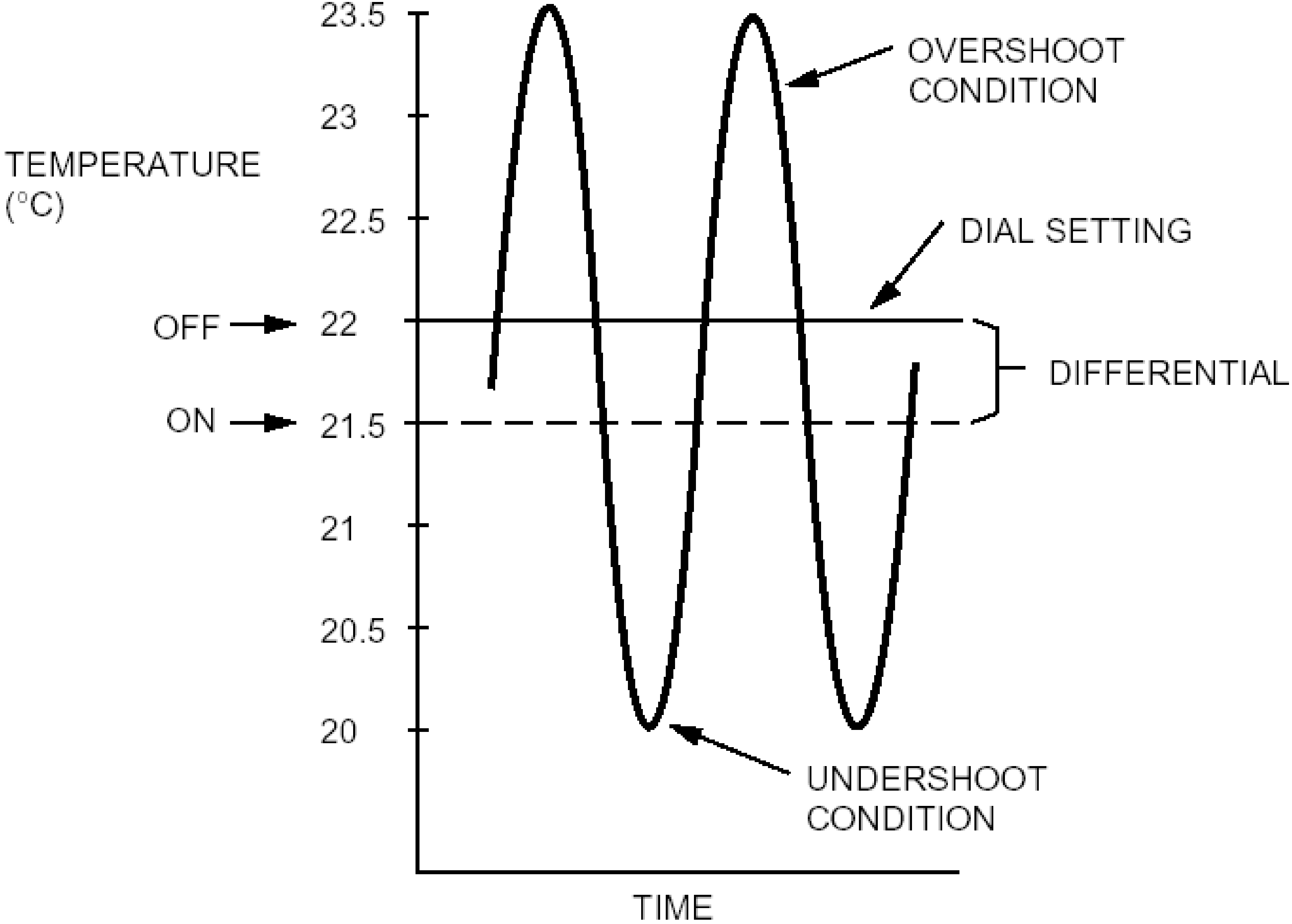
Fig. 1. Typical Control Loop.

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

Control fundamentals

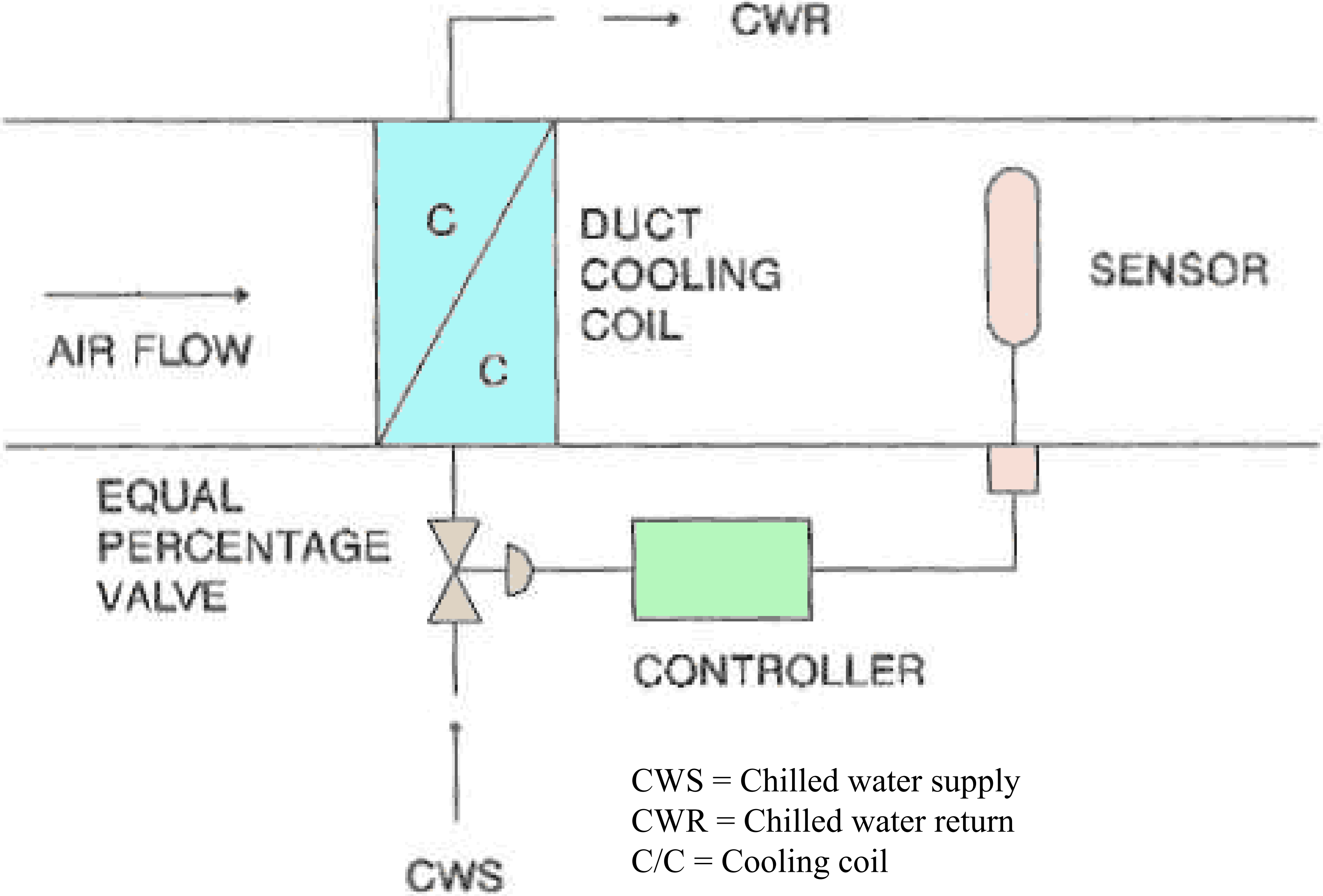
- Control modes
  - Two position (on/off) control
  - Proportional control
  - Integral control
  - Proportional + integral (PI) control
  - Proportional + integral + derivative (PID) control
- Technical terms
  - Set points, dead band, throttling range, offset, proportional band, integral time

Basic two-position (ON/OFF) control



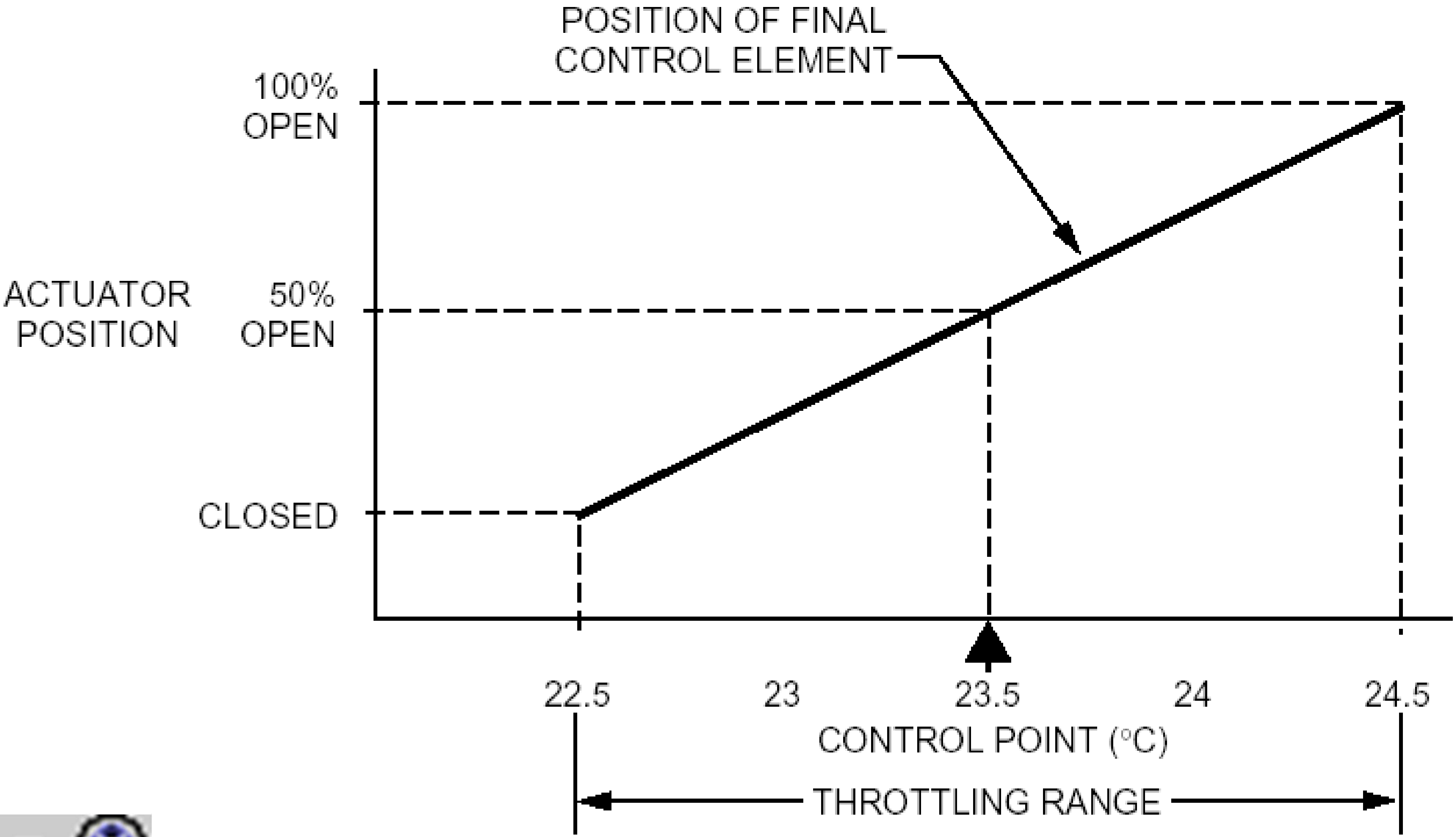
[Source: Honeywell, 1997. *Engineering Manual of Automatic Control for Commercial Buildings*]

Example: Discharge air control system



CWS = Chilled water supply
CWR = Chilled water return
C/C = Cooling coil

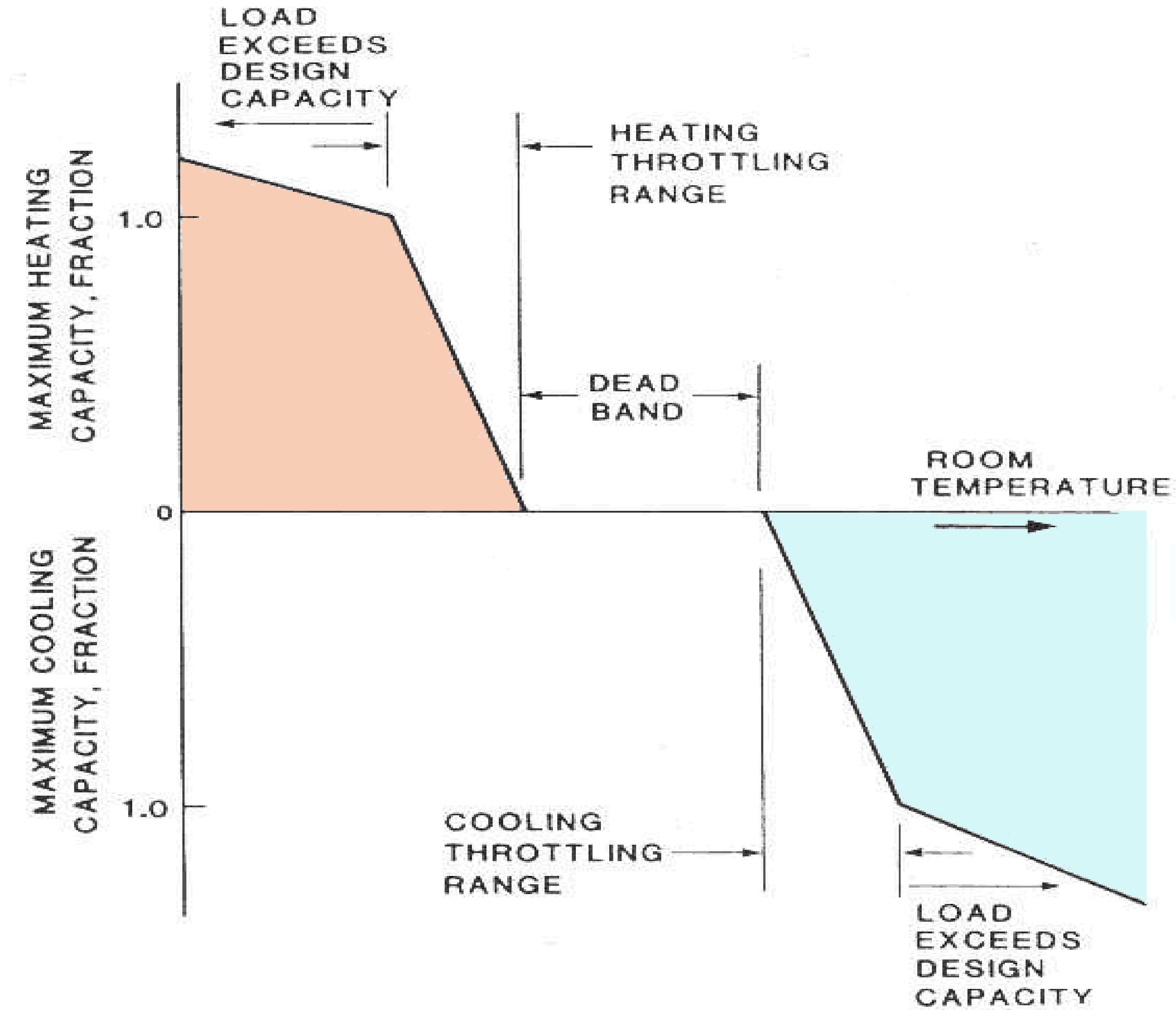
Actuator position and throttling range



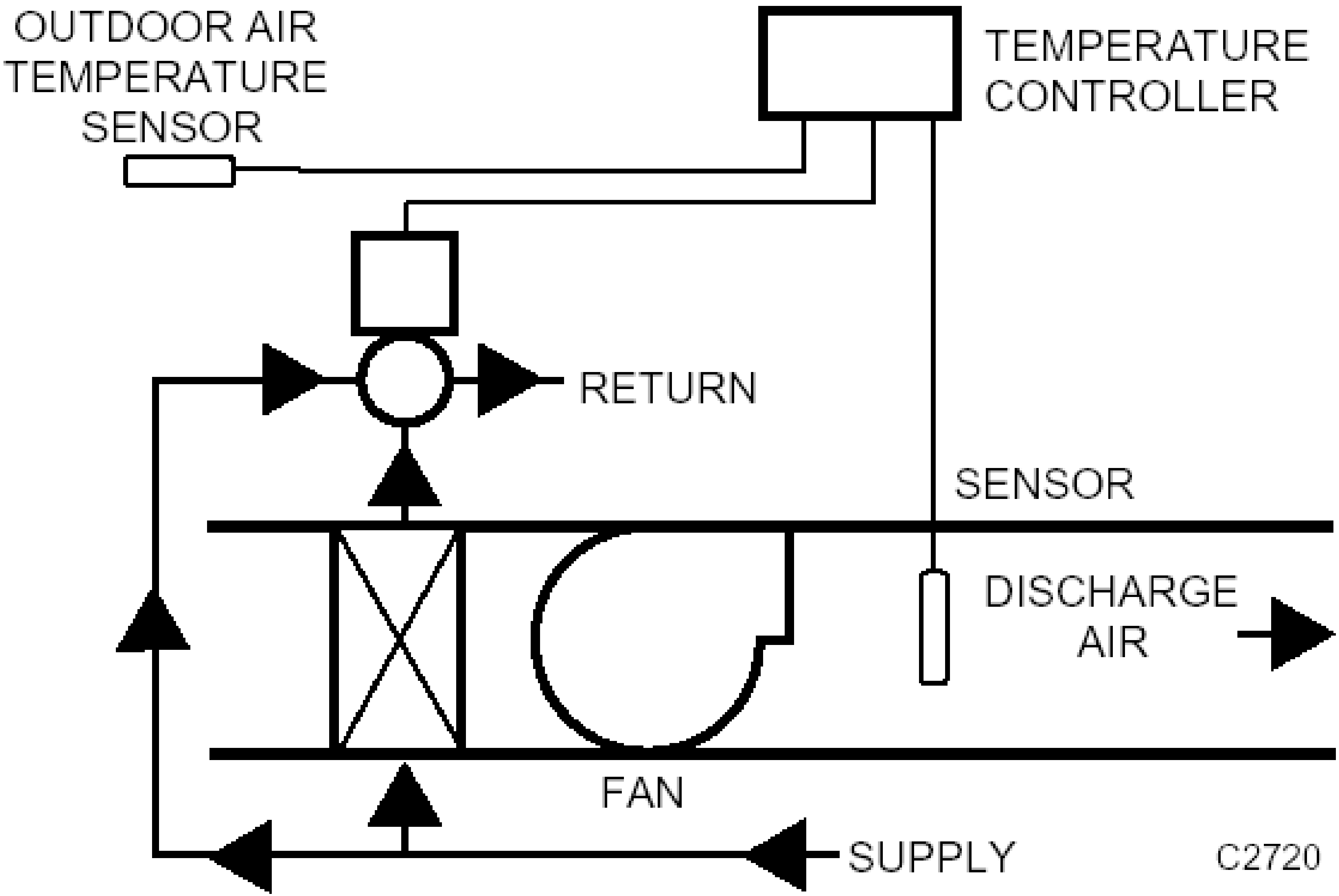
Video: Basics of Building Control System Part-2| Building Management System Training | BMS Training 2021 (9:46) https://youtu.be/jrwcZ0wTnJk

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

Thermostat model of proportional control with deadband and dual throttling range



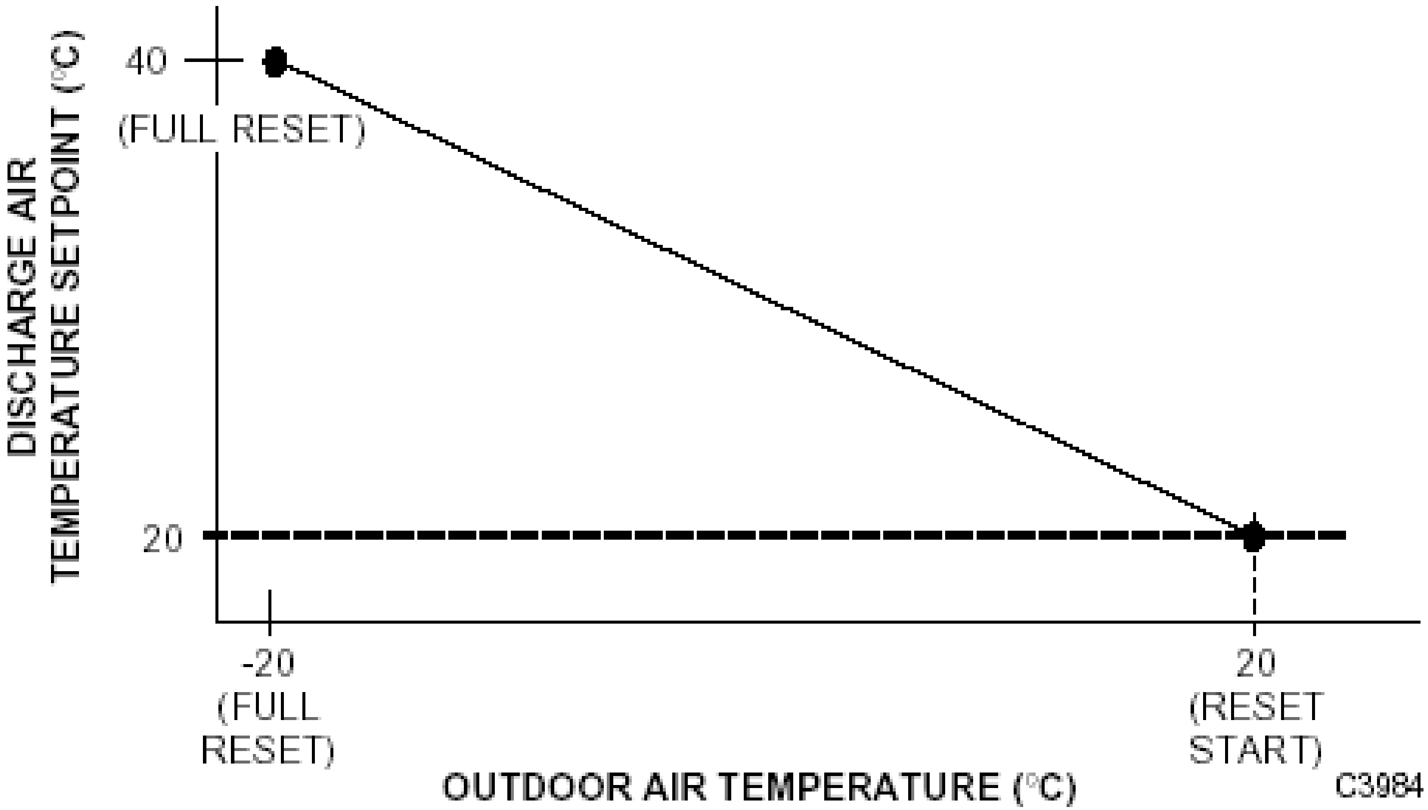
Discharge air control loop with reset



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

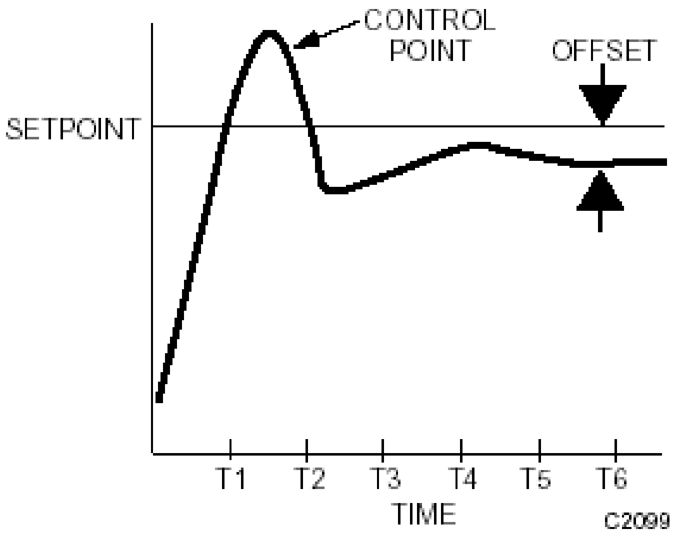
Typical reset schedule for discharge air control

Condition	Outdoor Air Temperature (°C)	Discharge Air Temperature (°C)
Outdoor design temperature	–20	40
Light load	20	20

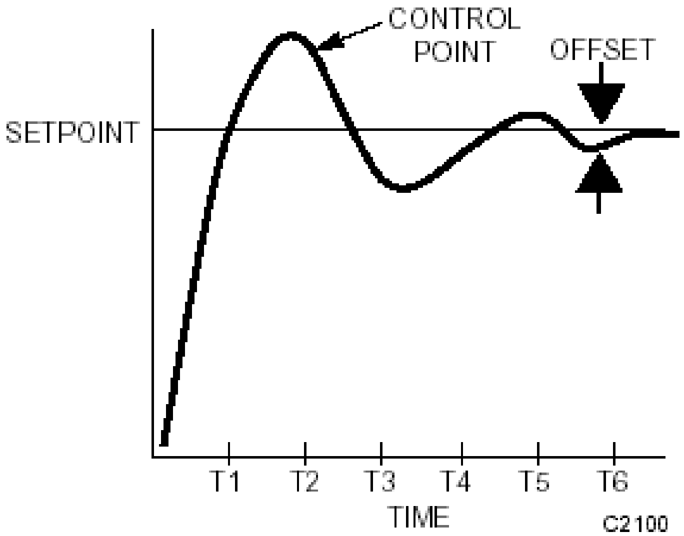


[Source: Honeywell, 1997. *Engineering Manual of Automatic Control for Commercial Buildings*]

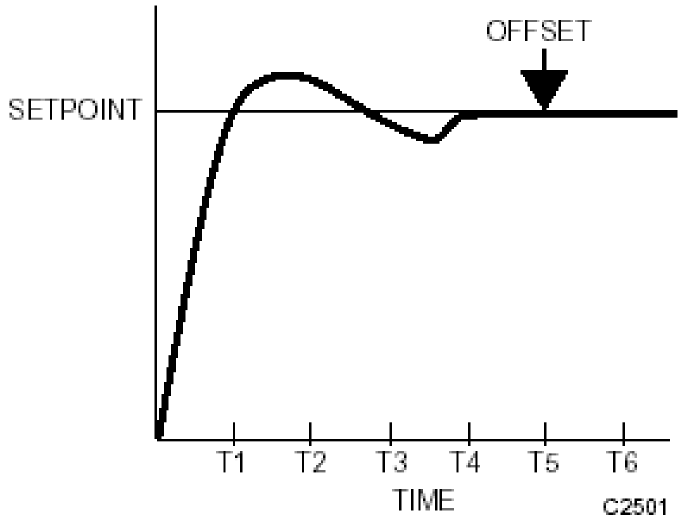
Proportional, integral and derivative (PID) control



Proportional Control



Proportional-Integral (PI) Control

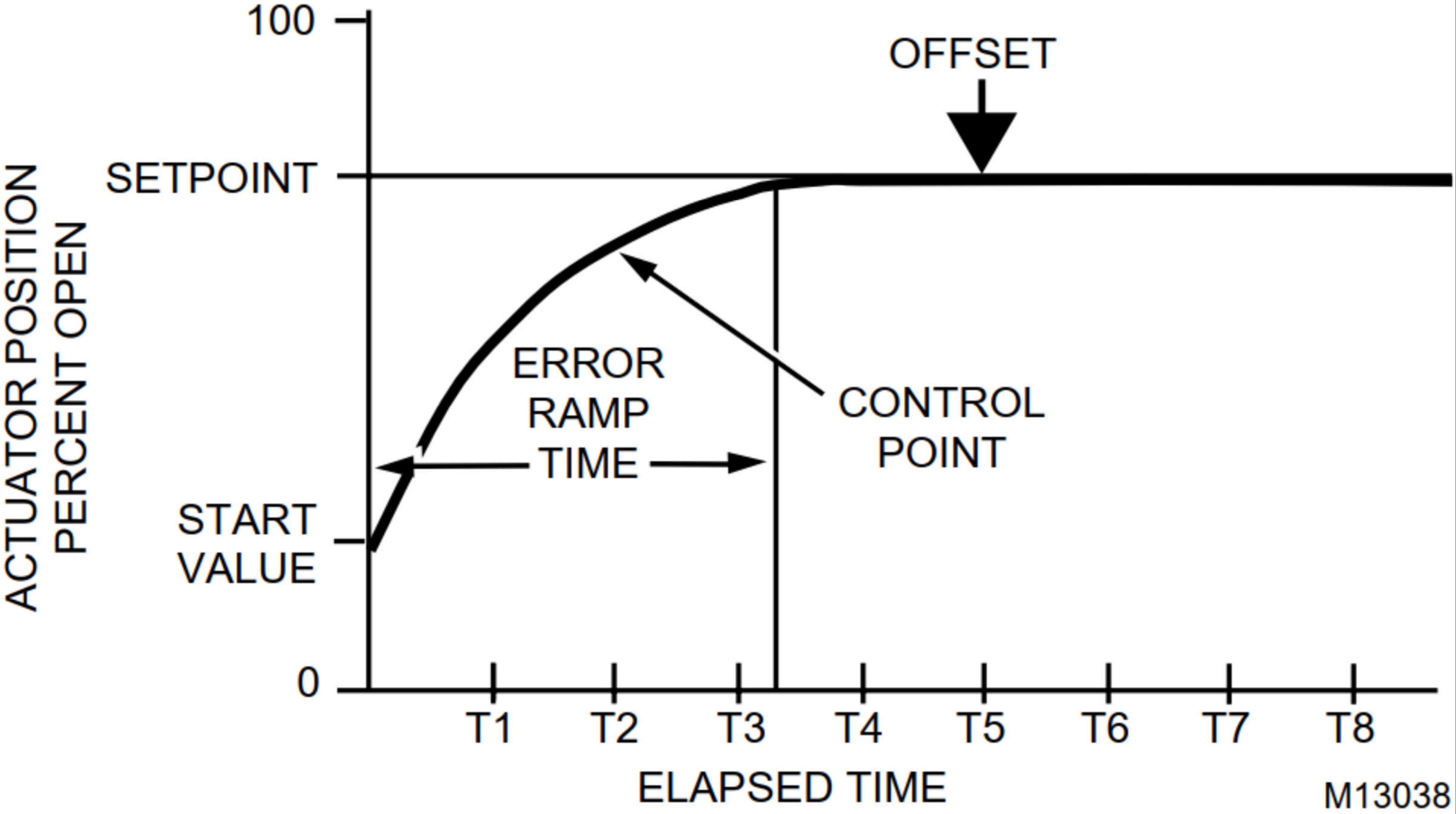


Proportional-Integral-Derivative (PID) Control

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

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

Enhanced proportional integral-derivative (EPID) control



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

Control fundamentals

- Choice of control mode
  - Degree of accuracy required; amount of offset
  - Type of load changes expected
    - Including amplitude, frequency & duration
  - System characteristics
    - Such as no. & duration of time lags, speed of response
  - Expected start-up situation
- In general, use the SIMPLEST mode

Recommended control modes for HVAC system

Application	**Control mode**
Space temperature	P, PID
Mixed air temperature	PI, Enhanced PID
Coil discharge temperature	PI, Enhanced PID
Chiller discharge temperature	PI, Enhanced PID
Air flow	PI (use wide proportional band & a fast reset rate), PID
Fan static pressure	PI, Enhanced PID
Humidity	P, possibly PI for tight control
Dewpoint temperature	P, possibly PI for tight control

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

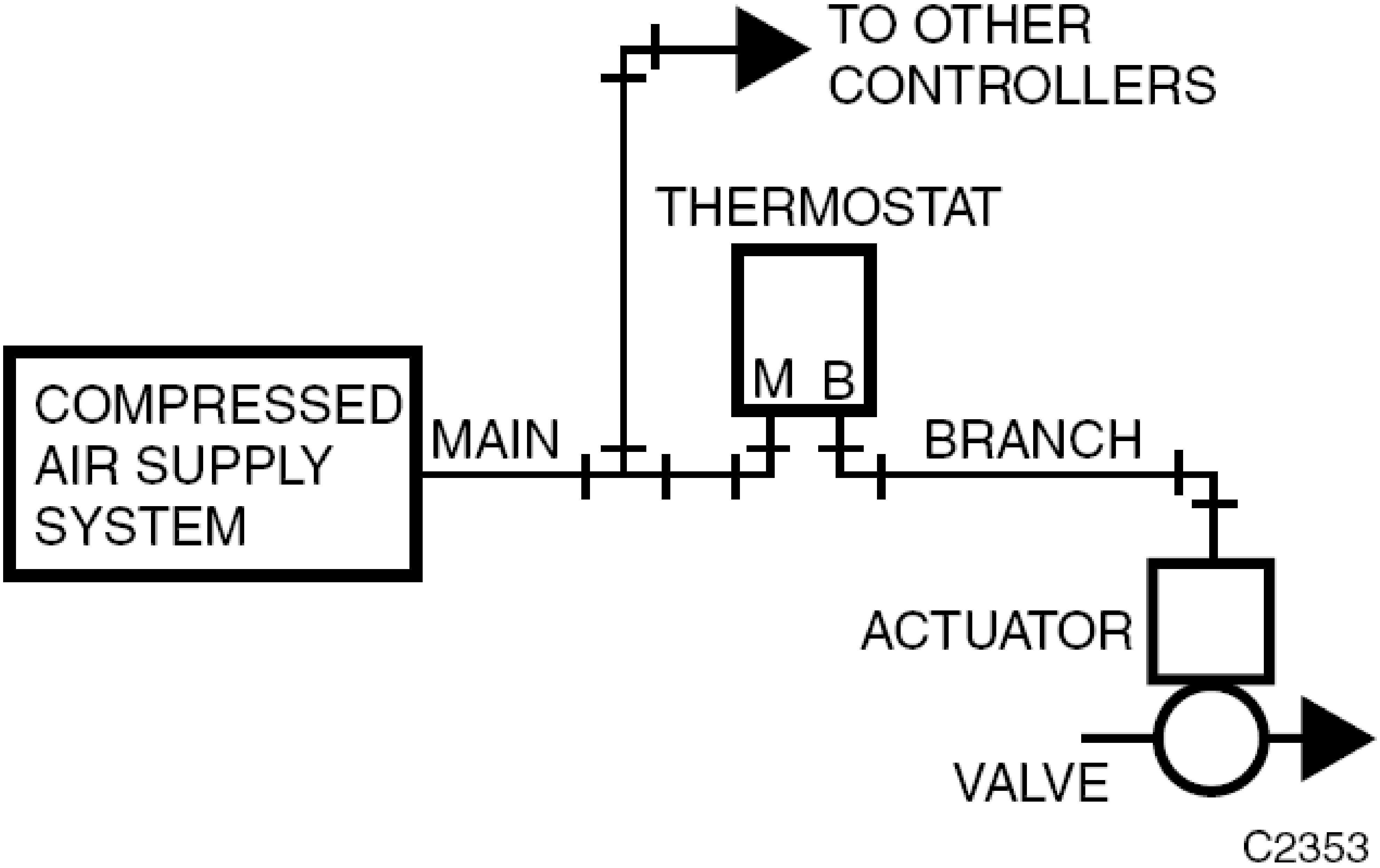
Control methods

- 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 methods

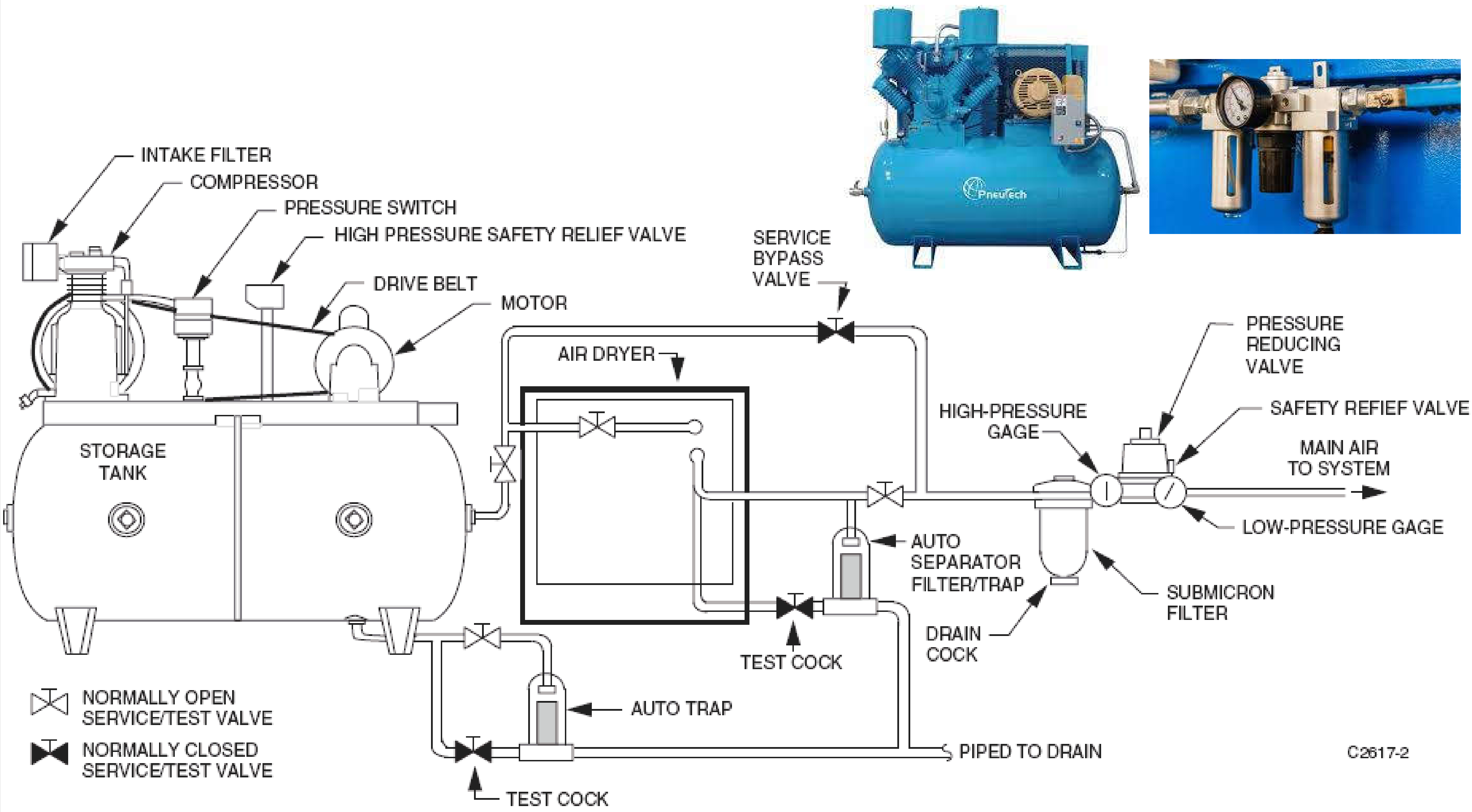
- Common control methods:
- 1) Pneumatic – apply compressed air or pressurized gases to create mechanical control
- 2) Electric – use electrical devices (e.g. relays, time clocks, thermostats, actuators)
- 3) Electronic – use electronic devices
- 4) Direct digital control (DDC) – apply microprocessor-based,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

Basic pneumatic control system



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

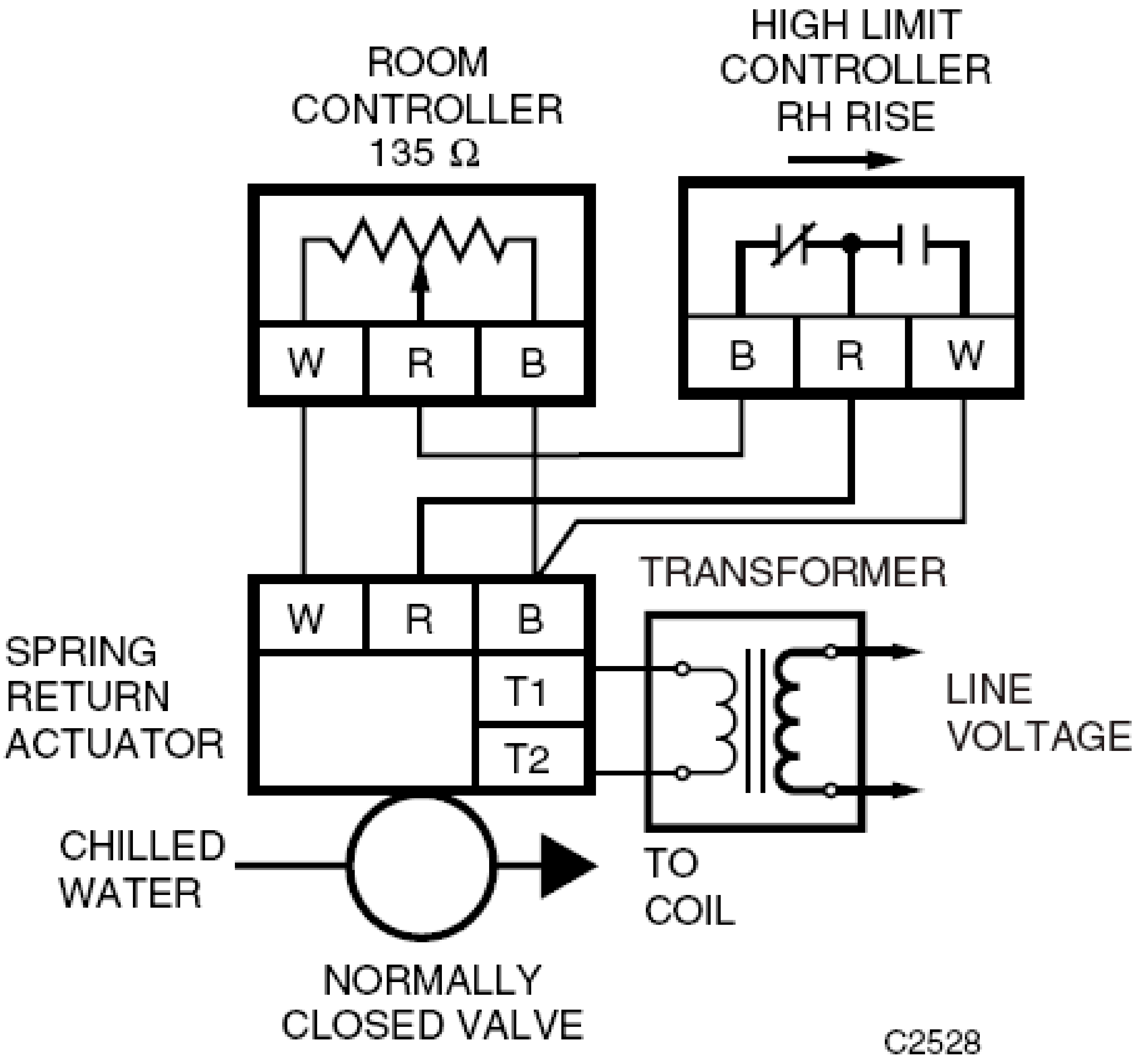
Typical compressed air supply system



You can hear the sound when the system is operating.

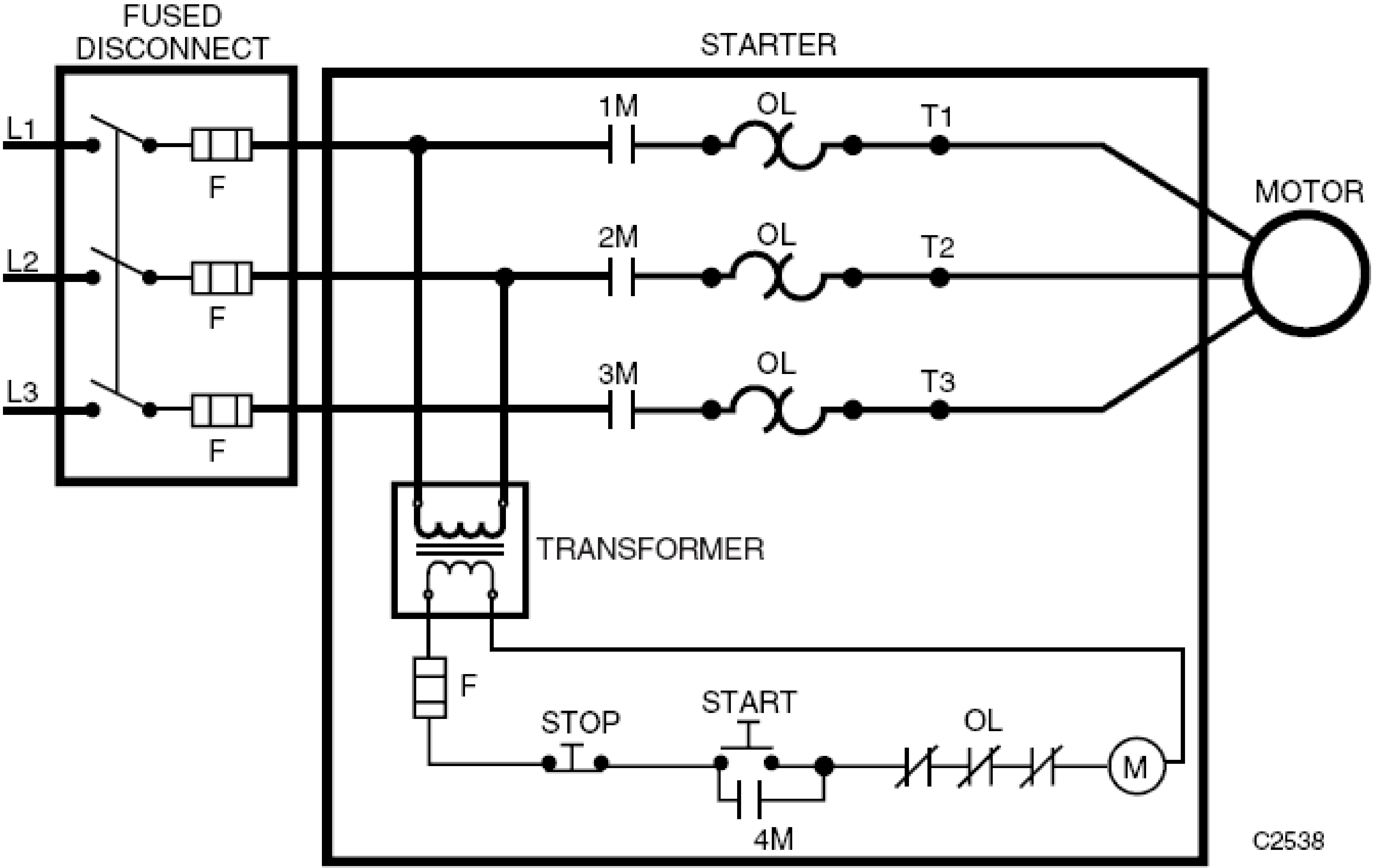
[Source: Honeywell, 1997. *Engineering Manual of Automatic Control for Commercial Buildings*]

Typical electric control circuit



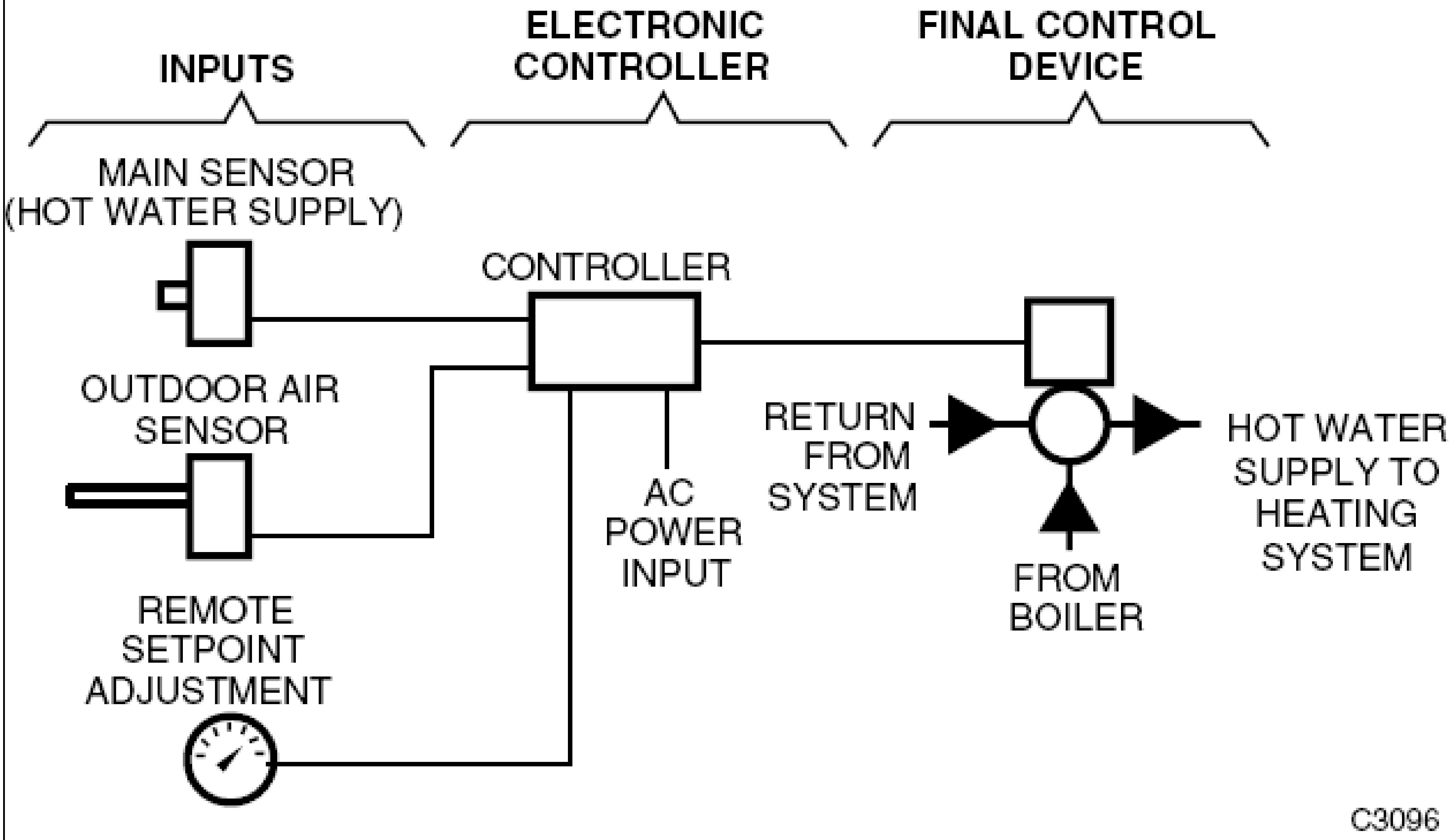
[Source: Honeywell, 1997. *Engineering Manual of Automatic Control for Commercial Buildings*]

Electric control with momentary push-button start-stop circuit



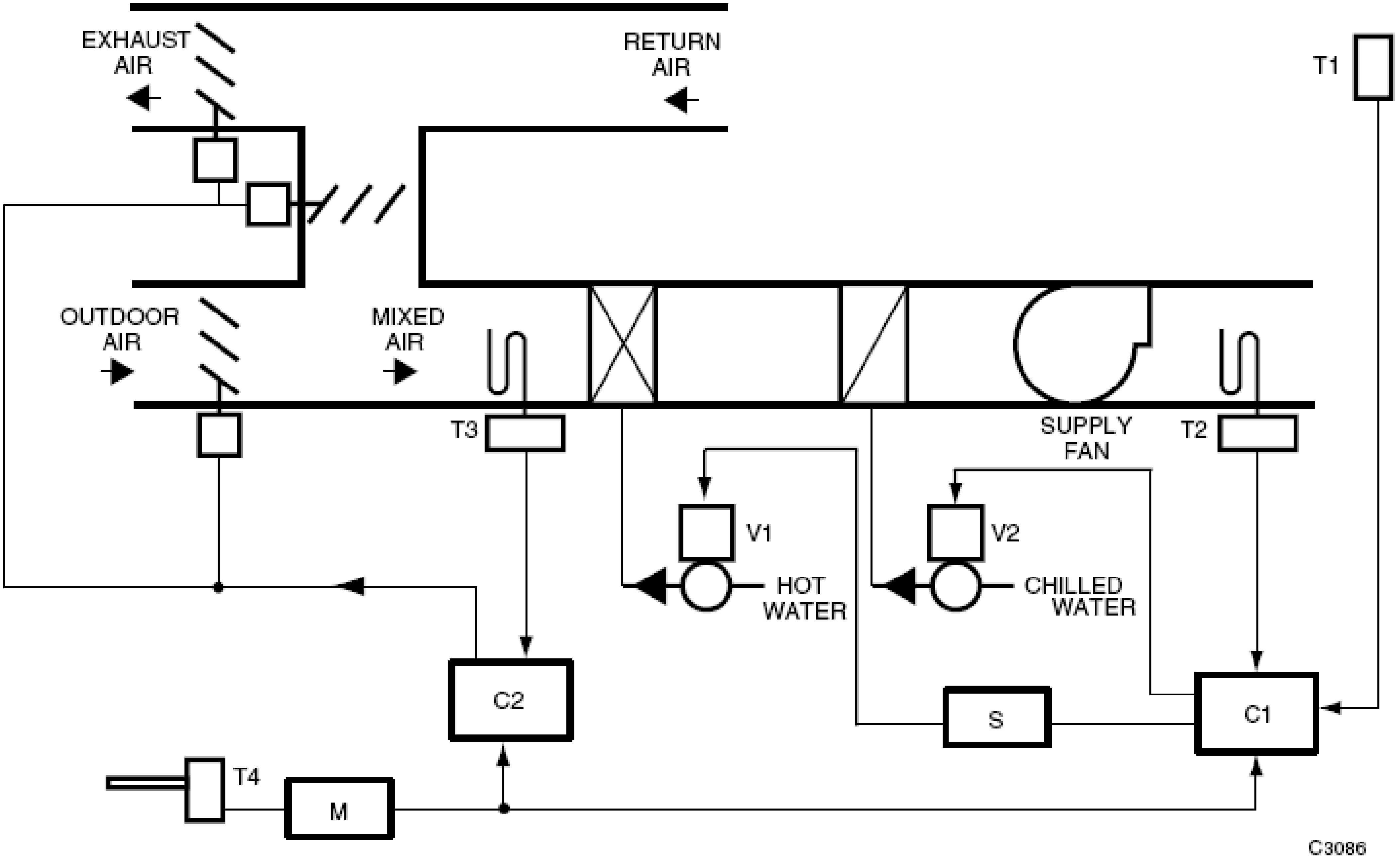
[Source: Honeywell, 1997. *Engineering Manual of Automatic Control for Commercial Buildings*]

Simple electronic control system



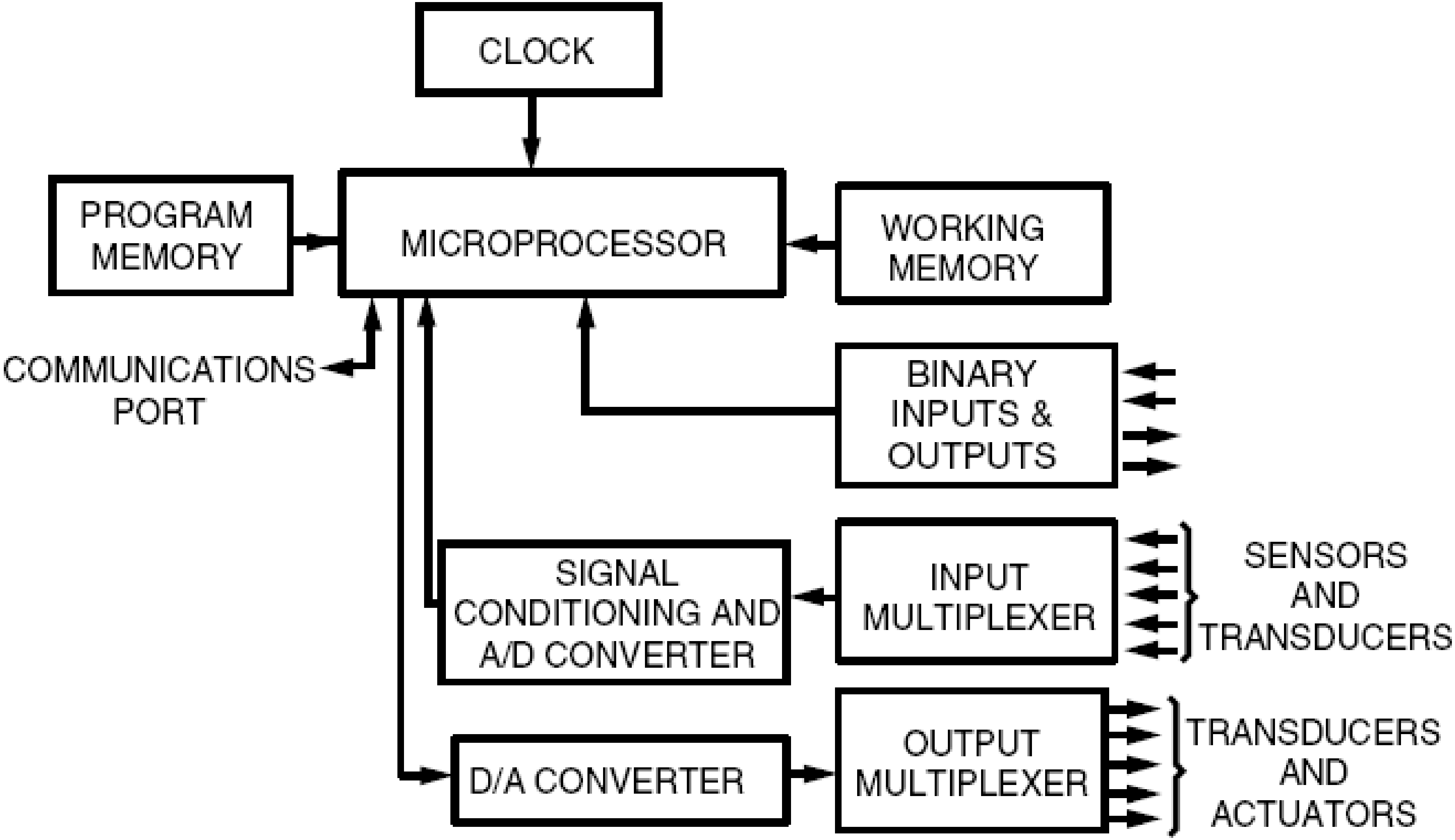
[Source: Honeywell, 1997. *Engineering Manual of Automatic Control for Commercial Buildings*]

Typical application with electronic controllers



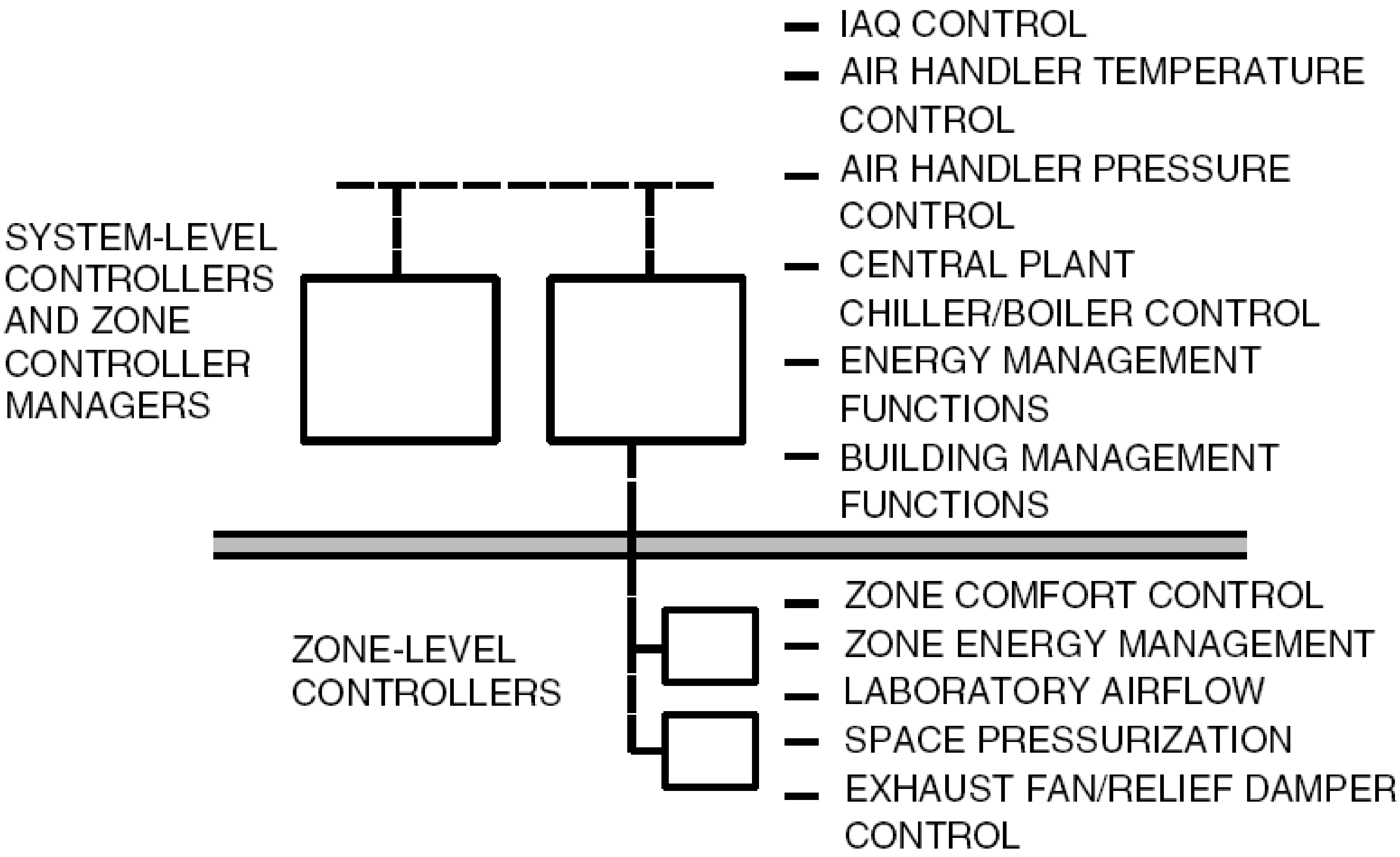
[Source: Honeywell, 1997. *Engineering Manual of Automatic Control for Commercial Buildings*]

Basic microprocessor/DDC controller configuration



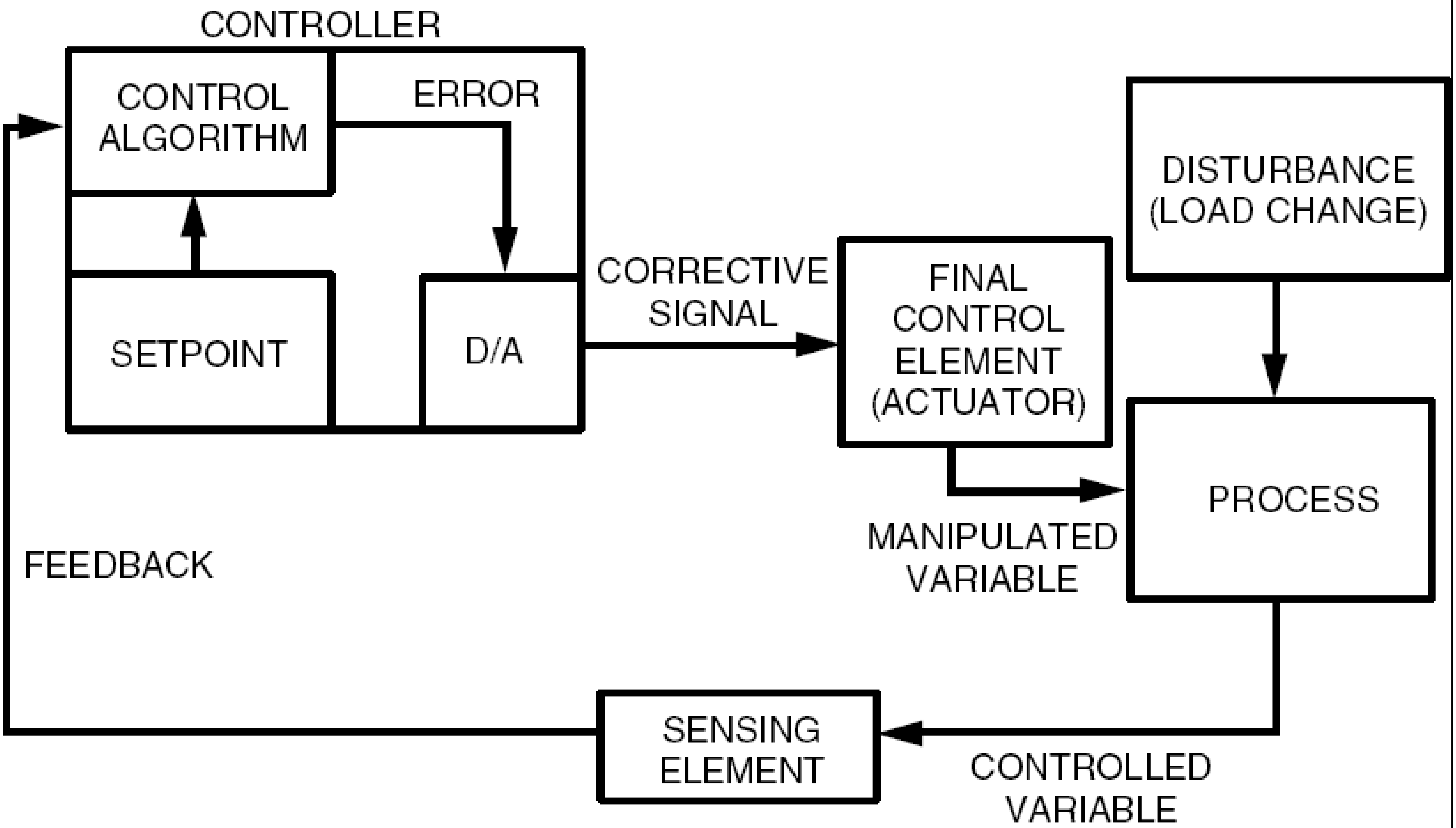
[Source: Honeywell, 1997. *Engineering Manual of Automatic Control for Commercial Buildings*]

Microprocessor/DDC zone- and system level controllers



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

Example of a simple DDC control loop



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

Select the right type of control for the application

Table 4. Characteristics and Attributes of Control Methods.

Pneumatic	Electric	Electronic	Microprocessor
Naturally proportional Requires clean dry air Air lines may cause trouble below freezing Explosion proof Simple, powerful, low cost, and reliable actuators for large valves and dampers Simplest modulating control	Most common for simple on-off control Integral sensor/ controller Simple sequence of control Broad environmental limits Complex modulating actuators, especially when spring-return	Precise control Solid state repeatability and reliability Sensor may be up to 300 feet from controller Simple, remote, rotary knob setpoint High per-loop cost Complex actuators and controllers	Precise control Inherent energy management Inherent high order (proportional plus integral) control, no undesirable offset Compatible with building management system. Inherent database for remote monitoring, adjusting, and alarming. Easily performs a complex sequence of control Global (inter-loop), hierarchial control via communications bus (e.g., optimize chillers based upon demand of connected systems) Simple remote setpoint and display (absolute number, e.g., 74.4) Can use pneumatic actuators

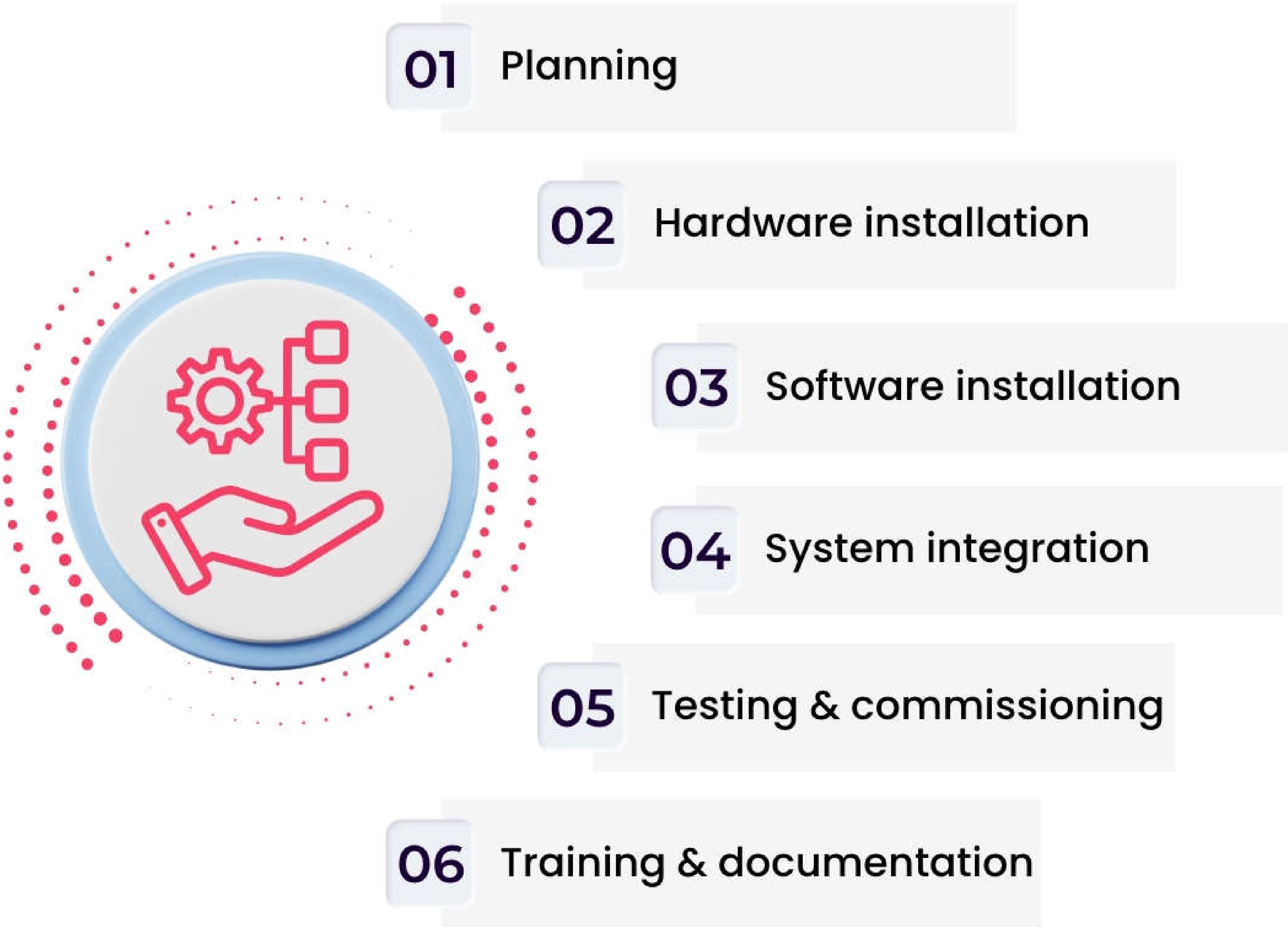
[Source: Honeywell, 1997. *Engineering Manual of Automatic Control for Commercial Buildings*]

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

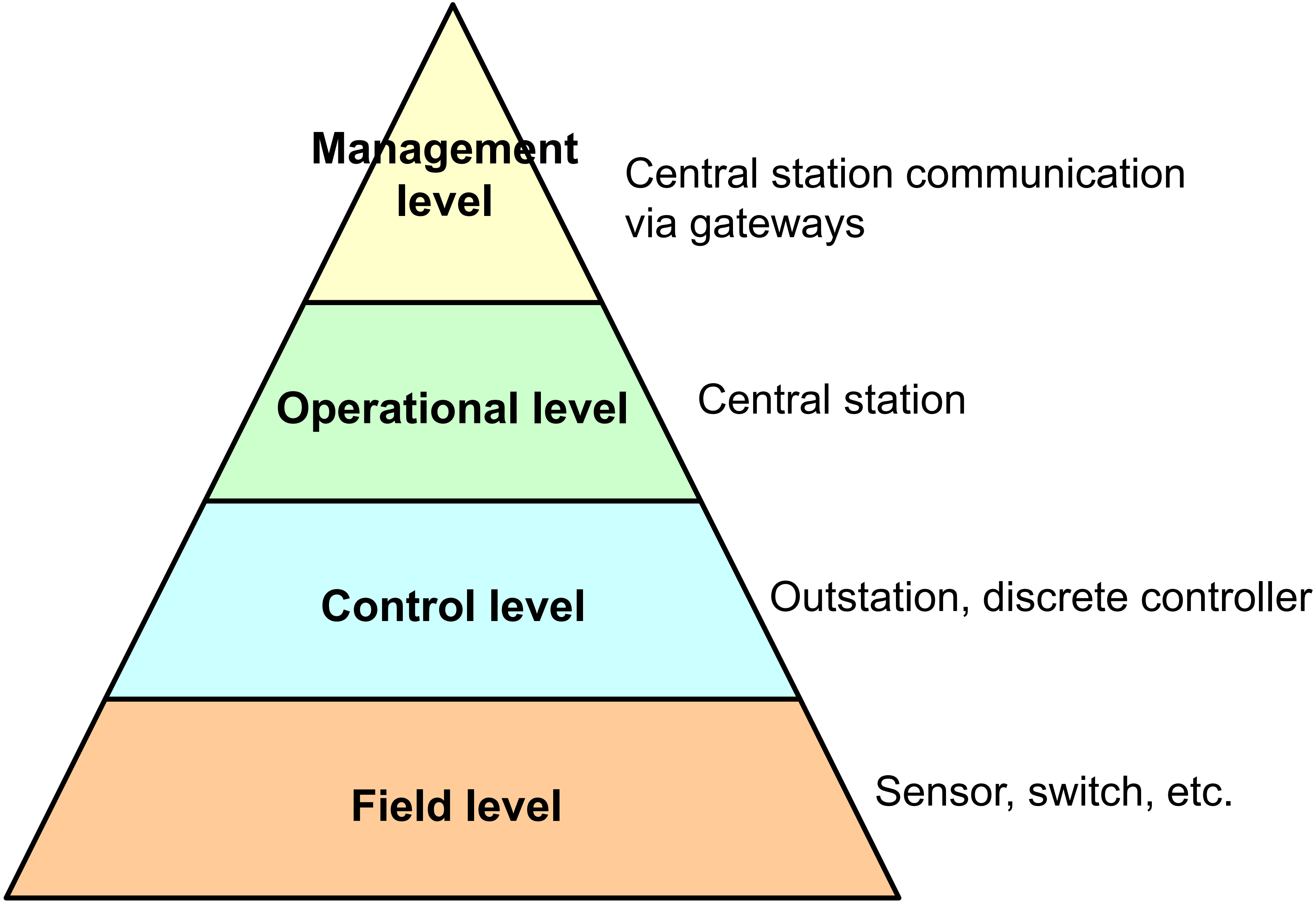
Carried out by consultants, control companies & HVAC contractors

Steps involved in implementing a BAS/BMS



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

Levels of control in building automation system

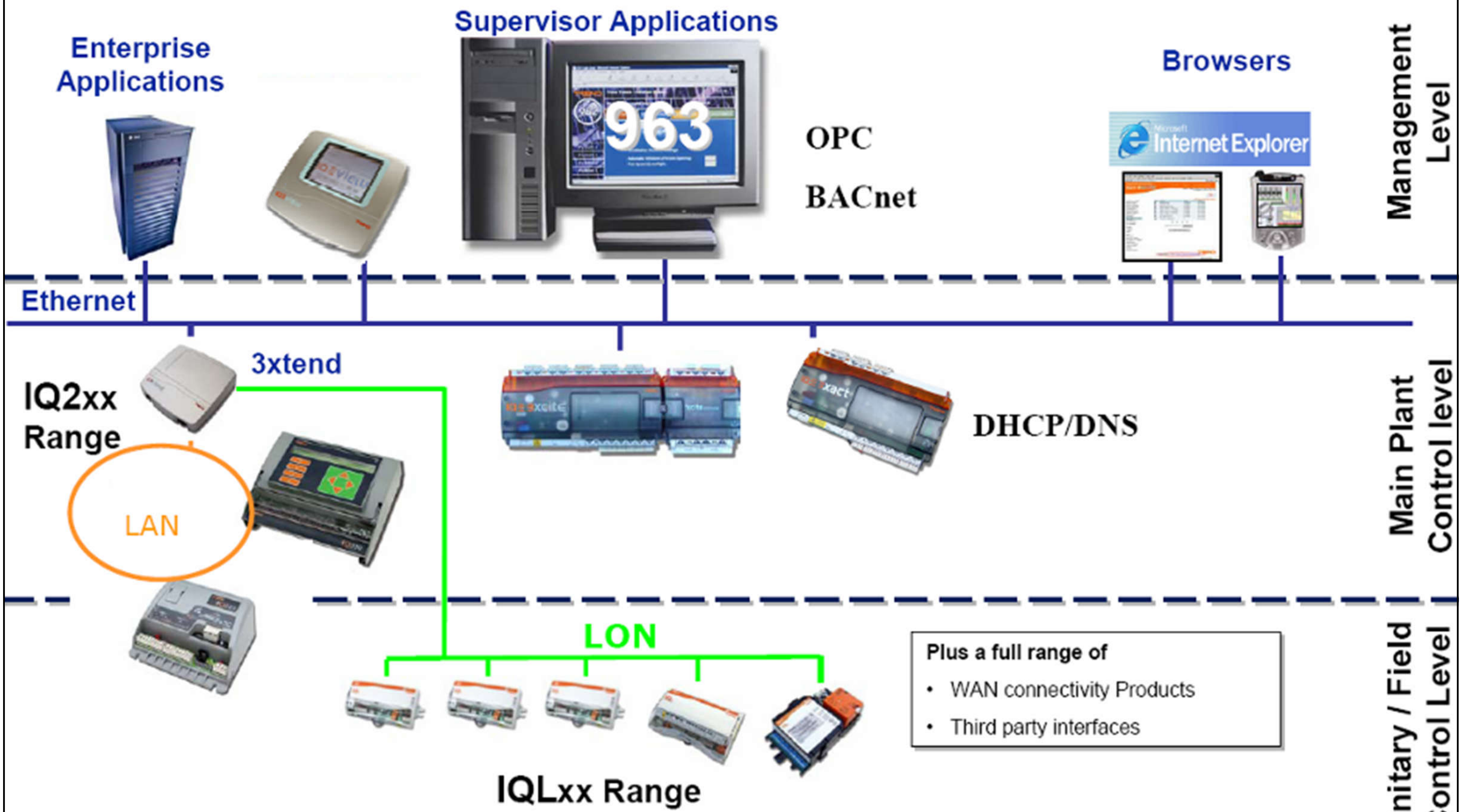


User interaction with BAS/BMS

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

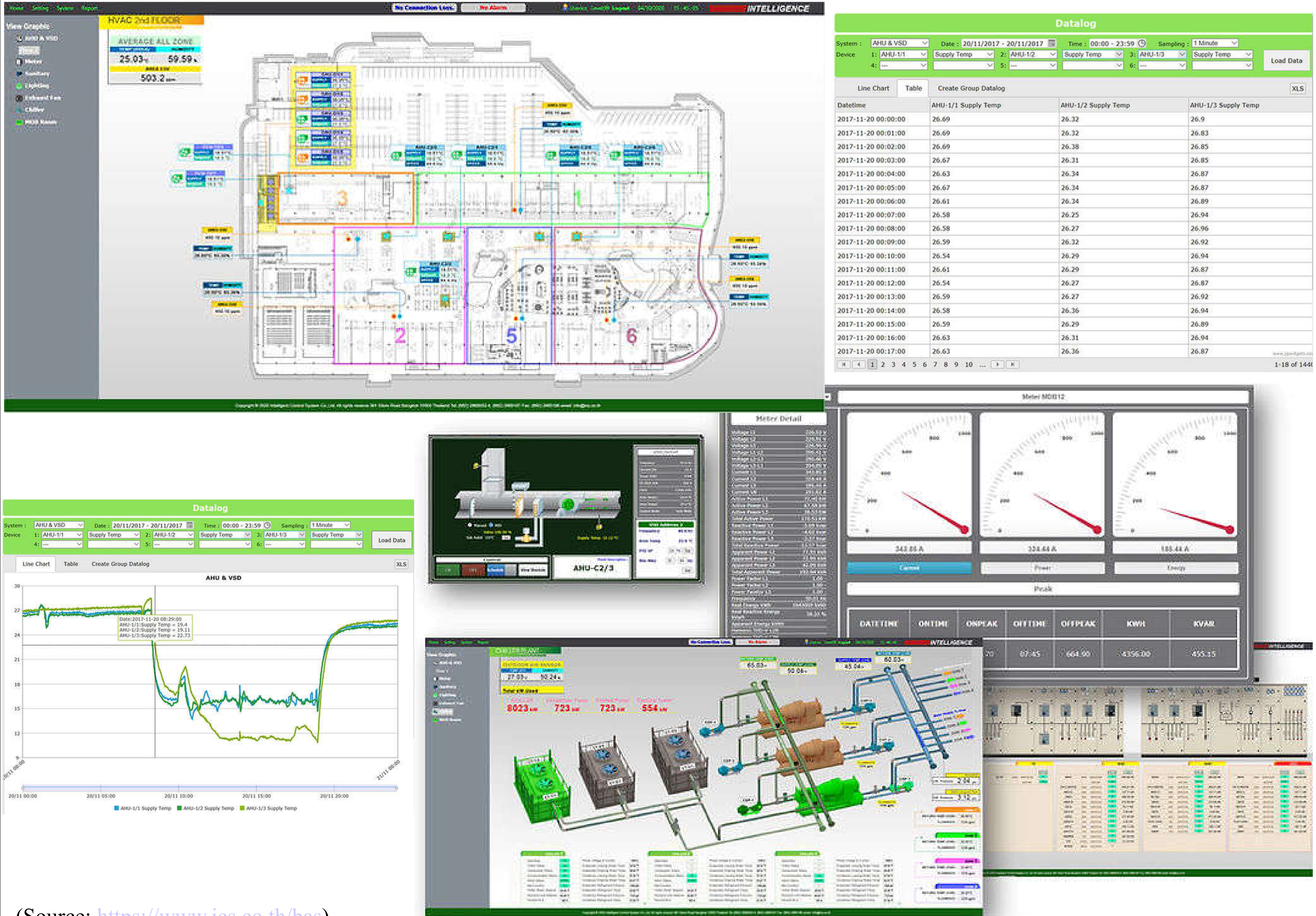
(Source: CIBSE, 2008. *Building Control Systems, CIBSE Guide H*, 2nd edition, Chartered Institution of Building Services Engineers (CIBSE), London.)

Example of system architecture for building management system



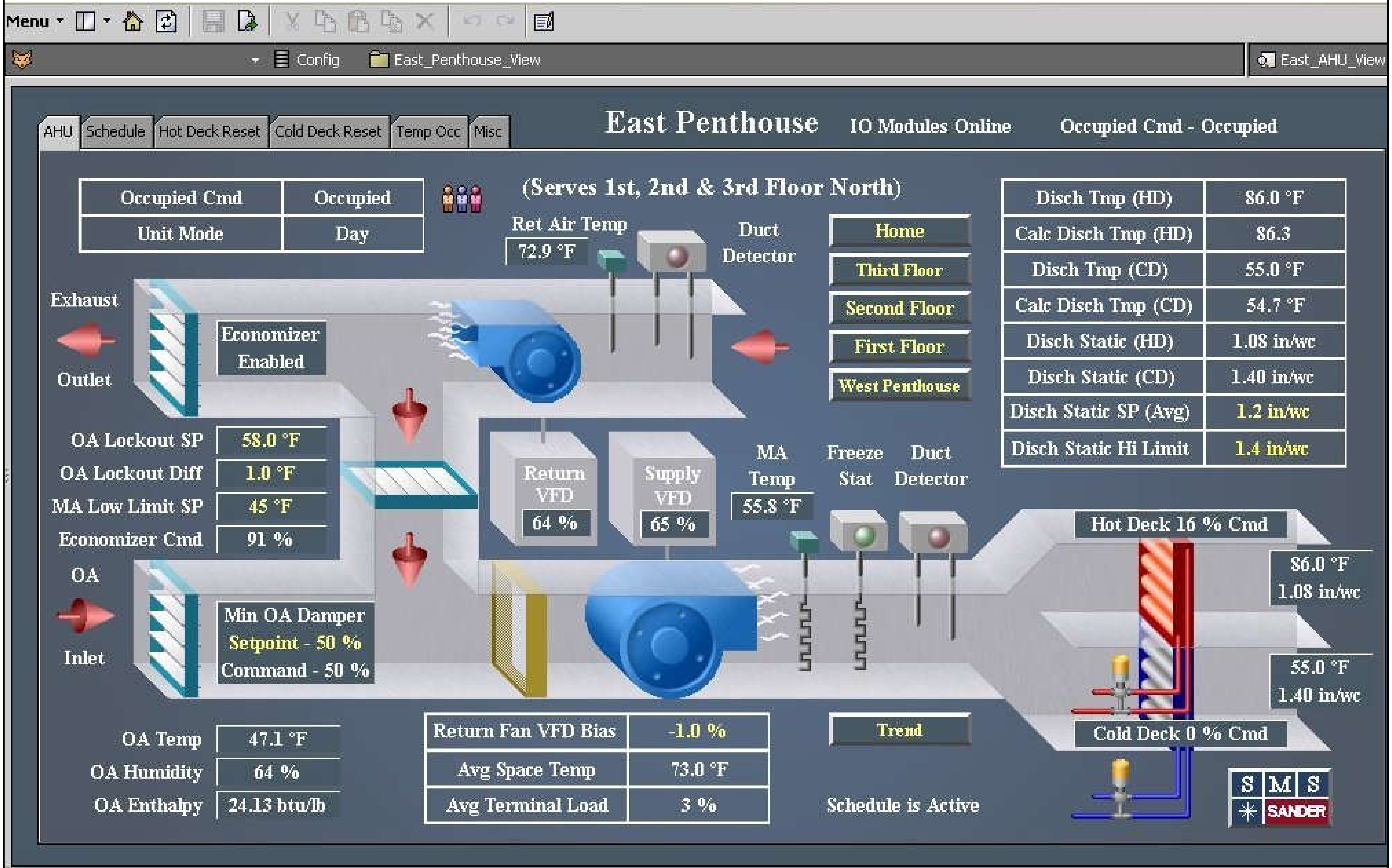
[Source: Trend Control Systems]

Examples of virtual control graphic for building automation system



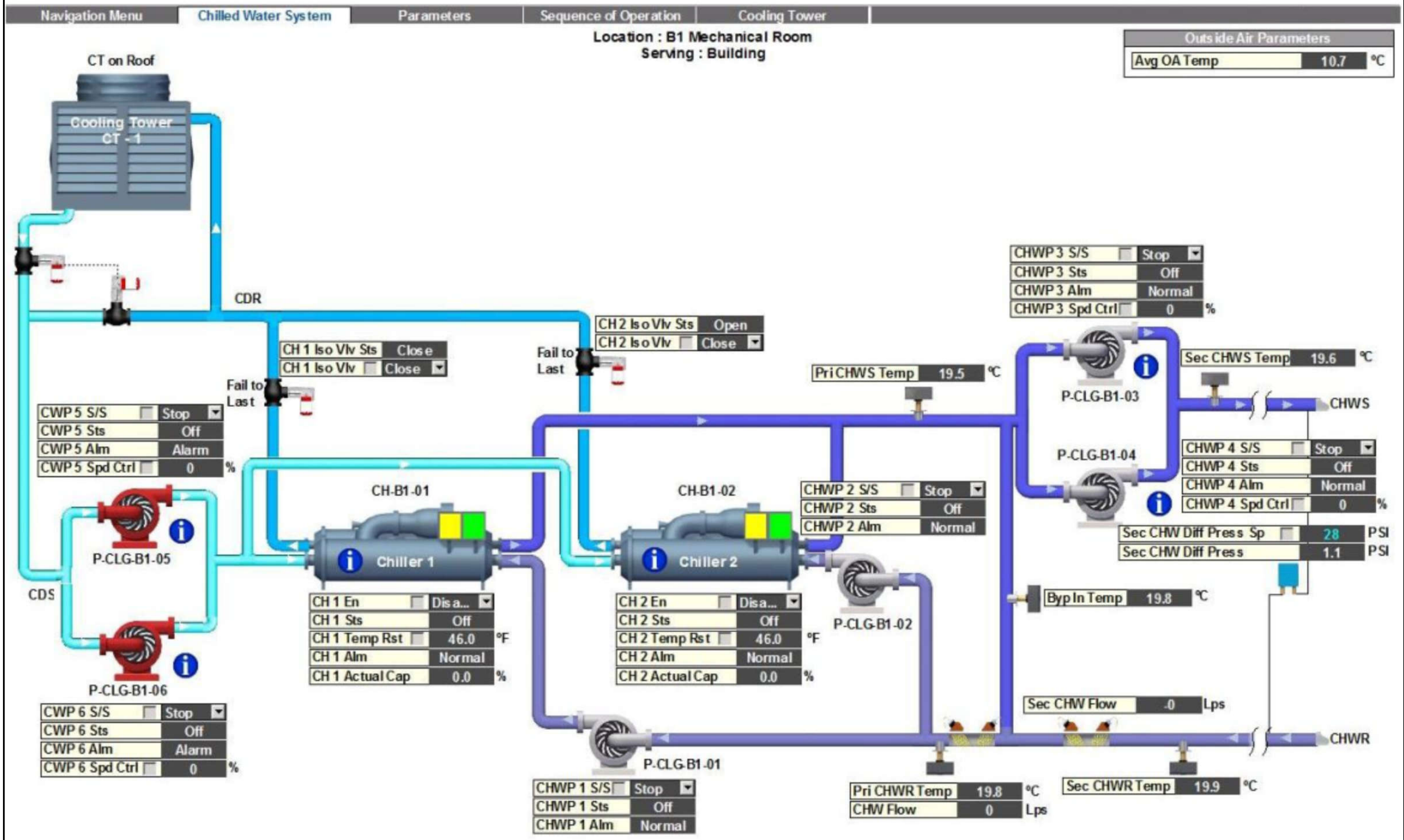
(Source: https://www.ics.co.th/bas)

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

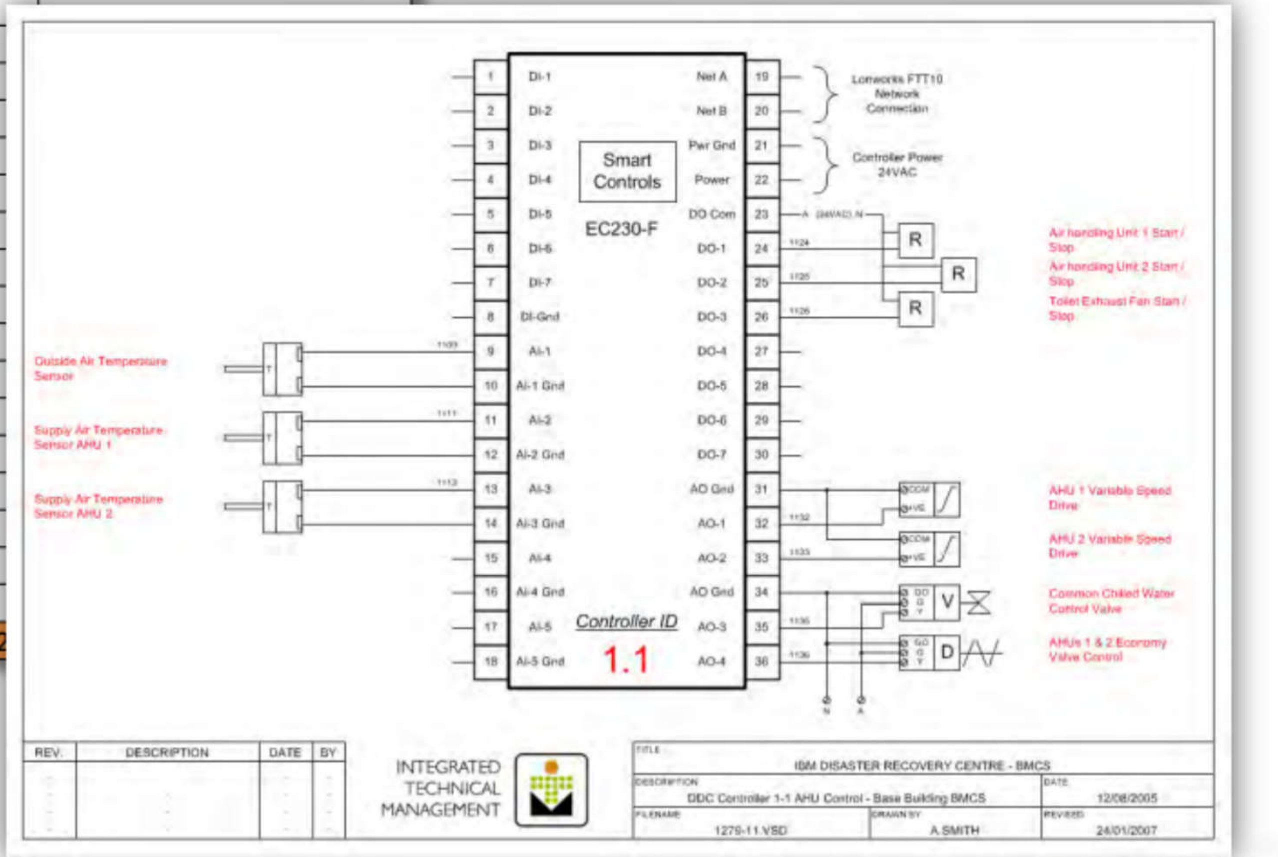
System design

- BAS documentation (cont’d)
  - 2. <u>Point Schedules</u>
    - Detail all connected devices & their point type
    - Critical for planning & system engineering
  - 3. <u>Control System Drawings</u>
    - 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

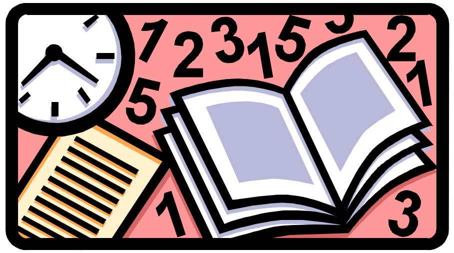
System design

- 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

Useful references



- Bode G., *et al.*, 2019. Cloud, wireless technology, internet of things: the next generation of building automation systems?, *Journal of Physics: Conference Series*, 1343 (1) 12059. https://doi.org/10.1088/1742-6596/1343/1/012059
- CIBSE, 2008. *Building Control Systems*, CIBSE Guide H, 2nd edition, Chartered Institution of Building Services Engineers (CIBSE), London.
- Honeywell, 1997. *Engineering Manual of Automatic Control for Commercial Buildings - Heating, Ventilating, Air Conditioning*, SI Edition., Honeywell, Inc., Minneapolis, MN.
- Steel C., 2019. *Code of Practice: Building Automation and Control Systems*, Institution of Engineering and Technology, London.

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