MEBS6005 Building Automation Systems

http://ibse.hk/MEBS6005/

Control Strategies

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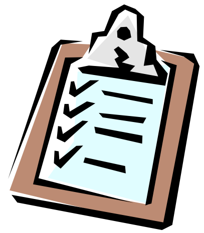


- Basic principles
- Typical control strategies
- Air handling systems
- Chiller system control
- Control of hydraulic circuits

Basic principles

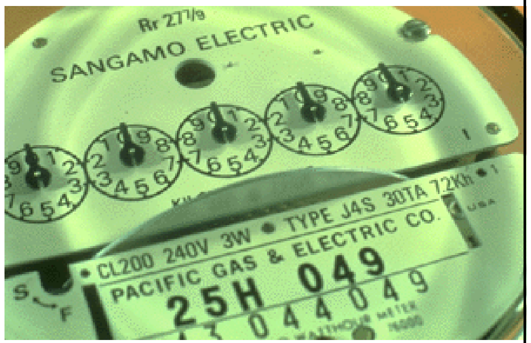
- In general, the control system:
  - Must meet the needs of the process
  - Should control the process as directly as possible
  - Should minimise energy consumption while meeting process goals
  - Must meet the budget
  - Must be designed for maximum simplicity
  - Must be easy to understand & maintain

Basic principles

- Benefits of good control strategies in buildings
  - 1) Enhance thermal comfort & indoor air quality
  - 2) Prevent building services systems from being on when not required, therefore saving energy
  - 3) Ensure services could be supplied at the right & favourable levels (e.g. temperature & humidity)
  - 4) Reduce maintenance requirements via minimizing use of facilities/equipment
  - 5) Reduce building energy consumption, operating costs & carbon emissions

Basic principles

- Control strategies for buildings
  - Aims:
    - Improve operating efficiency of equipment
    - Reduce operating costs through
      - Flexible scheduling, limiting operation, altering set points, utilising natural or free cooling
    - Reduce electrical consumption & demand
      - Energy (consumption) charge (kWh)
      - Demand charge (peak KW or KVA)



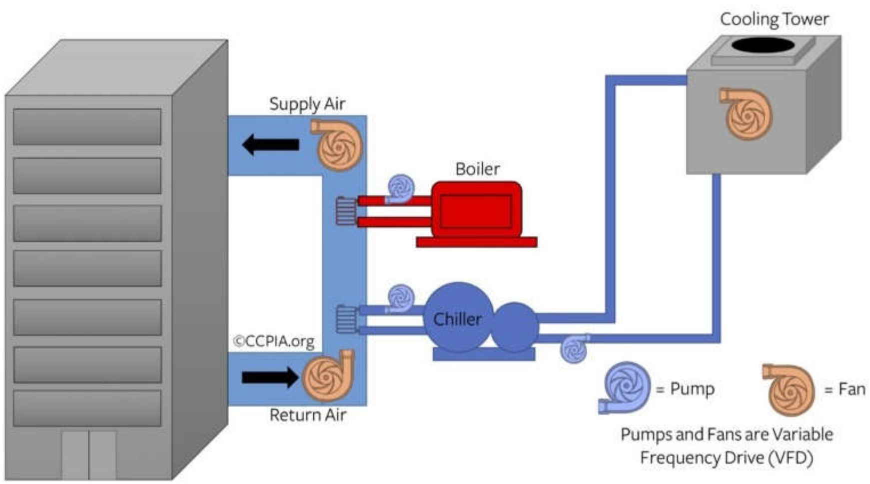
  - Operating modes, e.g. normal, fire, night cooling
  - Natural ventilation & mixed-mode ventilation

Basic principles

- Control strategies for BAS subsystems
  - Boilers – operating controls & limiting controls
  - Chillers – chiller plants, heat rejection system (e.g. cooling towers), chilled water distribution system
  - Hydraulic circuits – for cooling/heating applications, pumps, calorifiers
  - Central air handling plant – cooling/heating coils
  - Energy recovery – e.g. thermal wheels
  - Mechanical ventilation – outdoor air supply
  - Terminal units – fan coil units, VAV boxes

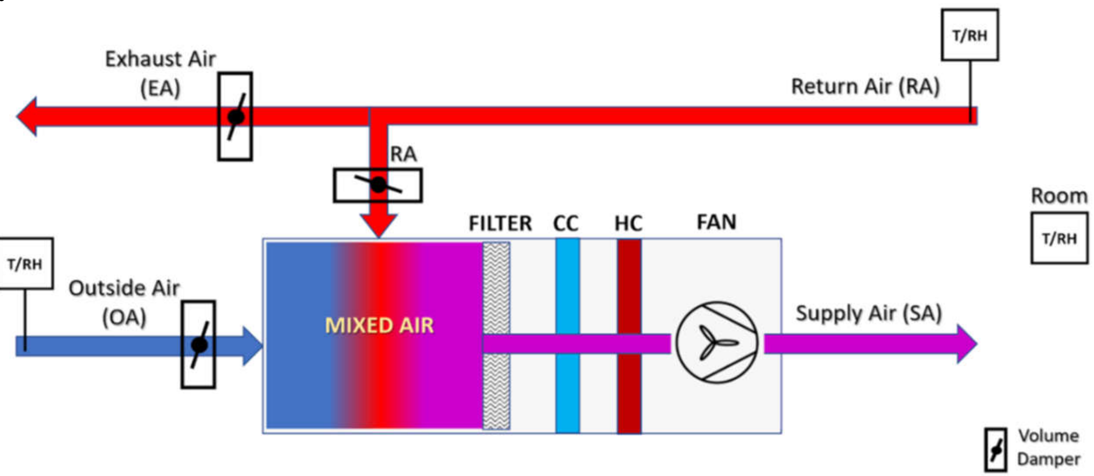
Basic principles

- Components of central HVAC plant loop:
  - Chiller controls
  - Boiler temperature sensor & control actuator
  - Fluid flow stations
  - Temperature sensors at inlet/outlet of coil
  - Control valves with actuator
  - Electric resistance control



Basic principles

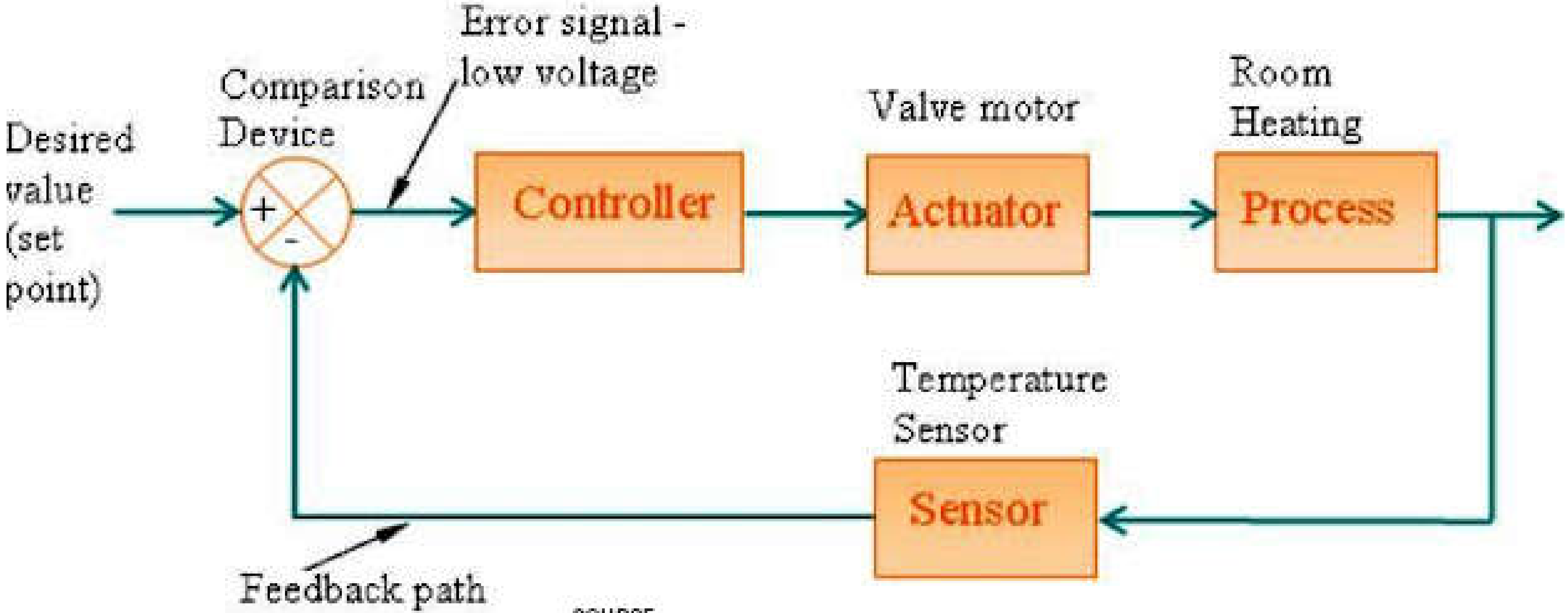
- Components of HVAC airside control:
  - Dampers: outdoor, return, exhaust & supply air
  - Variable speed drive fan
  - Differential pressure sensors across filters, coils
  - Air temperature sensors: outdoor, return, supply
  - CO_2 sensor: return air
  - Airflow station

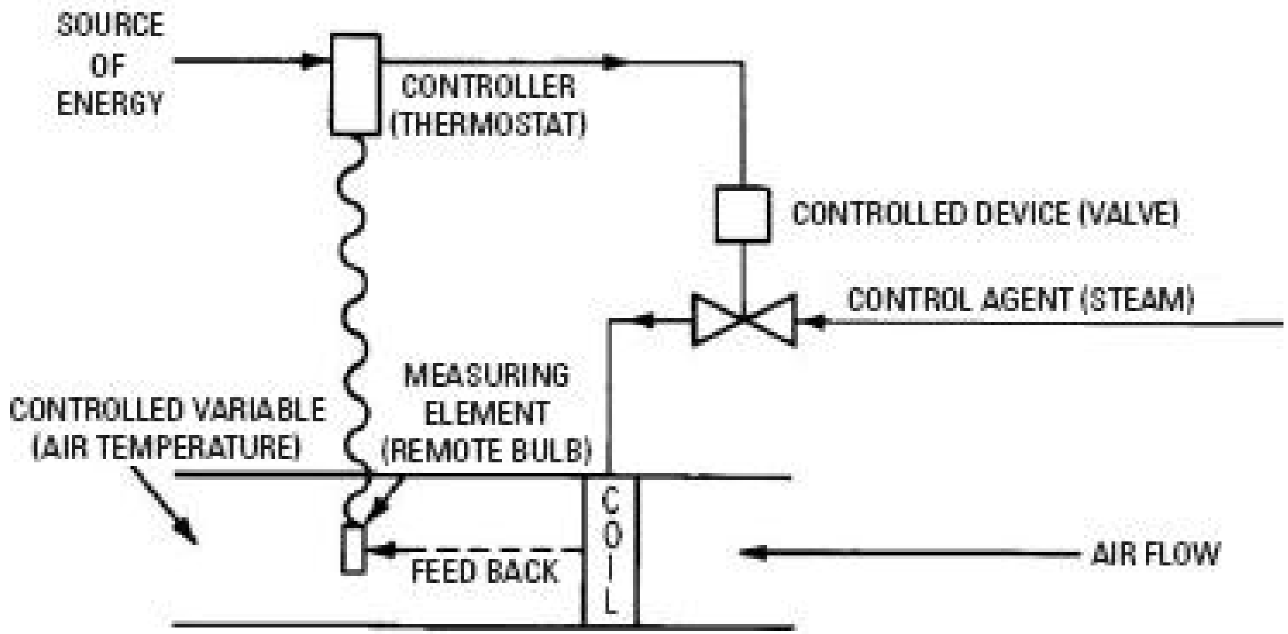


Basic principles

- Typical HVAC control applications:
  - Zone temperature monitoring & control
  - Zone variable air volume (VAV) control to zones
  - Zone CO_2 monitoring & control (air quality)
  - Air handling unit supply air temperature control
  - Air handling unit supply air flow / pressure control
  - Main plant chiller & boiler sequencing
  - Toilet, car park & general exhaust fan control
  - After hours building control

Major control system elements in a heating system control loop





(Source: http://www.electrical-knowhow.com/2012/04/hvac-control-systems-and-building.html)

Basic principles

- Control strategies for safe, effective operation
  - **Safety**: give adequate warning of any malfunction & if necessary, take appropriate action in the event of equipment failure
    - Alarms – to indicate to the operator that a system variable has exceeded a pre-determined limit
    - Interlocks – ensure that particular items of plant may only operate together, or are prohibited from operating simultaneously
    - Safety strategies – e.g. safety switches override normal plant operation to prevent harm to plant or personnel

Basic principles

- Selection switches
  - For each plant/equipment: MANUAL/OFF/AUTO
- Fire & smoke control (w/ firemen's override)
  - Usually separated from the HVAC & BAS
  - BAS receives fire alarm signals & must act accordingly, e.g. response to a fire alarm may be:
    - Plant shut-down, including supply & extract fans with inlet & exhaust dampers closed
    - Plant shut-down with the extract fan continuing to run with the exhaust damper open

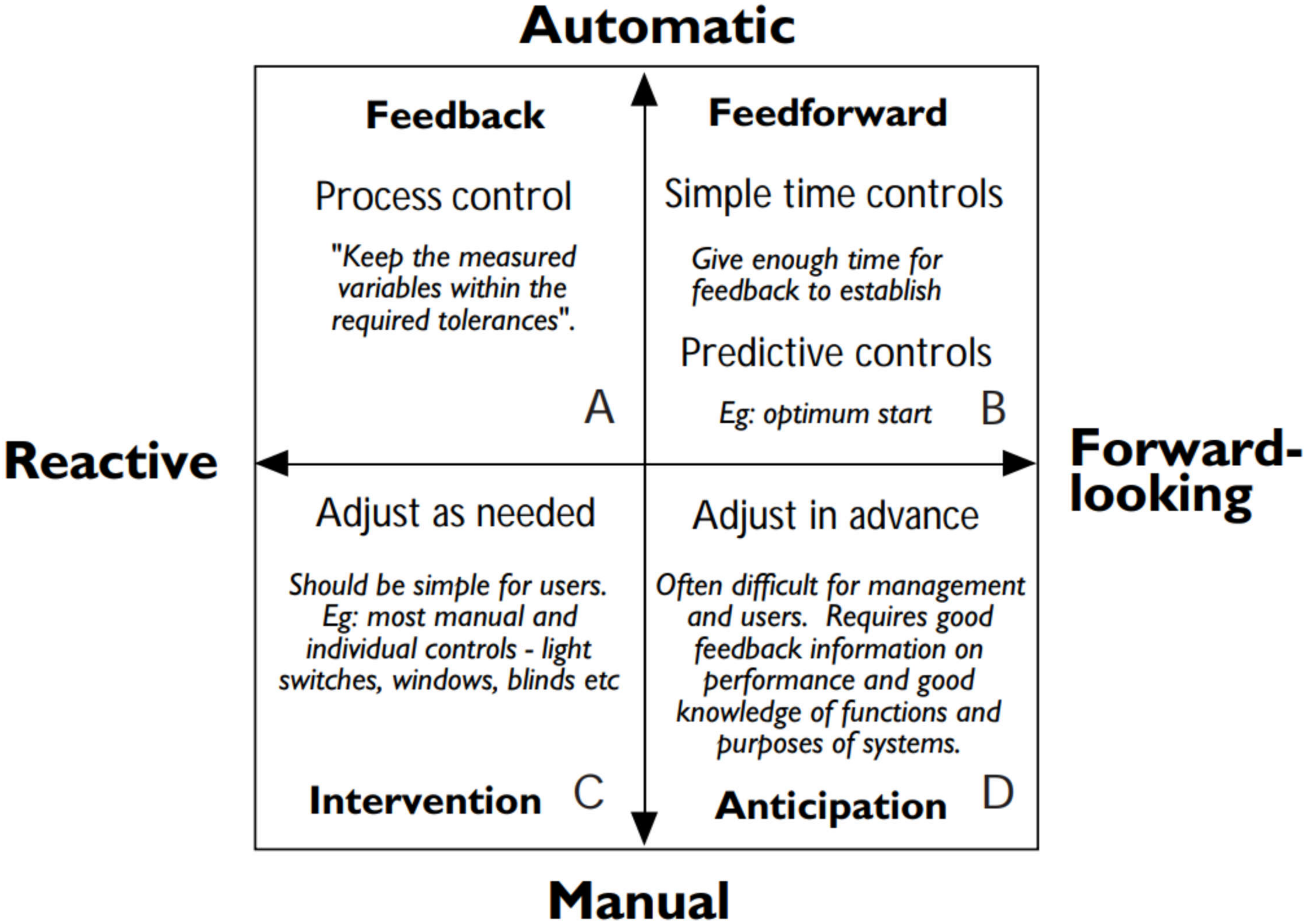
Basic principles

- Considerations on the choice of control mode
  - Degree of accuracy required & the amount of offset that is acceptable
  - Type of load changes expected, including amplitude, frequency & duration
  - System characteristics, e.g. the number & duration of time lags and speed of response of subsystems
  - Expected start-up situation
- In general, use the simplest mode that will meet the requirements

Basic principles

- Principles of the control strategies
  - A. Feedback: Automatic + Reactive
    - Close loop process control
  - B. Feedforward: Automatic + Forward looking
    - Time switches programmed, optimisers/prediction
  - C. Intervention: Adjust as needed
    - Occupants interact with the controls
  - D. Anticipation: Adjust in advance
    - Manual adjustment in advance of need

Control strategies for building services



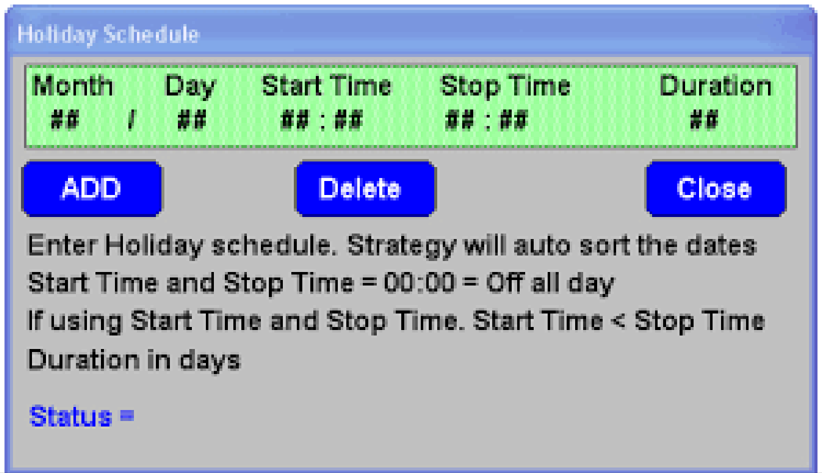
(Source: https://www.usablebuildings.co.uk/UsableBuildings/Unprotected/CtStrtSe.pdf)

Typical control strategies

- Typical control strategies to reduce building energy consumption:
  - Time of day (TOD) scheduling
  - Optimum start/optimum stop
  - Duty cycling
  - Demand limiting
  - Temperature reset
  - Airside economizer
  - Waterside economizer

Typical control strategies

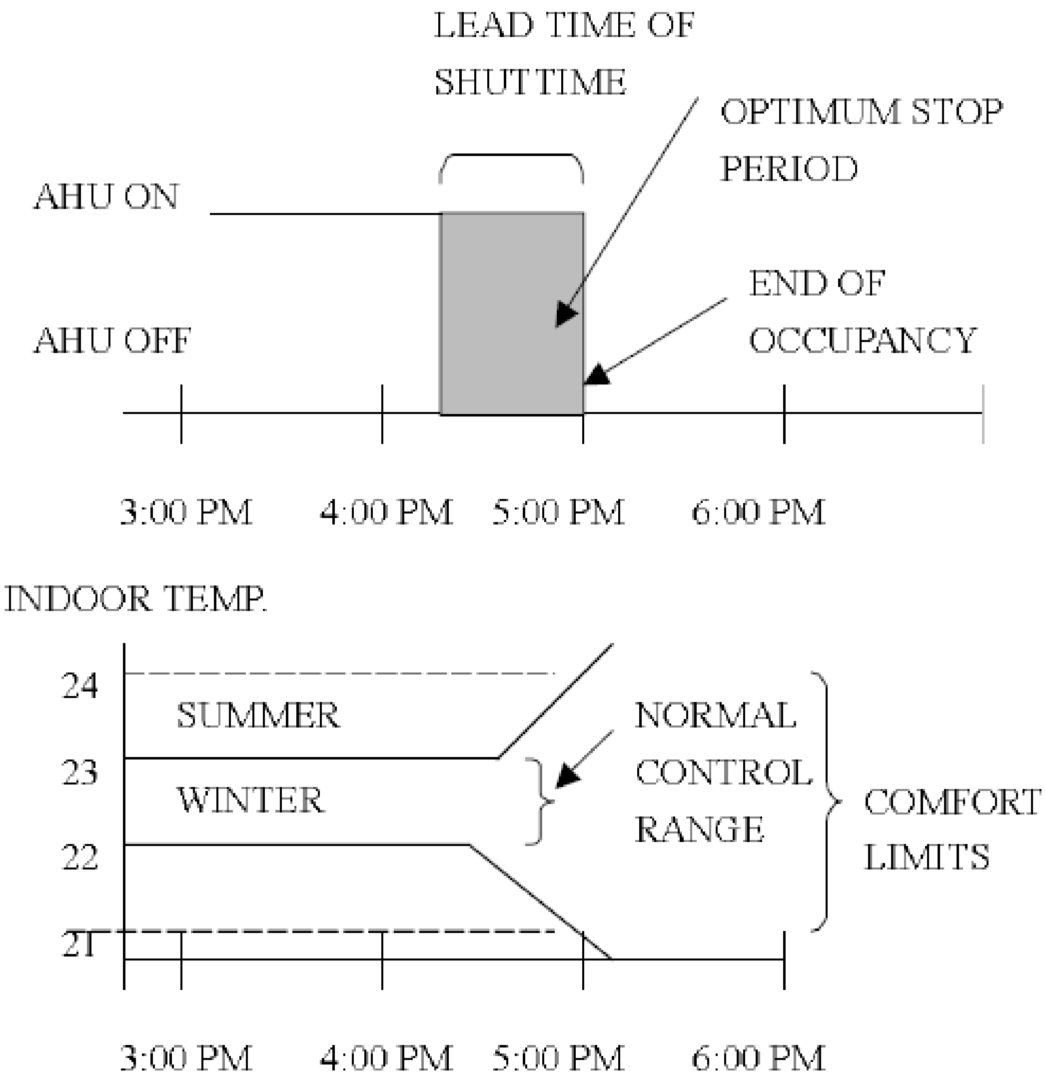
- Time of Day (TOD) scheduling
  - Turn off equipment when it is not needed
  - Reduce operating hours of equipment
  - Methods:
    - Time clocks (Timer)
    - Time of day programming, such as
      - Operating schedule: start/stop
        - Day, week, month or season
      - Holiday schedule



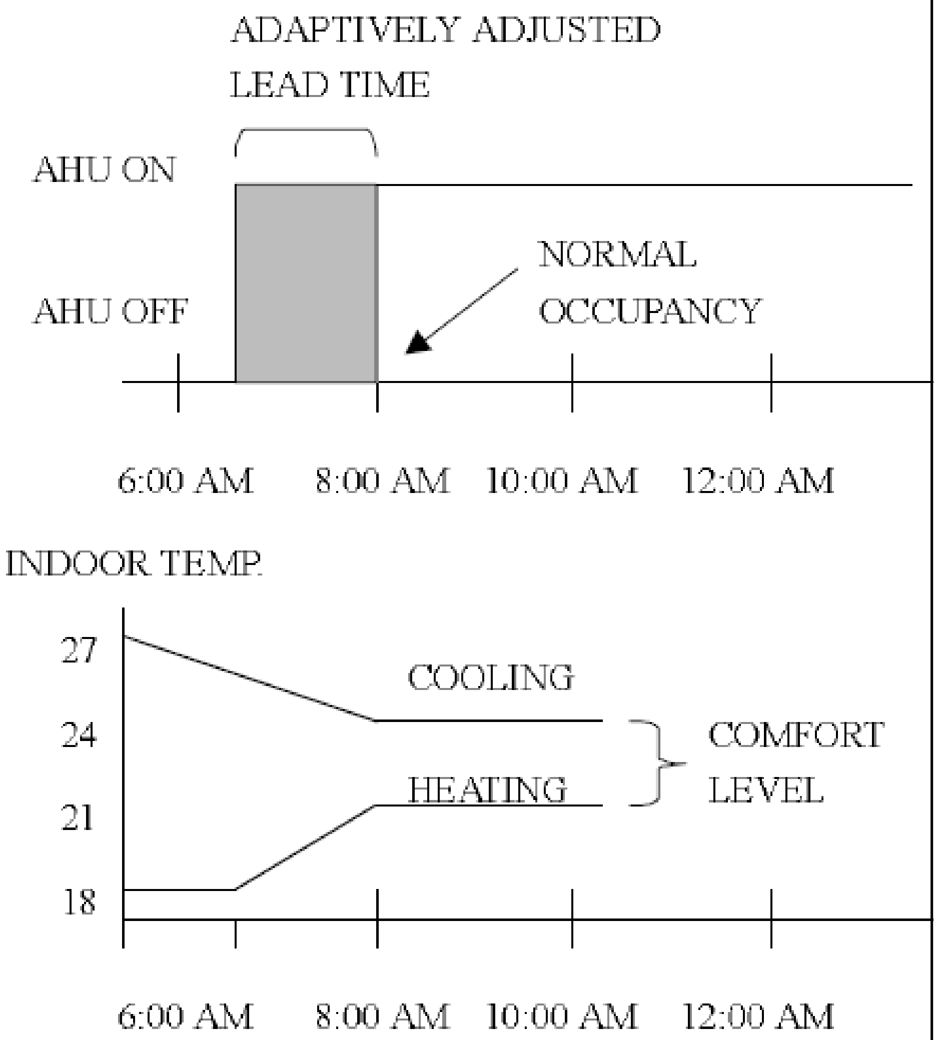
Typical control strategies

- Optimum start/optimum stop
  - Vary the scheduled start/stop times based upon current environmental conditions
  - Optimum start
    - Start as *late* as possible while ensuring comfort level
      - Variables: zone conditions, outsider air, thermal mass
  - Optimum stop
    - Time constant of a zone's thermal characteristics
      - Zones with large thermal capacities can be shut off earlier
    - Considerations: loss of air movement & background noise may be disruptive

Basic concepts of optimum start/optimum stop



Optimum Stop

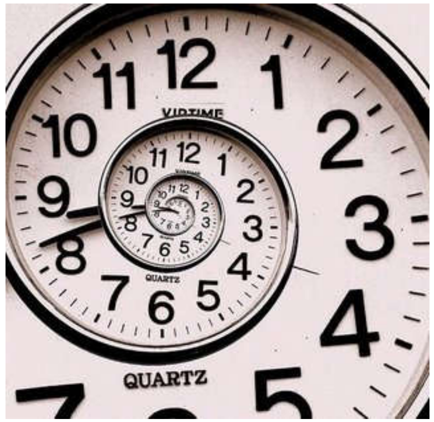


Optimum Start

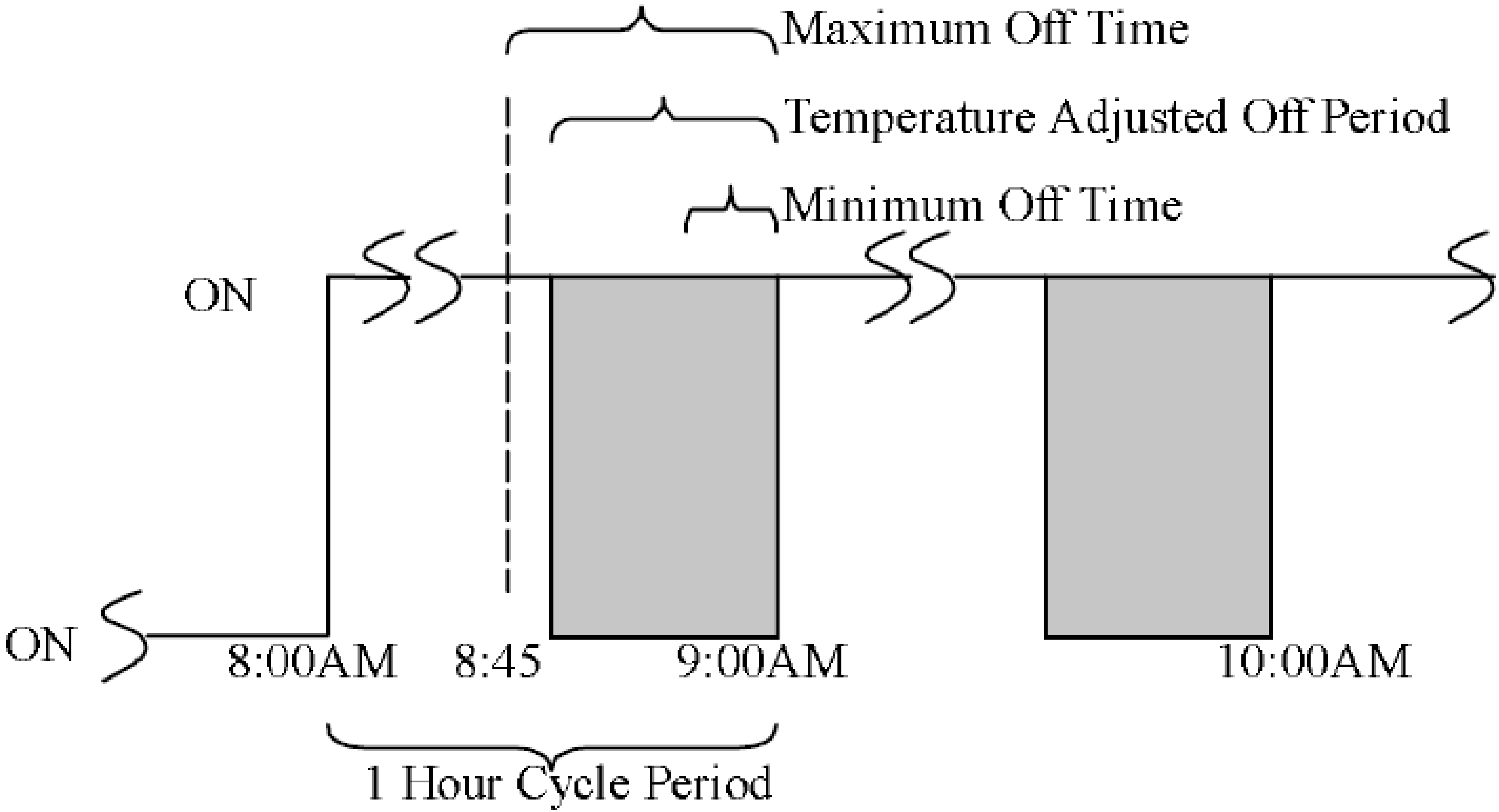
(Source: EMSD, 2002. *Guidelines on Application of Central Control and Monitoring Systems*, Energy Efficiency Office, Electrical and Mechanical Services Department (EMSD), Hong Kong. https://www.emsd.gov.hk/filemanager/en/content_725/Guidelines_CCMS.pdf)

Typical control strategies

- Duty cycling
  - Cycles equipment ON/OFF based on elapsed time
  - To improve overall operating efficiency
  - Two methods:
    - Based on time
    - A function of zone’s temperature
  - Drawbacks
    - Belt & bearing wear when aggressively scheduled
    - May generate noise in ductwork/pipework



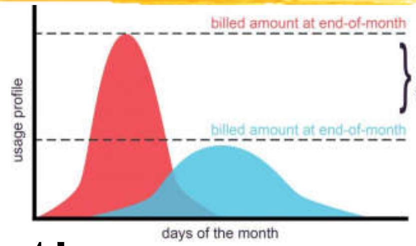
Duty cycle application



(Source: EMSD, 2002. *Guidelines on Application of Central Control and Monitoring Systems*, Energy Efficiency Office, Electrical and Mechanical Services Department (EMSD), Hong Kong. https://www.emsd.gov.hk/filemanager/en/content_725/Guidelines_CCMS.pdf)

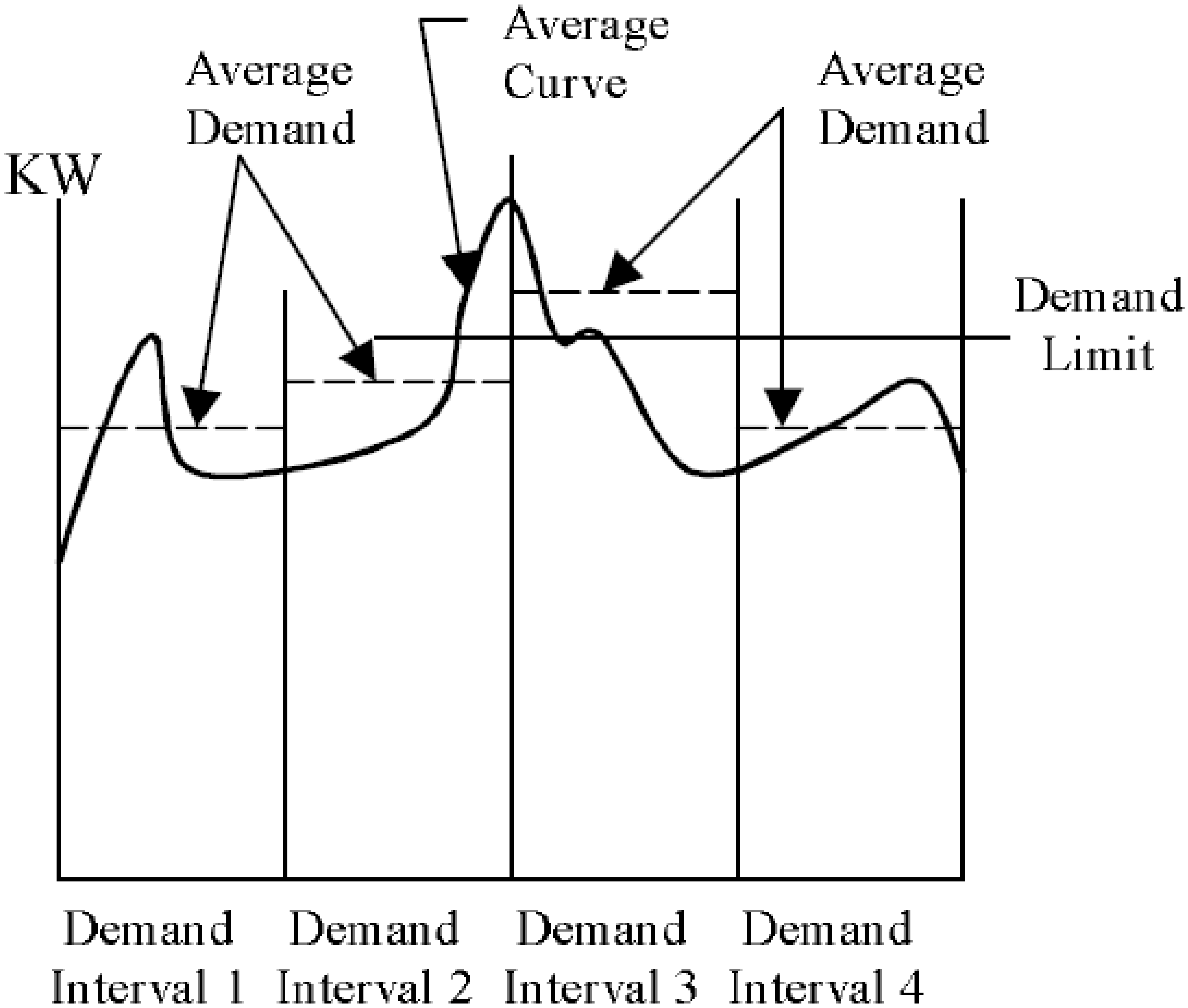
Typical control strategies

- Demand limiting



  - Cycle off or 'shedding' equipment to limit the peak electrical demand (e.g. for 'ratchet' demand charges apply)
  - Loads are restored when the demand decreases
  - Parameters:
    - Load's priority, min. operat. time, min. & max. off time
  - Drawbacks:
    - Periodic reductions in production or comfort

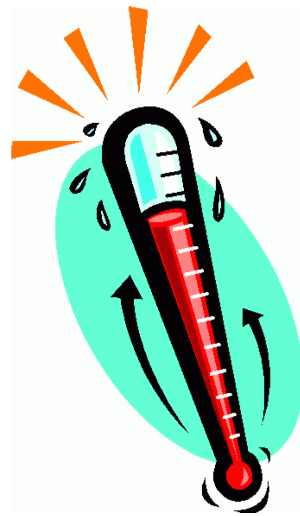
Typical power curve over four successive demand intervals



(Source: EMSD, 2002. *Guidelines on Application of Central Control and Monitoring Systems*, Energy Efficiency Office, Electrical and Mechanical Services Department (EMSD), Hong Kong. https://www.emsd.gov.hk/filemanager/en/content_725/Guidelines_CCMS.pdf)

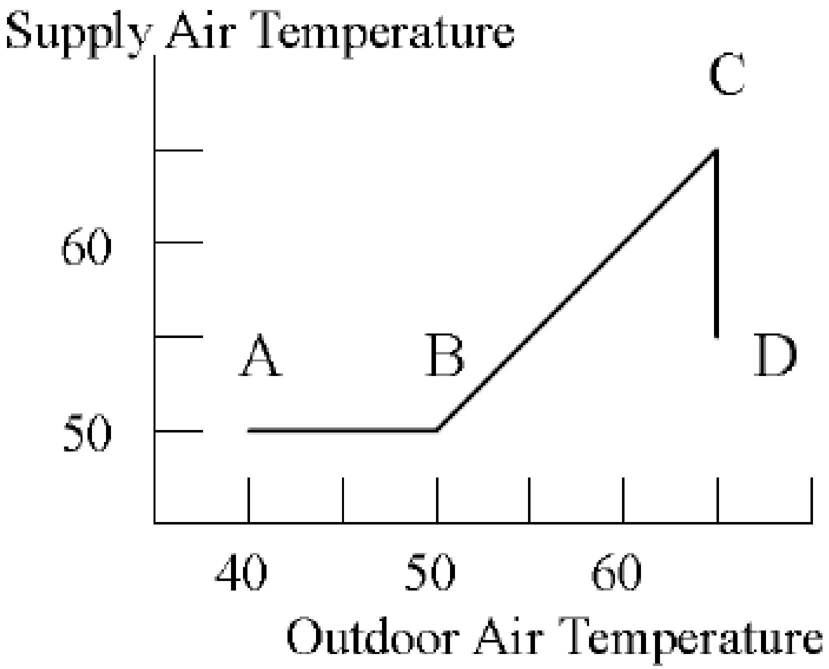
Typical control strategies

- Temperature reset
  - To reduce HVAC load & electrical consumption
  - Example:
    - Reset of discharge/supply air temperature
    - Reset of chilled water set points
  - Temp. in unoccupied zone is allowed to drift



- Other DDC software functions
  - Point trending: to analyse processes
  - Point commanding: override system status/values

Supply air temperature reset for a single duct VAV system

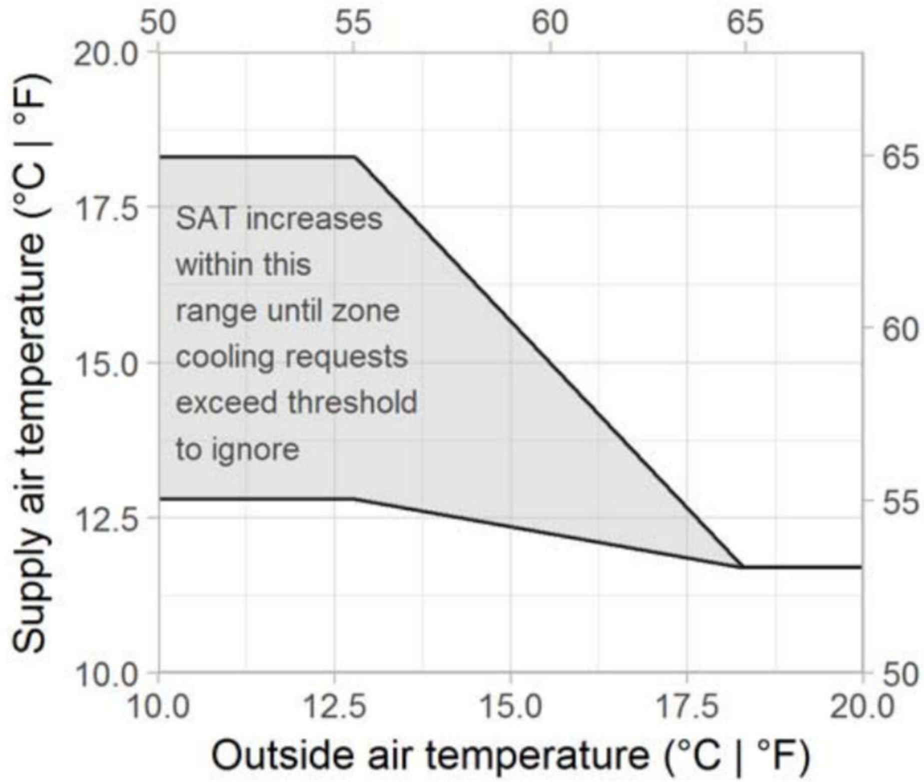


Note:

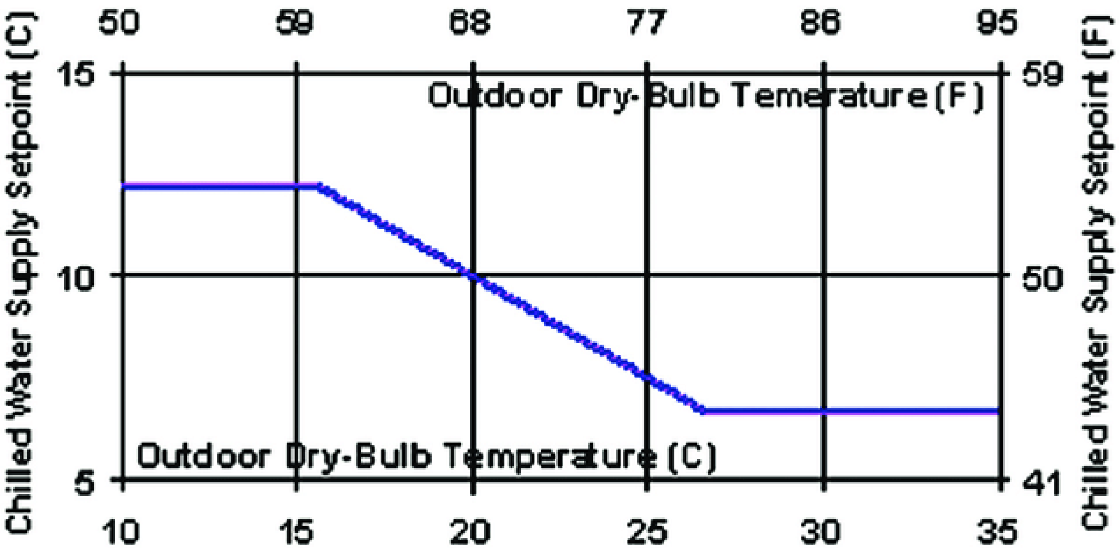
(1) A to B: Mix Outdoor and Return Air.

(2) B to C: 100% Outdoor Air

(3) C to D: Economizer Cooling or Enthalpy Control



Chilled-water temperature reset schedule

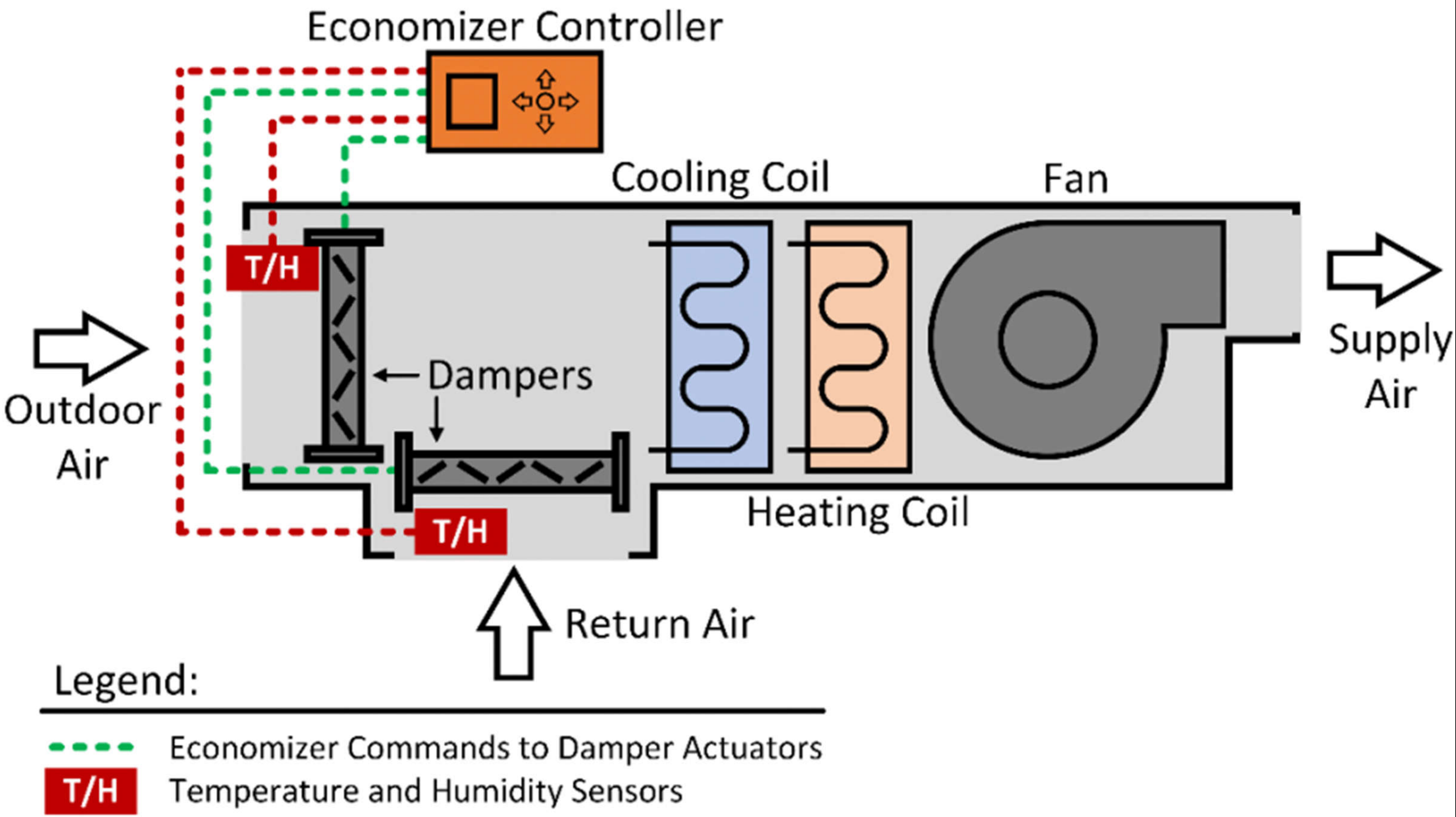


(Source: EMSD, 2002. *Guidelines on Application of Central Control and Monitoring Systems*, Energy Efficiency Office, Electrical and Mechanical Services Department (EMSD), Hong Kong. https://www.emsd.gov.hk/filemanager/en/content_725/Guidelines_CCMS.pdf)

Typical control strategies

- Airside economizers
  - Use outdoor air to help satisfy building cooling load (i.e. natural cooling or free cooling)
  - Control of economizer cycle: by monitoring the enthalpy or temperature of outside air
    - When outside air enthalpy/temp. drops below the limit, the position of the outside/return air dampers is modulated to introduce more outdoor air
  - Design issues: selection & placement of enthalpy sensors, humidity control, air duct size & air intake location

Schematic of an air-side economizer in a unitary HVAC system

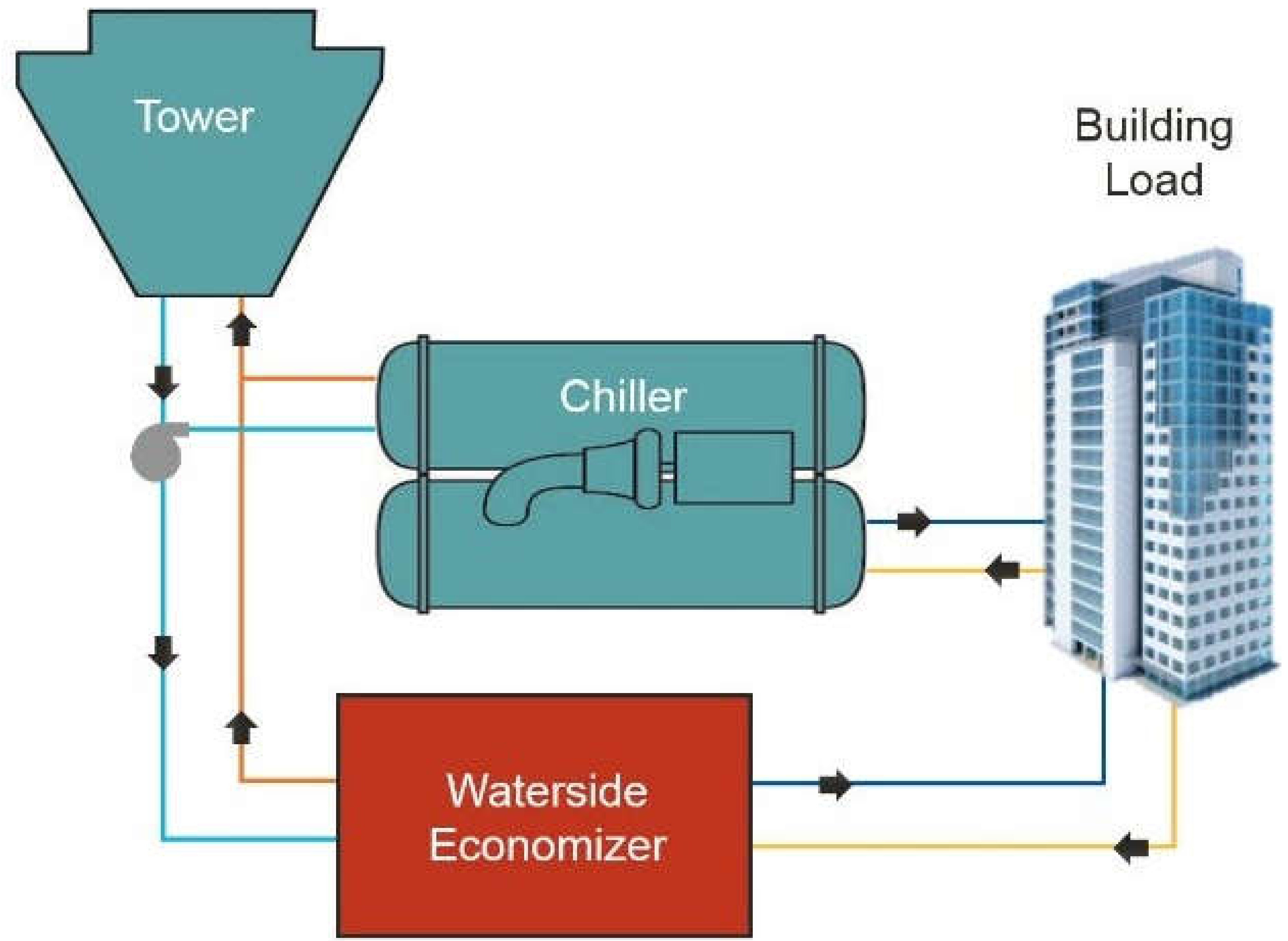


(Source: https://www.pnnl.gov/projects/om-best-practices/air-side-economizers)

Typical control strategies

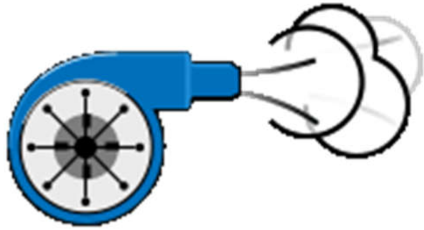
- Waterside economizers
  - A water-cooled chiller uses a separate "condenser" water loop to take away the heat gained in the chiller's refrigerant & release the heat in an evaporative cooling tower
  - Chiller-less (free) cooling when it is cold and dry enough outside
  - Can be integrated with the chiller or non-integrated

Basic concept of waterside economizer



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

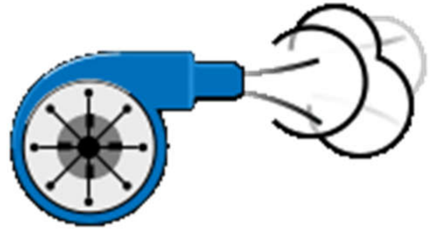
Air handling systems



- Air handling system control applications:
  - Ventilation Control Processes
    - Fan System Start-Stop Control
    - Fixed Quantity of Outdoor Air Control
    - Mixed Air Control
    - Economizer Cycle Control (outdoor air dry bulb or enthalpy)
    - Mixed Air Control with Economizer Cycle
    - Economizer Cycle Control of Space Temperature with Supply Air Temperature Setpoint Reset
  - Year-round System Control Process
    - Heating, Cooling, & Economizer

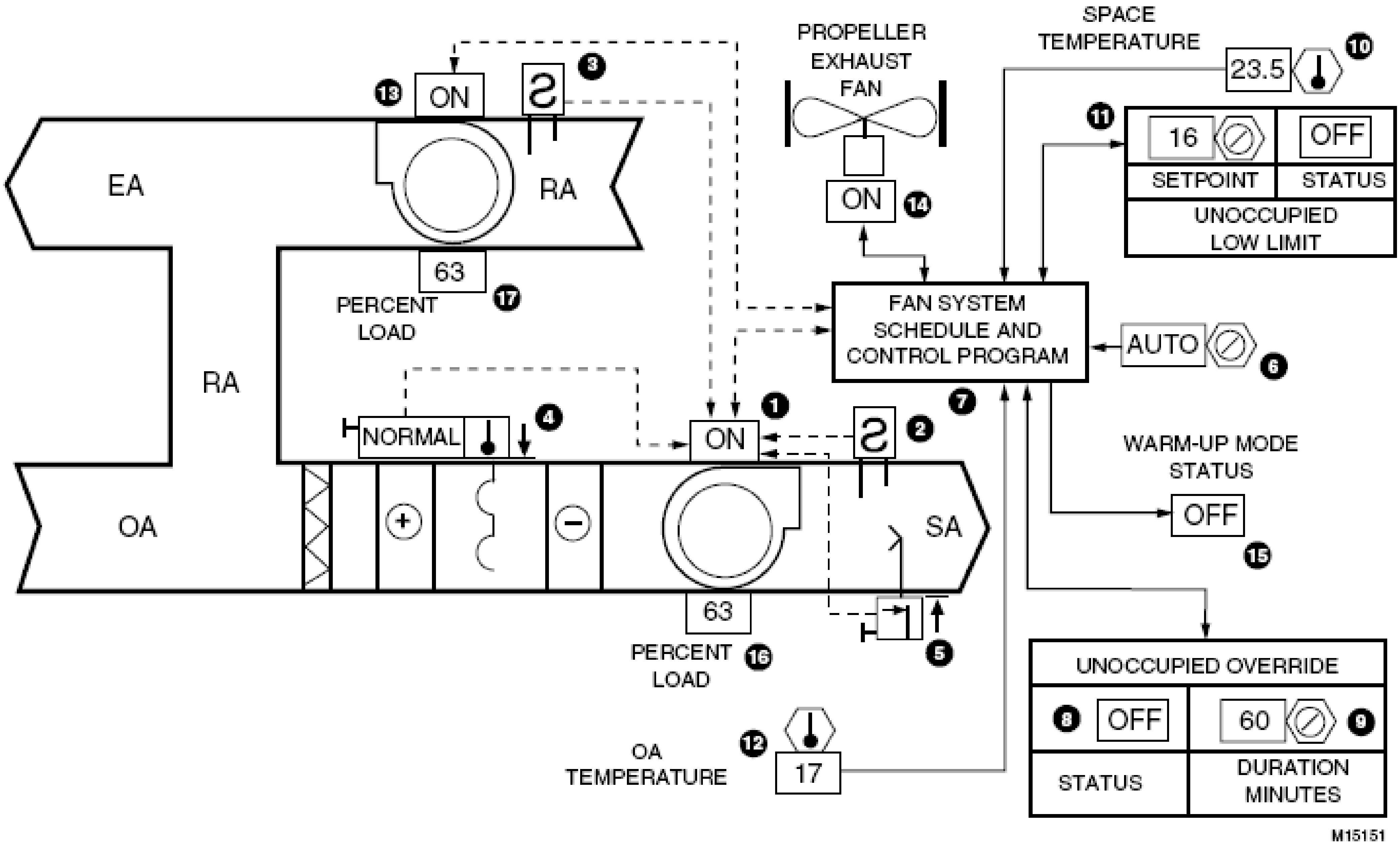
[Further info.: Honeywell, 1997. *Engineering Manual of Automatic Control for Commercial Buildings*, pp. 201-260]

Air handling systems



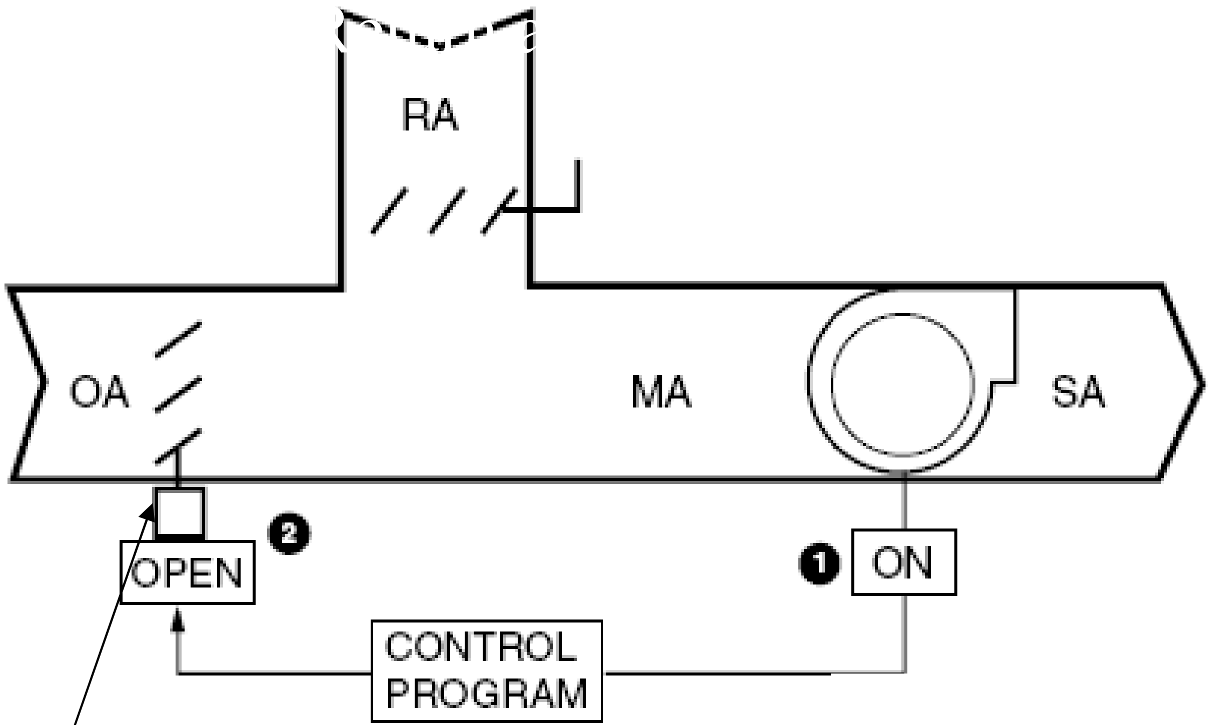
- Typical format for presenting the control system design
  - Functional description (w/ diagram)
  - Features
  - Conditions for successful operation
  - Limitations
  - Specifications
  - Psychrometric aspects

Fan system start-stop control

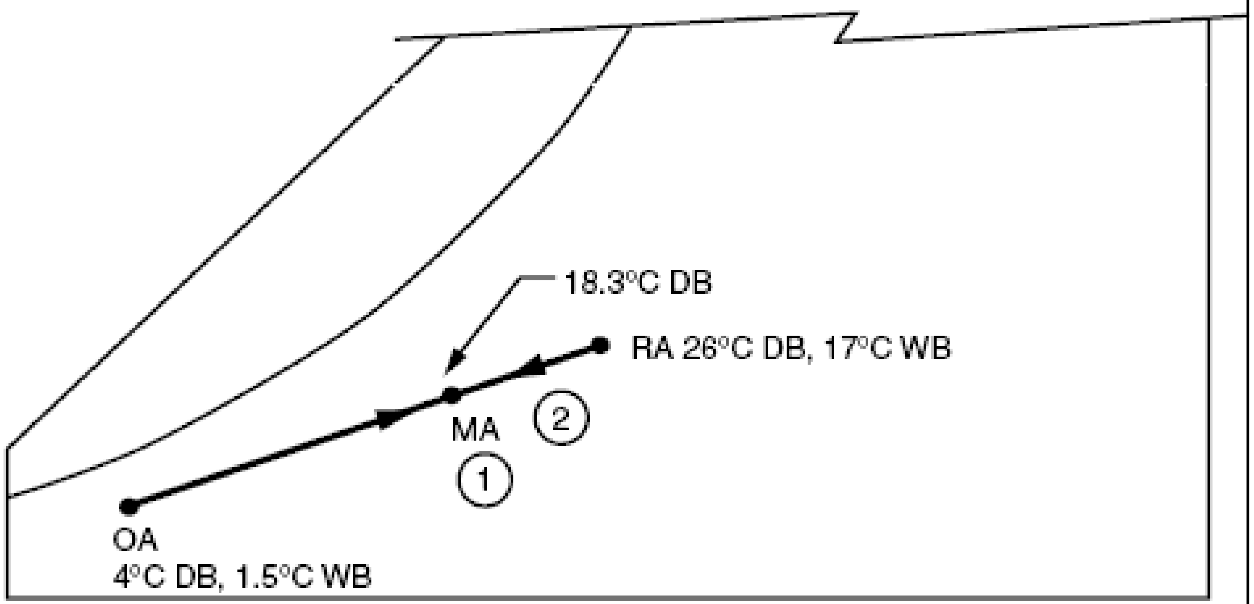


[Source: Honeywell, 1997. *Engineering Manual of Automatic Control for Commercial Buildings*]

Fixed quantity of outdoor air control

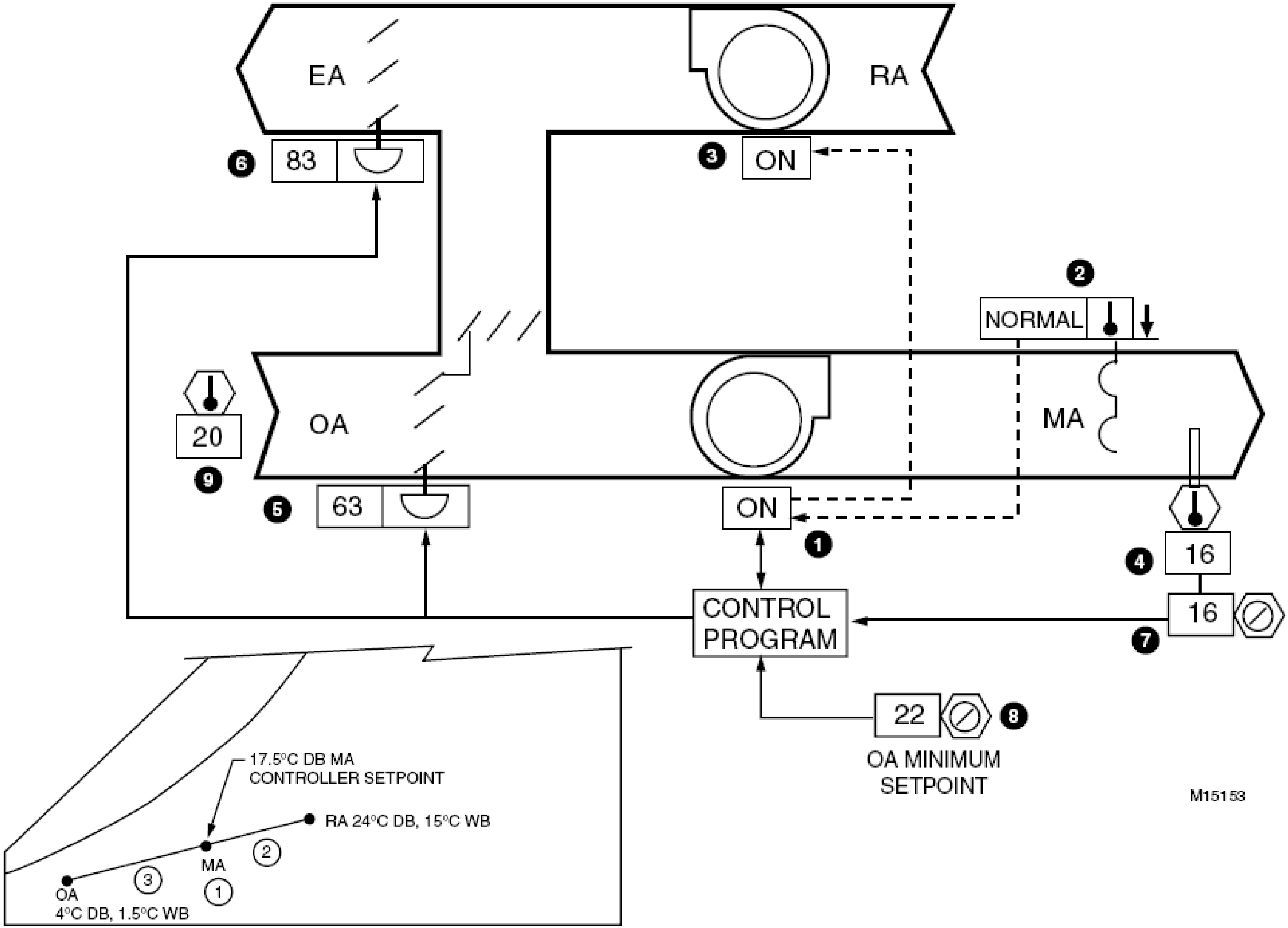


Two-position damper



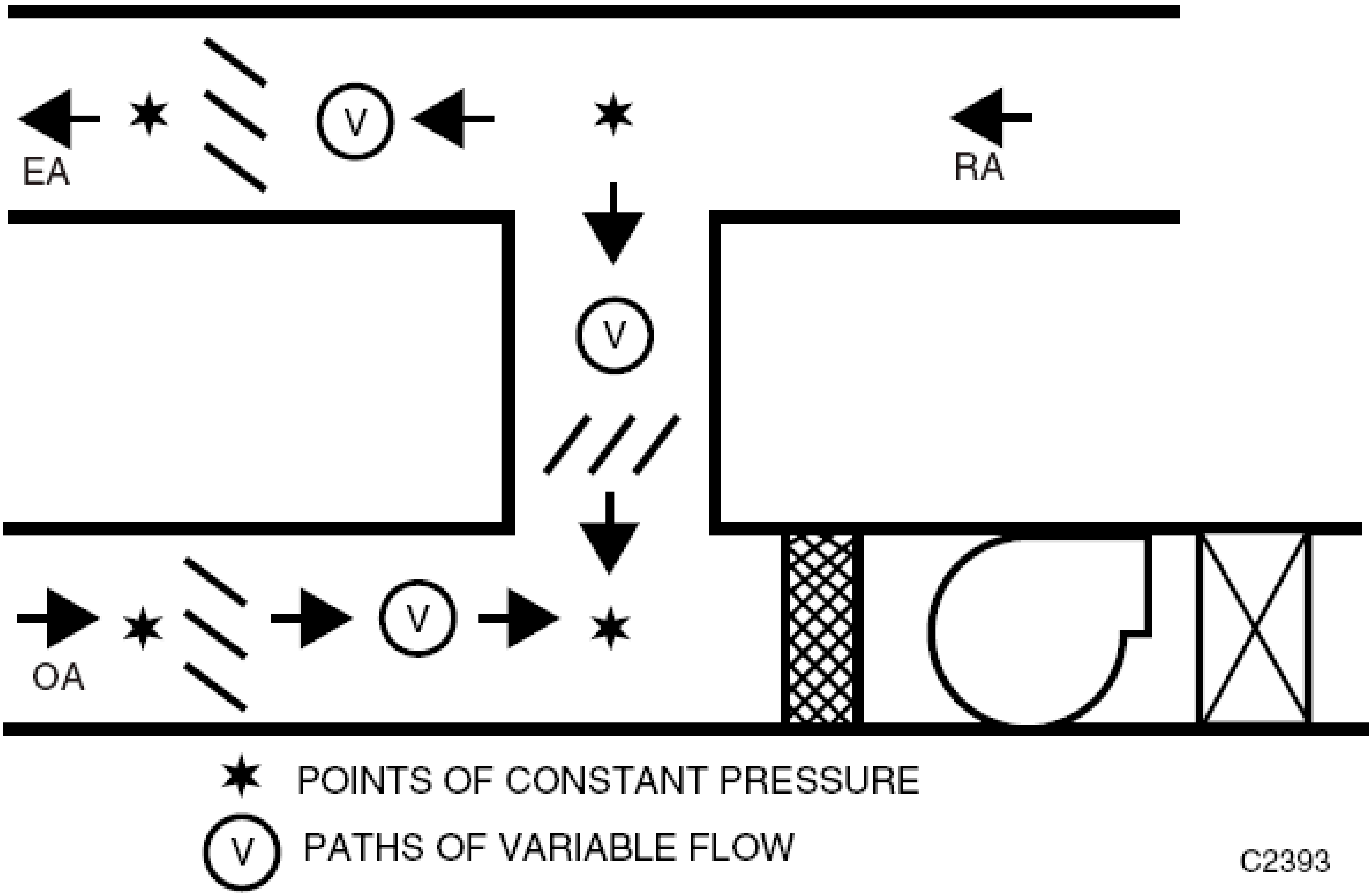
[Source: Honeywell, 1997. *Engineering Manual of Automatic Control for Commercial Buildings*]

Mixed air control



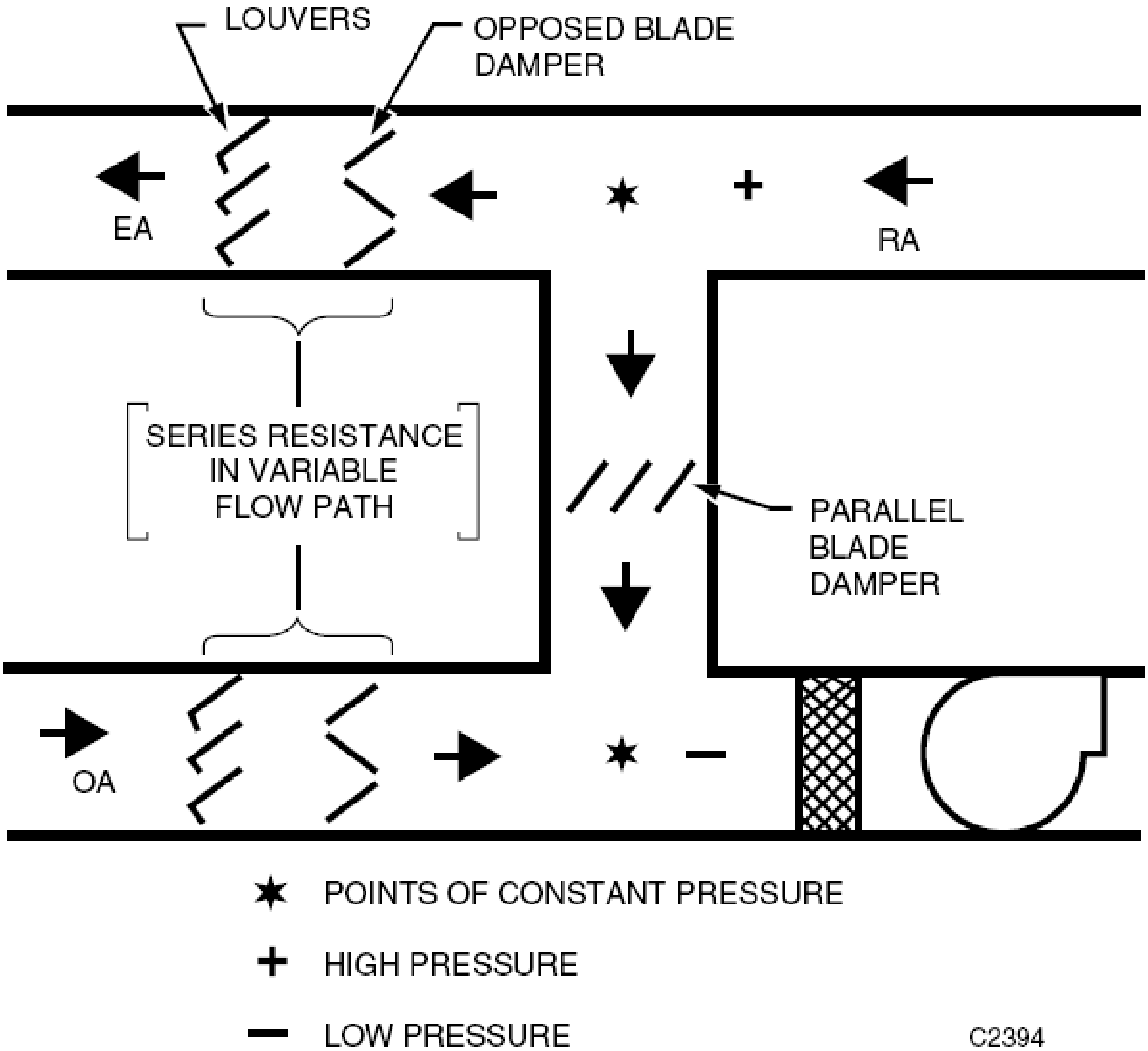
[Source: Honeywell, 1997. *Engineering Manual of Automatic Control for Commercial Buildings*]

Mixed air control system (parallel blade dampers)



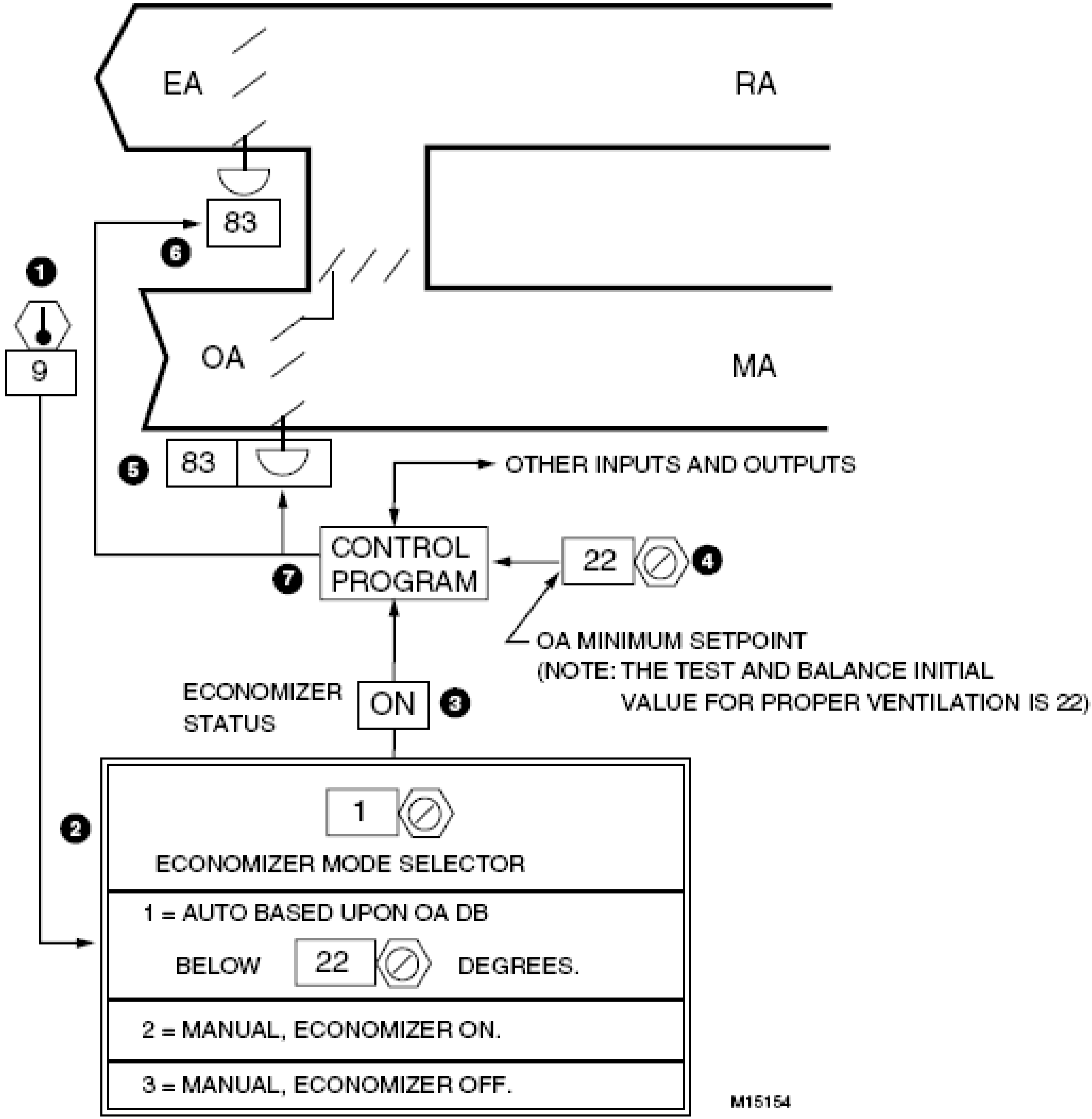
[Source: Honeywell, 1997. *Engineering Manual of Automatic Control for Commercial Buildings*]

Mixed air system with louvers



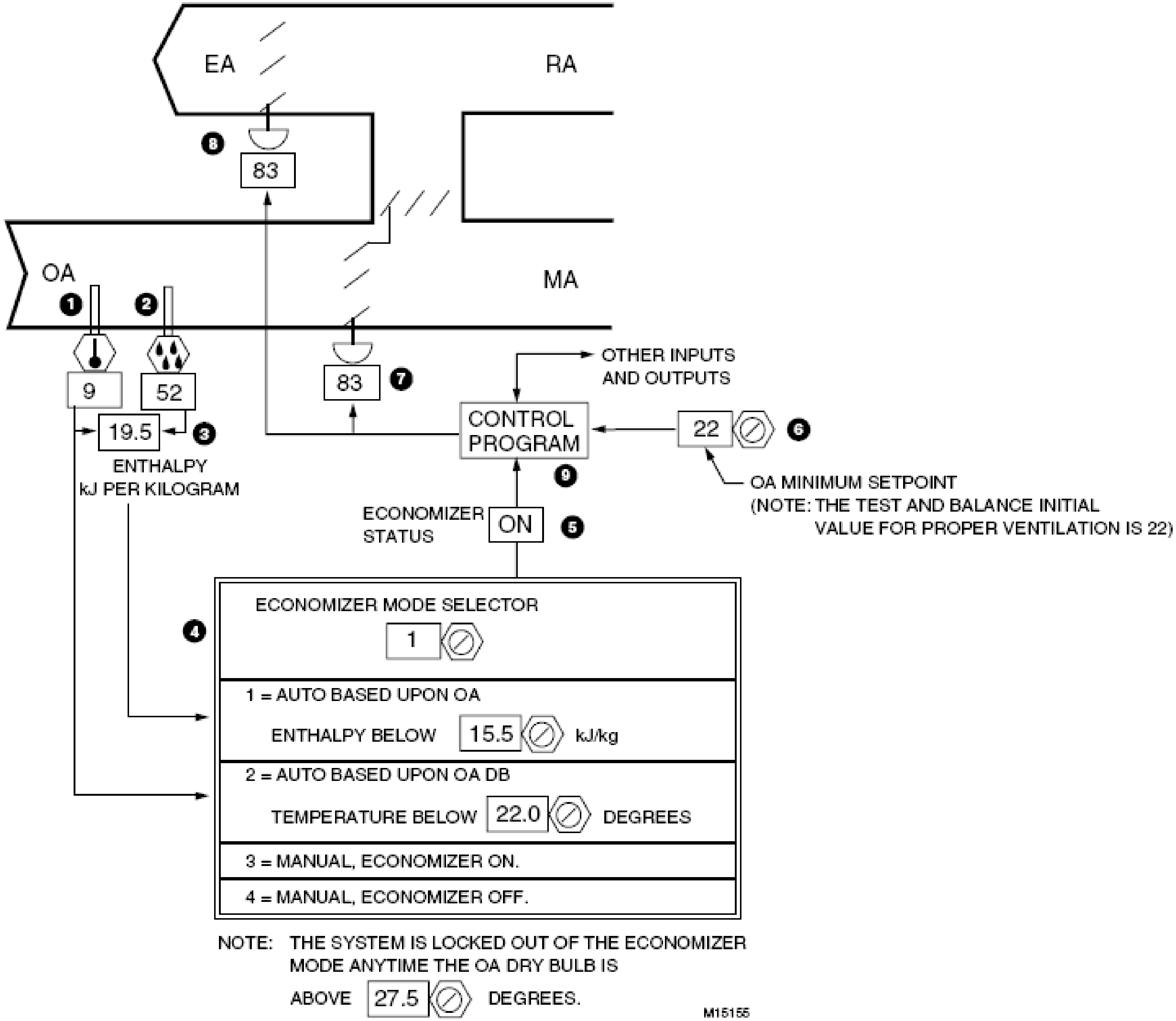
[Source: Honeywell, 1997. *Engineering Manual of Automatic Control for Commercial Buildings*]

Economizer cycle control (outdoor air dry bulb)



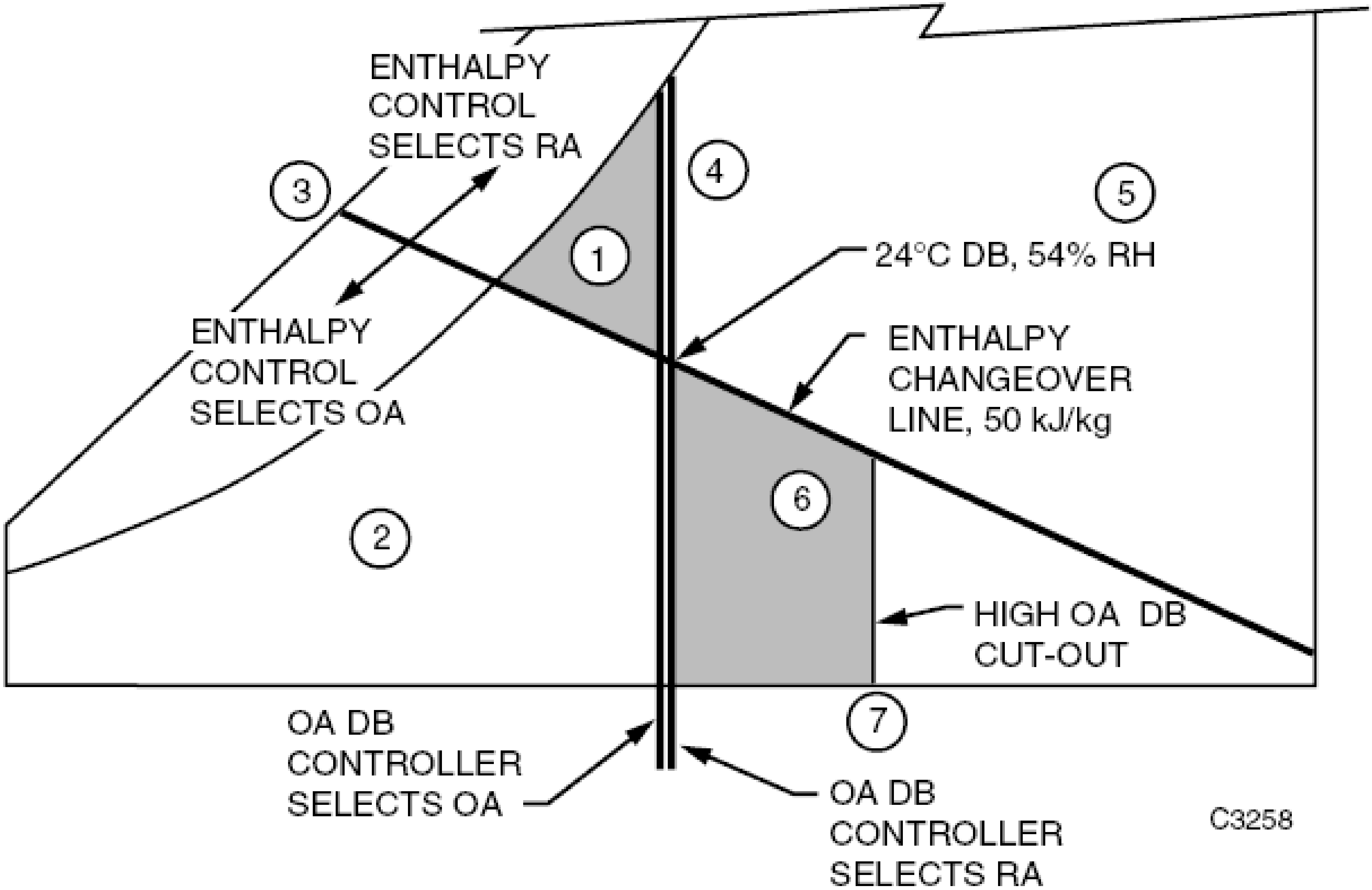
[Source: Honeywell, 1997. *Engineering Manual of Automatic Control for Commercial Buildings*]

Economizer cycle control (outdoor air enthalpy)



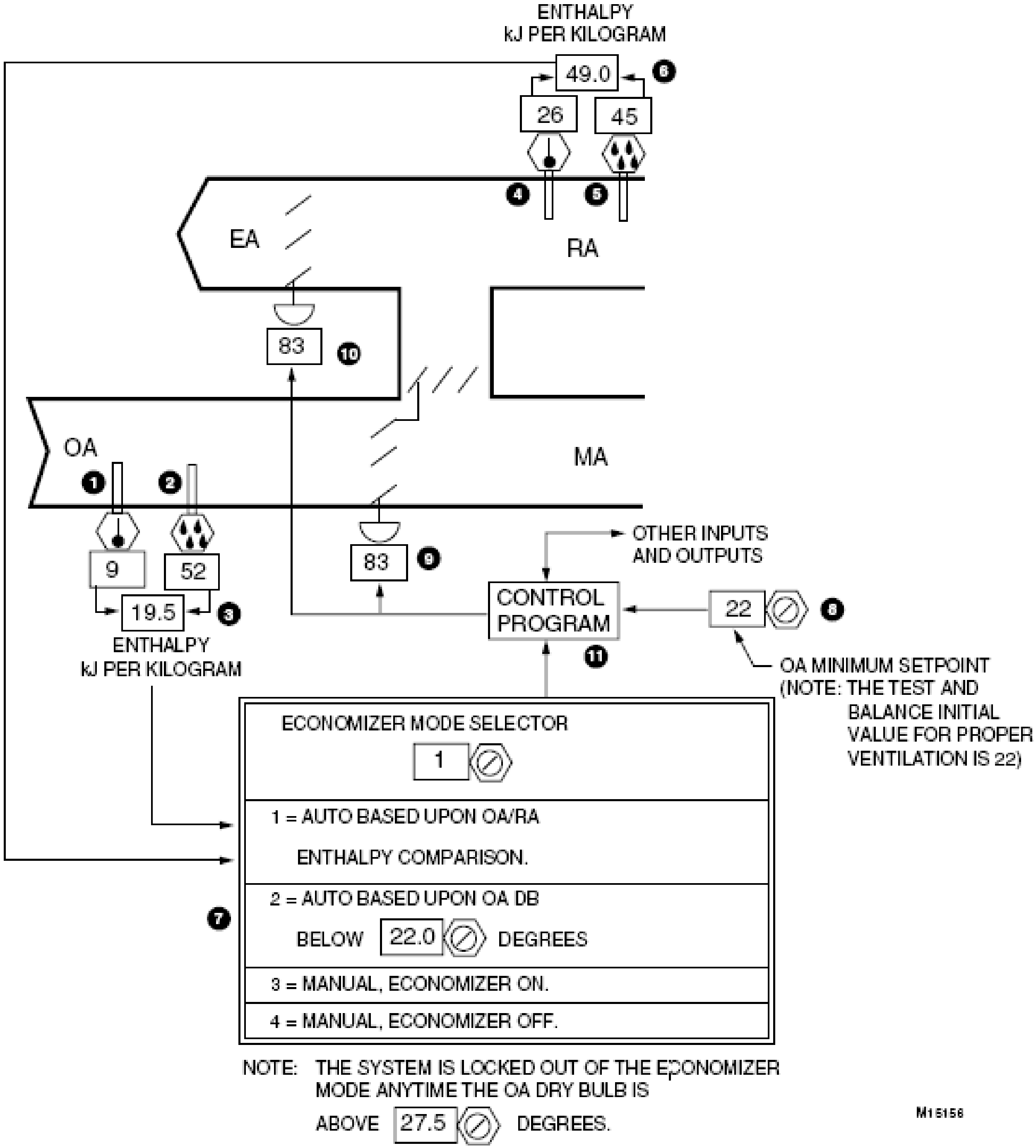
[Source: Honeywell, 1997. *Engineering Manual of Automatic Control for Commercial Buildings*]

Economizer cycle control (outdoor air enthalpy)



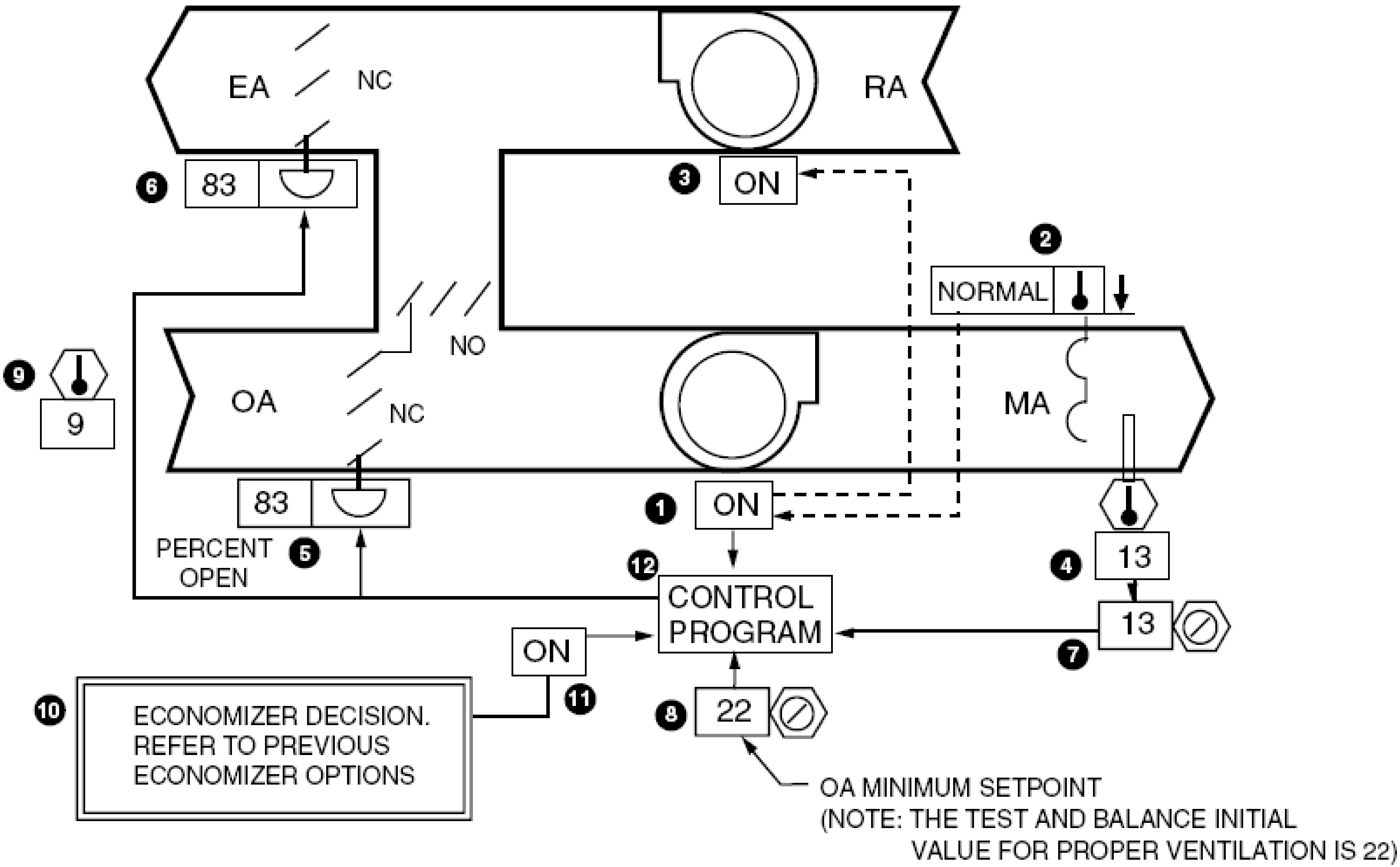
[Source: Honeywell, 1997. *Engineering Manual of Automatic Control for Commercial Buildings*]

Economizer cycle control (outdoor air/return air enthalpy comparison)



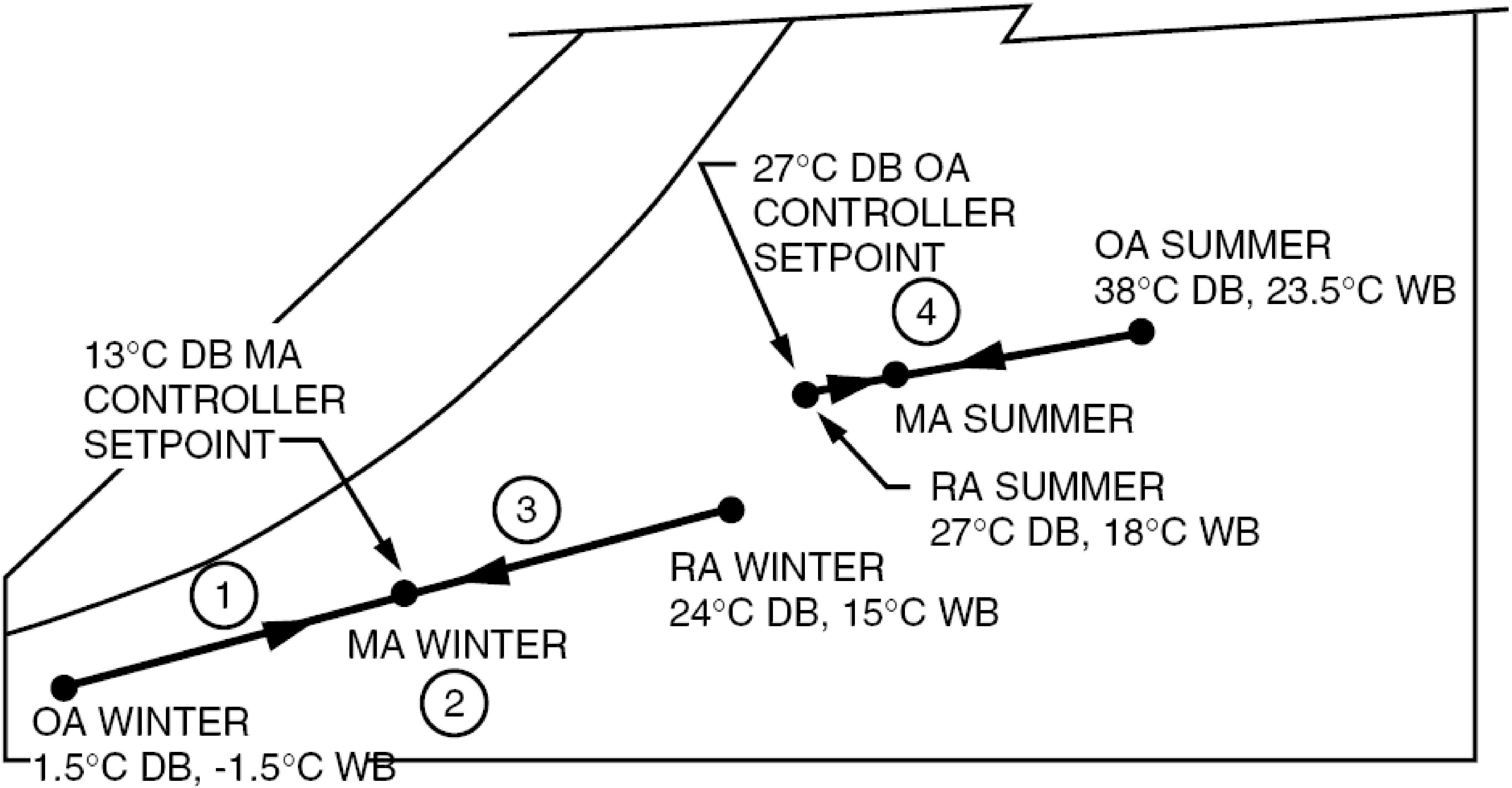
[Source: Honeywell, 1997. *Engineering Manual of Automatic Control for Commercial Buildings*]

Mixed air control with economizer cycle



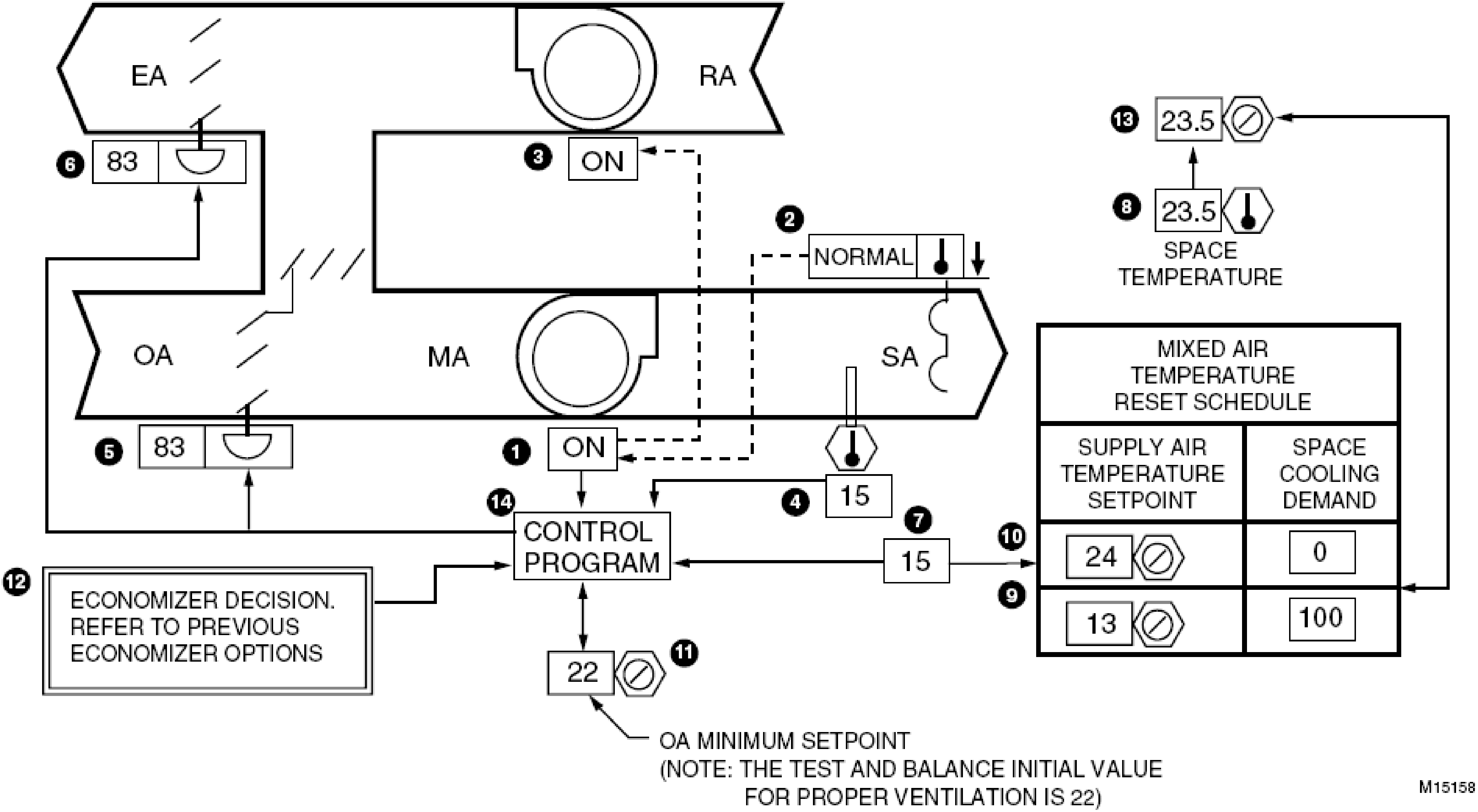
[Source: Honeywell, 1997. *Engineering Manual of Automatic Control for Commercial Buildings*]

Mixed air control with economizer cycle



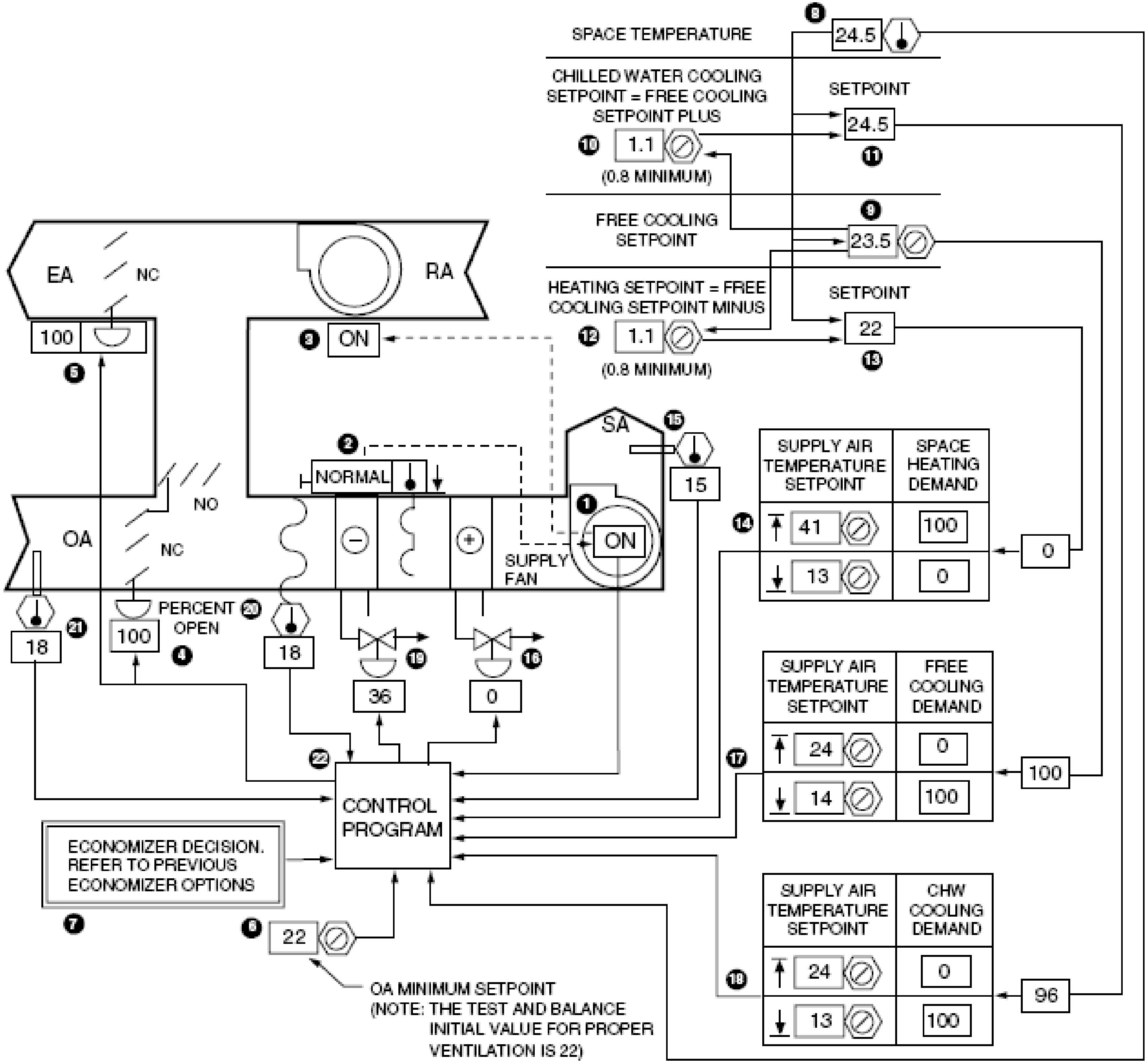
[Source: Honeywell, 1997. *Engineering Manual of Automatic Control for Commercial Buildings*]

Economizer cycle control of space temperature with supply air temperature setpoint reset



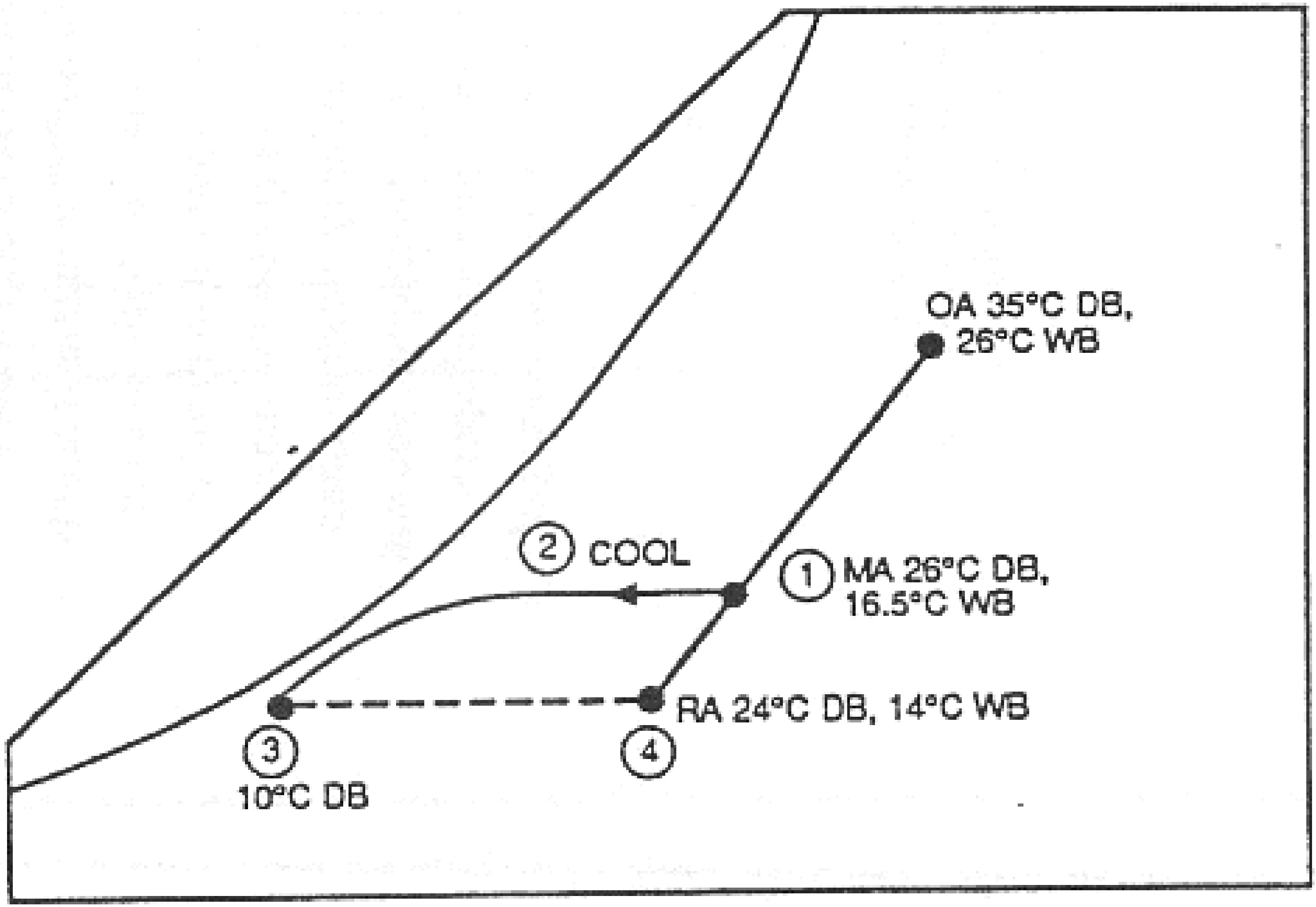
[Source: Honeywell, 1997. *Engineering Manual of Automatic Control for Commercial Buildings*]

Year-round system control – heating, cooling, and economizer



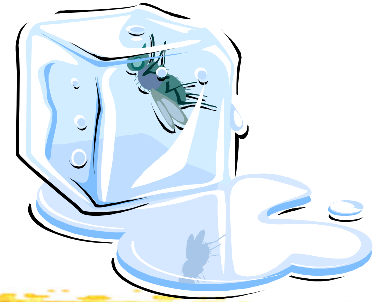
[Source: Honeywell, 1997. *Engineering Manual of Automatic Control for Commercial Buildings*]

VAV System with Cooling and Duct Reheat – Psychrometric Aspects



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

Chiller system control

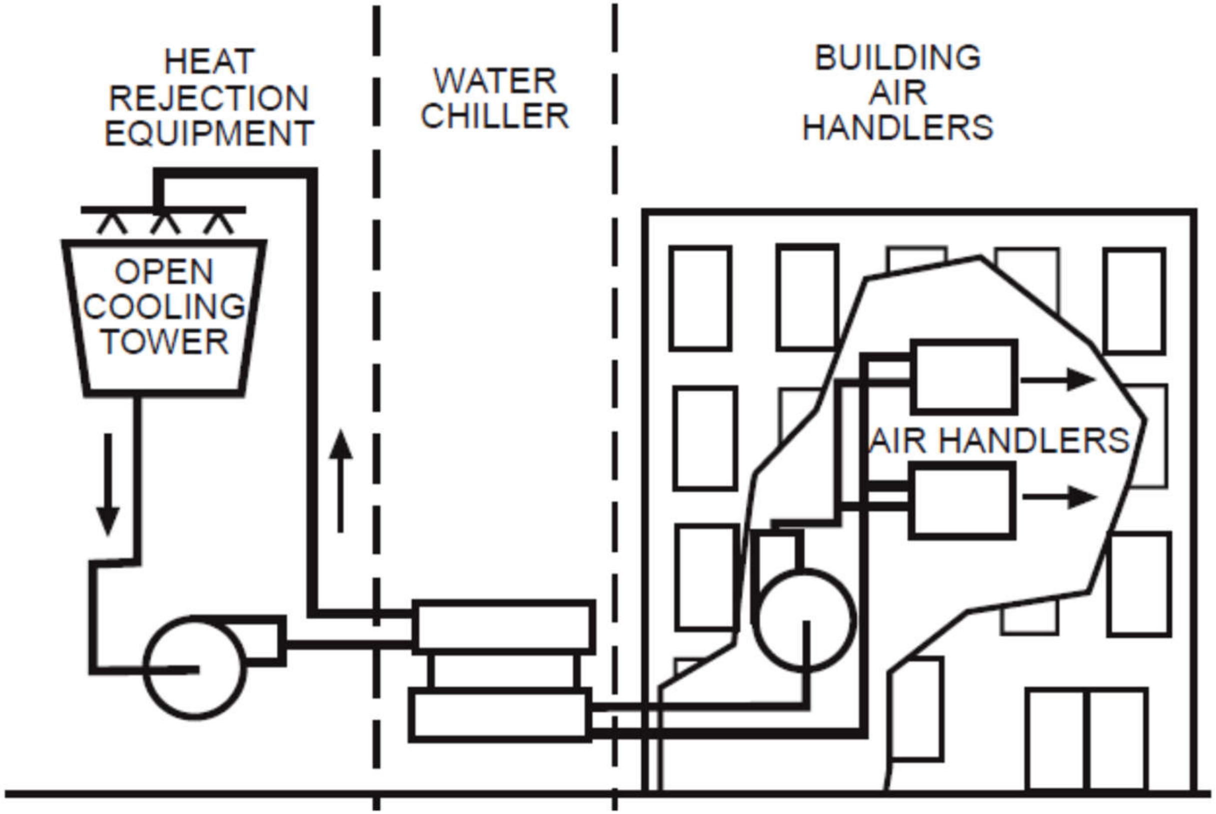


- Chiller plant is the major use of energy in many buildings
  - Chiller capacity controls
    - Usually factory installed by the chiller manufacturer
    - The BAS stages chillers on and off, provides chiller controls with a chilled water temperature setpoint, and controls the condenser water system
    - Chillers are usually controlled from their leaving water temperature; except that chillers using reciprocating compressors are often controlled from their entering water temperature

Chiller system control

- Types of chillers
  - Vapour compression
    - Most common type; electrically driven compressor
      - Centrifugal compressor
      - Reciprocating compressor
      - Screw compressor
      - Scroll compressor
  - Absorption
    - Use heat to drive the refrigeration cycle. They are used where heat is cheaply available; they have some advantages in large systems

Typical water chilling system and capacity control methods

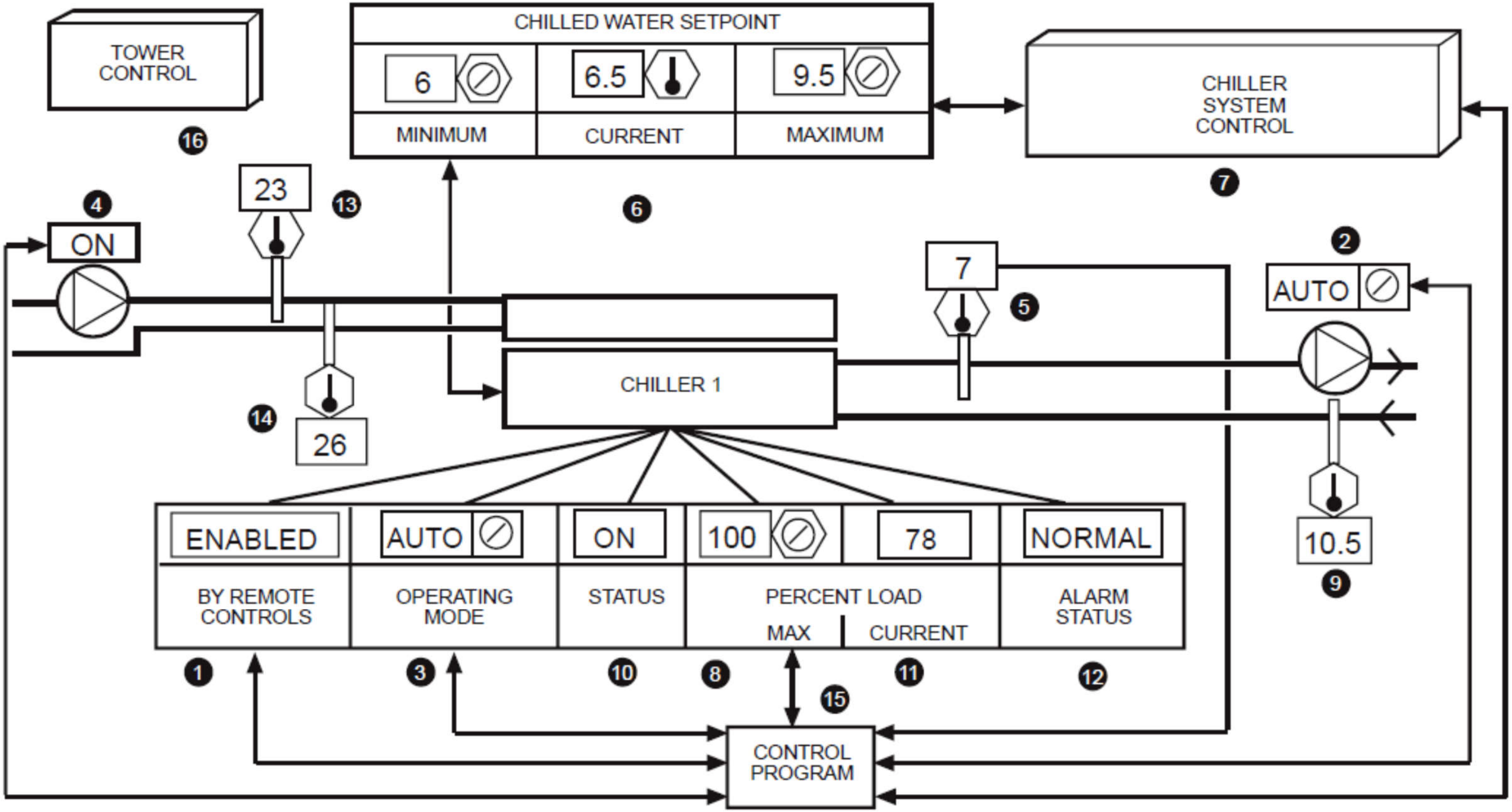


Compressor	**Application**	**Capacity control**
Centrifugal	All sizes	Inlet vane and VSD
Reciprocating	All sizes	Cylinder unloading
Screw	> 200 kW	Slide valve and VSD
Scroll	> 50 kW and < 200 kW	VSD

(VSD = variable speed drive)

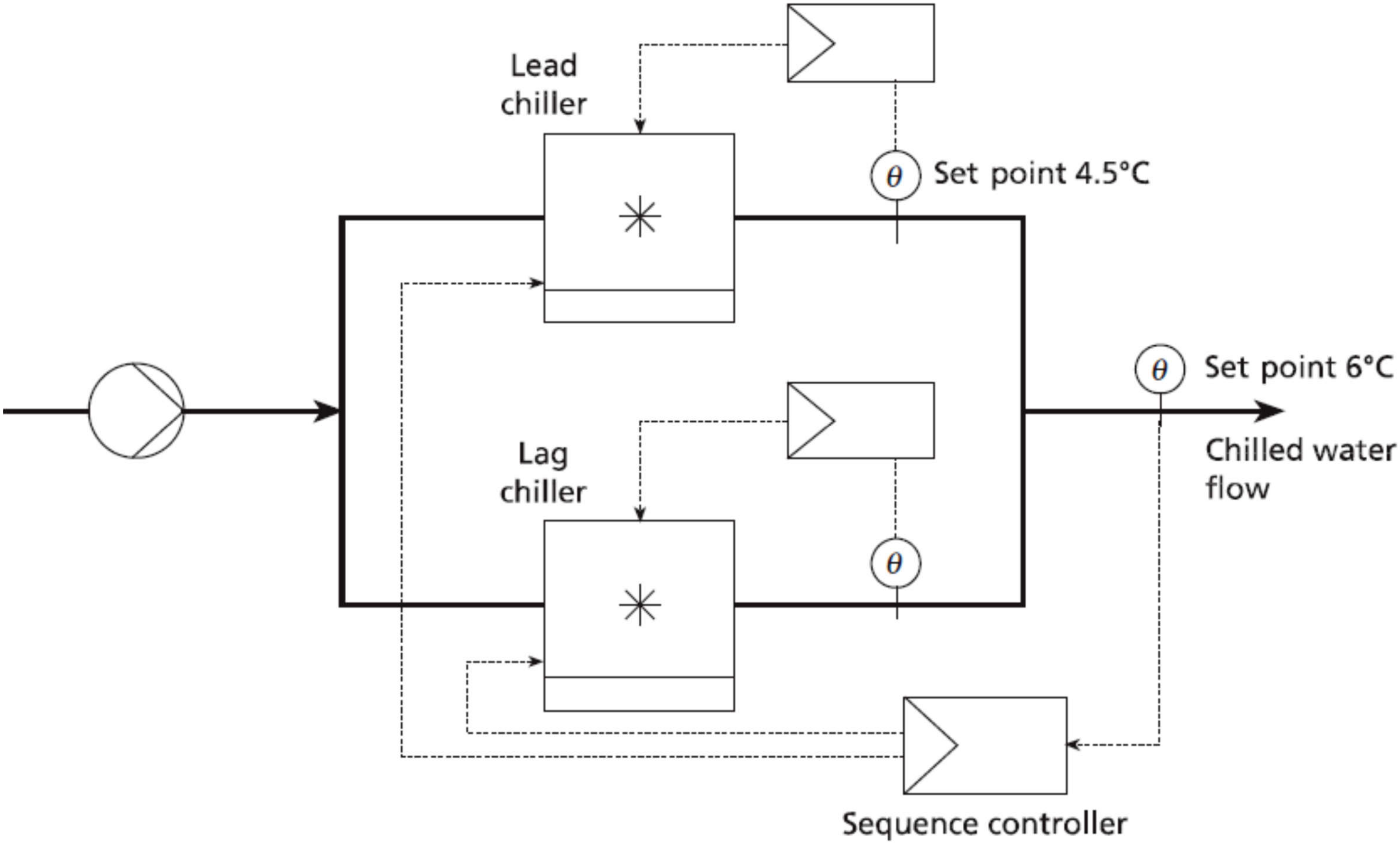
[Source: Honeywell, 1997. *Engineering Manual of Automatic Control: for Commercial Buildings* and CIBSE Guide H]

Single chiller control graphic



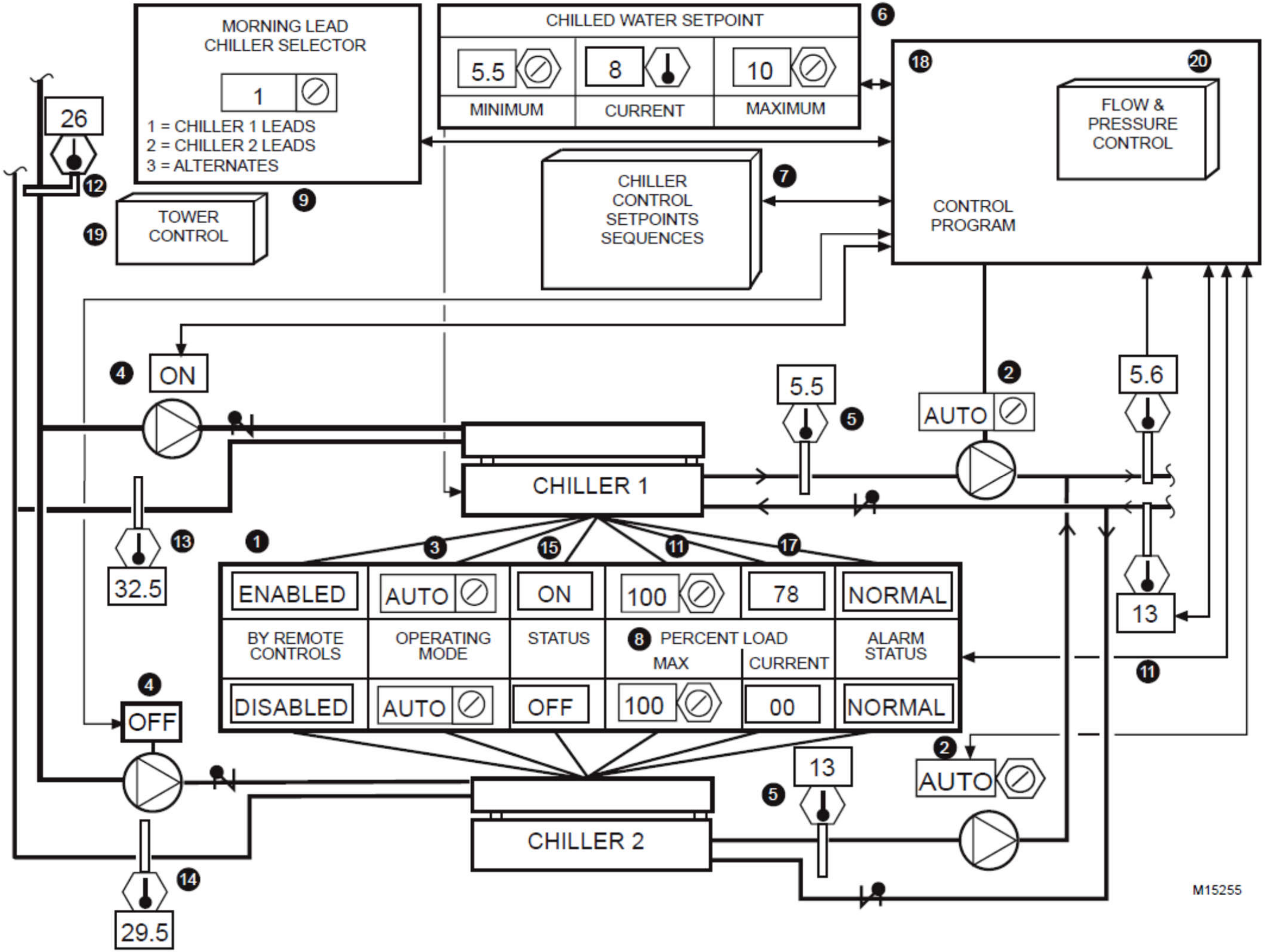
[Source: Honeywell, 1997. *Engineering Manual of Automatic Control: for Commercial Buildings*]

Two chillers in parallel operating under sequence controller



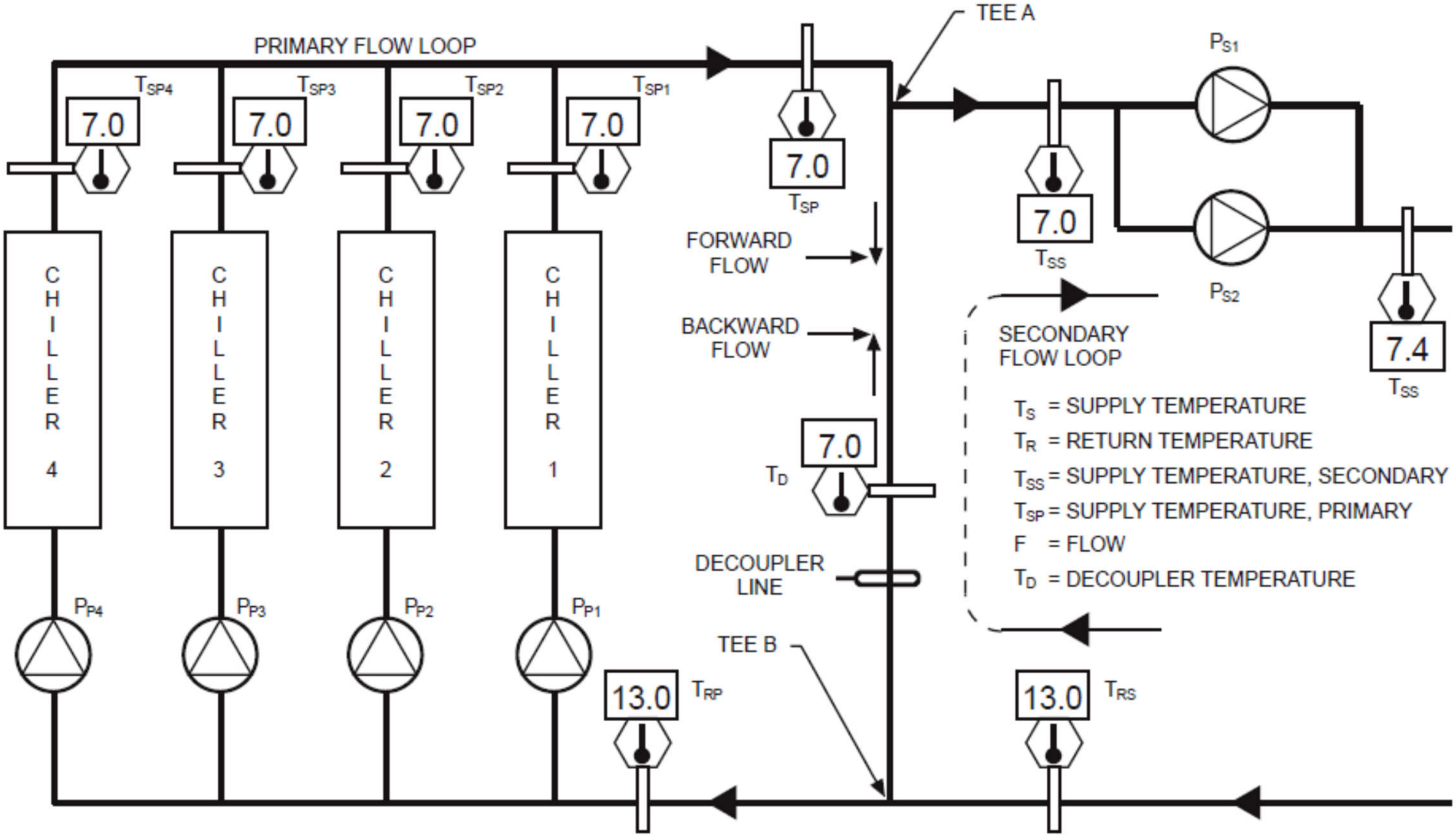
[Source: CIBSE, 2008. *Building Control Systems*, CIBSE Guide H, 2nd ed.]

Dual centrifugal chiller control graphic



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

Multiple equal sized chillers control graphic



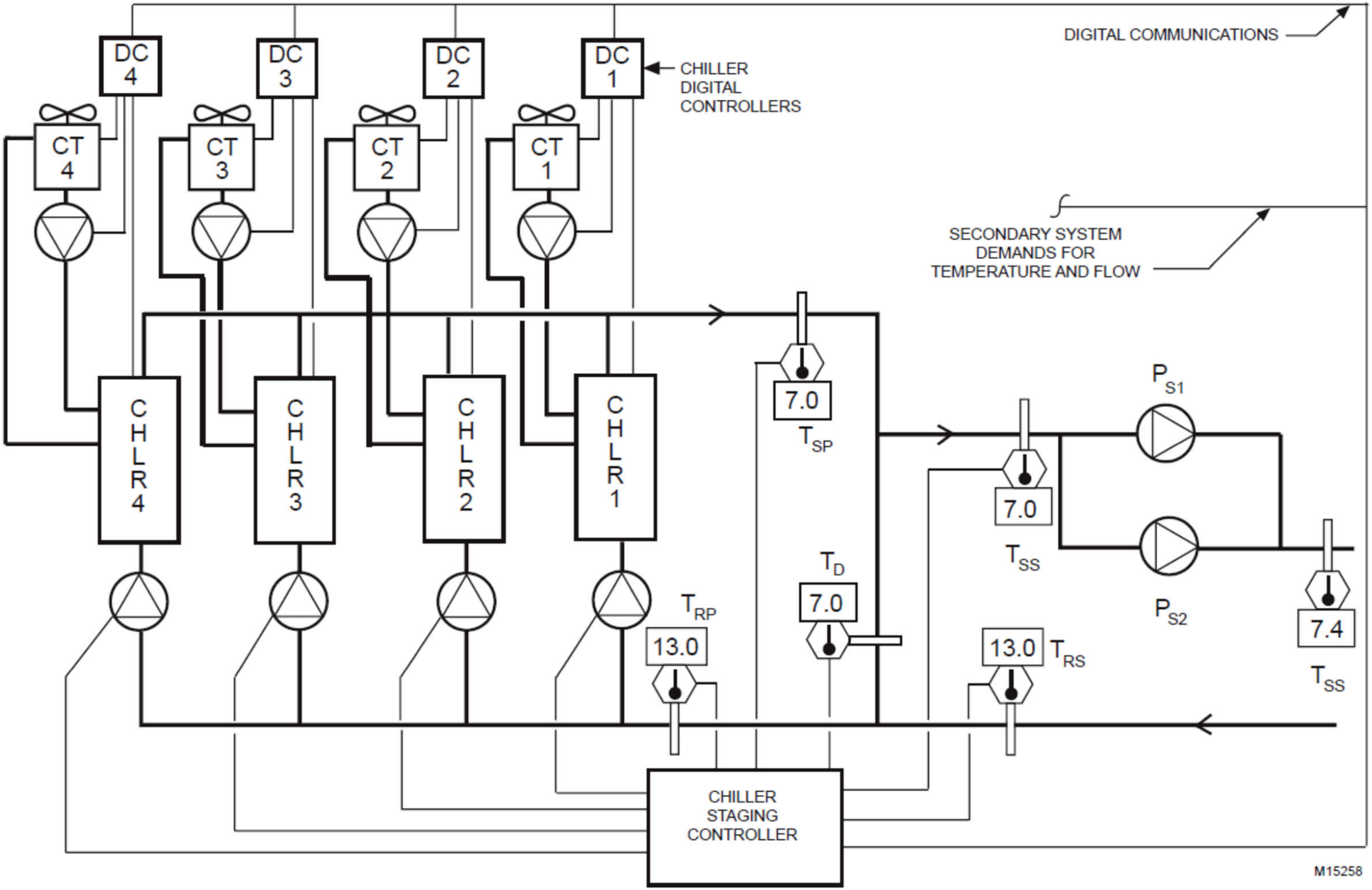
$$F_S = F_P \frac{\Delta T_P}{\Delta T_S}$$

WHERE F_S = SECONDARY FLOW
F_P = PRIMARY FLOW,
ΔT_P = DIFFERENTIAL TEMPERATURE, PRIMARY
ΔT_S = DIFFERENTIAL TEMPERATURE, SECONDARY

NOTE: F_P = SUM OF PRIMARY PUMP FLOWS BASED UPON TEST-AND-BALANCE DATA AND PUMP ON-OFF STATUS.

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

Typical digital controller configuration for multiple chillers

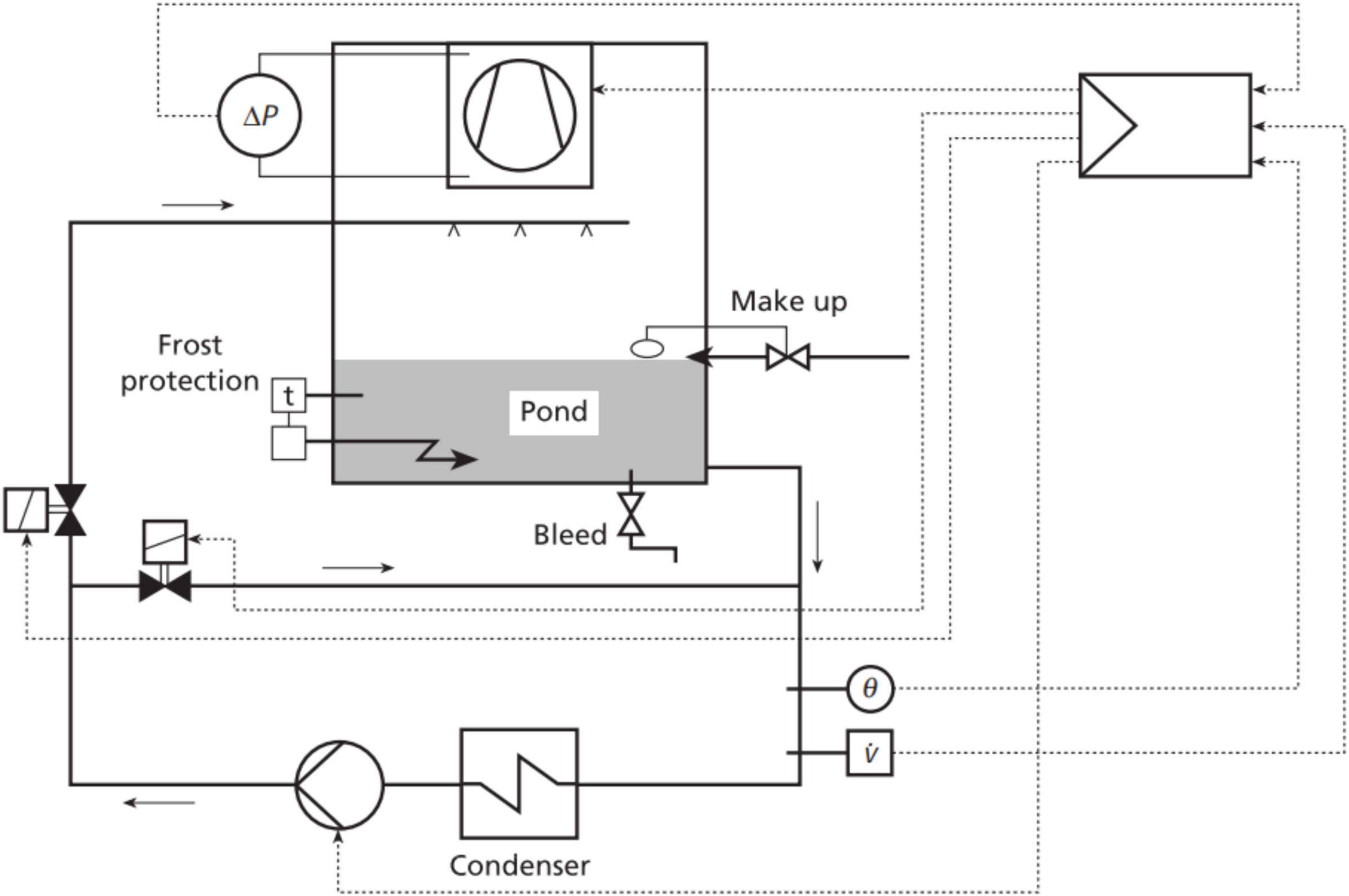


[Source: Honeywell, 1997. *Engineering Manual of Automatic Control: for Commercial Buildings*]

Chiller system control

- Control strategies for cooling tower operation:
  - 1. <u>Fixed set point</u>
    - Condenser temperature is controlled at a constant set point (26 to 28ºC), by the use of the modulating bypass valve & the cooling tower fan
  - 2. <u>Variable set point (fixed approach)</u>
    - Adjusts the set point of the condenser water temperature in accordance with a characteristic curve
  - 3. <u>Near optimal control</u>
    - Regulates the fan speed in proportion to the part load ratio (the actual load to the maximum system load)

Open circuit cooling tower with bypass circuit

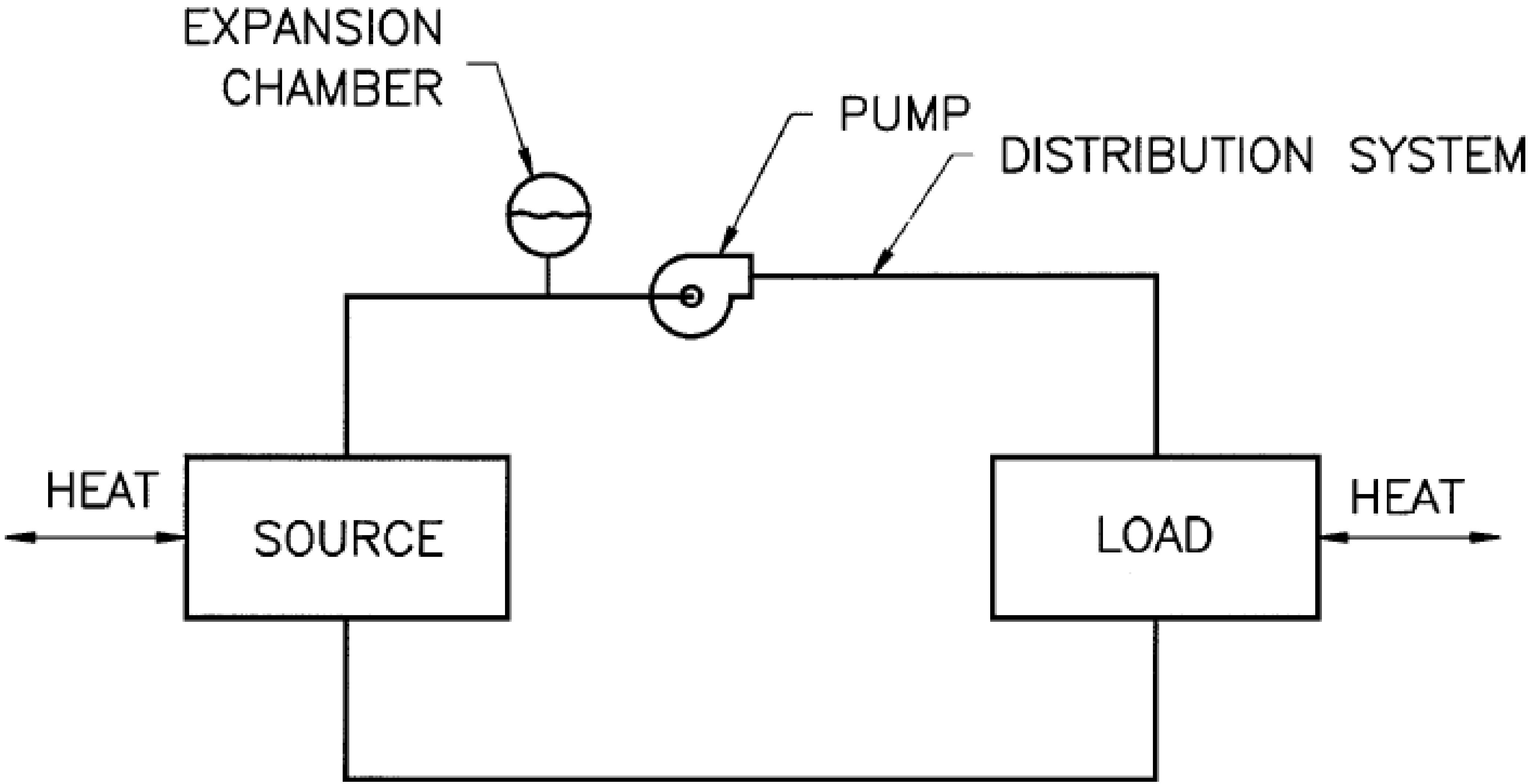


[Source: CIBSE, 2008. *Building Control Systems*, CIBSE Guide H, 2nd ed.]

Control of hydraulic circuits

- The variety of hydraulic circuits used in cooling & heating applications is very great
  - Achieve controllability under part load conditions
- Proper network design & balance is essential
- 3 simple principles for good controllability:
  - 1) Design flow must be available at all terminals
  - 2) Control valves must have sufficient authority
  - 3) Flows must be compatible at system interfaces

Basic components of HVAC water (hydronic) system

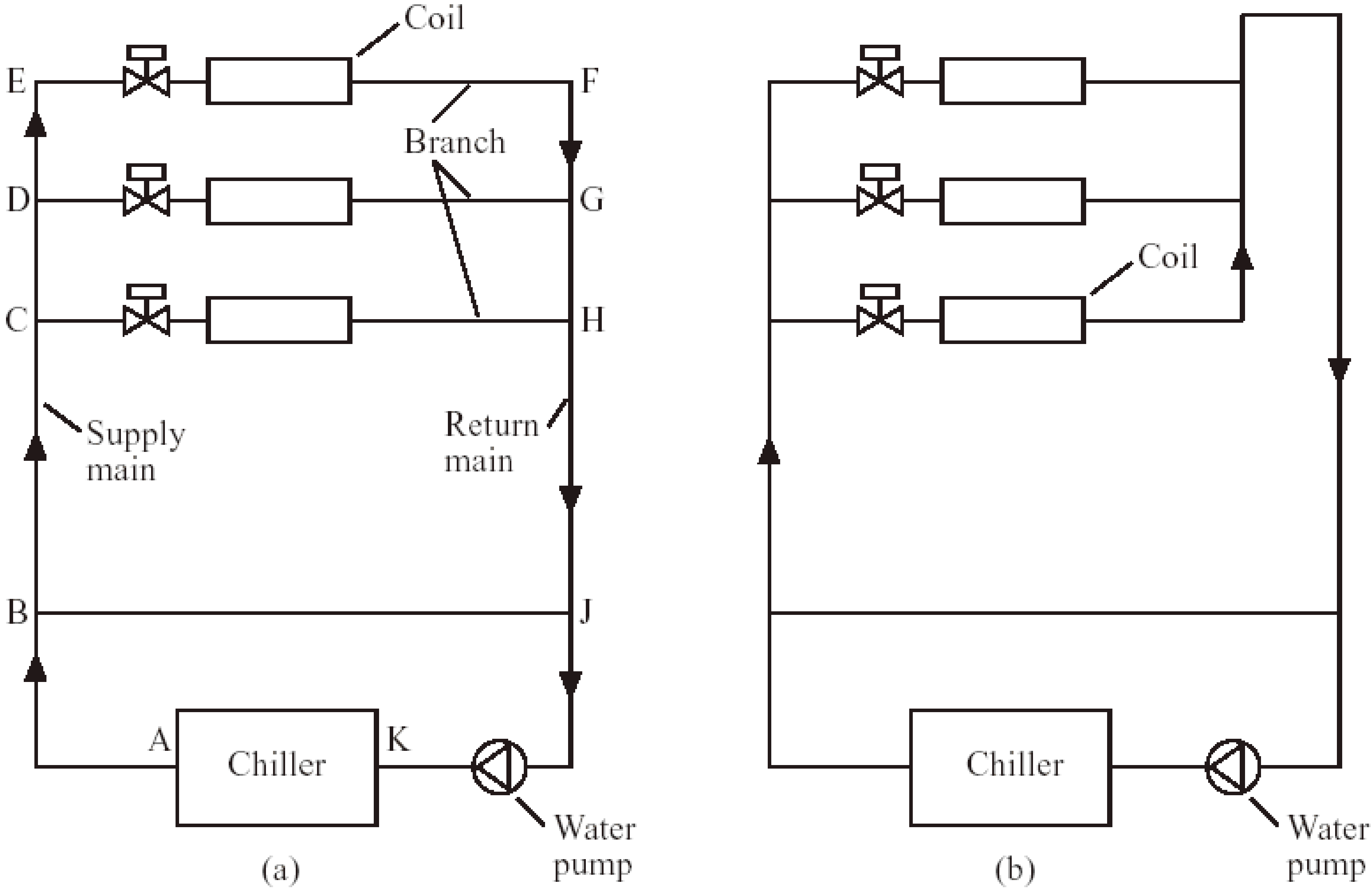


(Source: *ASHRAE HVAC Systems and Equipment Handbook 2004*)

Control of hydraulic circuits

- Modulation of pump-piping systems
  - 1. Throttle volume flow by using a valve
    - Change flow resistance – new system curve
    - Also known as "riding on the curve"
  - 2. Turn water pumps on or off in sequence
    - Sudden increase/drop in flow rate & head
  - 3. Vary the pump speed
    - System operating point move along the system curve
    - Requires the lowest pump power input

2-pipe direct and reverse return systems

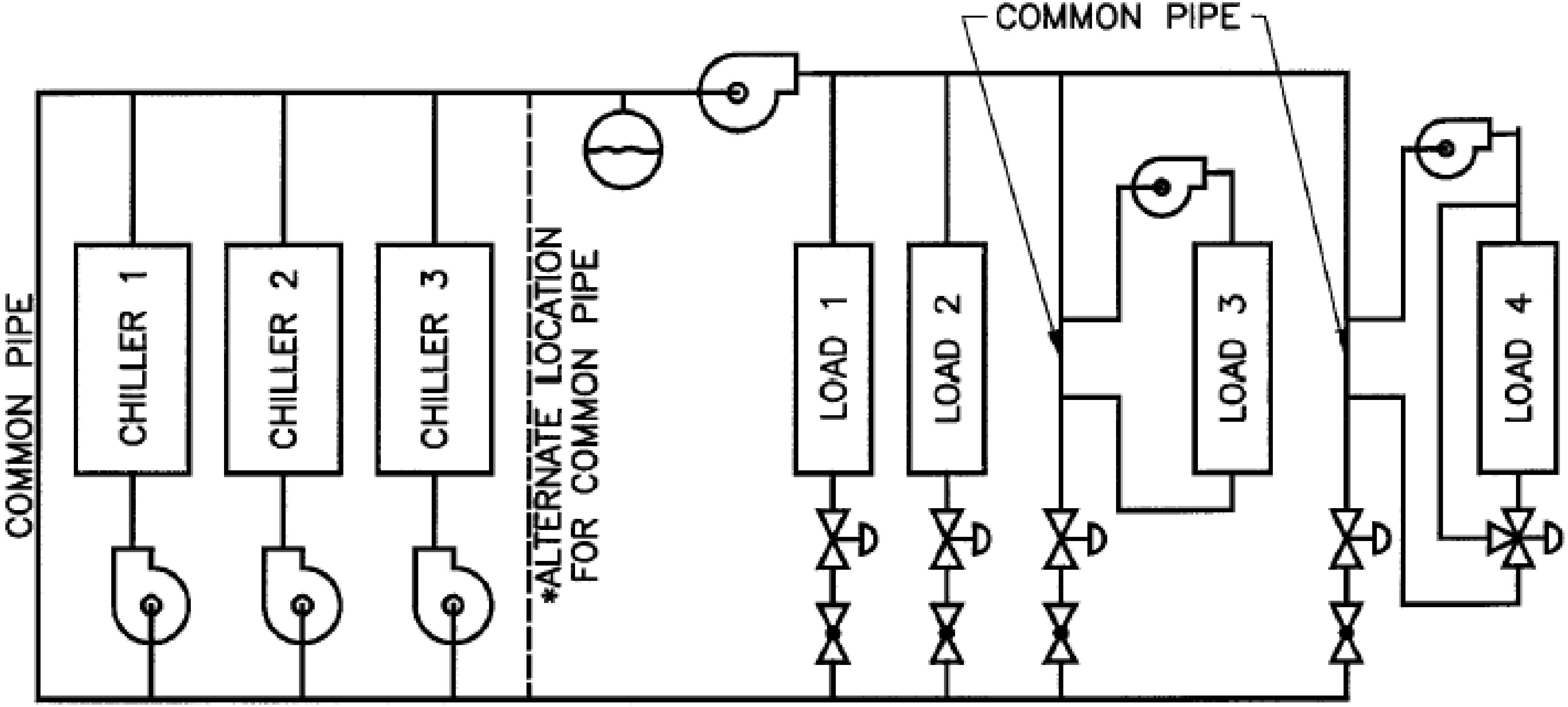


2-pipe direct return

2-pipe reverse return

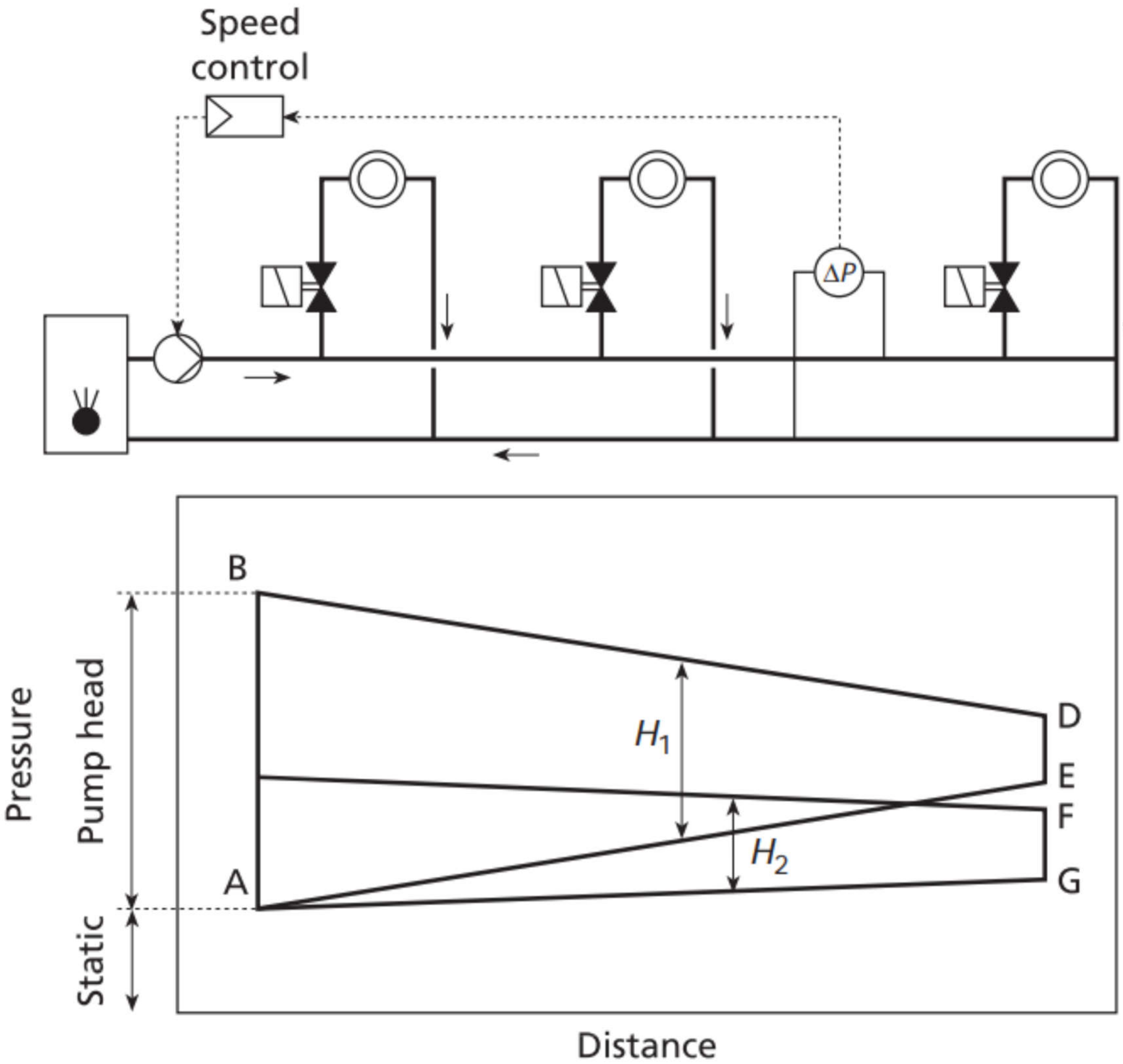
(Source: *ASHRAE HVAC Systems and Equipment Handbook 2004*)

Multiple chiller variable flow chilled water system (primary-secondary)



(Source: *ASHRAE HVAC Systems and Equipment Handbook 2004*)

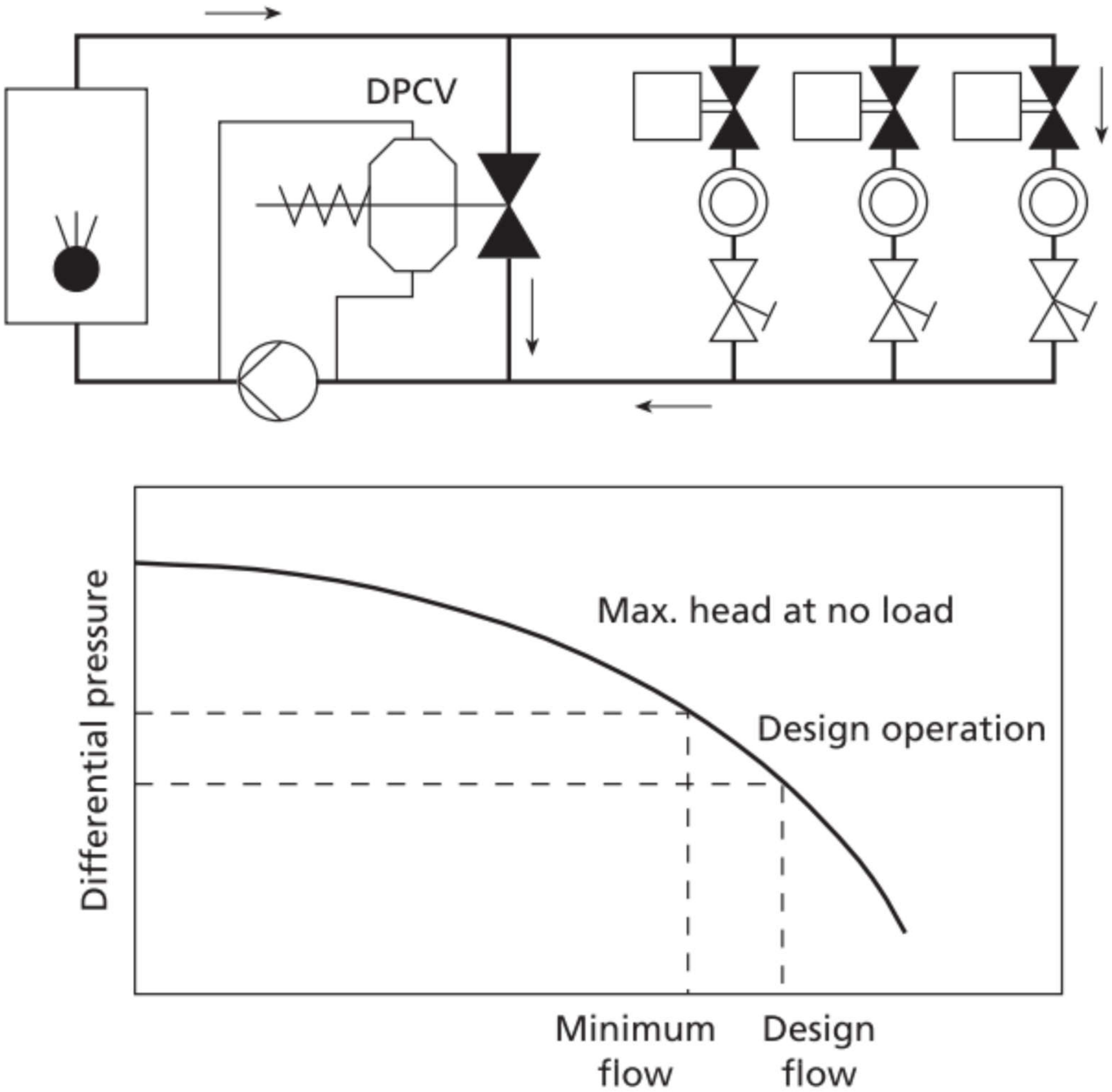
Control of differential pressure at index circuit



Pressure distribution at maximum (H_1) & low (H_2) demand

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

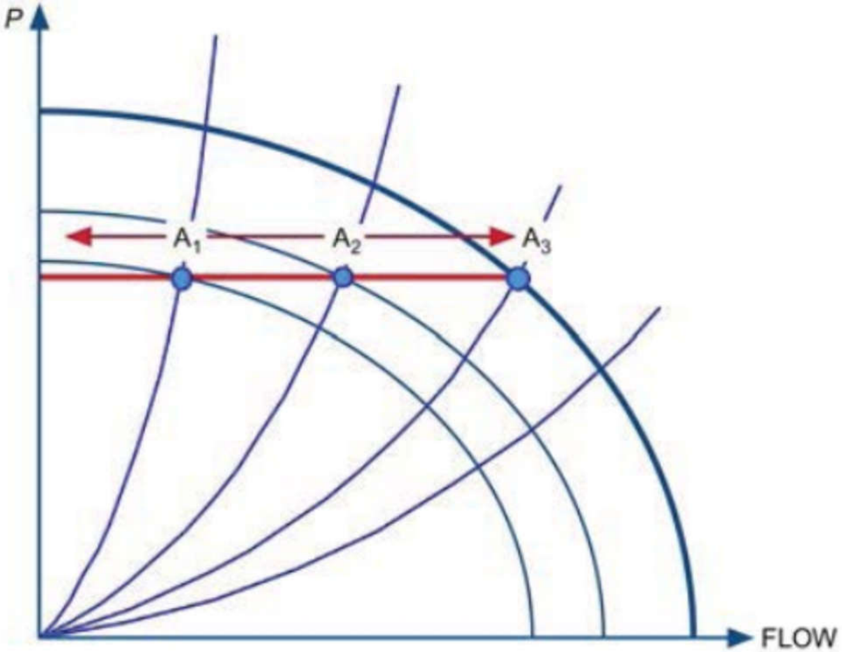
Differential pressure control valve (DPCV)



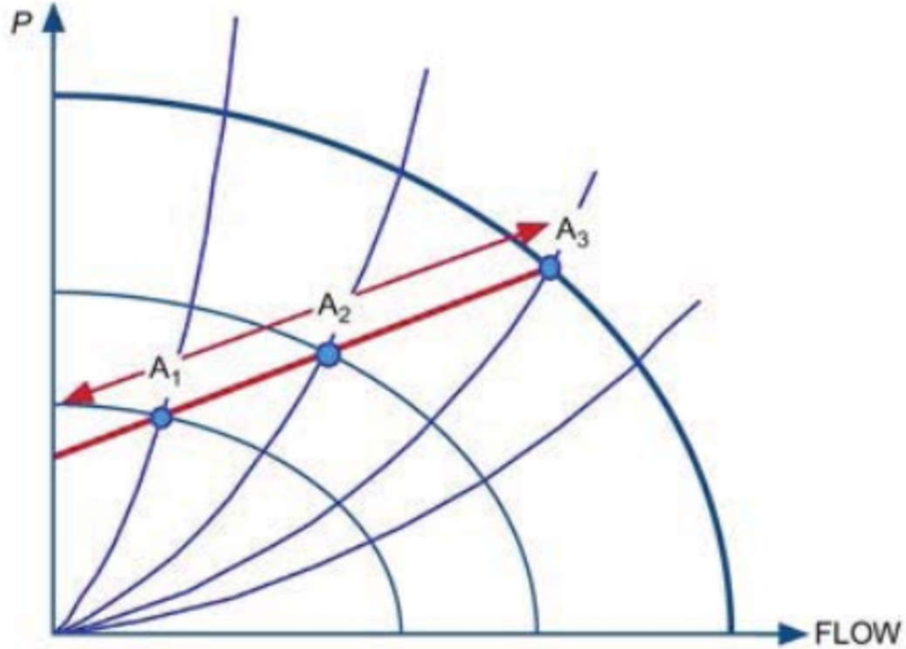
The DPCV opens to allow flow through the bypass leg as the differential pressure across the pump rises. This maintains flow through the plant as the throttling valves close down.

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

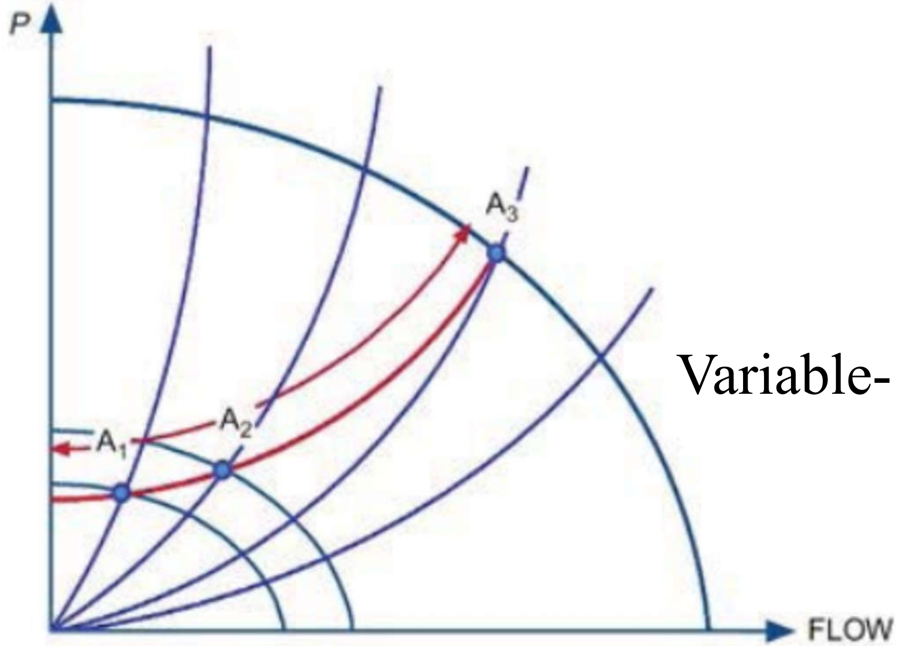
Differential pressure control with predefined control curves



Constant-pressure control



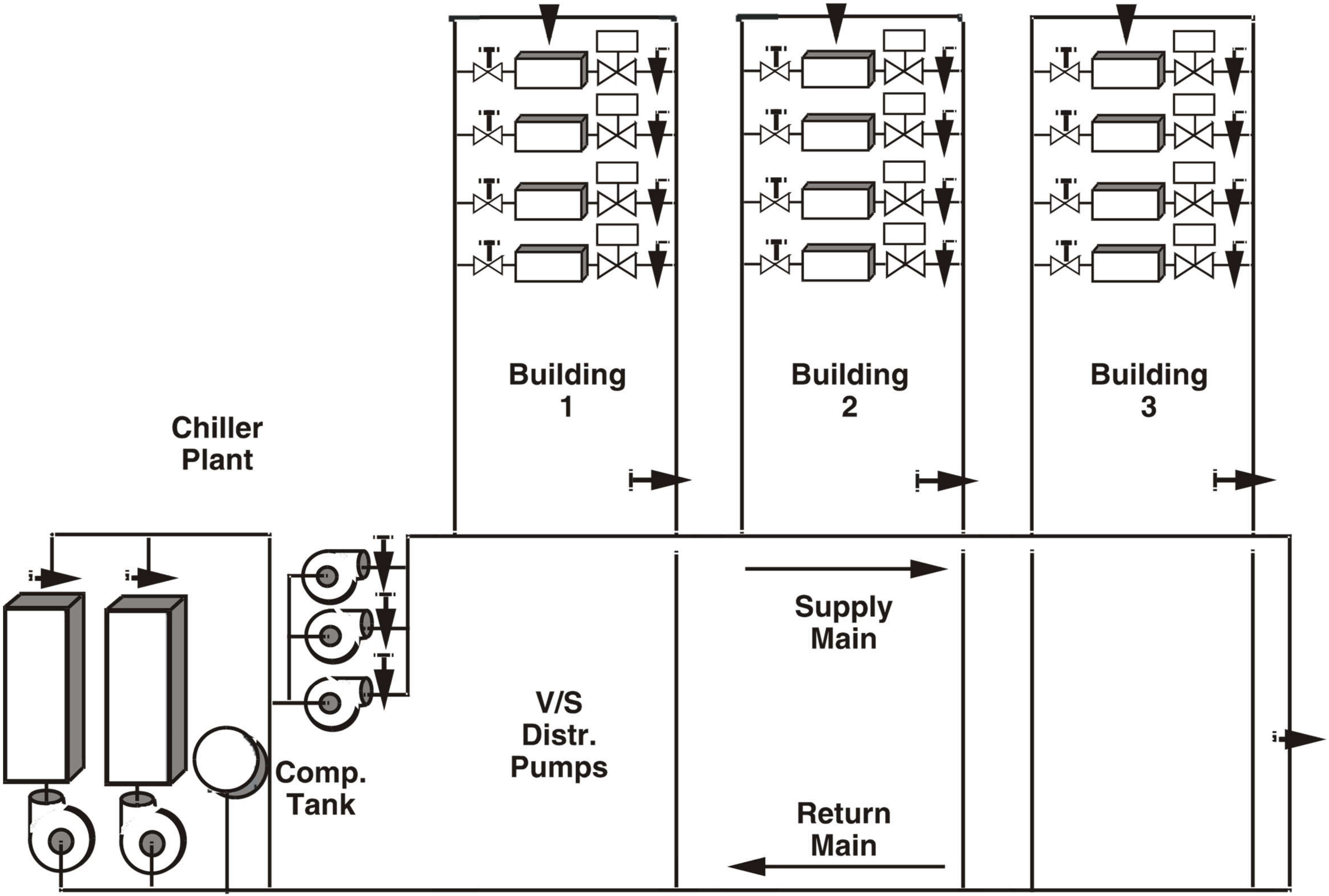
Variable- (Proportional-) pressure control



Variable- (Quadratic-) pressure control

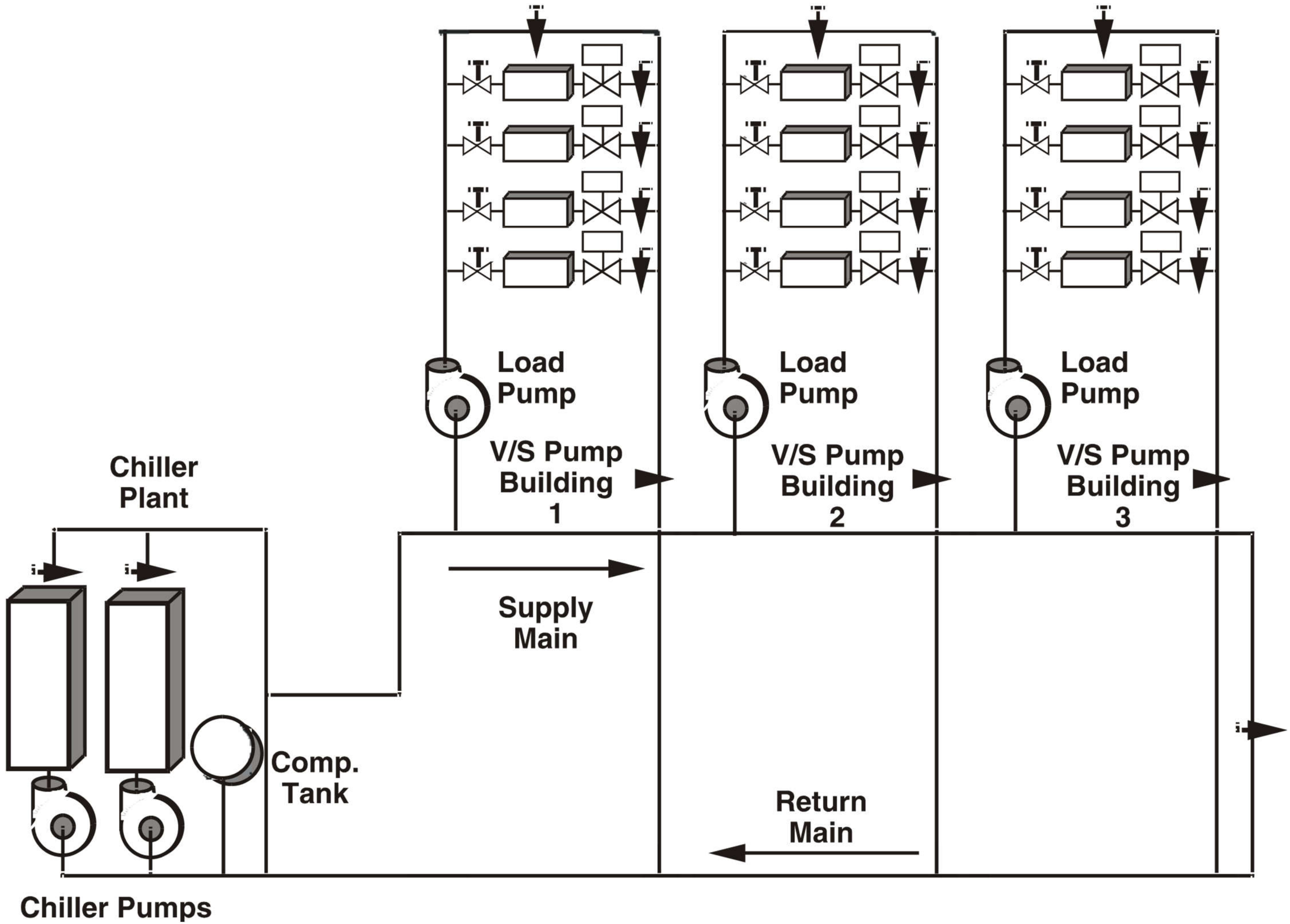
(Source: *ASHRAE HVAC Systems and Equipment Handbook 2016*)

Primary-secondary variable speed central pumping



(Source: *Fundamentals of Water System Design*)

Variable speed distributed pumping



(Source: *Fundamentals of Water System Design*)

Further reading

- Best Practices for Air-Side Economizers Operation and Maintenance https://www.pnnl.gov/projects/om-best-practices/air-side-economizers
- Chiller Plant Control https://hvac-eng.com/chiller-plant-control/
- CIBSE, 2008. *Building Control Systems*, CIBSE Guide H, 2nd ed., Butterworth-Heinemann, Oxford.
  - Chapter 5 Control strategies for subsystems