Hardware Components in BAS/BEMS

(Part I – Sensors, Actuators, Controllers)

Contents

- Sensors and Actuators
  - Temperature, humidity, flow sensors
  - Valve, damper actuators
- Controllers
  - Pneumatic, electrical, electronic, DDC
- DDC Controllers
  - Elements, I/O, connections to external devices
  - Sampling, A/D & D/A conversion
  - Types of DDC controllers
  - Six steps of DDC system design

Hardware Components in BAS/BEMS

- Sensors and Actuators

Sensors

- Sensing devices
  - Temperature
  - Humidity/moisture
  - Pressure
  - Flow
  - Proof of operation (e.g. for safety interlock)
- Design factors: accuracy, reliability, repeatability, precision

Temperature sensors

- Temperature sensing elements can be
  - Bimetal strip
  - A rod-and-tube element
  - A sealed bellows
  - A sealed bellows attached to a capillary or bulb
  - A resistive wire
  - A thermistor or resistance temp. device (RTD)
    - Rapid response to temperature
  - A thermocouple
    - Wide range and rapid response

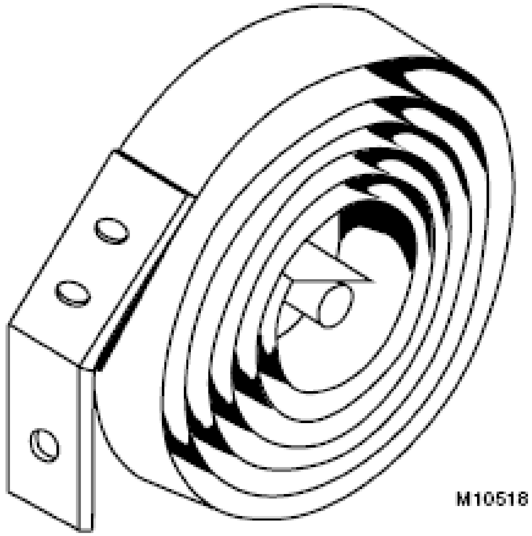


Fig. 49. Coiled Bimetal Element.

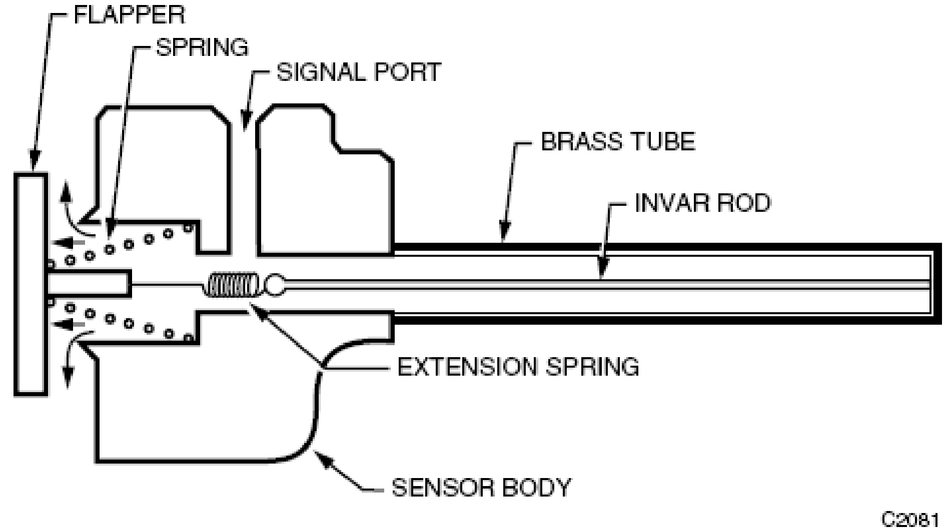


Fig. 50. Rod-and-Tube Element.

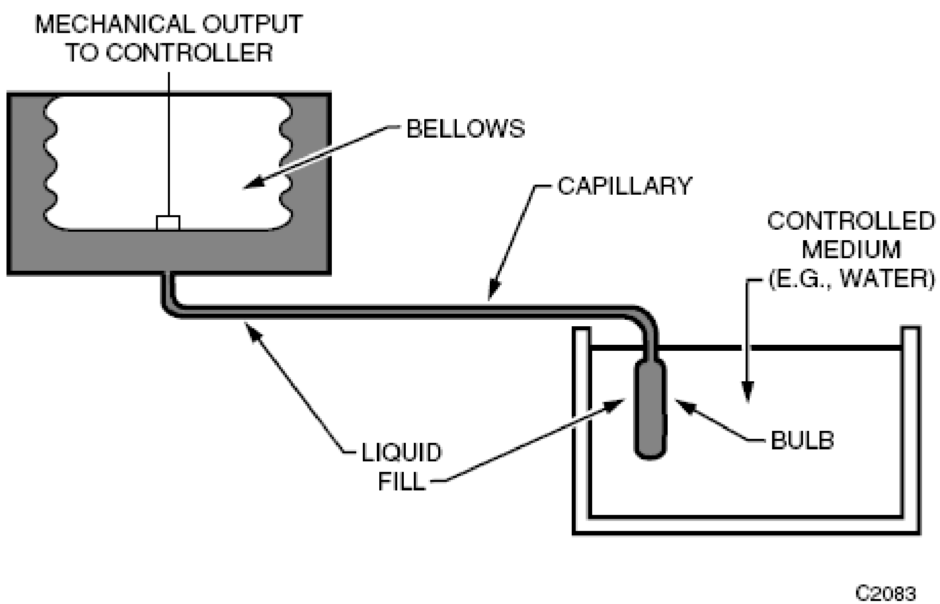


Fig. 51. Typical Remote-Bulb Element.

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

Moisture Sensors

- Moisture sensing elements
  - Mechanical – expand and contract as the moisture level change (“hygroscopic”), e.g. nylon
  - Electronic – change in either the resistance or capacitance of the element
    - Can be affected by temperature changes
    - Temperature compensation may be needed
  - A dew point sensor senses dew point directly or detects condensation on a cooled surface

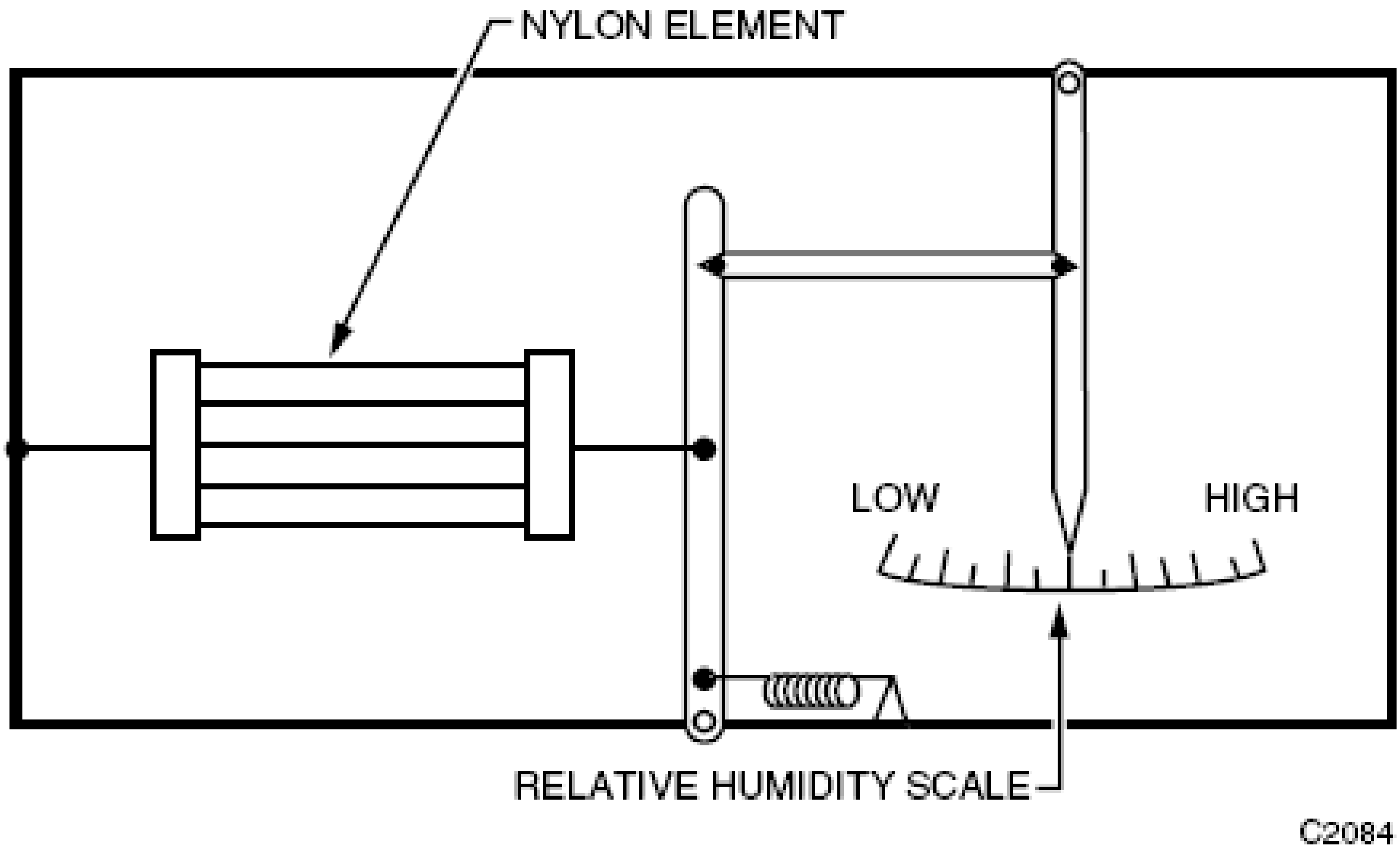


Fig. 52. Typical Nylon Humidity Sensing Element.

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

Flow Sensors

- Flow sensors
  - Sense the rate of liquid and gas flow
    - Flow is difficult to sense accurately under all conditions
  - Selecting the best flow-sensing technique for an application requires considering many aspects
    - Level of accuracy required
    - The medium being measured
    - The degree of variation in the measured flow

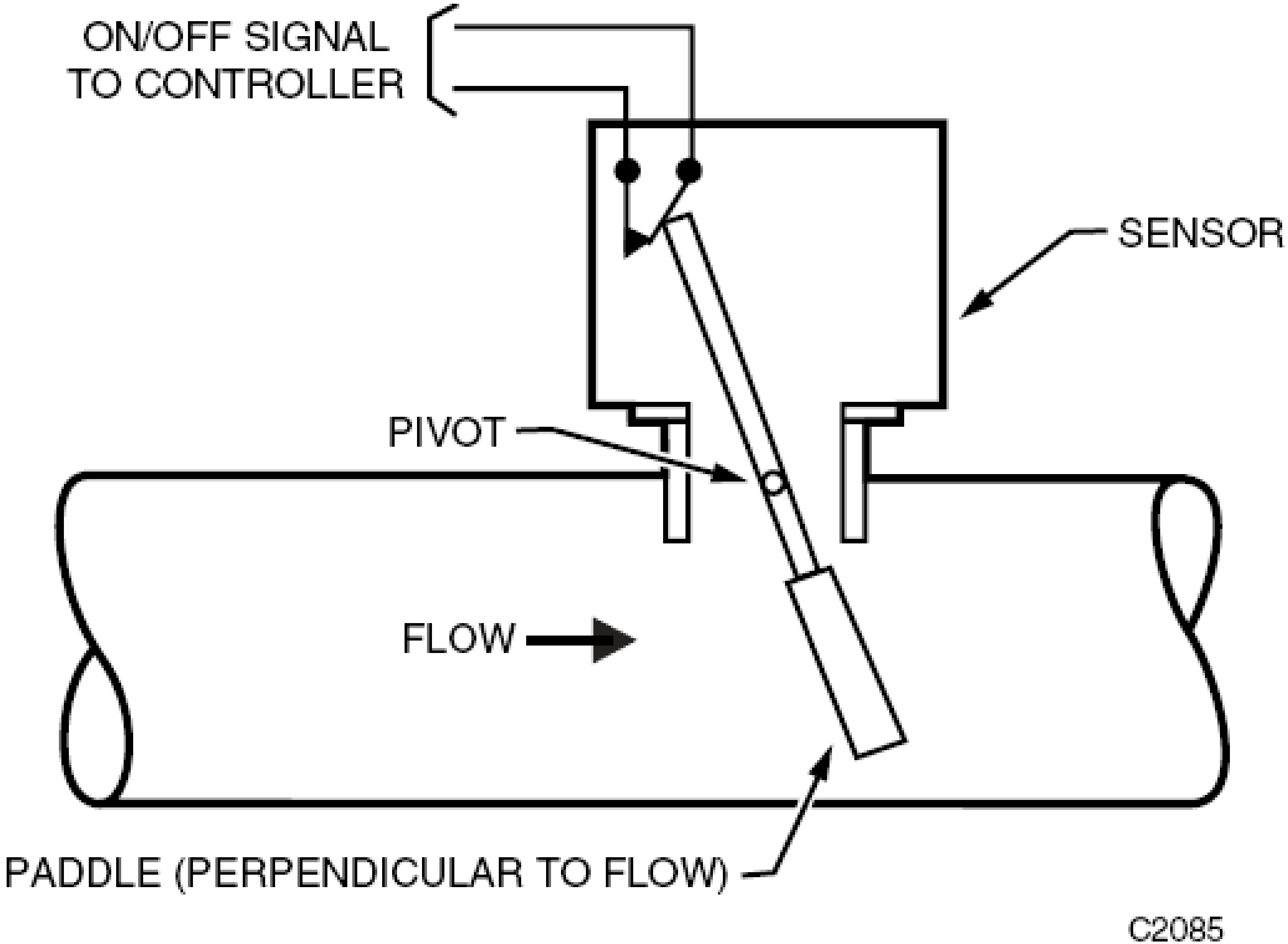


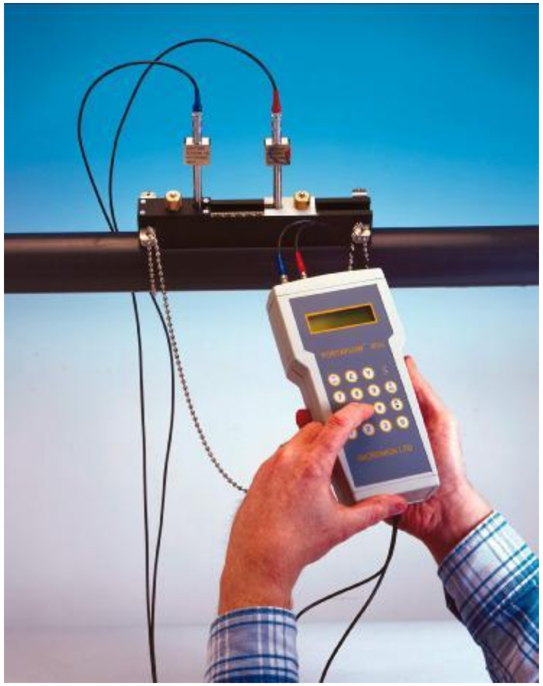
Fig. 53. Paddle Flow Sensor.

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

Flow Sensors

- Selecting flow measuring devices
  - What flow meters measure (volume/mass)
  - Methodology of flow meters
    - Differential pressure
    - Magnetic
    - Turbine
    - Ultrasonic
  - Selection criteria & considerations

Differential Pressure



Ultrasonic

Electromagnetic

Turbine

Transducers & Actuators

- Transducers
  - Convert (change) sensor inputs and controller outputs from one analogue form to another, more usable, analogue form, e.g. pressure-to-voltage

- Actuators
  - A device that converts electric or pneumatic energy into a rotary or linear action, e.g. for valves and dampers (can be pneumatic or electrical controlled)

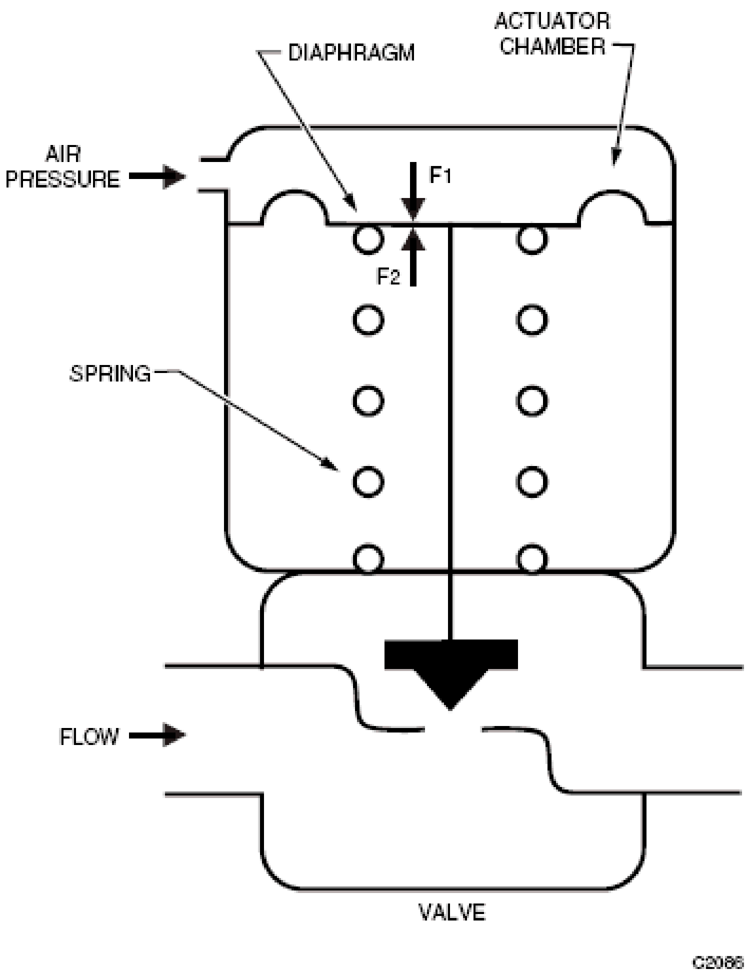
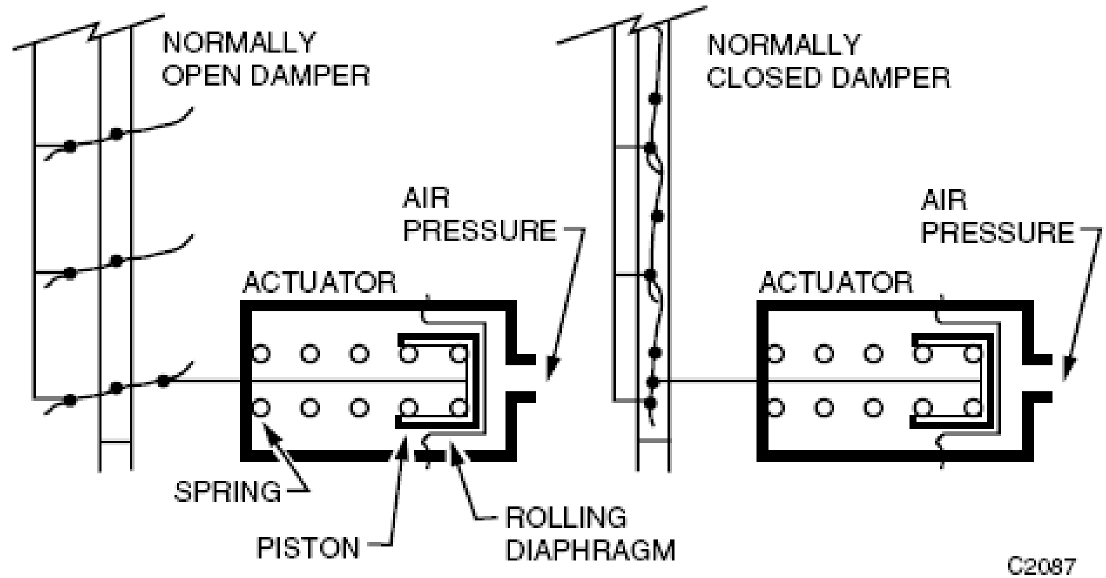


Fig. 54. Typical Pneumatic Valve Actuator.



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

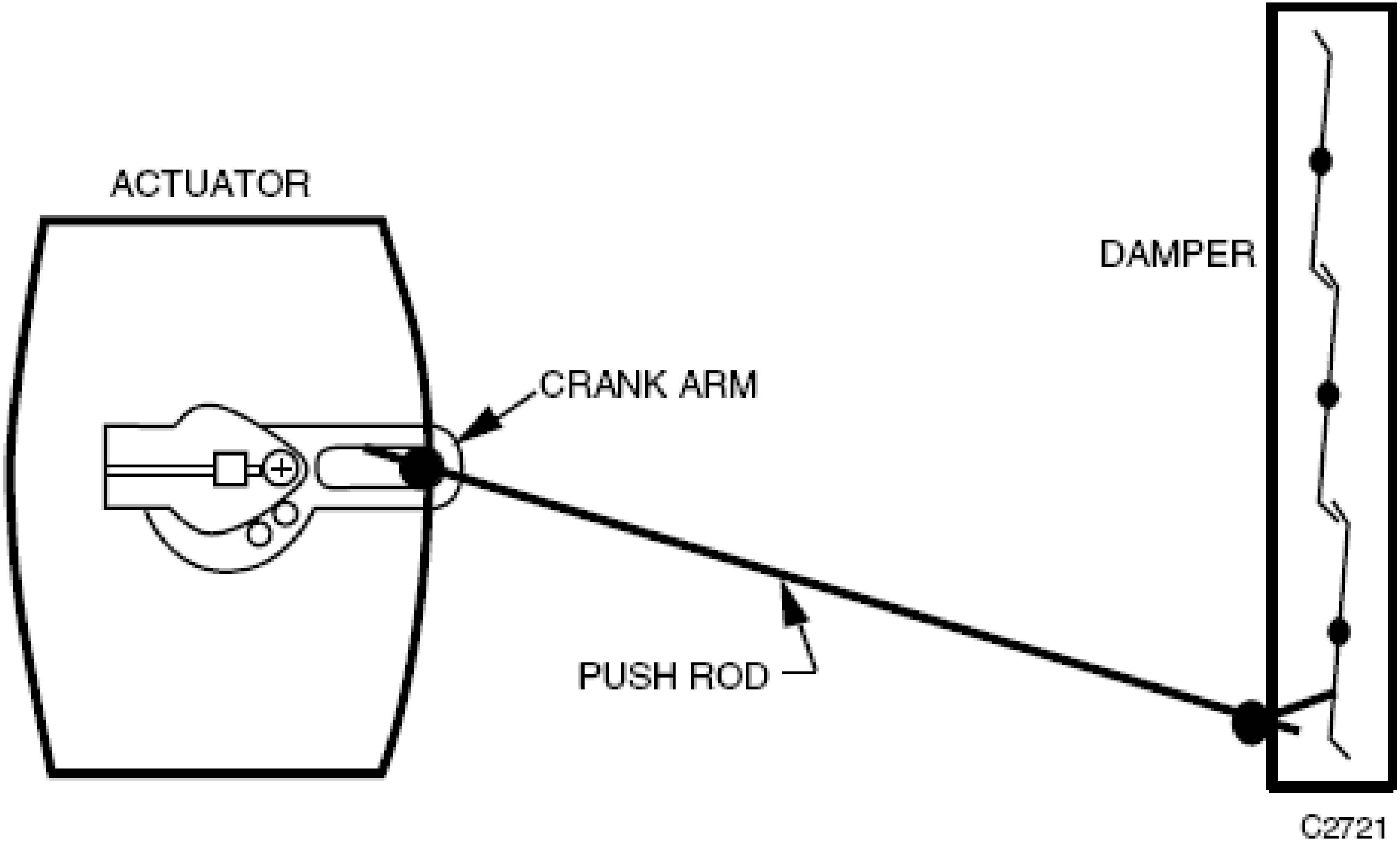


Fig. 56. Typical Electric Damper Actuator.

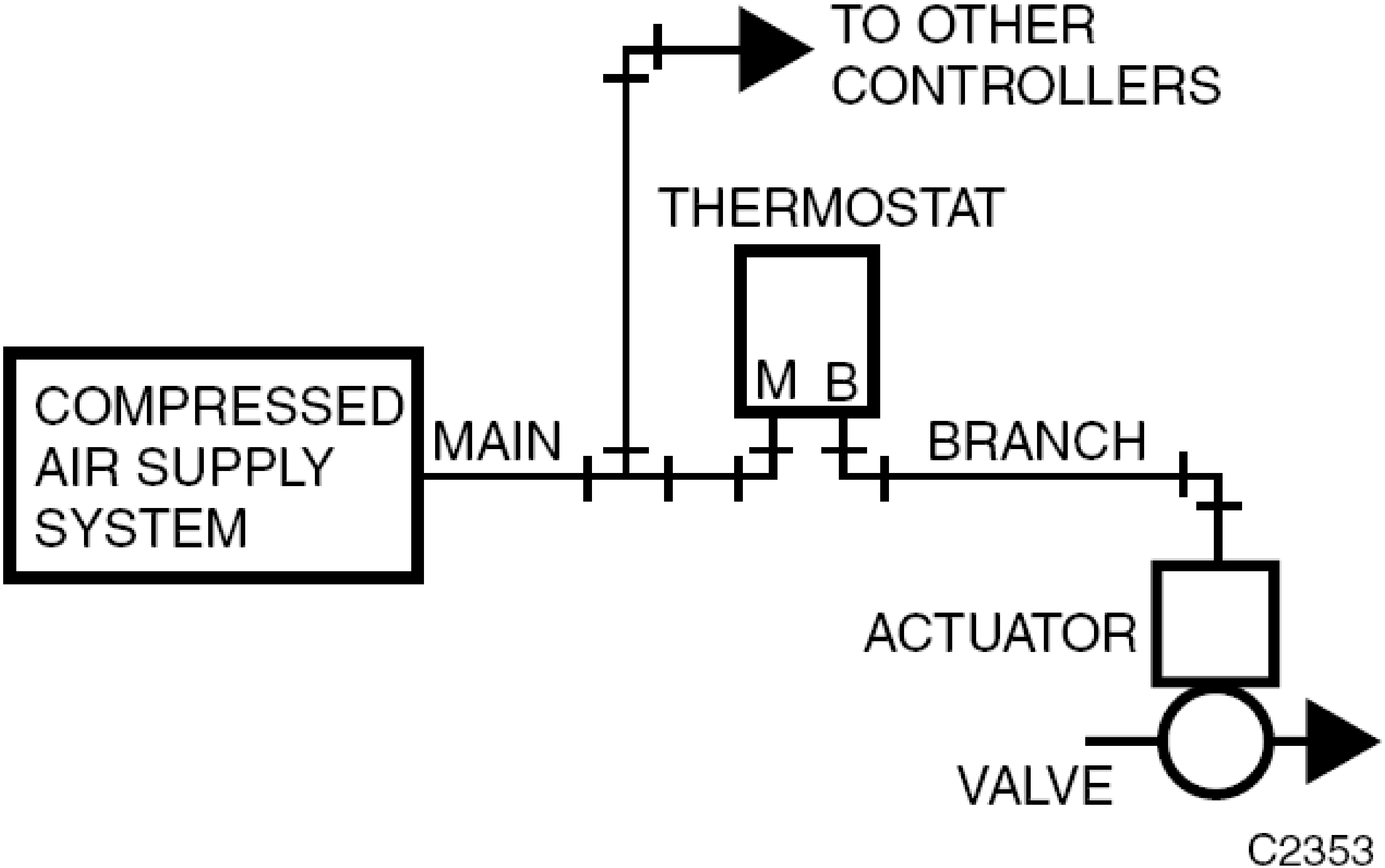
[Source: Honeywell, 1997. *Engineering Manual of Automatic Control: for Commercial Buildings*]

Hardware Components in BAS/BEMS

- Controllers

Controllers

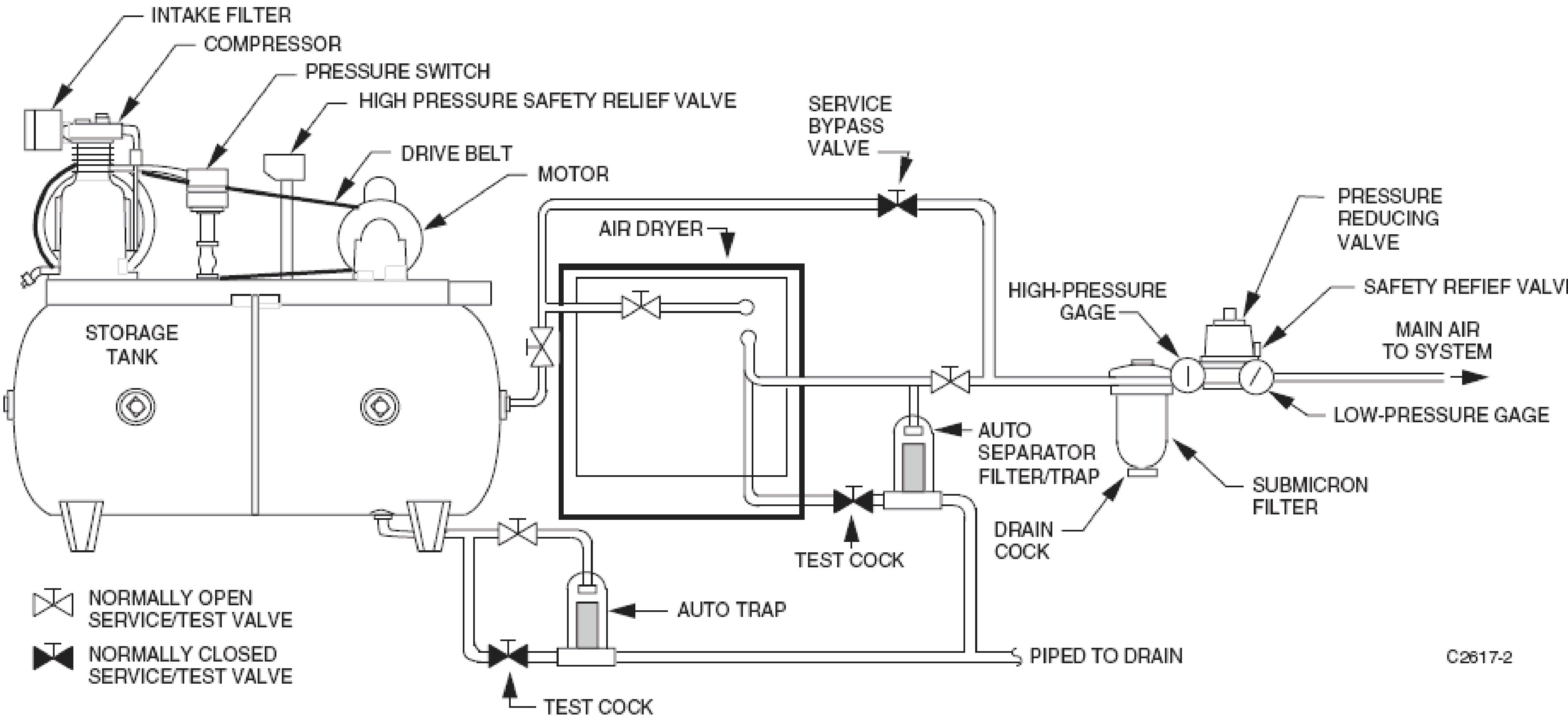
- 1) Pneumatic controllers
- 2) Electric controllers
- 3) Electronic controllers
- 4) Microprocessor-based/DDC



Basic pneumatic control system

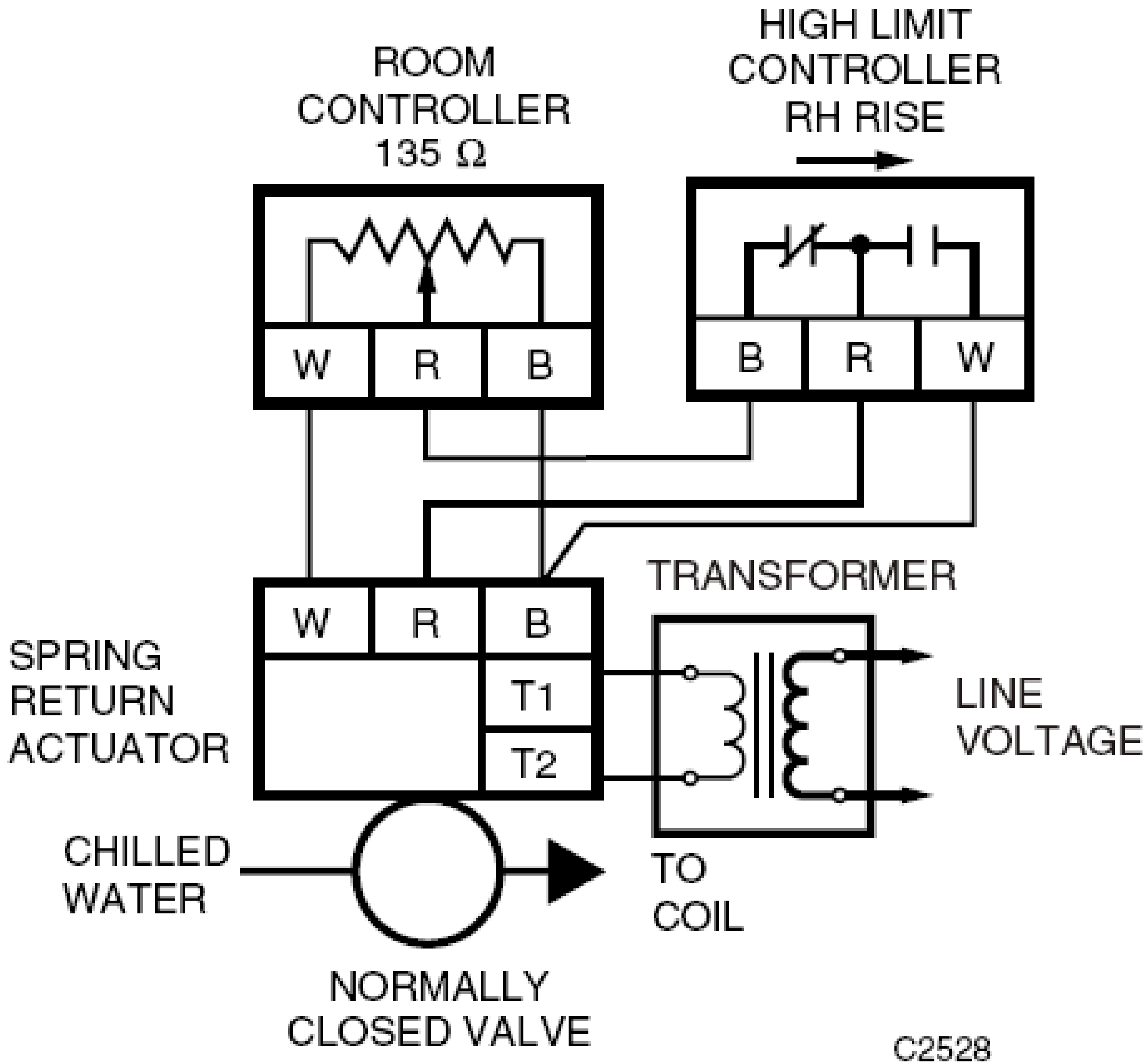
[Source: Honeywell, 1997. Engineering Manual of Automatic Control for Commercial Buildings]

You can hear the sound when the system is operating.



Typical compressed air supply system

[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]

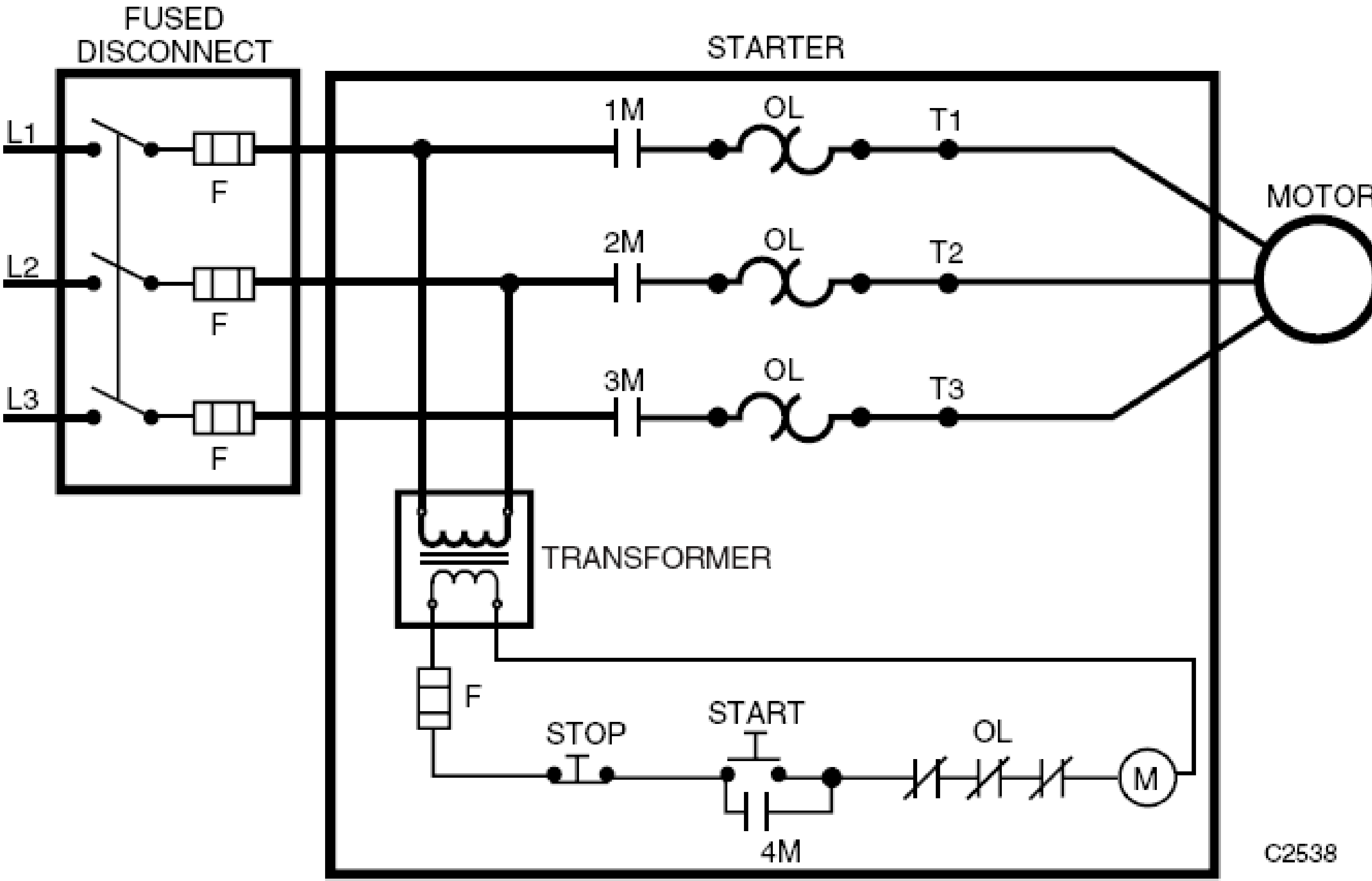
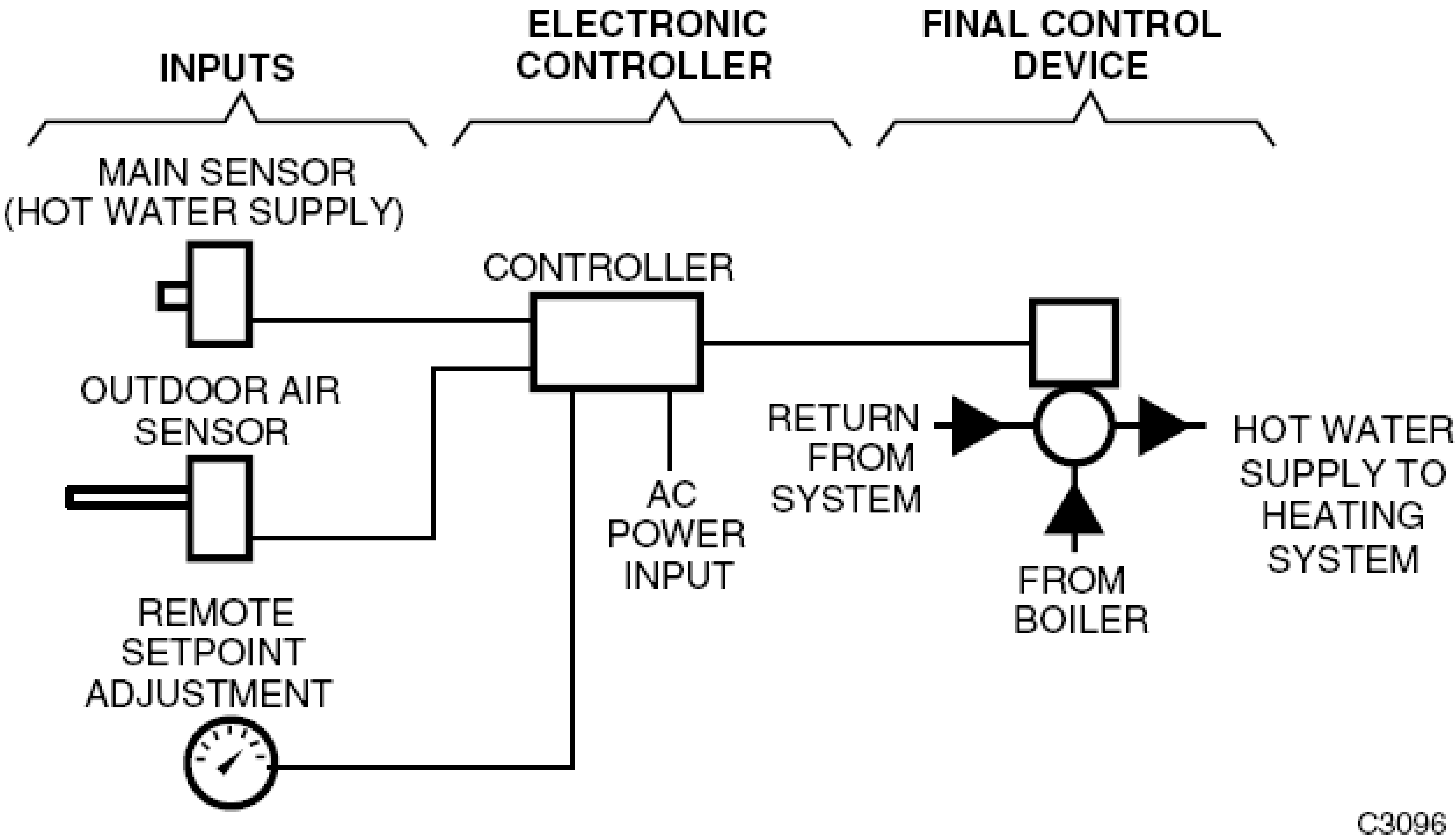


Fig. 35. Momentary Push-button Start-Stop Circuit.

[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]

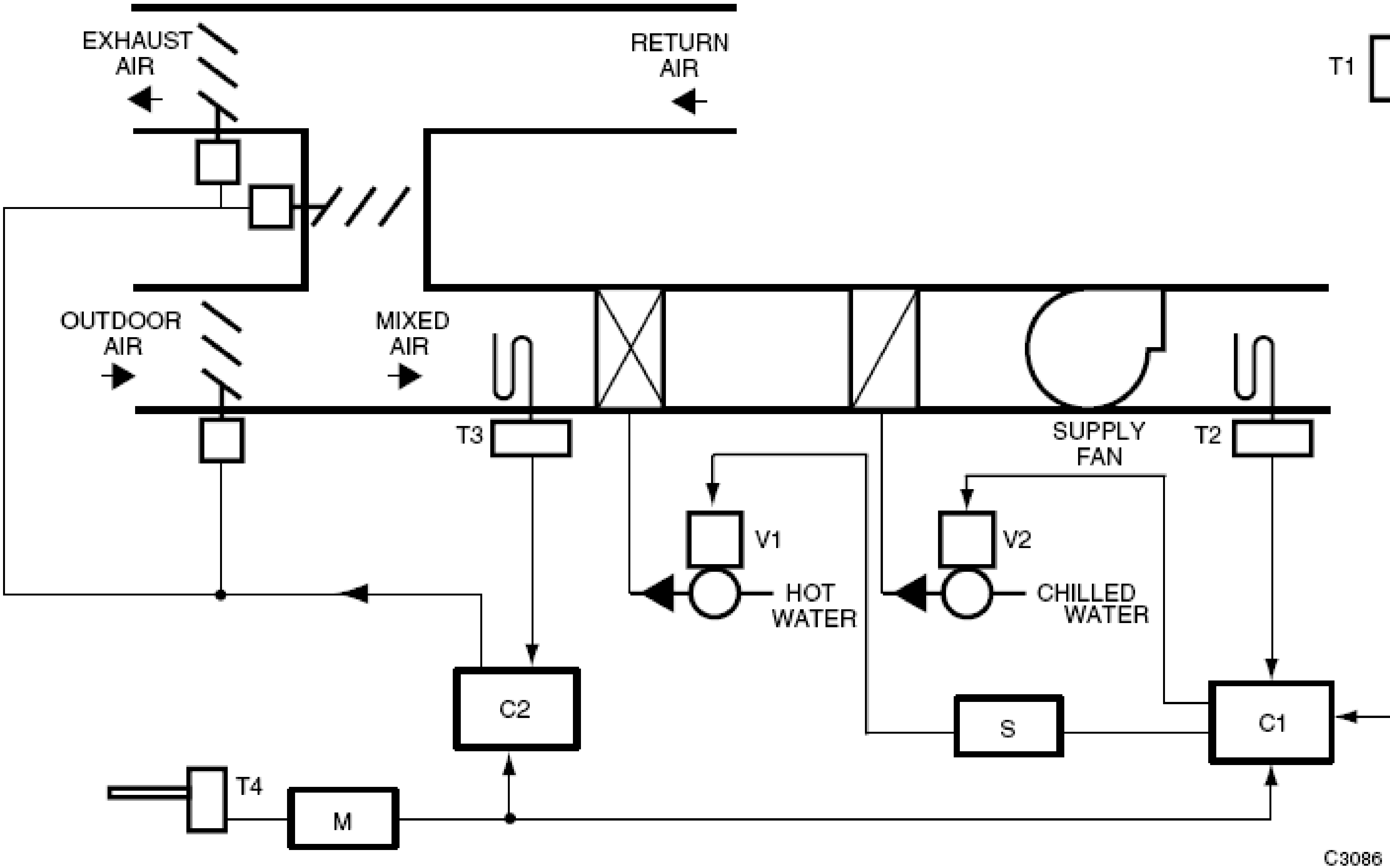


Fig. 22. Typical Application with Electronic Controllers.

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

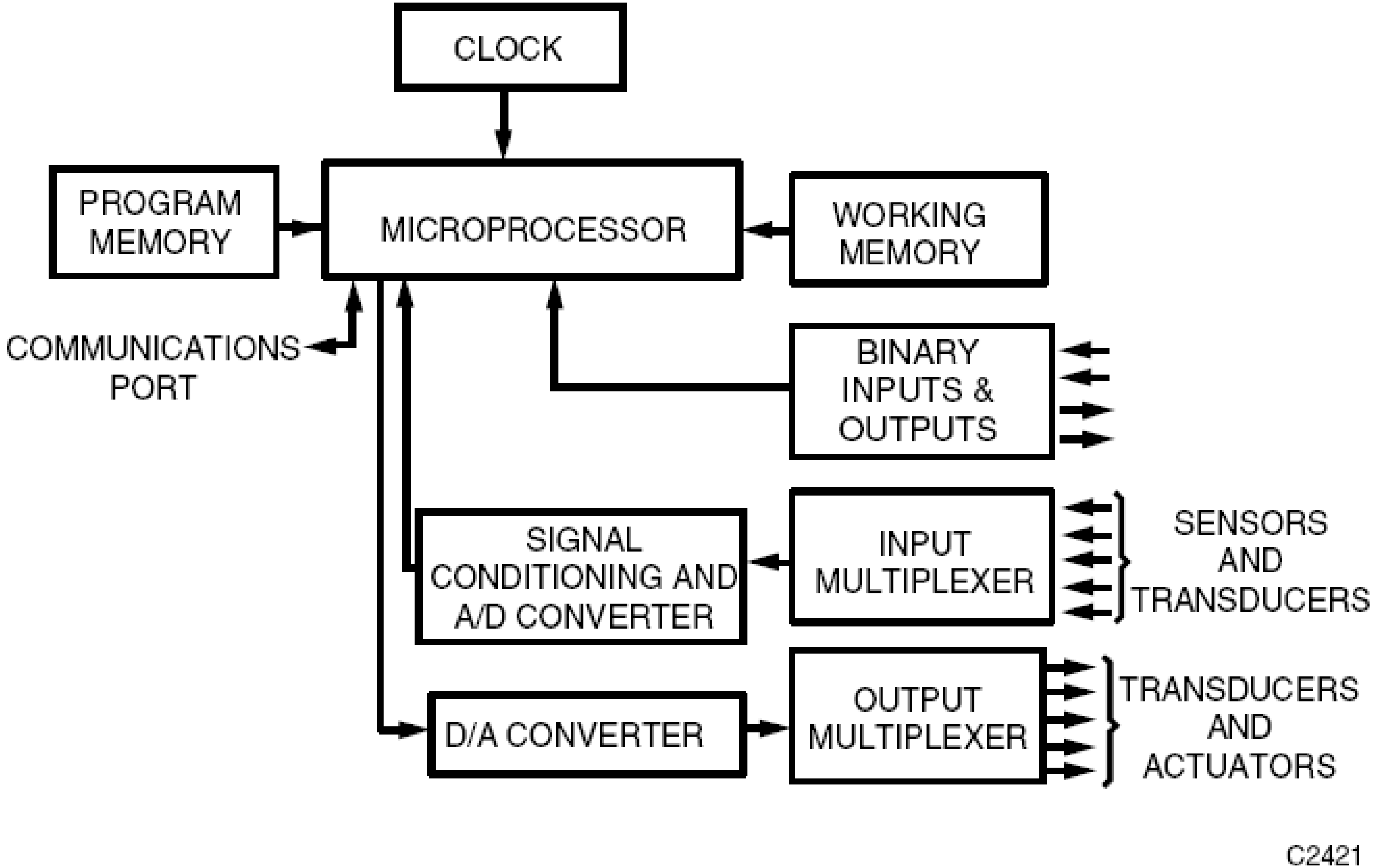


Fig. 3. Microprocessor Controller Configuration for Automatic Control Applications.

Basic microprocessor/DDC controller

[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	Most common for simple on-off control	Precise control	Precise control
Requires clean dry air	Integral sensor/ controller	Solid state repeatability and reliability	Inherent energy management
Air lines may cause trouble below freezing	Simple sequence of control	Sensor may be up to 300 feet from controller	Inherent high order (proportional plus integral) control, no undesirable offset
Explosion proof	Broad environmental limits	Simple, remote, rotary knob setpoint	Compatible with building management system. Inherent database for remote monitoring, adjusting, and alarming.
Simple, powerful, low cost, and reliable actuators for large valves and dampers	Complex modulating actuators, especially when spring-return	High per-loop cost	Easily performs a complex sequence of control
Simplest modulating control		Complex actuators and controllers	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*]

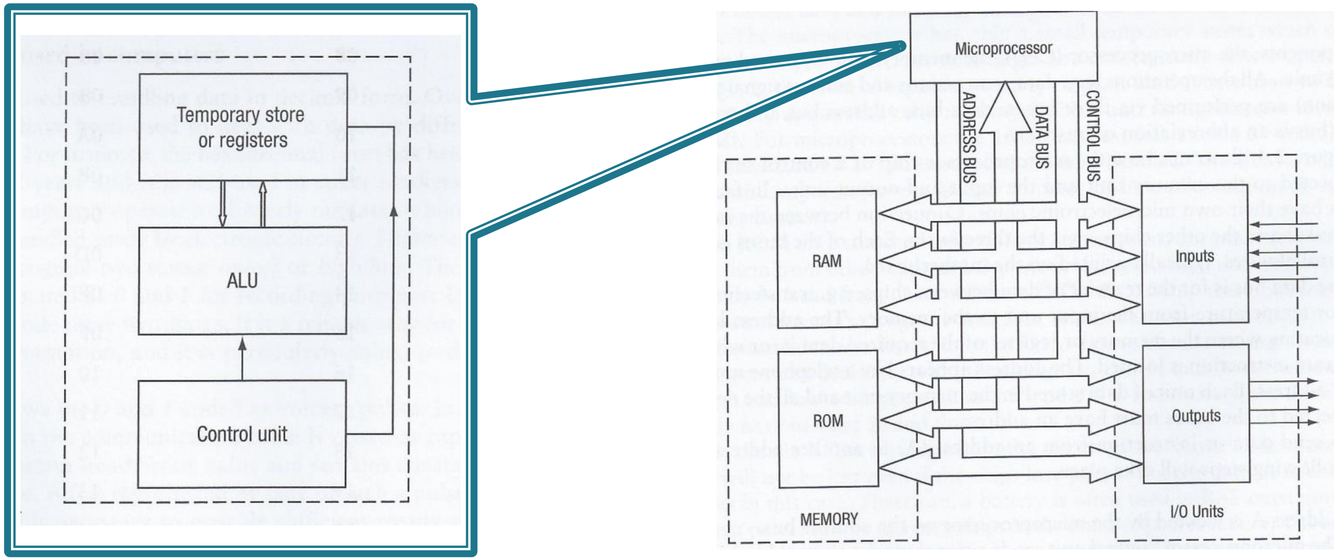
Hardware Components in BAS/BEMS

- Direct Digital Controller (DDC)

Elements of a DDC

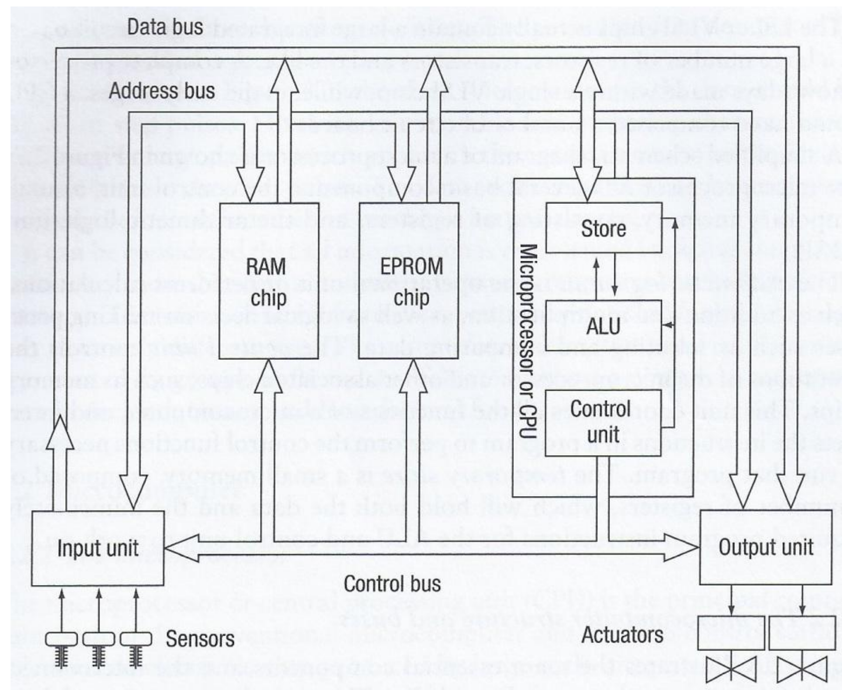
- A DDC is essentially a microcomputer being adapted for the special purpose of programmed control of control loops.

- Hardware includes
  - Enclosure with power spike protection
  - Power supply for converting AC power supply to DC
  - CPU board
  - Input/Output (I/O) Card / Modules – for signal conditioning, i.e. converting field signals to machine readable signals)
  - I/O termination board – allowing field sensors and actuators to be connected to the I/O card
  - Battery backup
  - Communications networking



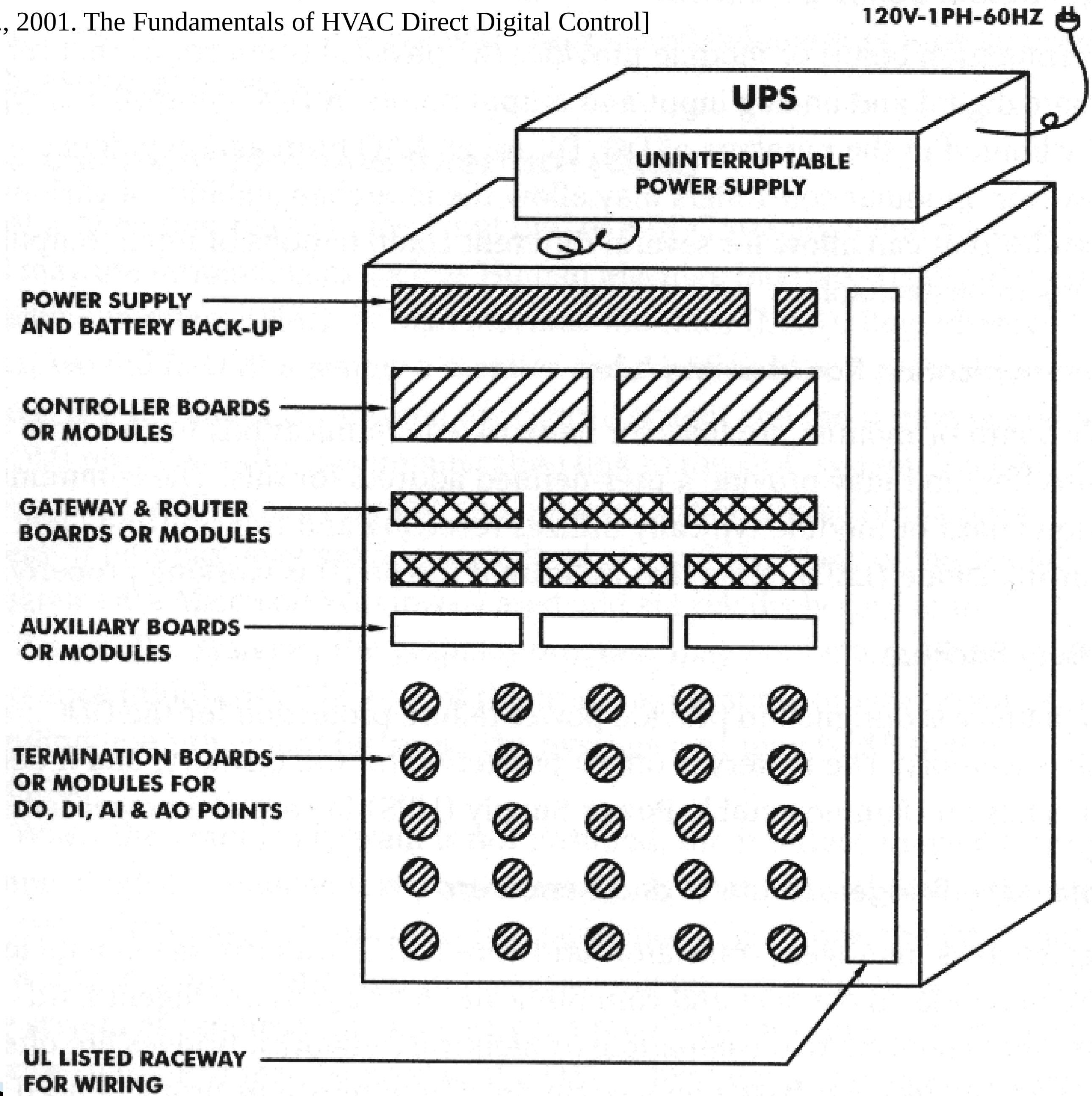
Microprocessor principle architecture

Architecture of a DDC unit



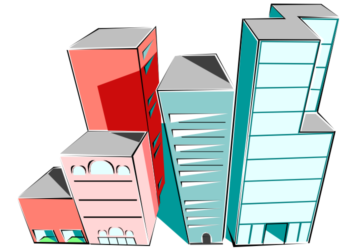
[Source: Wang S., 2010. Intelligent Buildings and Building Automation]

[Source: Shadpour, F., 2001. The Fundamentals of HVAC Direct Digital Control]

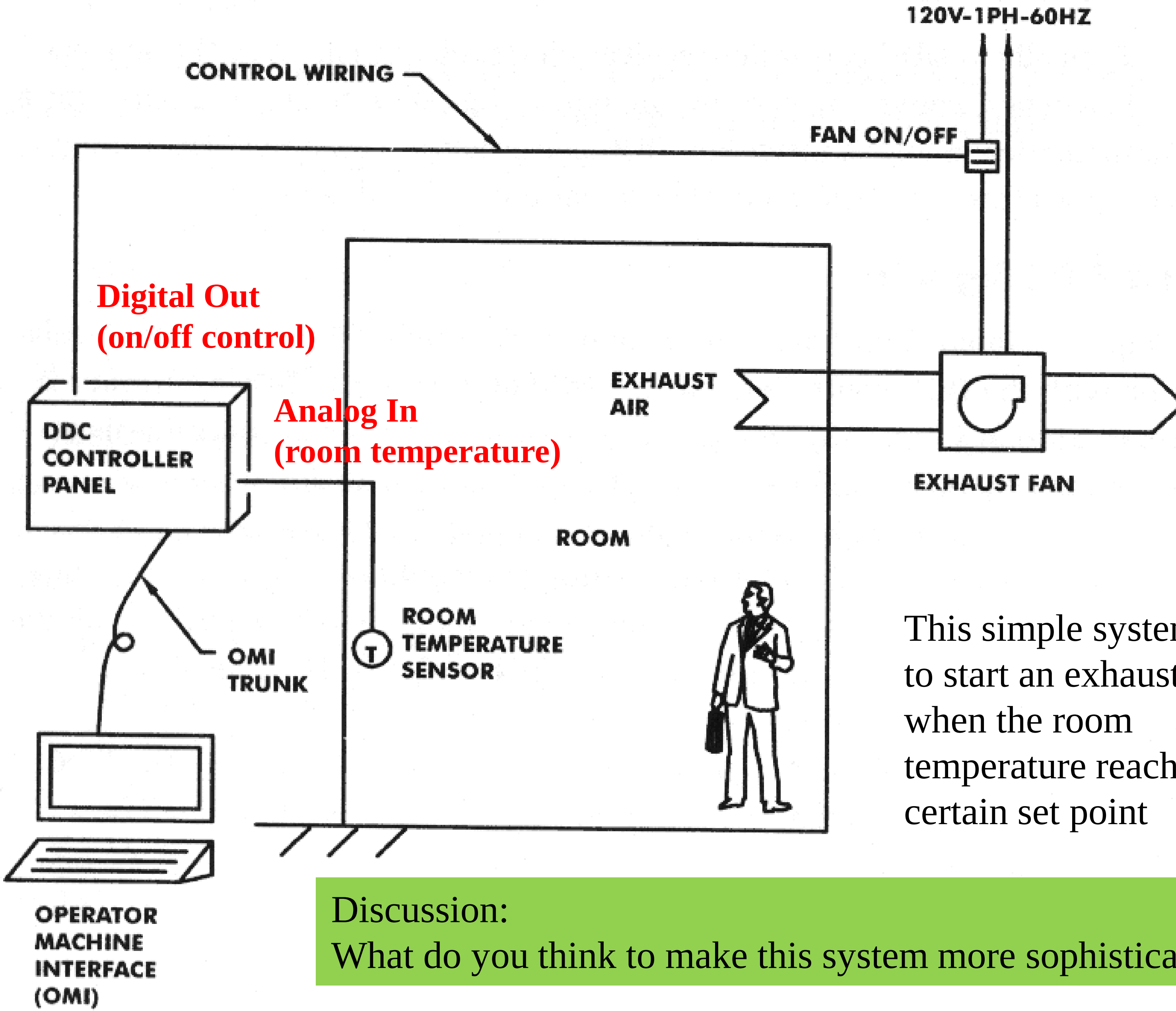


A DDC general-purpose controller

I/O of DDC



- **Analog input** (AI)
  - Proportional or variable input signals
  - Usually in 0-12VDC, 4-20mA, 0-1000Ω signals
- **Analog output** (AO)
  - Proportional output signals from DDC to controlled devices
  - Usually in variable voltage or current
  - Other signal requirements (e.g. pneumatic pressure, pulse) will be converted by signal transducers
- **Digital input** (DI)
  - Contacts of circuit with low voltage
  - Making or breaking the contact provides a voltage signal to be picked up by the DDC
- **Digital output** (DO)
  - Contact enclosures providing a voltage to make or break a relay
- **Universal points**
  - Any combination of inputs and outputs can be brought into and out of the DDC without the need for specific 'analog' or 'digital' cards as I/O cards
  - Bring in flexibility for the users



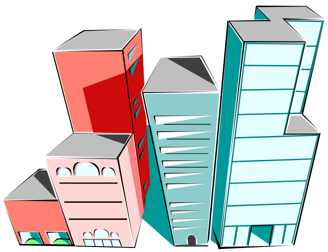
This simple system tries to start an exhaust fan when the room temperature reaches a certain set point

Discussion:
What do you think to make this system more sophisticated?

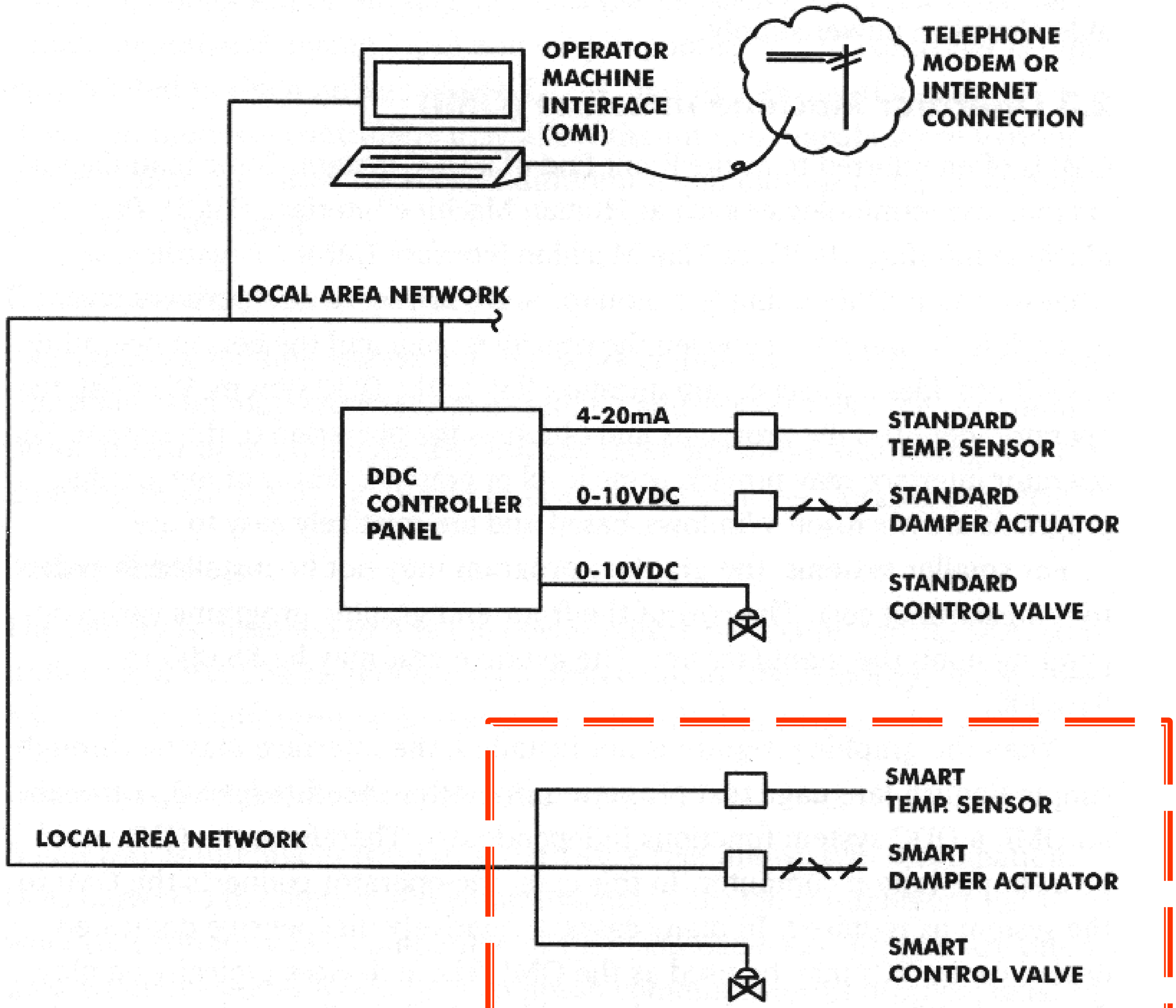
A simple DDC control system

[Source: Shadpour, F., 2001. The Fundamentals of HVAC Direct Digital Control]

Externally Connected Devices to DDC



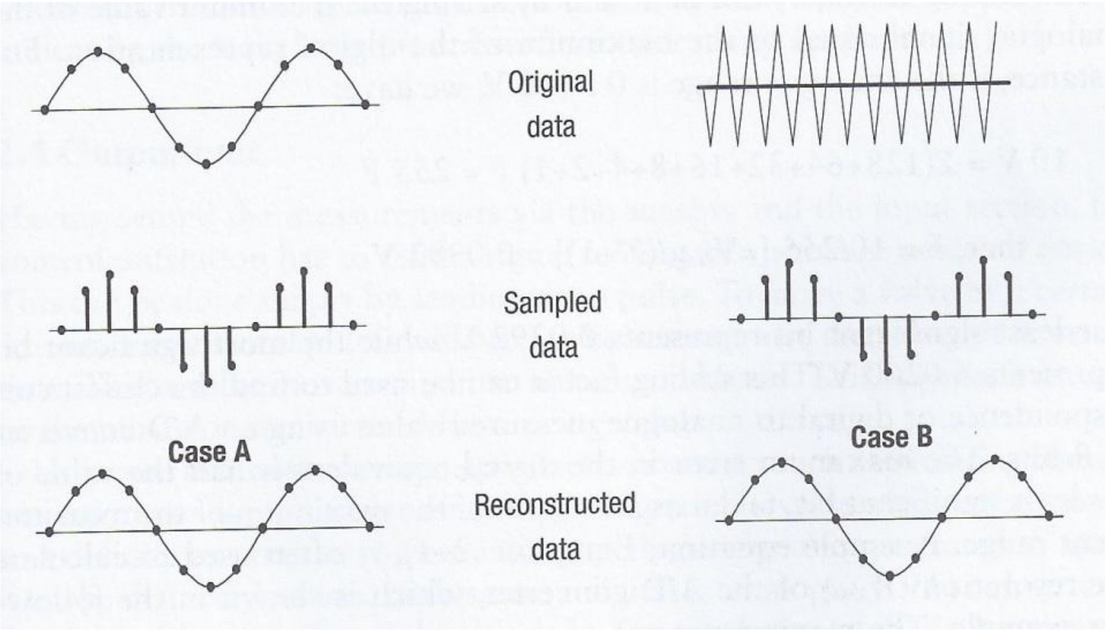
- Uninterruptable power supply (UPS)
  - Considerations to be made to providing UPS for main computer and DDC units (and powered by essential power supply)
- Operator Machine Interface (OMI)
  - Human-machine or person-machine interface
  - A monitor and a keyboard or a personal computer that can retrieve data from the DDC as well as plugin program firmware into the DDC to change the specific functions of it
- Smart sensors and actuators
  - Contain intelligence & some form of control capability
  - May transmit/receive signal directly to/from the network



[Source: Shadpour, F., 2001. The Fundamentals of HVAC Direct Digital Control]

Importance of proper sampling

- DDCs perform calculations in digital format
- Sensors/actuators are, however, analogue
- Thus a A/D or D/A conversion is always required
- Since DDCs collect data in regular time intervals, the actual measured analogue data are sampled at a specific time and the data are ‘reconstructed’
- The sampling speed is thus important for proper sensing and controlling



Successful Sampling　　　　Unsuccessful Sampling

- Guideline for sampling
  - A signal contains frequency no more than f_{max}
  - Minimum sampling frequency = 2 x f_{max}
  - Common sampling frequency > 10 x f_{max}

A/D & D/A conversion

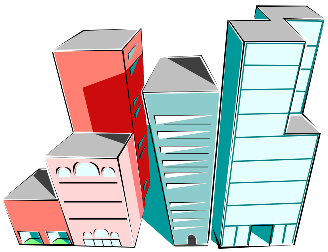
- A/D & D/A converters are usually in designed by a number of bit (e.g. 8-bit) → the full scale signal can be divided into $2^8 - 1$=255 segments
- E.g. a 10V voltage signal in a 8-bit A/D conversion, each bit will represent
  - $\frac{10V}{2^8-1} = 0.0392$V
  - Error = ½ of 1 bit = 0.0196V

- The representation of 1 bit of information is named 'resolution', thus
  - $R_{A/D} = \frac{\text{Measurement Band}}{2^n - 1}$
    (n = number of bits of the controller)
- More bits of the controller improves the precision
- This is similar for D/A conversions
  - $R_{D/A} = \frac{\text{Output Band}}{2^n - 1}$

- Exercise
  What is the number of bits required if the precision is to be better 0.1% error in an A/D conversion?

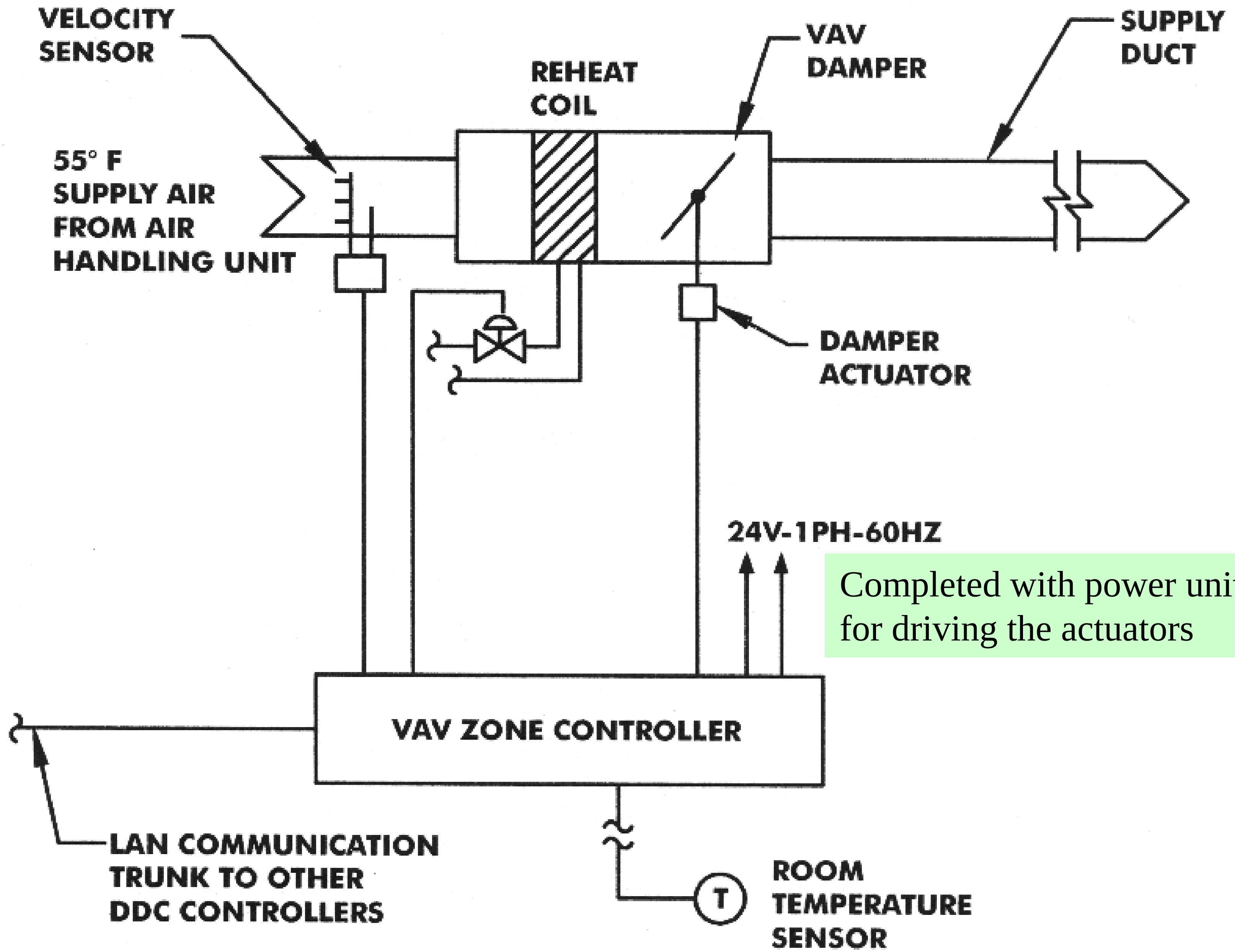
- Solution
  - Minimum resolution = 2 x error = 0.2%
  - $R_{A/D} = \frac{\text{Measurement Band}}{2^n - 1}$
  - $0.002 = \frac{1}{2^n - 1}$
  - $n = 8.97$ (minimum 9 bits must be used)

Types of DDC controllers



- Types
  - 1. Application specific
  - 2. General purpose
  - 3. Programmable logic (for industrial process)

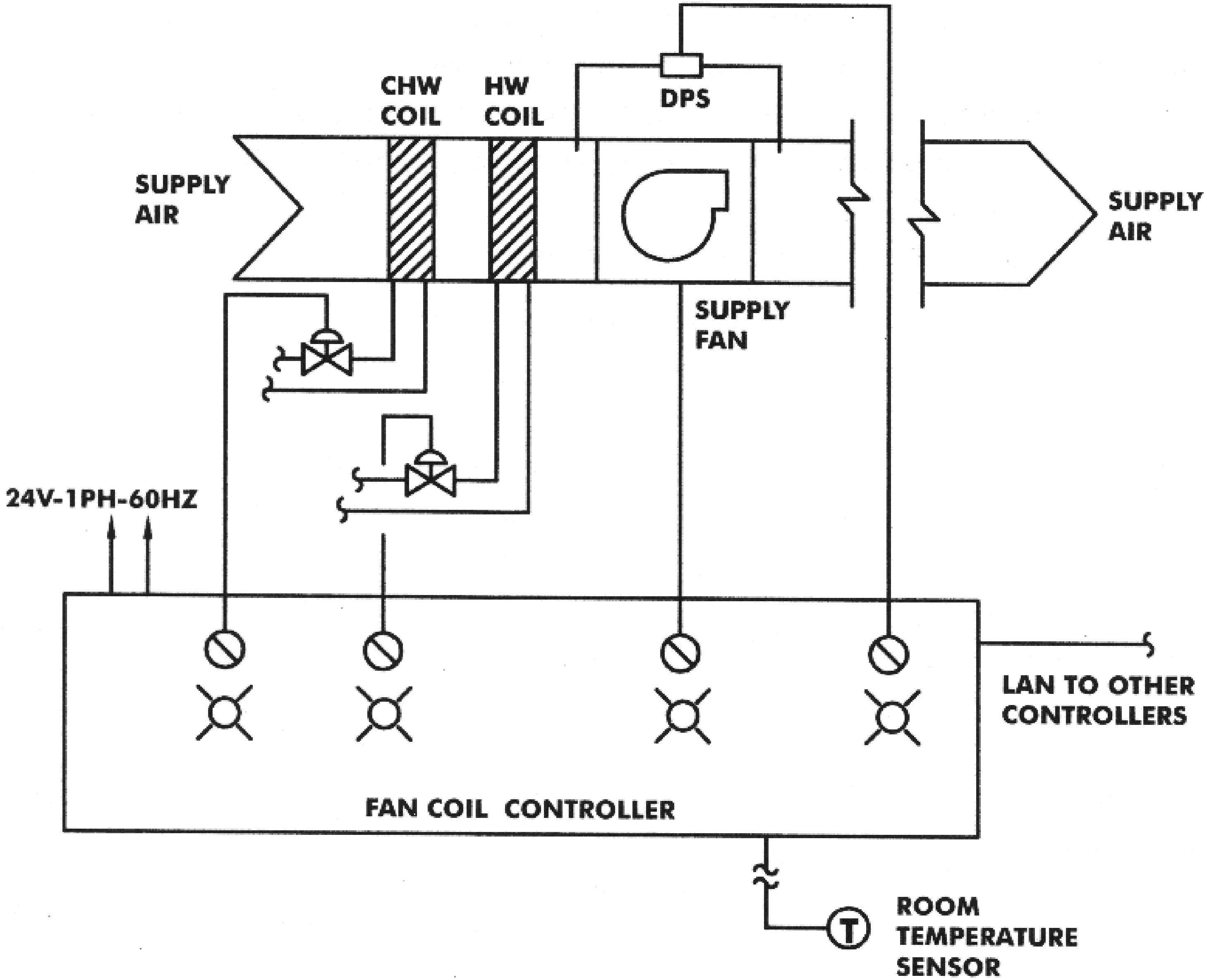
- Selection factors to consider
  - Number of points being monitored & controlled
  - Locations of points being monitored & controlled
  - Application of the system being monitored & controlled



Completed with power unit for driving the actuators

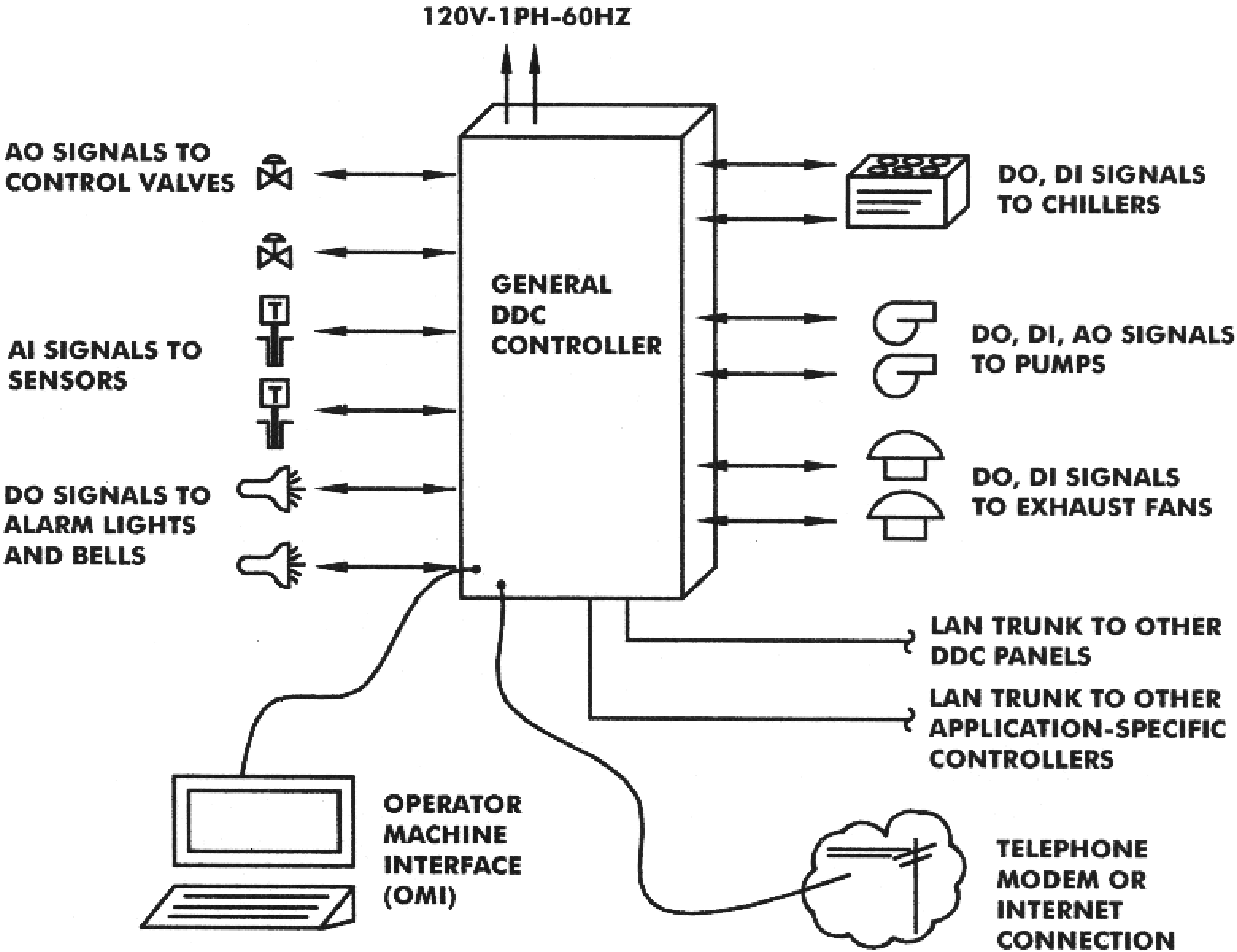
VAV zone controller (application specific)

[Source: Shadpour, F., 2001. The Fundamentals of HVAC Direct Digital Control]



Fan coil controller (application specific)

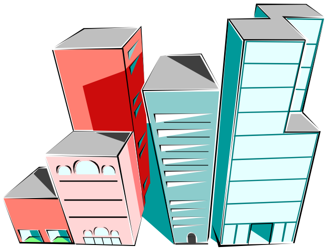
[Source: Shadpour, F., 2001. The Fundamenta[illegible]VAC Direct Digital Control]



General purpose DDC controller

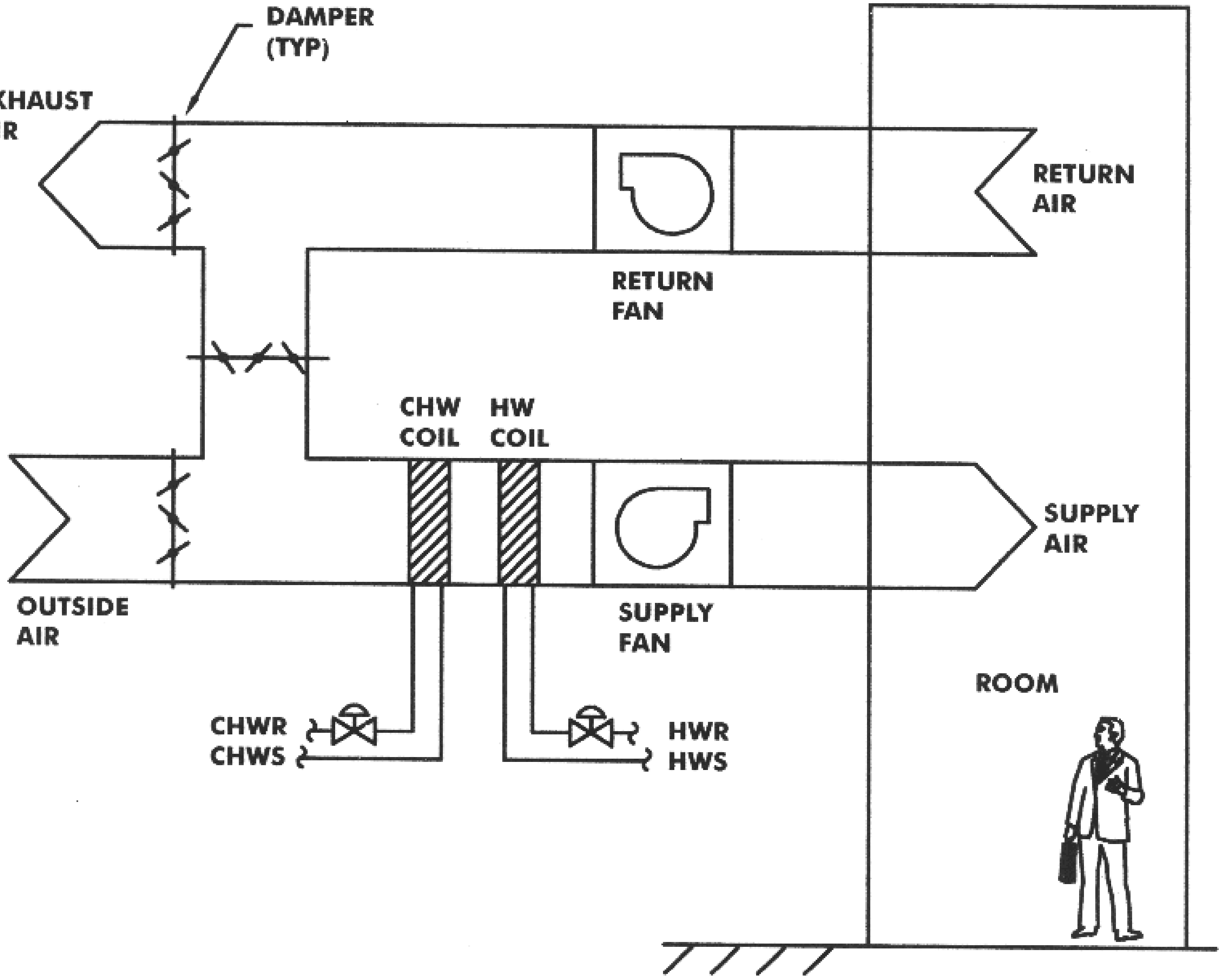
[Source: Shadpour, F., 2001. The Fundamentals of HVAC Direct Digital Control]

DDC System Design



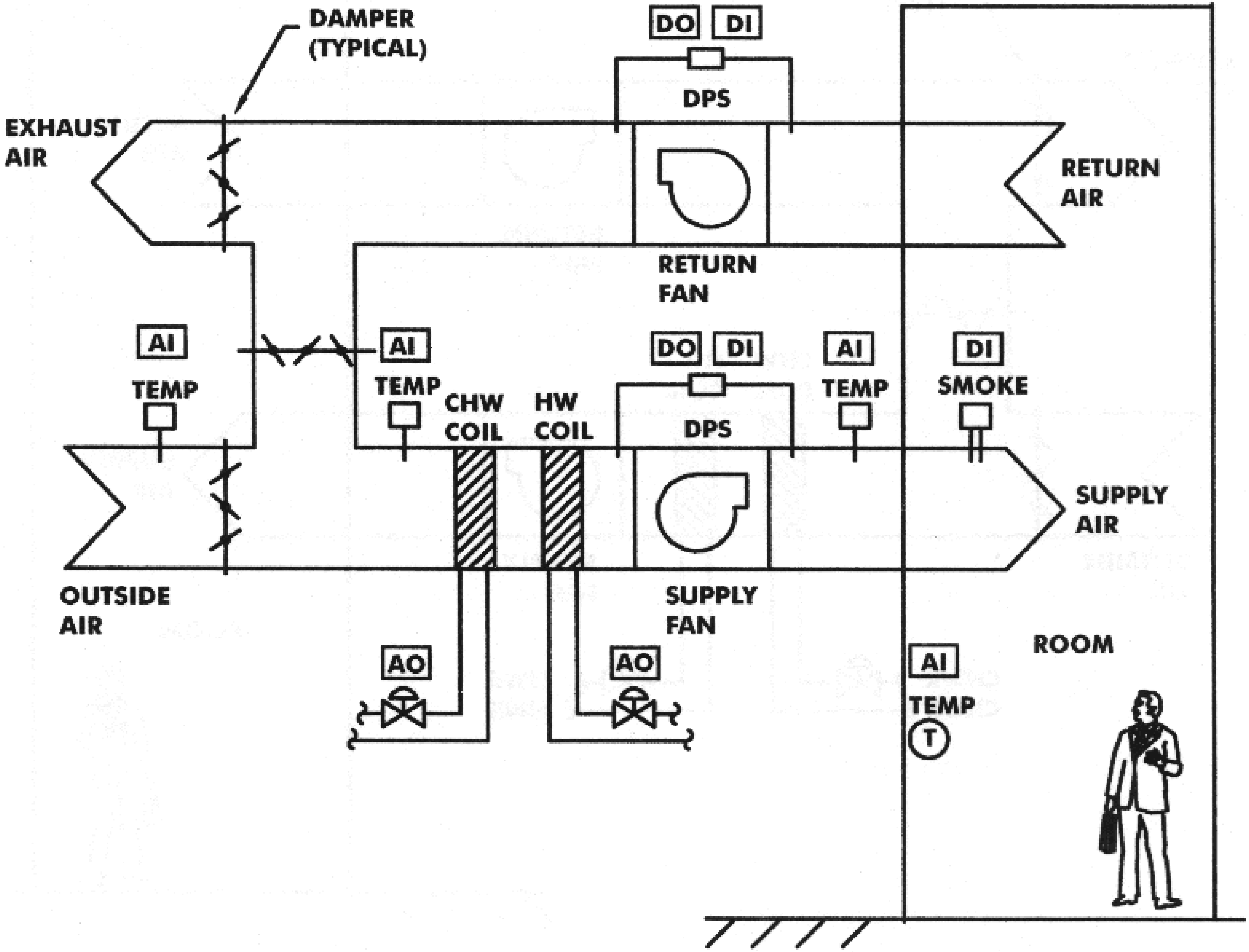
- Six steps of DDC system design
  1. System schematic
  2. Control point designations
  3. Point list
  4. DDC system architecture
  5. Sequence of operation
  6. Specifications

- * It is important to fully understand the design principle and designer's idea of the specified system



System schematic for a constant volume single zone AHU

[Source: Shadpour, F., 2001. The Fundamentals of HVAC Direct Digital Control]



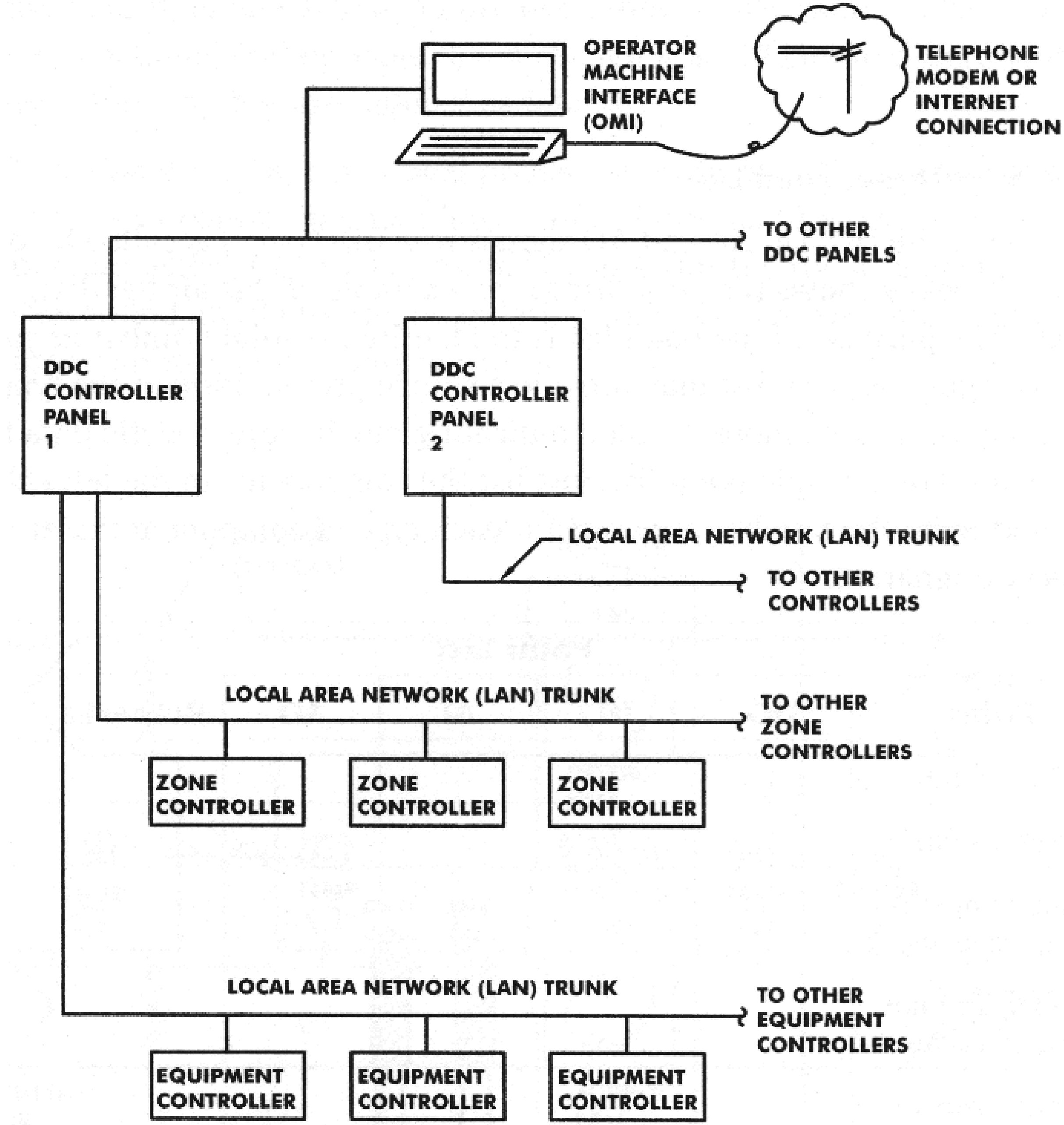
Control point designations for a constant volume single zone AHU

[Source: Shadpour, F., 2001. The Fundamentals of HVAC Direct Digital Control]

Point List					
Point	**DO**	**DI**	**AI**	**AO**	**Remarks**
Supply fan	1	1			
Return fan	1	1			
Duct temperature sensors			3		
Chilled and hot water valves				2	
Room temperature sensor			1		
Smoke detector		1			
Total	2	3	4	2	**(total 11 points)**

Table 1-1: An example of a point list. The purpose of a point list is to identify the total number of each point category.

[Source: Shadpour, F., 2001. The Fundamentals of HVAC Direct Digital Control]



An example of **DDC system architecture**

[Source: Shadpour, F., 2001. The Fundamentals of HVAC Direct Digital Control]

Sequence of Operations

1. *DDC system architecture*
   a. *The DDC system consists of a local area network of seven DDC panels*
   b. *Provide the programming and operator machine interface (OMI) through a personal computer. Locate the OMI computer in the facility engineer's office.*
   c. *Display the following alarm conditions at the OMI computer:*
      - *Supply fan failure*
      - *Return fan failure*
      - *Room air temperature above 78° F or below 68° F designated (adjustable)*

2. *Air handling control*
   a. *Operate supply fan SF-1 continuously at all times*
   b. *Operate return fan RF-1 continuously at all times*
   c. *Modulate chilled water and hot water valves in order to obtain optimum discharge temperature*
   d. *Reset discharge temperature set point based upon room temperature in accordance with the following table statement:*

Room Temperature (° F)	*Discharge Temperature Set Point (° F)*
65	*85*
85	*55*

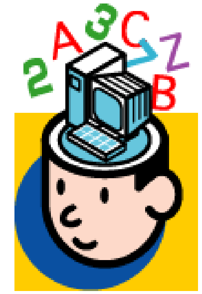
Figure 1-5: An example of sequence of operations.

[Source: Shadpour, F., 2001. The Fundamentals of HVAC Direct Digital Control]

Show on Drawings	**Indicate in Specifications**
Location of devices	Technical details Quality of components (standards) Functions to be carried out
Size of components	Material required
Quantity of components	Equipment schedule Workmanship

[Source: Shadpour, F., 2001. The Fundamentals of HVAC Direct Digital Control]

Exercise



- Draw a schematic diagram of a constant volume (CAV) single zone air handling system
- Identify the control point designations & type of signals
- Prepare a sequence of operations for this system
- What happens if FIRE happens in the room? What are the safety control actions?