Building Management System Part IV

Dr. KTMU Hemapala

Intelligent Building and BMS

A building that uses both technology and process to create a facility that is safe, healthy and comfortable and enables productivity and well being for its occupants. An intelligent building provides timely, integrated system information for its owners so that they may make intelligent decisions regarding its operation and maintenance. An intelligent building has an implicit logic that effectively evolves with changing user requirements and technology, ensuring continued and improved intelligent operation, maintenance and optimization. It exhibits key attributes of environmental sustainability to benefit present and future generations."

Source: CABA's Convergence of Green and Intelligent Buildings Report

Definition of Intelligent Building Technologies

“ The use of integrated technological building systems, communications and controls to create a building and its infrastructure which provides the owner, operator and occupant with an environment which is flexible, effective, comfortable and secure.”

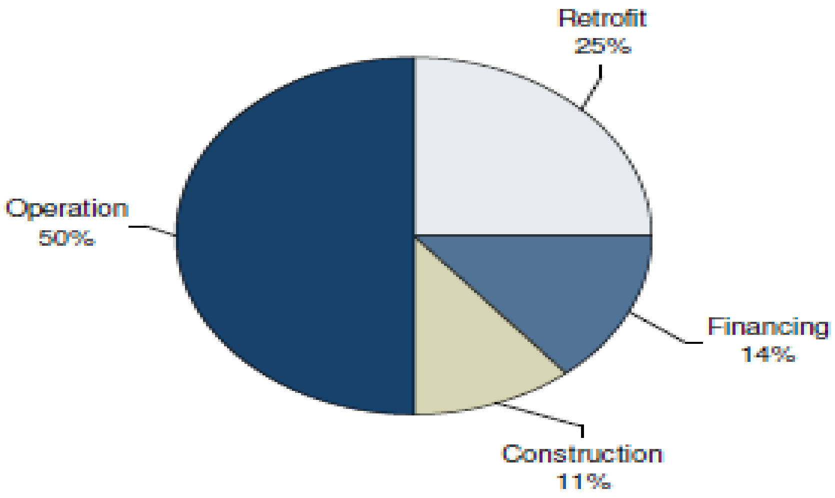
Source: Technology Roadmap for Intelligent Buildings (http://www.caba.org/trm)

Life Cycle Cost

www.frost.com

Why will intelligent technologies cost less than traditional technologies?

Building's Life Cycle Cost Over 40 Years



Source: ASHRAE

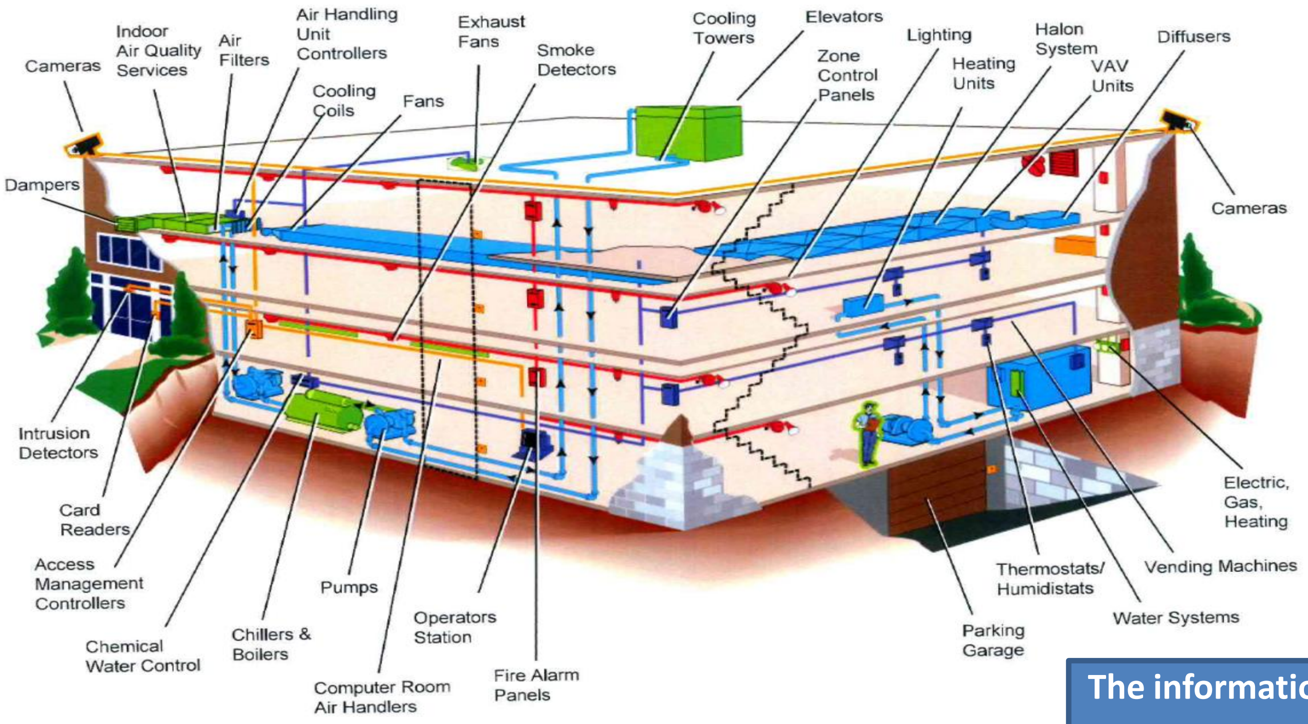
FROST & SULLIVAN

www.caba.org/brightgreen

Source: CABA's Convergence of Green and Intelligent Buildings Report

How will the Smart Grid impact buildings?

- Intelligent / Converged building



Information collected and analysed:

- Energy consumption
- Overview of cost per energy supplier
- Building occupancy
- Building usage
- Overview of operational cost (by section, building)
- Bench mark data (property cost per sq. metre, energy cost per sq metre)

The information management system optimises the decision

- Building management & investment decisions
- Outsourcing strategies
- Space allocation
- Choice of suppliers
- Implementation of demand response strategies

Source: CABA's 2011 Smart Grid Impact on Intelligent Buildings

CABA

CABA RESEARCH PROGRAM

BUILDING & ENERGY MGT. SYSTEMS

1. Energy Information Systems (EIS)
2. Building Management Systems (BMS)
3. Energy Management and Control Systems (EMCS)
4. Enterprise Energy Management (EEM)
5. Demand Response Systems (DRS)
6. Advanced Demand Response Systems (ADRS)
7. Intelligent Energy Management Systems (IEMS)
8. Integrated Building Management Systems (IBMS)

Source: WebGen Systems

Factors influence Thermal Comfort

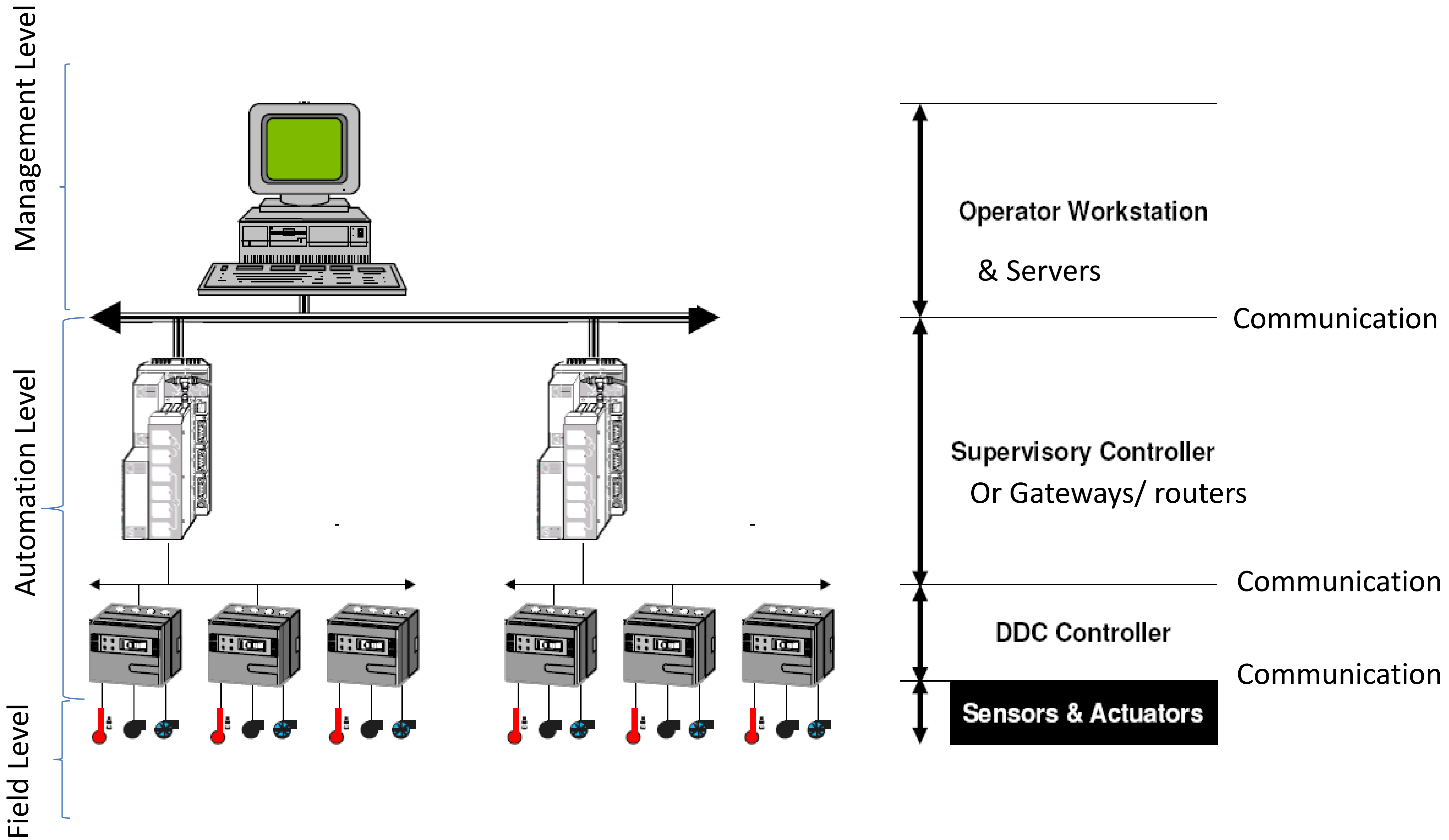
– Air Temperature
– Air Velocity
– RH
– Radiant Environment
– Clothing & Activity Level

HVAC system maintains,

– Temperature
– Humidity
– Air Distribution
– Indoor Air Quality

To ensure the comfortable and healthy environment

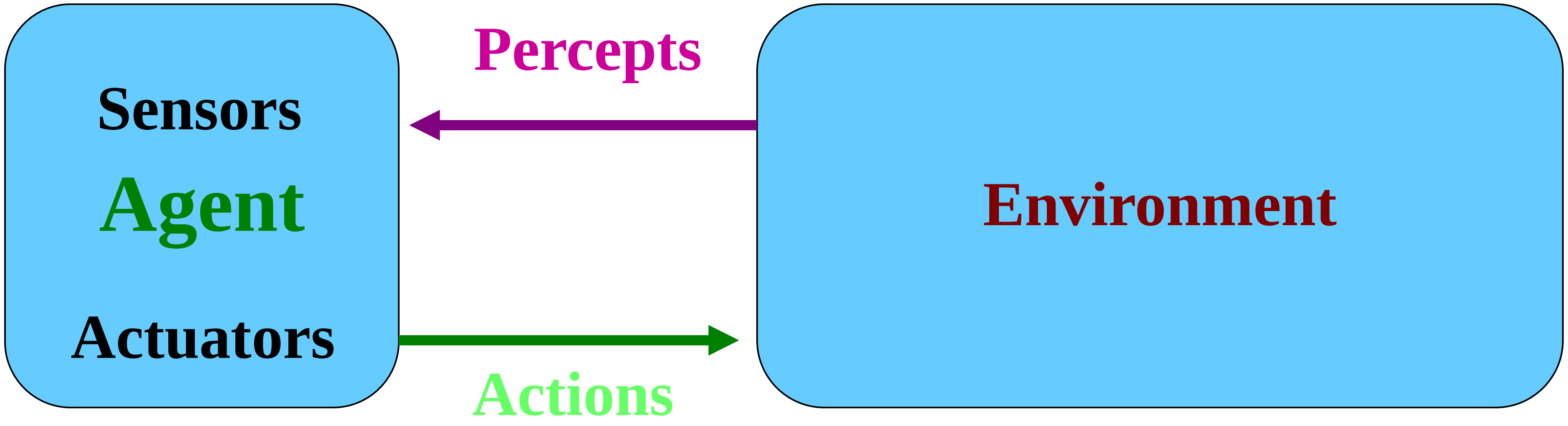
Thermal comfort and minimum health requirement must be achieved by the basic controls of AC system, while the optimal control of the systems aims at providing satisfied thermal comfort and indoor air quality with minimum energy input



Management Level
Automation Level
Field Level
Operator Workstation
& Servers
Communication
Supervisory Controller
Or Gateways/ routers
Communication
DDC Controller
Communication
Sensors & Actuators

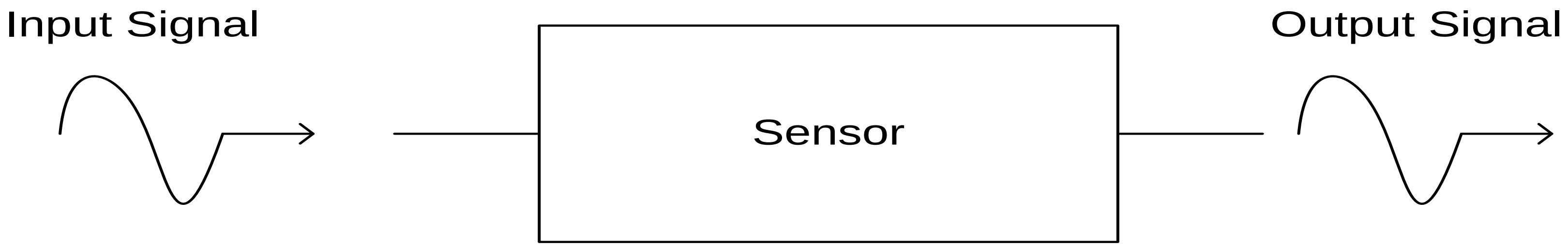
Agents for BMS Development

- Agents or Building Agents: An agent is anything (hardware/ software) that percepts information from its environment through sensors and acting upon that environment through actuators.



What are Sensors?

- American National Standards Institute (ANSI) Definition
  - A device which provides a usable output in response to a specified measurand



- A sensor acquires a physical parameter and converts it into a signal suitable for processing (e.g. optical, electrical, mechanical)

- A transducer
  - Microphone, Loud Speaker, Biological Senses (e.g. touch, sight,…ect)

Sensor

- Sophistication in the computing and software functions cannot compensate for inaccurate information. (By poor quality , wrong mounting)
- There are 3 elements
  - **Sensing element** – a component that undergoes measurable change (V,I or R)
  - **Transducer** – an active signal that produces an electrical signal which is a function of the change in the sensing element.
  - **Transducer** – Standardized function of the change.
  - In Practice Transducer and Transmitter combined. Also do remove noise , averaging over time, linearization.
  - Some time sensing element directly connect to the Controller then Signal conditioning take place in the Controller.

– Sensor Types

- **Status Sensor** Provides binary outputs (whether signal is above the threshold or not)
- **Analogue Sensor** Not discrete signal
- **Sensor Controller** – Thermostats

Sensors…

- Analogue sensors – 2 type
  - Passive Sensor – No transducer available , no external power needed
  - Active Sensor – signal conditioning is incorporated in the sensor , external power needed
- Standard Electrical Signals
  - 4 – 20 ma – Current Signal (0 ~ 20 mA)
  - 0 – 10 Vdc – Voltage Signal (0 ~5 Vdc)
  - Voltage Free Contact (NO or NC)
  - Pulses
  - Via High Level interfacing
  - Additional Data Processing – calibration, compensation, calculation – Eg -Enthalphy

Sensors….

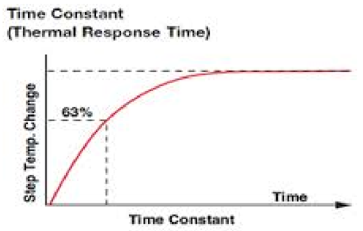
Active Analogue Sensor

Passive Analogue Sensor

Stats Sensor

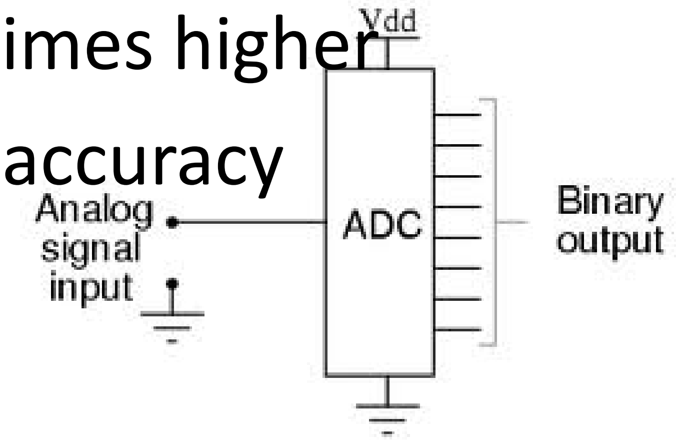
Technical Specifications of Sensors…

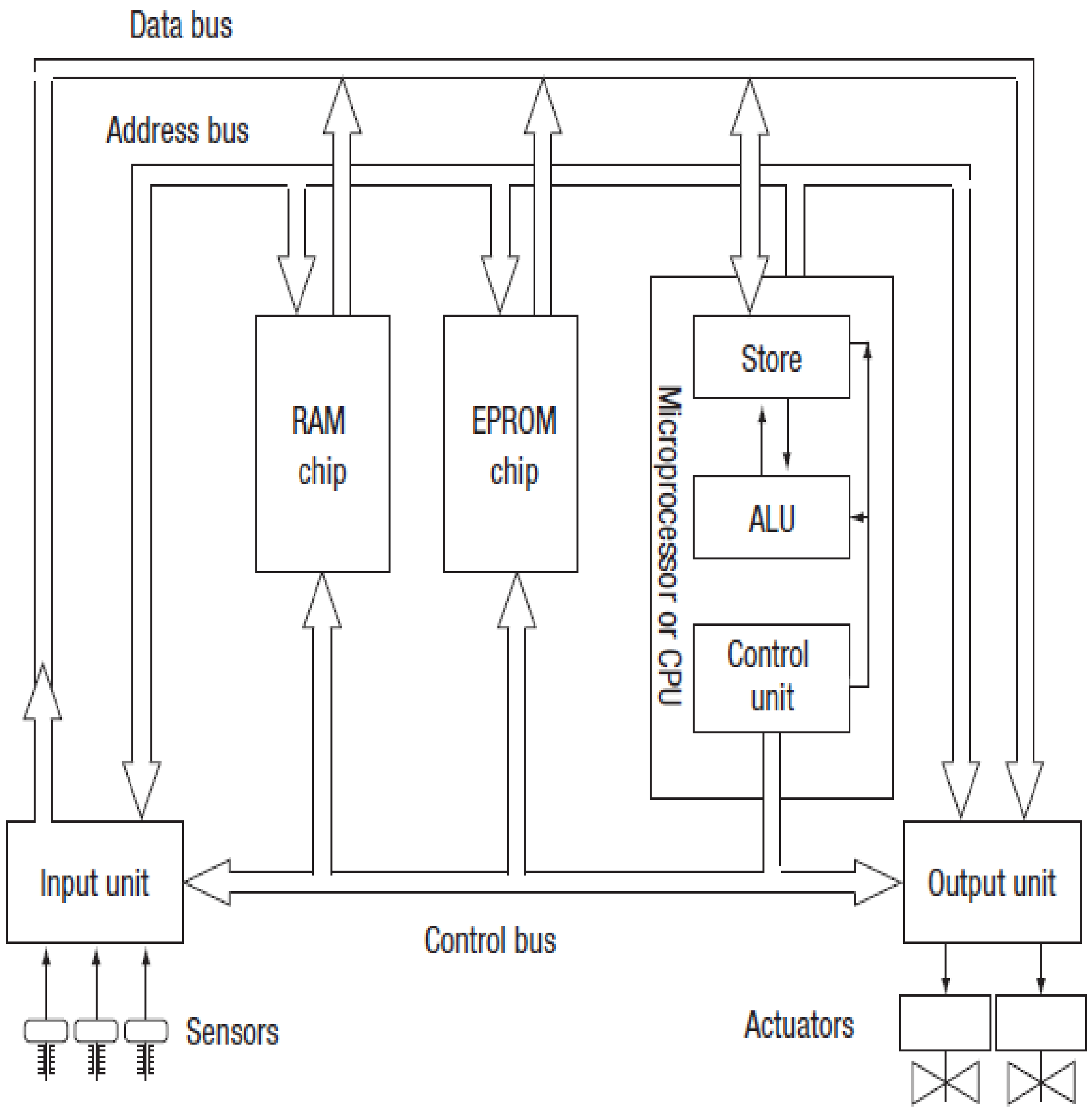
- Range – operation Range
- Sensitivity – how much will the input variable must change to produce an output
- Linearity – if not linear , signal conditioning needed
- Resolution - the ability of a sensor to see small differences in readings
- Stability - another way of stating drift. That is, with a given input you always get the same output
- Repeatability - This is the ability of a sensor to repeat a measurement when put back in the same environment.
- Hysteresis - A linear up and down input to a sensor, results in an output that lags the input
- Drift - This is the low frequency change in a sensor with time
- Response Time - The **time** constant of any **sensor** is **defined** as the **time** required for that **sensor** to respond to 63.2 of it.
- **Accuracy** - is the degree of closeness of measurements of a quantity to that quantity's actual (true) value.
- **Precision** - also called reproducibility or repeatability, is the degree to which repeated measurements under unchanged conditions show the same results



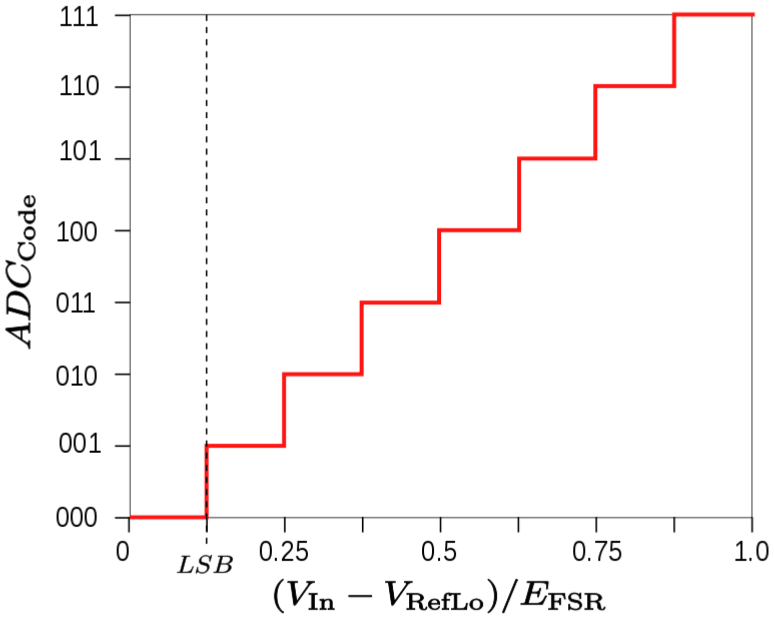
Input Units and Signal Conversion

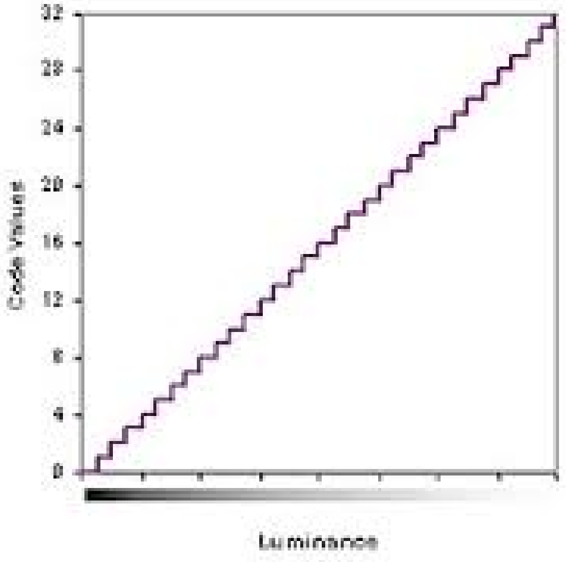
- Input & Output interface provide link to the Microprocessor
- Analogues signals to be converted to Bits and Bytes
- A/D conversion and Sampling
- Sampling frequency twice higher than signal frequency *(Shannon's sampling theory)*
- In Practices 10 times higher
- A/D conversion accuracy





8 Bit A/D Conversion Vs 16 Bits A/D Conversion





n-bit	Number of steps	Step Size (mV)
8	2^8 = 256	5/255 = 19.61
10	2^10 = 1024	5/1023 = 4.89
12	2^12 = 4096	5/4095 = 1.22
16	2^16 = 65536	5/65535 = 0.076

Example

A signal ranging from 0 to 10 V comes from a temperature sensor corresponding to the temperature ranging from –20°C to 80°C. What is the resolution of an 8-bit A/D converter?

Solution….

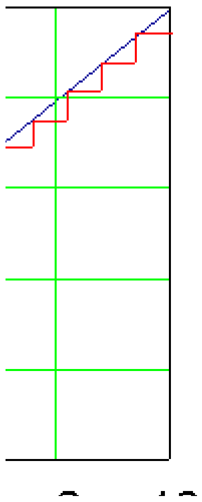
Solution

Resolution may be defined as the change in the input signal for the digital output to change by the least significant bit (the last bit on the right of a binary number). An 8-bit word can be used to represent in binary the numbers from 0 to 255 (2^8 numbers including 0), so the resolution is:

$$10/(2^8-1) = 0.0392 \text{ V} = 39.2 \text{ mV}$$

or $$(80-(-20))/(2^8-1) = 0.392 \text{ K}$$

(Note: the resolution of this A/D, 0.392 K, is too low for many applications, indicating the 8-bit length is not sufficient for many applications.)



Sensors Used in BMS

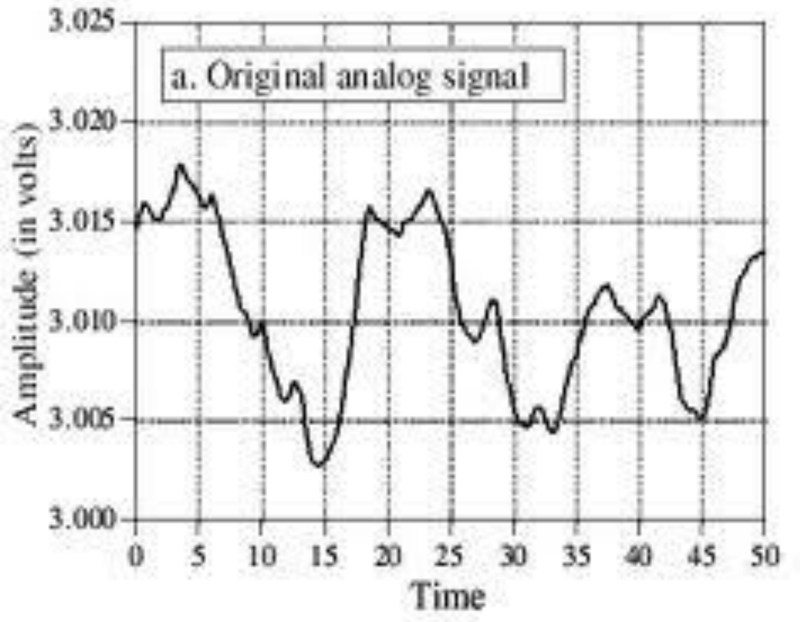
- Analogue signal sensors
  - Temperature sensor / type
  - Pressure sensor /type
  - Humidity sensor / type
  - CO_2 sensor
  - Flow sensor / type
  - Other sensor (vibration , air speed, CO ,VOC, level)

- Digital signal sensors
  - Switches
  - Status detection
  - Detection sensor

- Pulse Generator & Metering
  - meters

Analogue Sensor

"Analogue sensors produce continuous output signals (eg voltage) which is usually proportional to the amount measured. Physical quantities such as speed, pressure, temperature, pressure, strain and displacement are all analogue quantities."



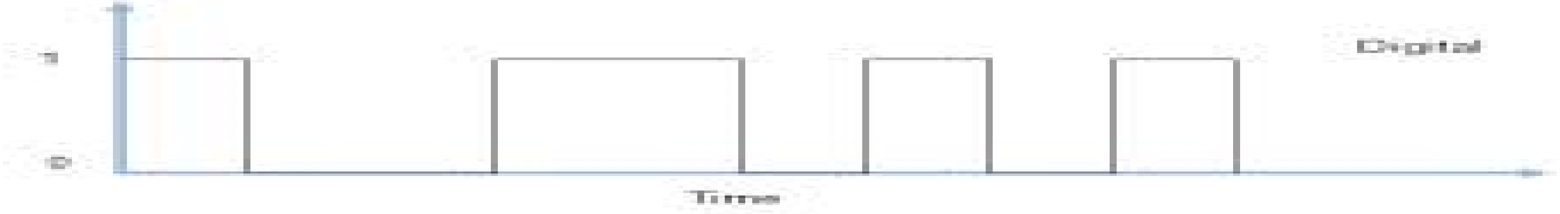
V = IR

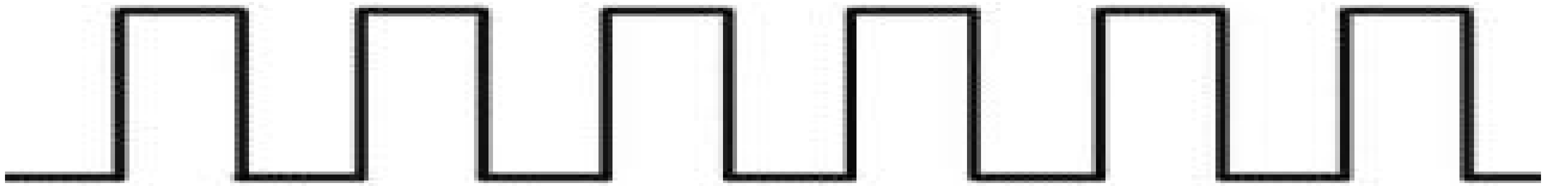
Q = CV

$$\mathcal{F} = \phi \mathcal{R}_m,$$

Digital Switches (Sensors)

“signal that is a representation of a sequence of discrete values”





Detectable Phenomenon

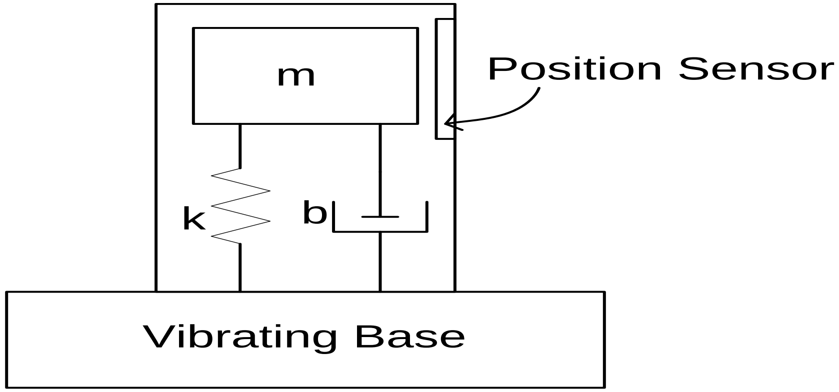
Stimulus	Quantity
Acoustic	Wave (amplitude, phase, polarization), Spectrum, Wave Velocity
Biological & Chemical	Fluid Concentrations (Gas or Liquid)
Electric	Charge, Voltage, Current, Electric Field (amplitude, phase, polarization), Conductivity, Permittivity
Magnetic	Magnetic Field (amplitude, phase, polarization), Flux, Permeability
Optical	Refractive Index, Reflectivity, Absorption
Thermal	Temperature, Flux, Specific Heat, Thermal Conductivity
Mechanical	Position, Velocity, Acceleration, Force, Strain, Stress, Pressure, Torque

Choosing a Sensor

Environmental Factors	Economic Factors	Sensor Characteristics
Temperature range	Cost	Sensitivity
Humidity effects	Availability	Range
Corrosion	Lifetime	Stability
Size		Repeatability
Overrange protection		Linearity
Susceptibility to EM interferences		Error
Ruggedness		Response time
Power consumption		Frequency response
Self-test capability		

Accelerometer

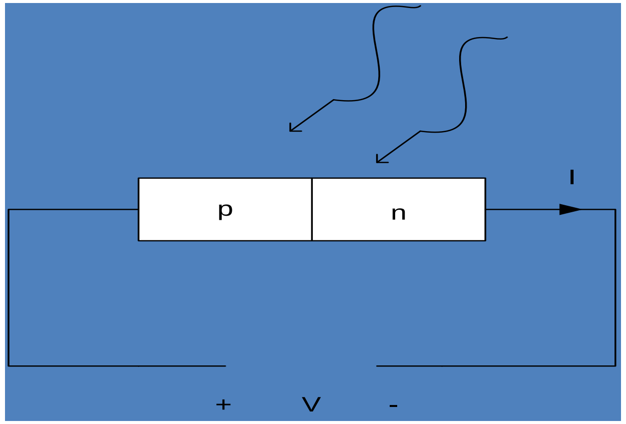
- Accelerometers are used to measure along one axis and is insensitive to orthogonal directions
- Applications
  - Vibrations, blasts, impacts, shock waves
  - Air bags, washing machines, heart monitors, car alarms
- Apply $f = ma$



Light Sensor

- Light sensors are used in cameras, infrared detectors, and ambient lighting applications

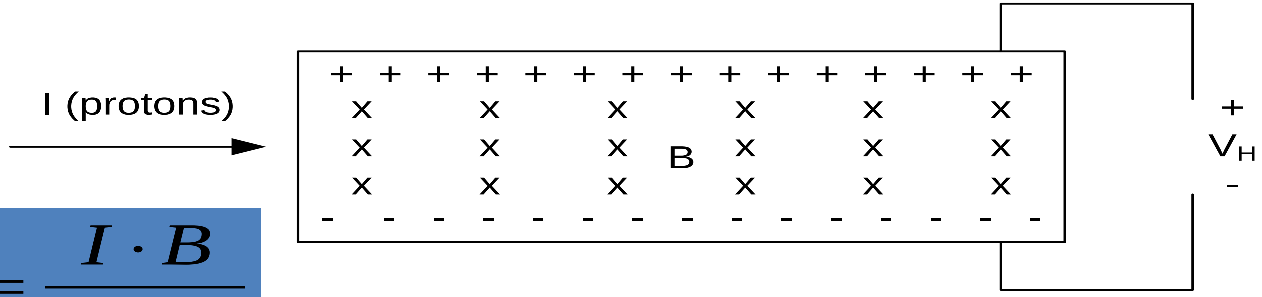
- Sensor is composed of photoconductor such as a photo-resistor, photodiode, or phototransistor



Magnetic Field Sensor

- Magnetic Field sensors are used for power steering, security, and current measurements on transmission lines

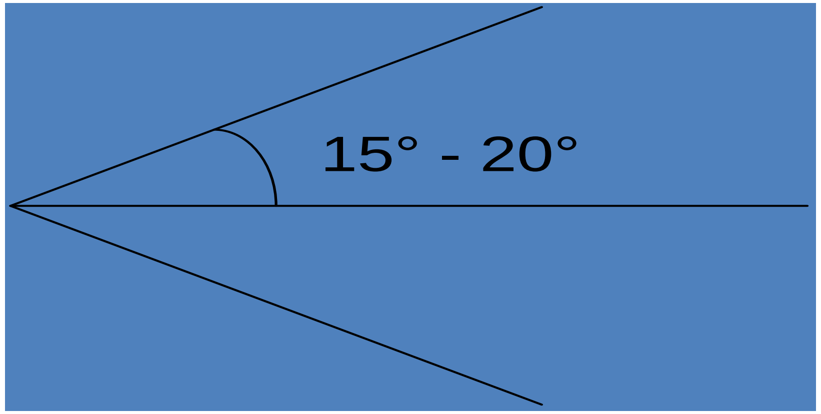
- Hall voltage is proportional to magnetic field
- BMS security checking



$$V_H = \frac{I \cdot B}{n \cdot q \cdot t}$$

Ultrasonic Sensor

- Ultrasonic sensors are used for position measurements
- Sound waves emitted are in the range of 2-13 MHz
- **So**und **N**avigation **A**nd **R**anging (SONAR)
- **Ra**dio **D**etection **A**nd **R**anging (RADAR) – EM waves

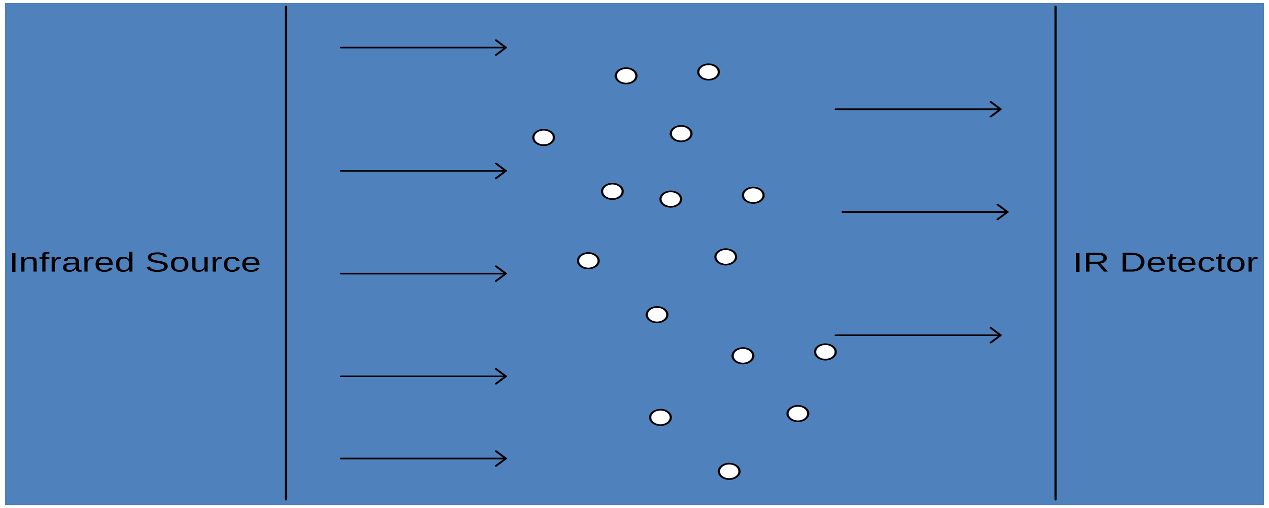


Photogate

- Photogates are used in counting applications (e.g. finding period of period motion)
- Infrared transmitter and receiver at opposite ends of the sensor
- Time at which light is broken is recorded

CO_2 Gas Sensor

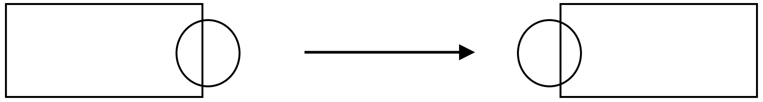
- CO_2 sensor measures gaseous CO_2 levels in an environment
- Measures CO_2 levels in the range of 0-5000 ppm
- Monitors how much infrared radiation is absorbed by CO_2 molecules

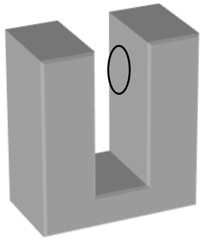


Infrared Sensors

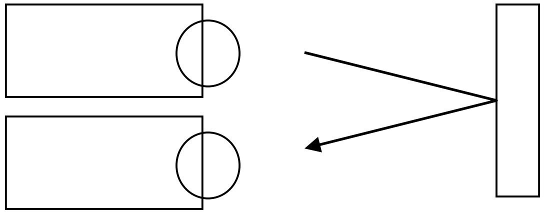
- Intensity based infrared
  - Reflective sensors
  - Easy to implement
  - susceptible to ambient light
- Modulated Infrared
  - Proximity sensors
  - Requires modulated IR signal
  - Insensitive to ambient light
- Infrared Ranging
  - Distance sensors
  - Short range distance measurement
  - Impervious to ambient light, color and reflectivity of object

Intensity Based Infrared

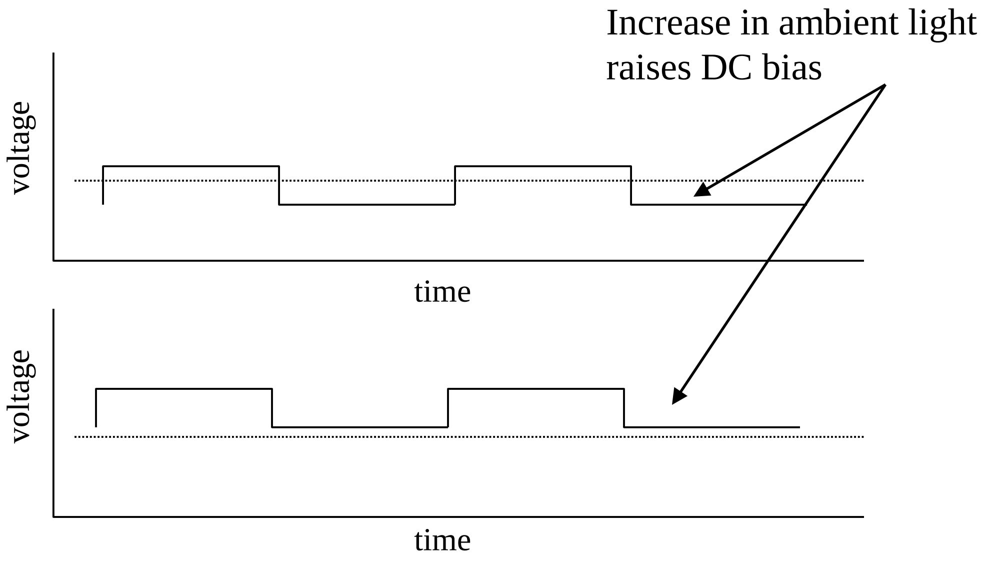




Break-Beam sensor



Reflective Sensor



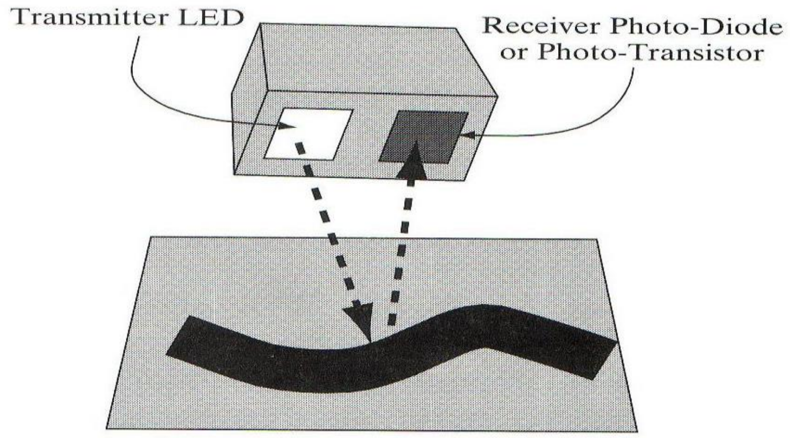
- Easy to implement (few components)
- Works very well in controlled environments
- Sensitive to ambient light

IR Reflective Sensors

- Reflective Sensor:
  - Emitter IR LED + detector photodiode/phototransistor
  - Phototransistor: the more light reaching the phototransistor, the more current passes through it
  - A beam of light is reflected off a surface and into a detector
  - Light usually in infrared spectrum, IR light is invisible

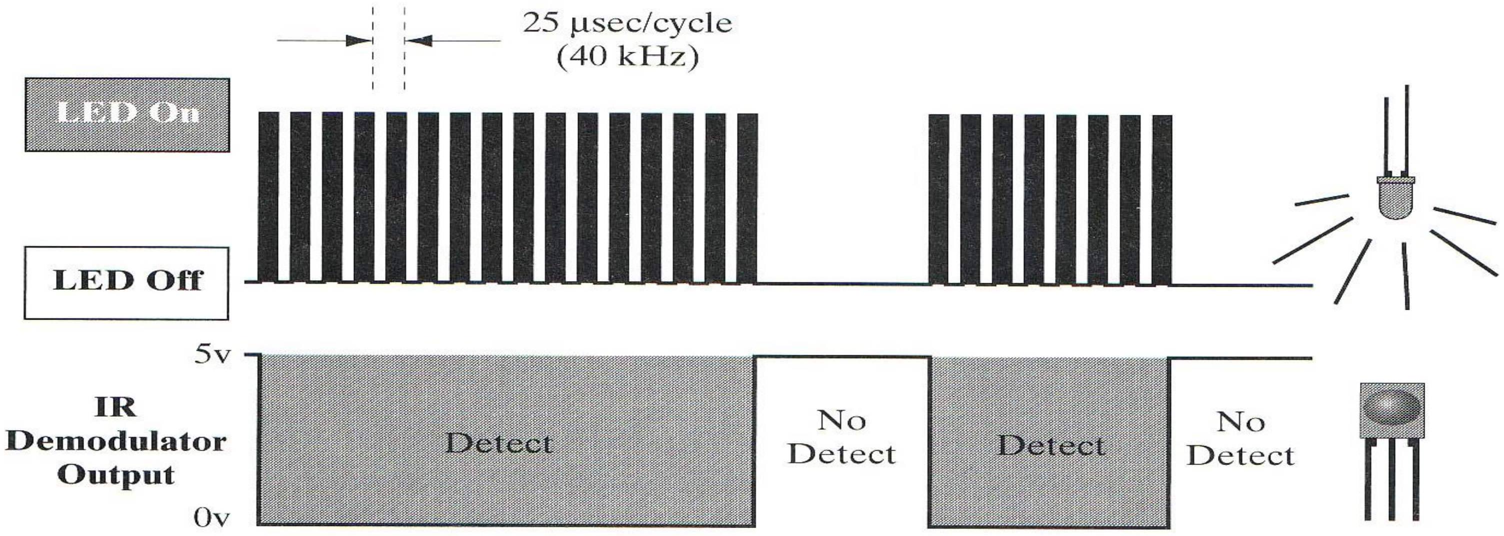
- Applications:
  - Object detection,
  - Line following, Wall tracking
  - Optical encoder

- Drawbacks:
  - Susceptible to ambient lighting
    - Provide sheath to insulate the device from outside lighting
  - Susceptible to reflectivity of objects
  - Susceptible to the distance between sensor and the object



Modulated Infrared

- Modulation and Demodulation
  - Flashing a light source at a particular frequency
  - Demodulator is tuned to the specific frequency of light flashes. (32kHz~45kHz)
  - Flashes of light can be detected even if they are very week
  - Less susceptible to ambient lighting and reflectivity of objects
  - Used in most IR remote control units, proximity sensors

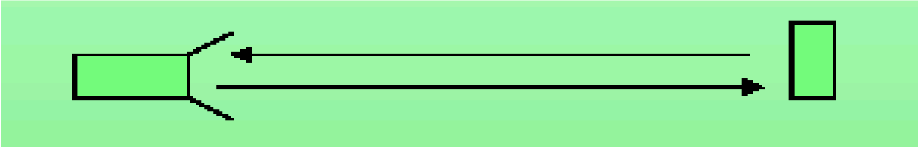


Negative true logic:

Detect = 0v

No detect = 5v

Range Finder



- Time of Flight
- The measured pulses typically come form ultrasonic, RF and optical energy sources.
  - **D = v * t**
  - D = round-trip distance
  - v = speed of wave propagation
  - t = elapsed time
- Sound = 0.3 meters/msec
- RF/light = 0.3 meters / ns (Very difficult to measure short distances 1-100 meters)

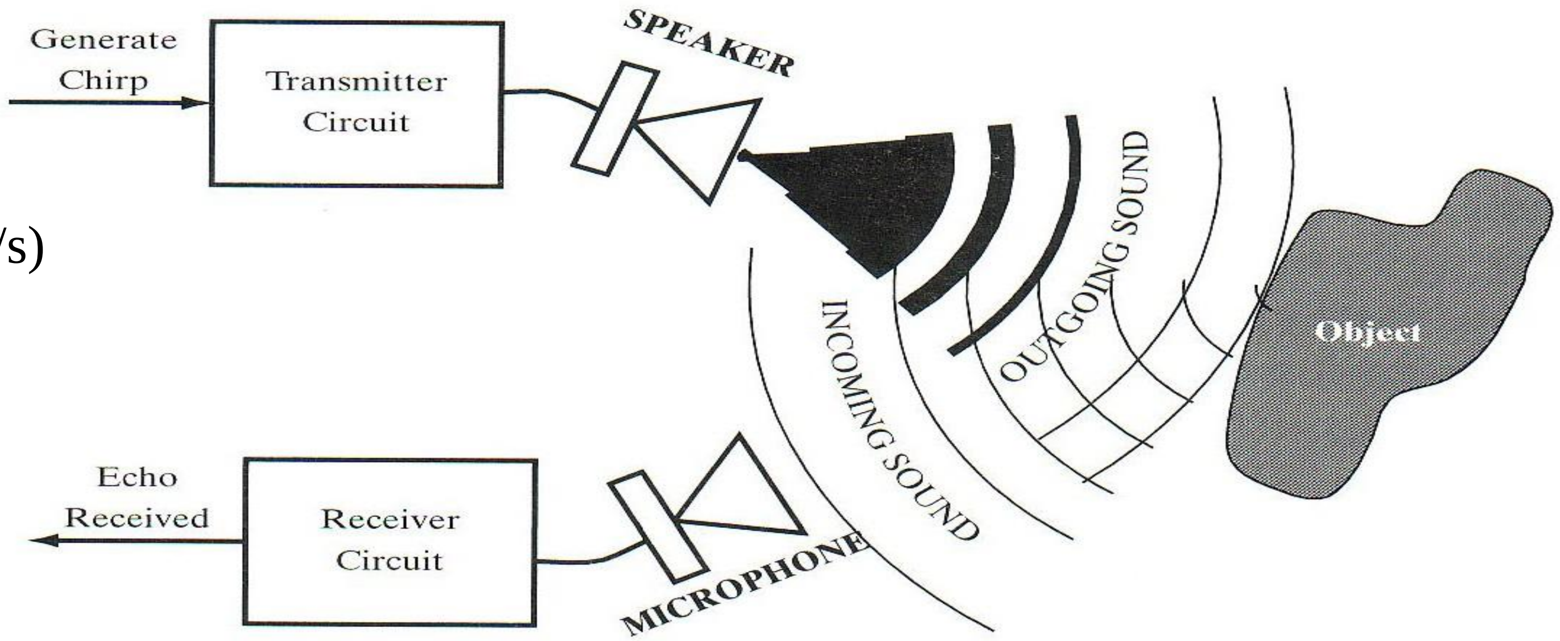
Ultrasonic Sensors

- Basic principle of operation:
  - Emit a quick burst of ultrasound (50kHz), (human hearing: 20Hz to 20kHz)
  - Measure the elapsed time until the receiver indicates that an echo is detected.
  - Determine how far away the nearest object is from the sensor

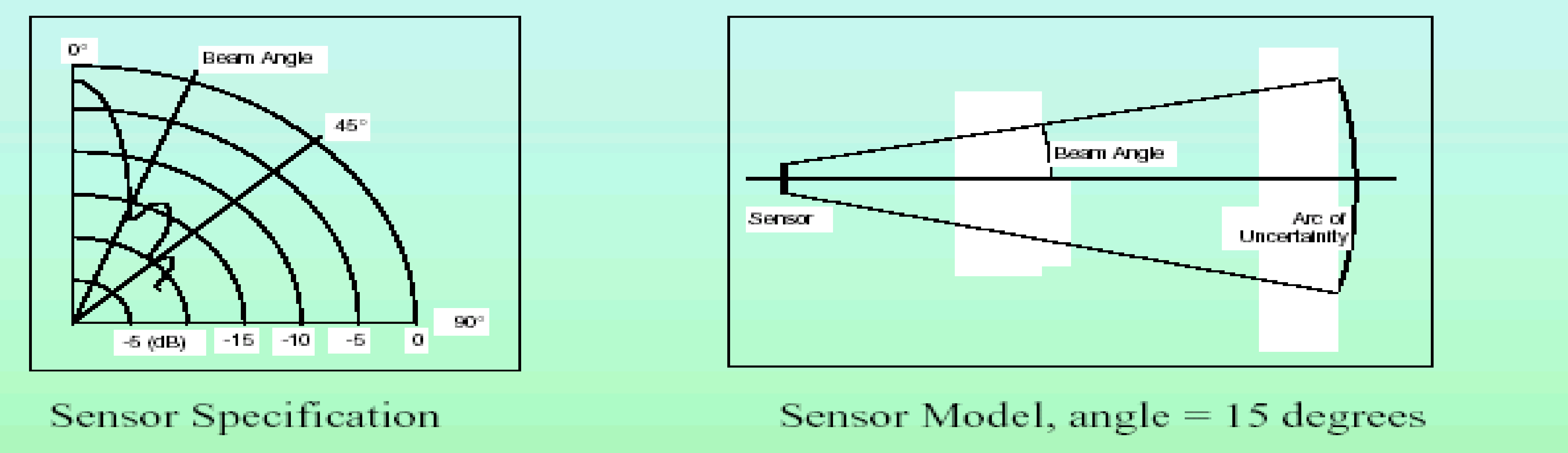
- **D = v * t**

D = round-trip distance
v = speed of propagation(340 m/s)
t = elapsed time

Bat, dolphin, …



Ultrasonic Sensors



- Ranging is accurate but bearing has a 30 degree uncertainty. The object can be located anywhere in the arc.
- Typical ranges are of the order of several centimeters to 30 meters.
- Another problem is the propagation time. The ultrasonic signal will take 200 msec to travel 60 meters. (30 meters roundtrip @ 340 m/s)

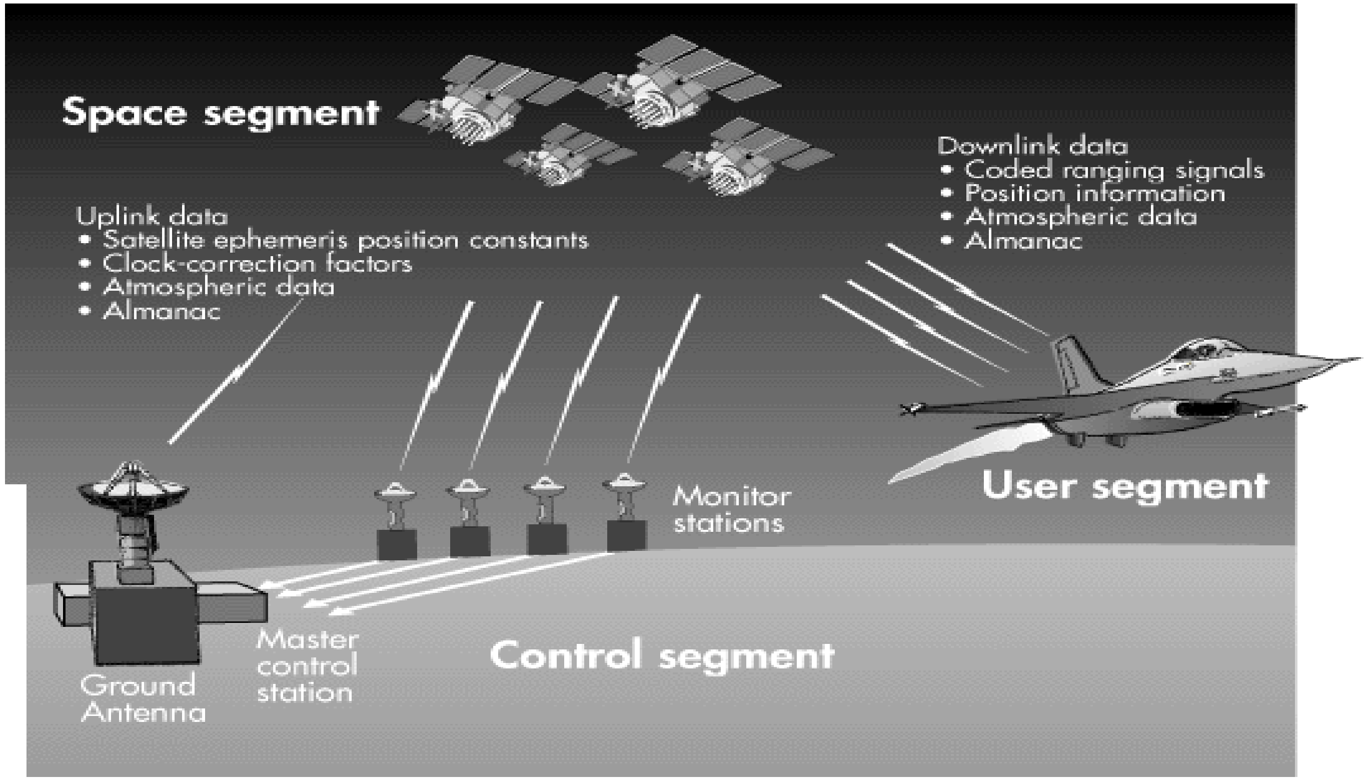
Laser Ranger Finder

- Range 2-500 meters
- Resolution : 10 mm
- Field of view : 100 - 180 degrees
- Angular resolution : 0.25 degrees
- Scan time : 13 - 40 msec.
- These lasers are more immune to Dust and Fog

Global Positioning System (GPS)

24 satellites (+several spares)

broadcast time, identity, orbital parameters (latitude, longitude, altitude)



Space Segment

Temperature Measuring

- Bimetal
- Rod and Tube
- Sealed Bellows
- Remote Bulb
- Thermistor
- Resistance Temperature Detector – RTD
- Thermocouple

Bimetal – for Both ON/OFF and Proportional controlling
Less expensive , accuracy will drift over time

Rod & Tube – Metal Rod and Tube combination – immersion type temp sensor

Sealed Bellows / Remote Bulb– a balloon filled with gas , vapor – old thermostats

Temperature Sensor

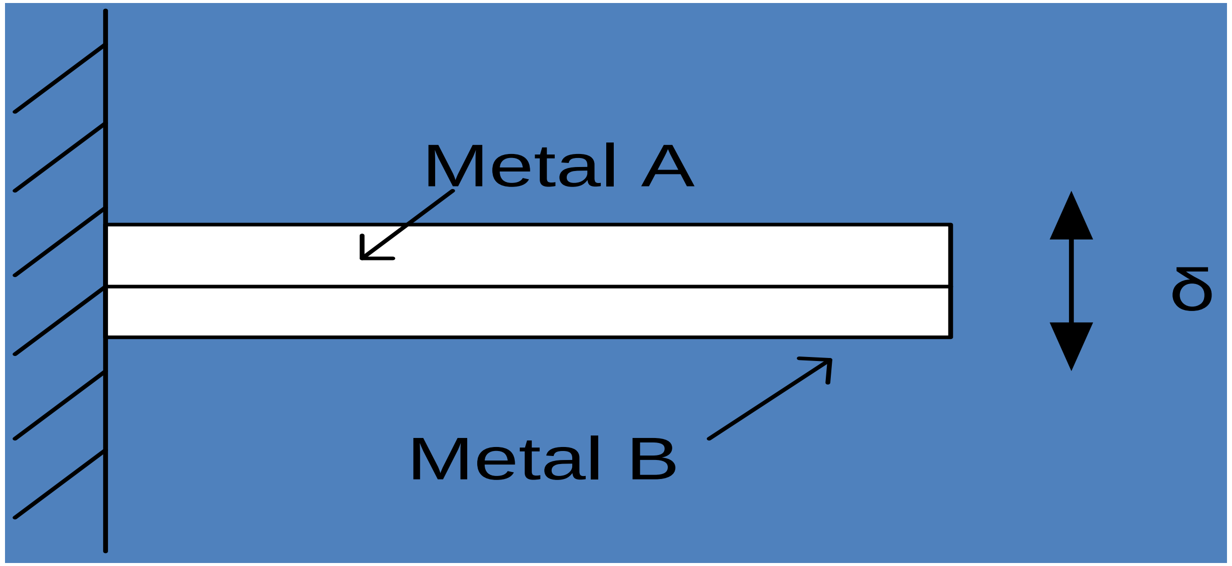
- Temperature sensors appear in building (BMS) , chemical process plants, engines, appliances, computers, and many other devices that require temperature monitoring

- Many physical phenomena depend on temperature, so we can often measure temperature indirectly by measuring pressure, volume, electrical resistance, and strain

Temperature Sensor

- Bimetallic Strip

$$L = L_0[1 + \beta(T - T_0)]$$



- Application
  - Thermostat (makes or breaks electrical connection with deflection)

Temperature Sensor

- Resistance temperature device.

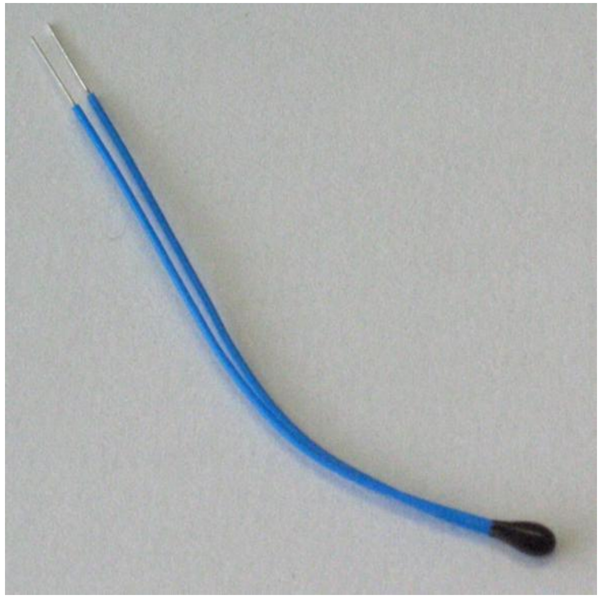
$$R = R_0[1+\alpha(T - T_0)]$$

$$R = R_0 e^{\gamma\left[\frac{1}{T}-\frac{1}{T_0}\right]}$$

Employ this sensor whenever it needs to measure temperature in BMS

Thermistor

- A thermistor is a type of resistor whose resistance varies significantly with temperature
- Use Ceramic , Polymer
- Mostly Nonlinear
- Large response for small change
- Low cost
- Good for a limited range



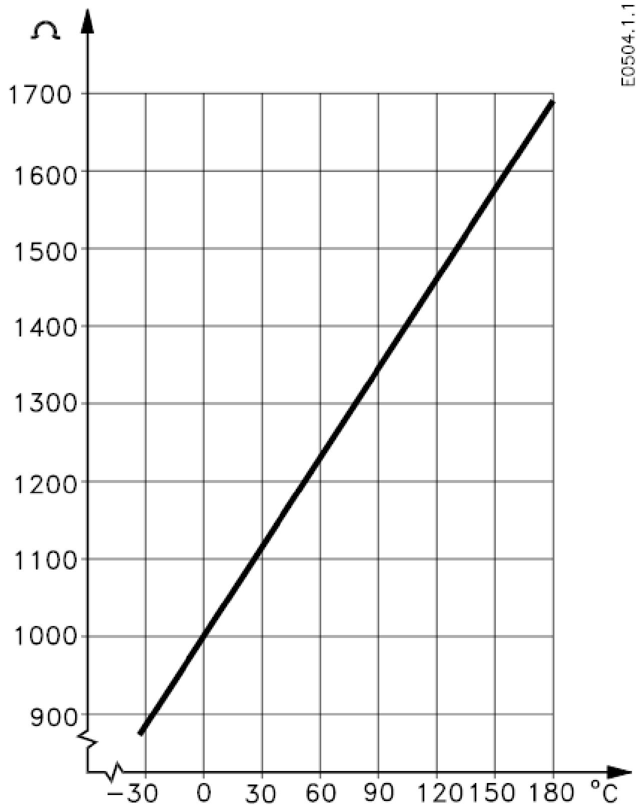
NTC – Type Sensor
PTC – Type Sensor

$$\Delta R = k\Delta T$$

Resistance Temperature Detector – RTD

- Metal
- Platinum, Nickel, Copper , ect
- Platinum liner 0 ~ 300 F 0.3% - Tolerance
- Some time Integrated to a Circuit to produce 0~10 Vdc , 4 ~ 20 mA
- PT1000- has a resistance of 1000 ohms at 0 °C and 138.4 ohms at 1000 °C.

Pt 1000 temp Characteristic curve

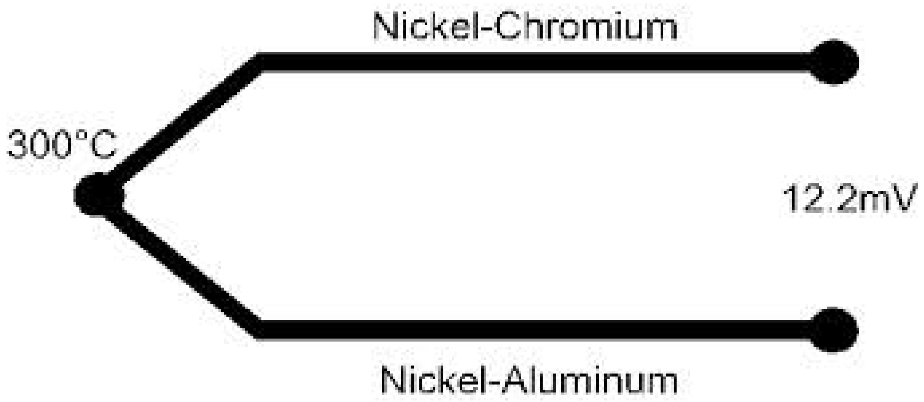


Resistance characteristics

- excellent accuracy over a wide temperature range (from -200 to +850 °C.

Thermocouple

- A thermocouple is a temperature-measuring device consisting of two dissimilar conductors that contact each other at one or more spots
- Suitable for High Temperature applications



Biggest Problems of the sensors are the Errors
Sources of error of Sensors

- **Interchangeability:** the “closeness of agreement”
- **Insulation Resistance**: Error caused by the inability to measure the actual resistance of element.
- **Stability:** Ability to maintain R vs T over time as a result of thermal exposure.
- **Repeatability:** Ability to maintain R vs T under the same conditions after experiencing thermal cycling throughout a specified temperature range.
- **Hysteresis**: Change in the characteristics of the materials from which the sensor is built due to exposures to varying temperatures.
- **Self Heating:** Error produced by the heating of the sensor element due to the power applied.
- **Time Response:** Errors are produced during temperature transients because the sensor cannot respond to changes fast enough.
- **Thermal EMF**: Thermal EMF errors are produced by the EMF adding to or subtracting from the applied sensing voltage, primarily in DC systems.

Type Of Temperature sensor

1. Room sensors for wall mounting

2. Room sensors for flush mour

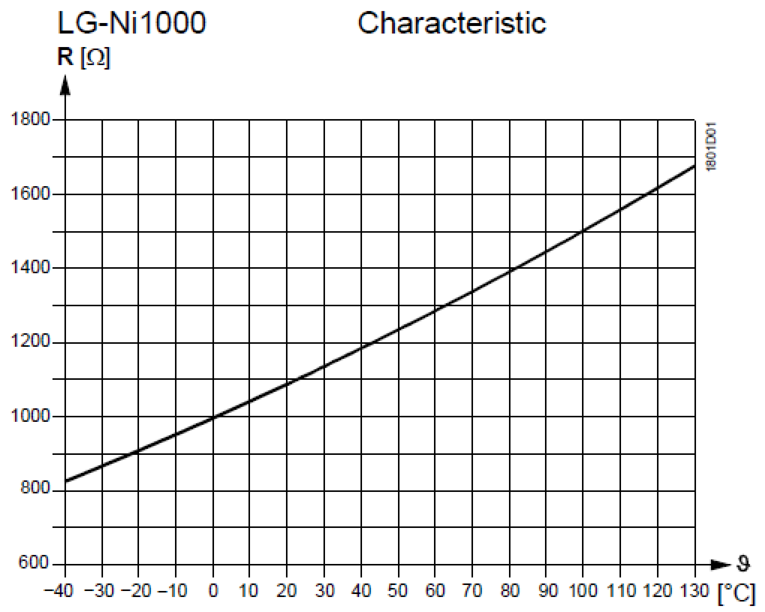
3. Duct sensors
4. Immersion sensors

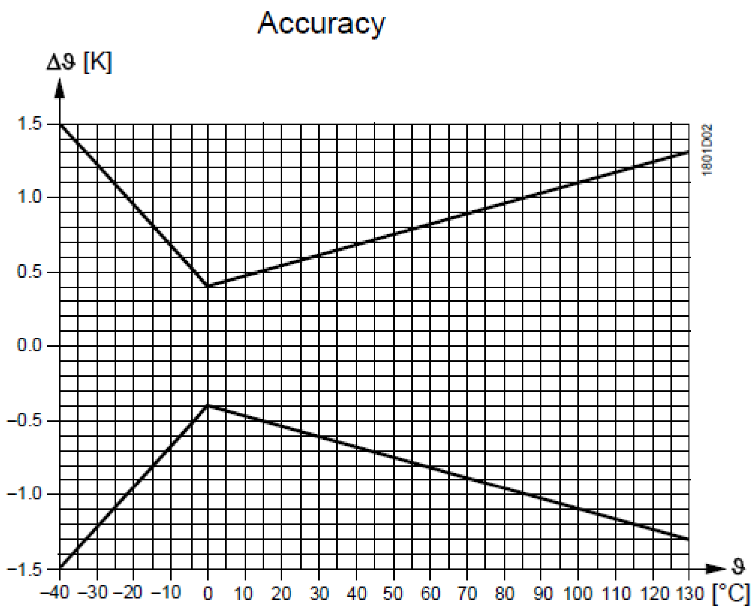
5. Strap-on sensors
6. Outside sensors

7. Cable sensors

Parameters of Temperature Sensors

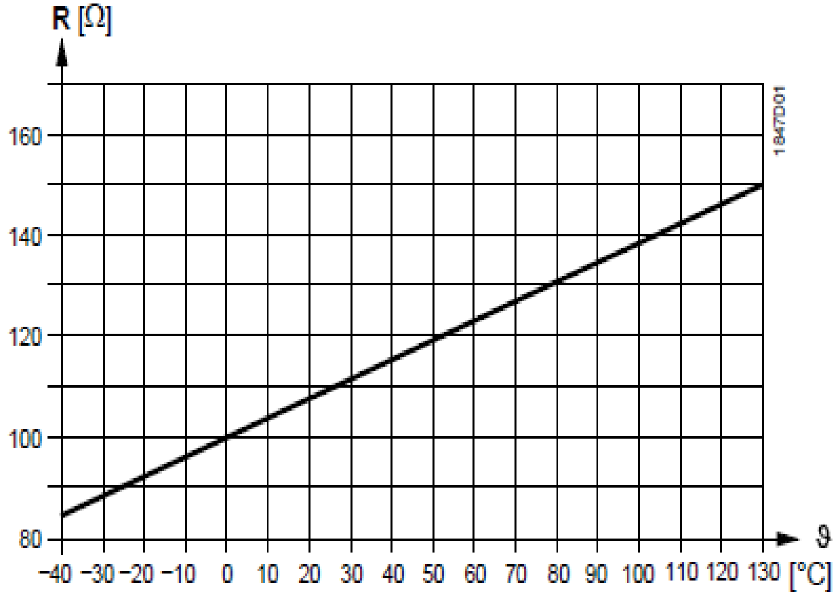
Type reference	*Sensing element*	*Range of use*	*Time constant*
QAD22	LG-Ni 1000	-30…+130 °C	3 s
QAD2010	Pt 100	-30…+130 °C	3 s
QAD2012	Pt 1000	-30…+130 °C	3 s
QAD2030	NTC 10k	-30…+125 °C	6 s



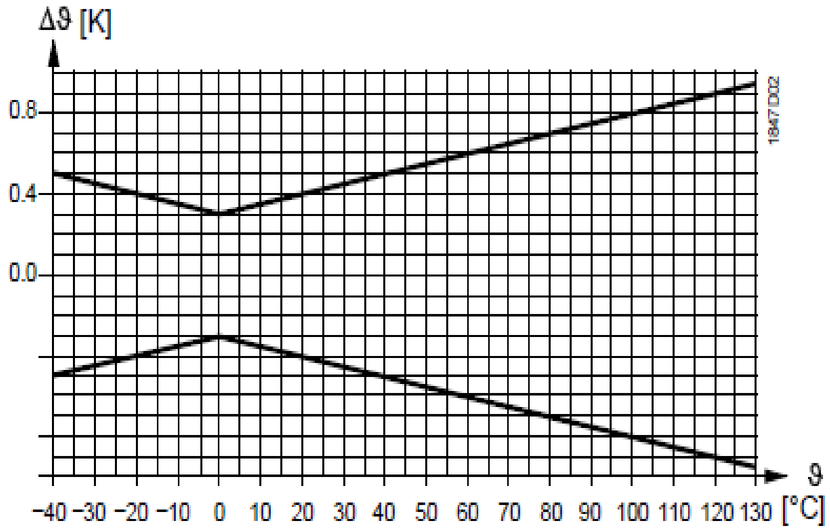


Pt 100 (Kl. B)

Characteristic

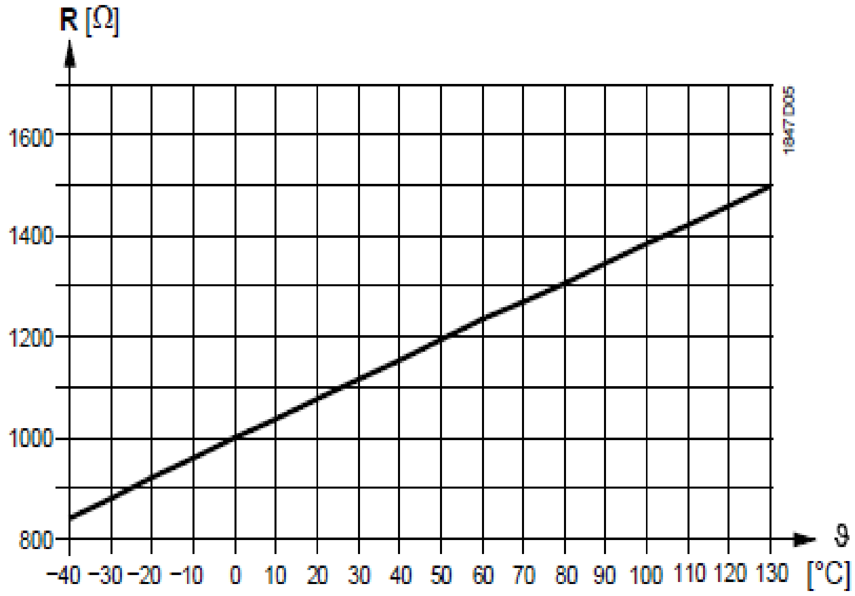


Accuracy

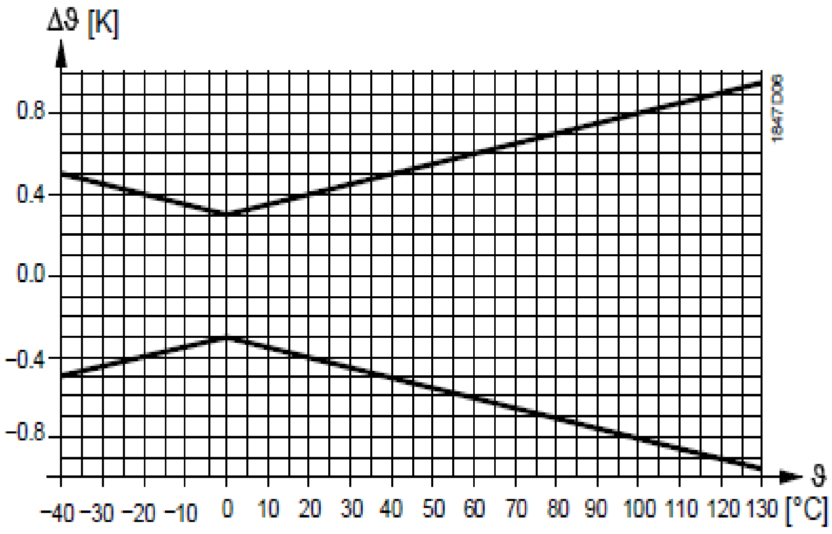


Pt 1000 (Kl. B)

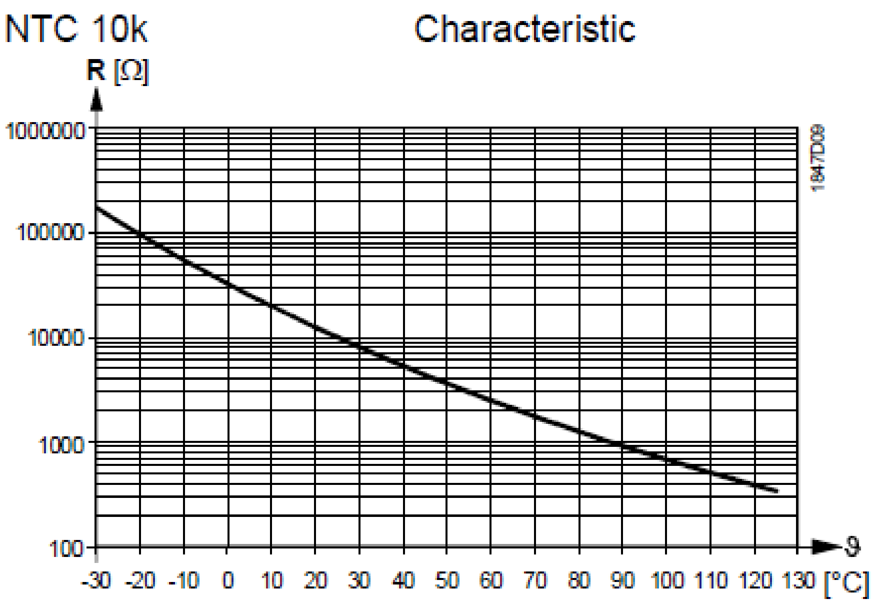
Characteristic

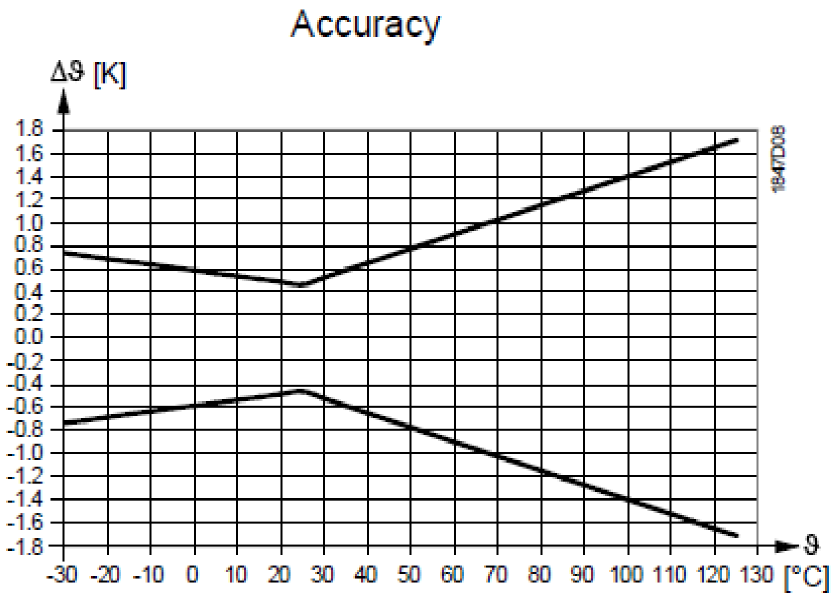


Accuracy



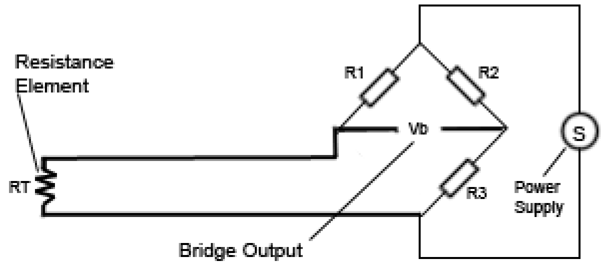
NTC 10k





Legend		
	R	Resistance in Ohm
	ϑ	Temperature in degrees Celsius
	Δϑ	Temperature differential in Kelvin

Measuring the R in DDC

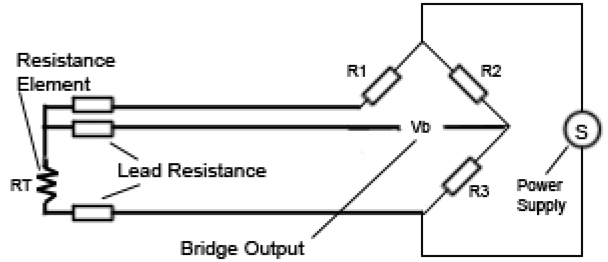


Two Wires

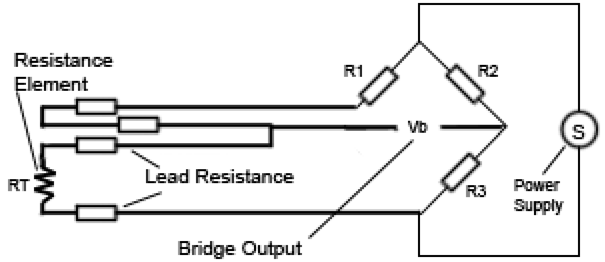
$$R_x = \frac{V_i - 2V_0}{V_i + 2V_0}\,R$$

R= *R1, R2, R3*

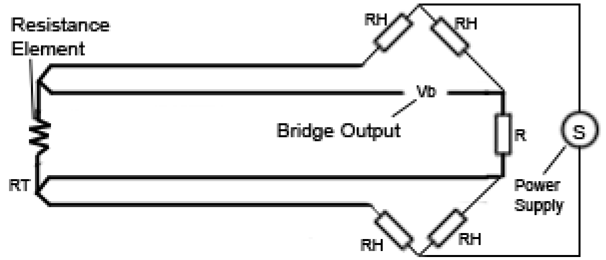
$R_x = R_{RTD} + 2R_L$



Three wires



Four Wire



Four Wire - Kelvin Connection – for laboratory usage mostly

Time Constant

- The Thermal Time Constant is a measurement of the time required for the sensor to respond to a change in the ambient temperature. The technical definition of Thermal Time Constant is, "The time required for a sensor to change 63.2% of the total difference between its initial and final body temperature when subjected to a step function change in temperature, under zero power conditions".

Temperature Sensors

Sensor Type	Primary Use	Advantages	Disadvantages
RTD	General Purpose, Air, Water, Steam	Very Accurate, Interchangeable, Stable	Relatively Expensive , not very sensitive
Thermistor	High Sensitivity Applications, Chilled water metering	Large Change in Resistance for a small change in Temperature - Sensitivity	Nonlinear, Fragile, Self-heating
Thermocouple	High Temperature Applications Boiler , Stack gas	Inexpensive , Self-powered, Rugged	Low – Voltage output, not very sensitive

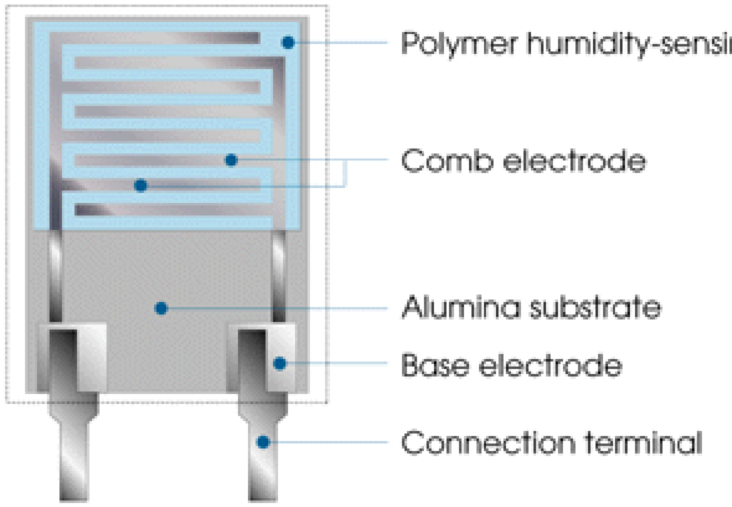
Humidity Sensor

- Thin-film polymers sensor
- Chilled mirror sensor
- Relative humidity / Dew point
- Hygroscopic Element is used , mechanical operation
- A humistor is a type of variable resistor whose resistance varies based on humidity.
- An Active Sensor

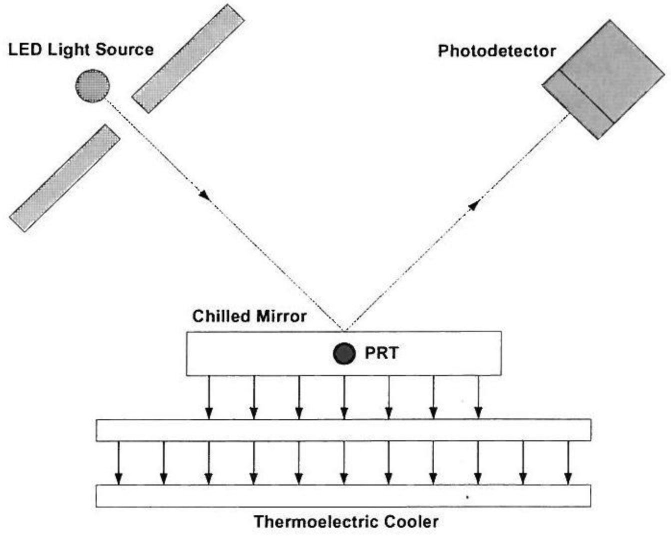
$$C = \frac{q}{V}.$$

Humidity Sensor

Basic structure of resistance change-type humidity sensors

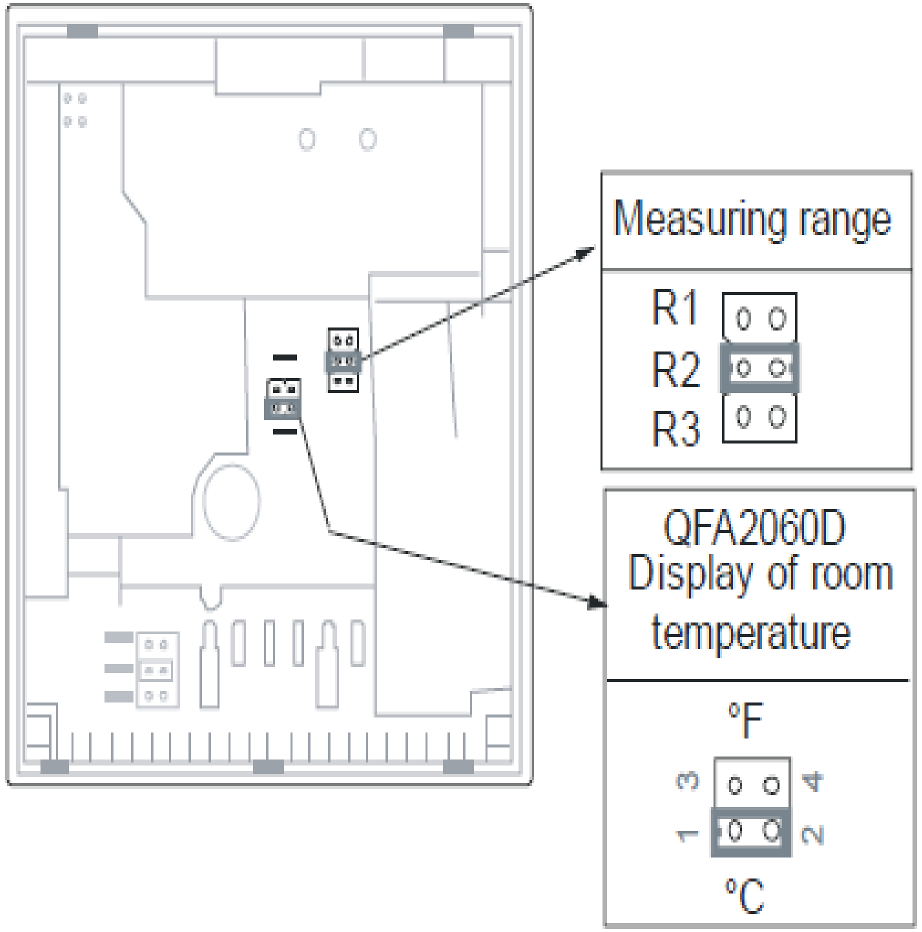


Chilled mirror sensor



Humidity Sensors

Sensor Type	Primary Use	Advantages	Disadvantages
Thin Film Polymer	Relative humidity	Inexpensive	contamination
Chilled Mirror	Dew point Temperature	Precise measurement	Periodic Cleaning, expensive



Testfunction activ					
	U1	U2	BS-MS	I1	I2
	5 V	0 V	≙ –35 °C	12 mA	4 mA
	0 V	5 V	≙ 20 °C	4 mA	12 mA
	5 V	10 V	≙ 75 °C	12 mA	20 mA
	10 V	5 V	≙ 20 °C	20 mA	12 mA

1857Z01en

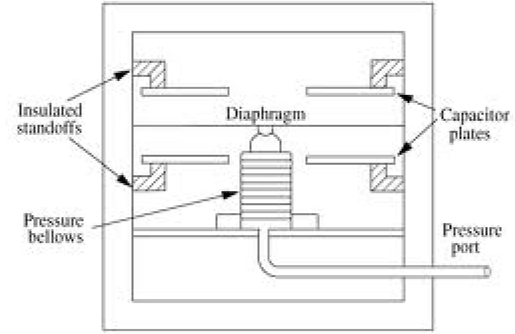
Pressure Sensor

- Absolute pressure sensor: measures the pressure relative to perfect vacuum.
- Gauge pressure sensor: measures the pressure relative to atmospheric pressure.
- Vacuum pressure sensor: Vacuum pressure sensors measure pressure that is less than 0 PSI.
- Differential pressure sensor: measures the difference between two pressures points.
- Sealed pressure sensor: Measures the pressure relative to some fixed

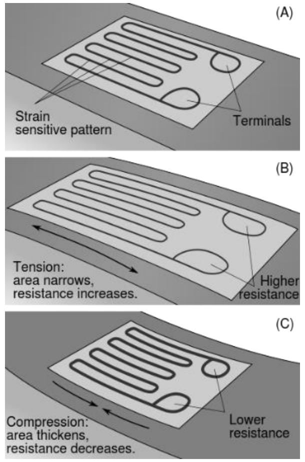
Pressure Sensors

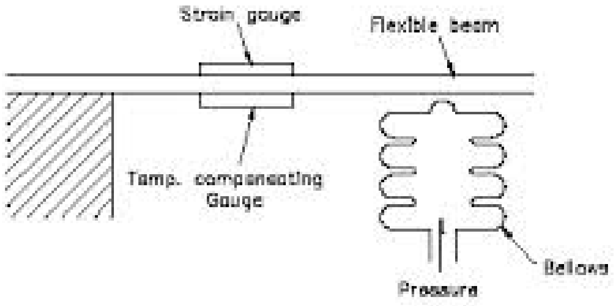
Pressure Sensors

- **Capacitive**

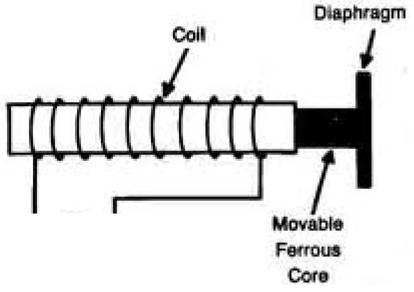


- **Strain Gauge**



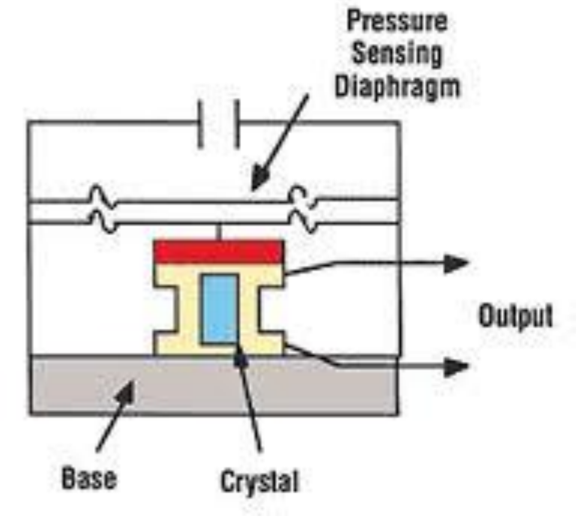


- **Inductive Transducers**

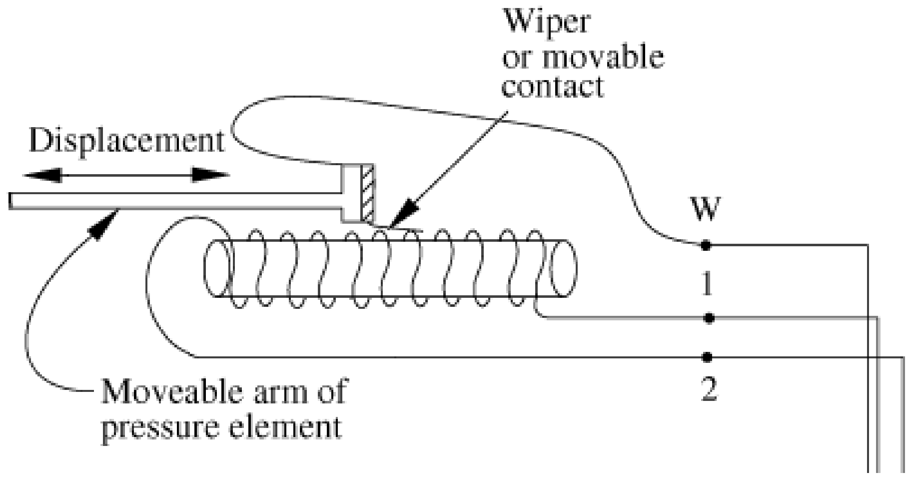


Pressure Sensor

- **Piezoelectric**



- **Potentiometric**



Pressure Sensors

Sensor Type	Primary Use	Advantages	Disadvantages
Capacitive	Low Pressure Air, Duct Static, Filter DP	Inexpensive	Signal Conditioning is complex, low output
Inductive	Low Pressure Air, fume hood DP	Rugged Construction	Expensive , temperature compensation may be difficult
Strain Gauge	High Pressure , Chilled water , Steam	Linear Output	Low Output Signal
Piezoelectric	Fluctuating pressure , sound, mechanical vibration	Wider Pressure range	Calibration problem
Potentiometric	General Purpose	Inexpensive , High output	Low accuracy , large size, wear and tear

Flow Sensor

In VAV system: the measurement of Air Volume to the space

(Air Velocity (fpm) = 4005 velocity pressure)

fpm -feet per minute

Volume flow is usually measured in cubic feet per minute (CFM).

***velocity pressure** - the moving air acquires a force or pressure component in its direction or motion due to its weight and inertia*

It is measured in inches of water column (w.c.) or water gage (w.g.)

***static pressure -** In operating duct systems, a second pressure is always present. It s independent of air velocity or movement. it act equally in all directions*

***Total pressure-** is the combination of static and velocity pressures

In HVAC Flow is mostly measure in pipe or Duct

Flow measurements

$$\frac{v^2}{2} + gz + \frac{p}{\rho} = \text{constant}$$

Flow Measuring is mostly done through Pressure Measuring but not always

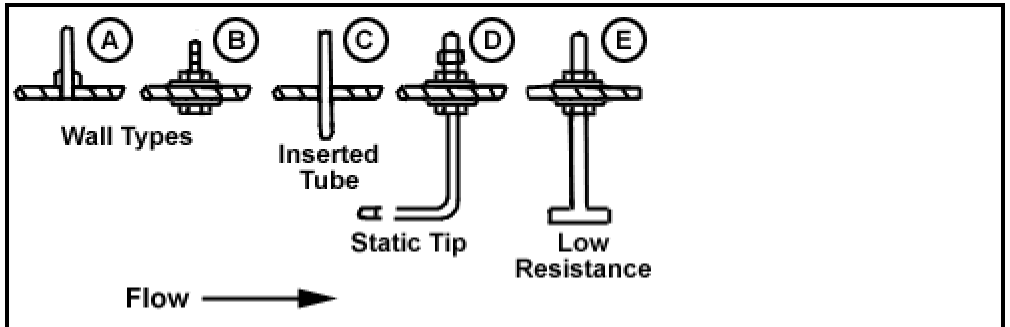


Fig. 1 - Types of Static Pressure Sensing Devices

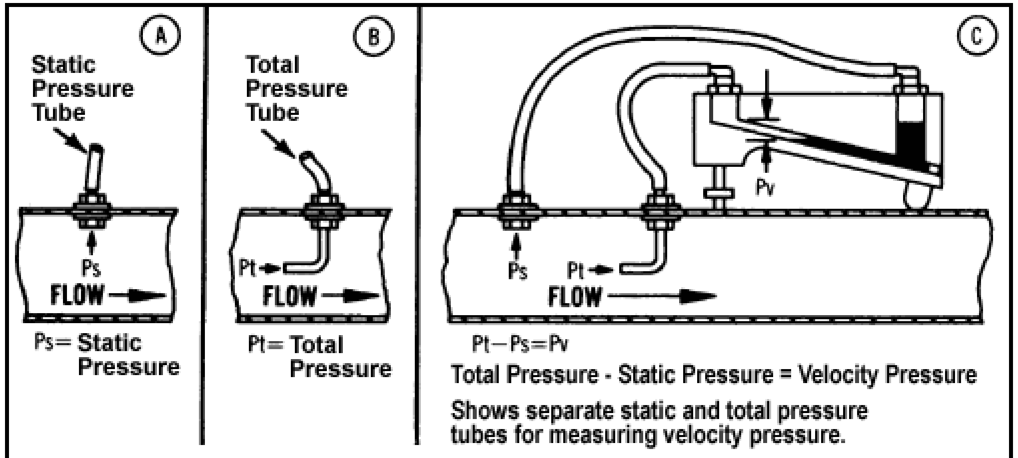
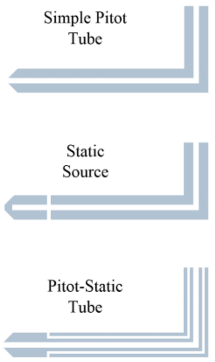


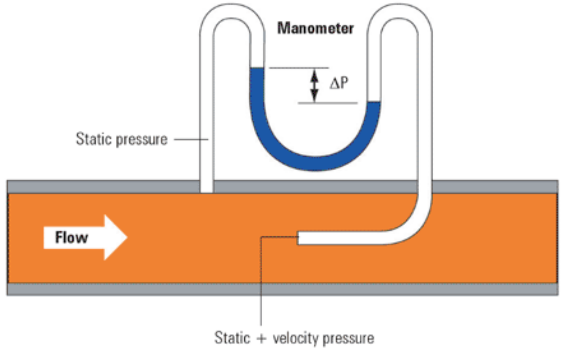
Fig. 2 -- Types of Pressure Measurements

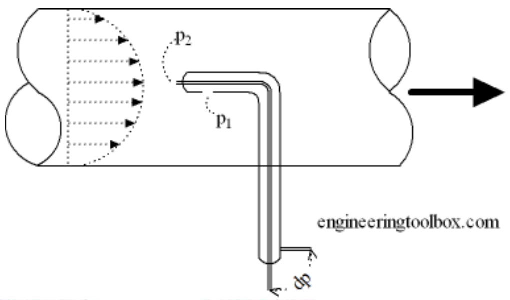
Total Pressure = Static Pressure + Velocity Pressure

Flow Sensor/meters

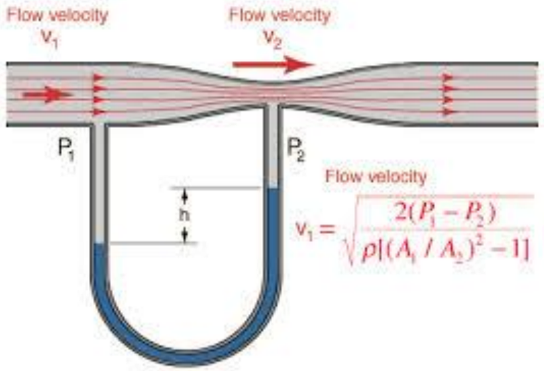
- Pitot Tubes

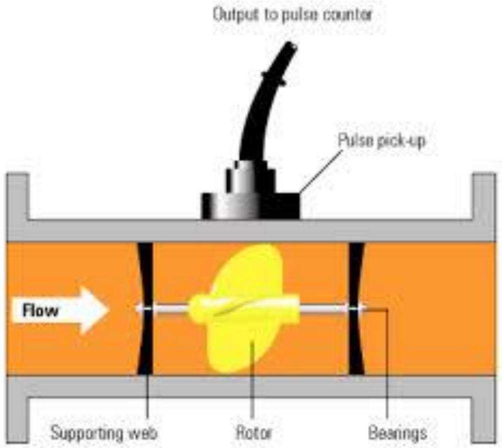




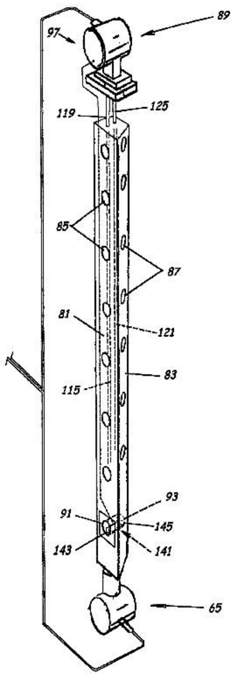


- Venturi Flow meter





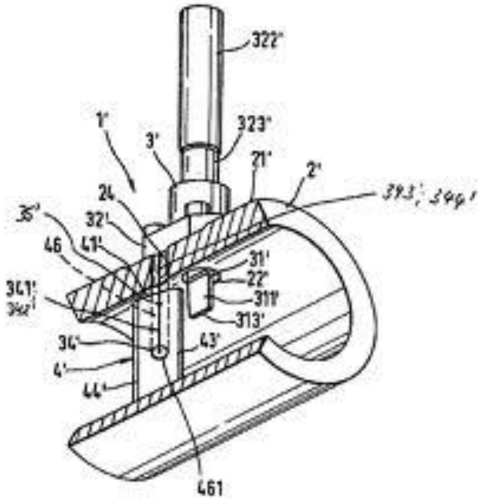
- Turbines

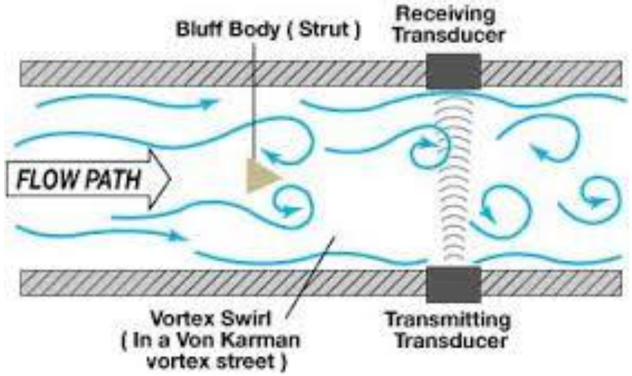


Annubar

Flow Sensor/meters

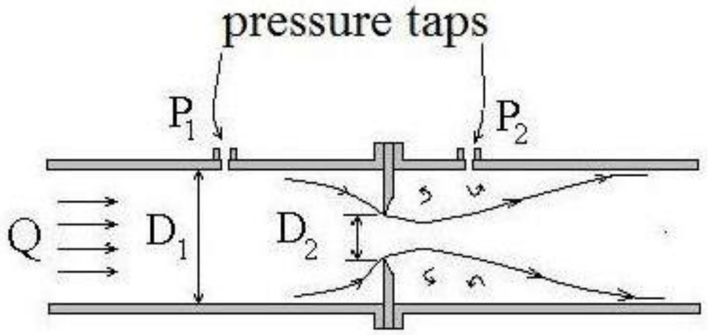
- Vortex





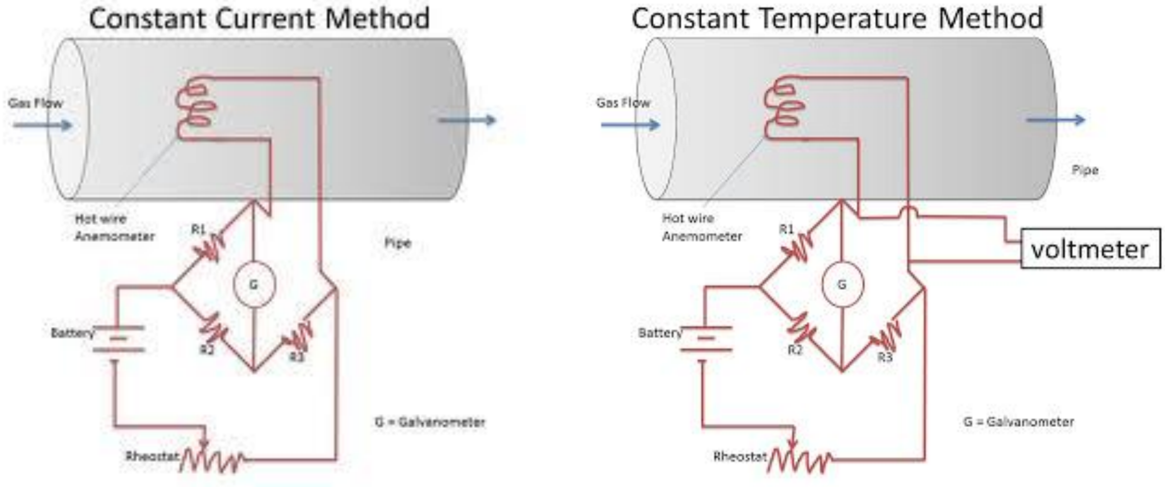
Flow Sensor/meters

- Orifice Plate



Orifice Meter Parameters

- Hot Wire Anemometers



Electromagnetic Flow Meters

use a magnetic field applied to the metering tube, which results in a potential difference proportional to the flow velocity perpendicular to the flux lines
The potential difference is sensed by electrodes aligned perpendicular to the flow and the applied magnetic field.

All electromagnetic flowmeters are based on Faraday's law of induction:

$U_M = B \cdot v \cdot d \cdot k$

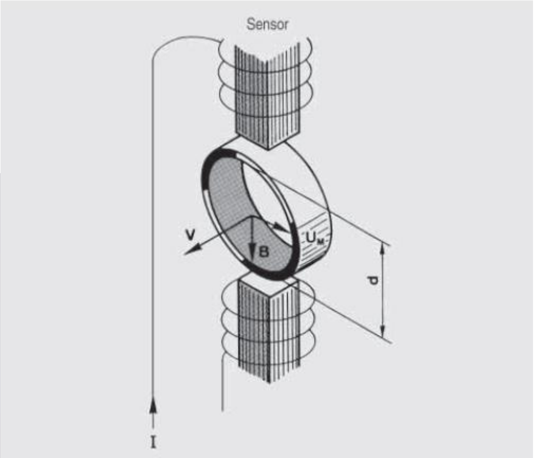
U_M = Measured voltage induced in the medium perpendicular to the magnetic field and the flow direction. The voltage is tapped at two point electrodes.

B = Magnetic flux density which permeates the flowing medium perpendicular to the flow direction.

v = flow velocity of medium

d = internal diameter of metering tube

k = proportionality factor or sensor constant

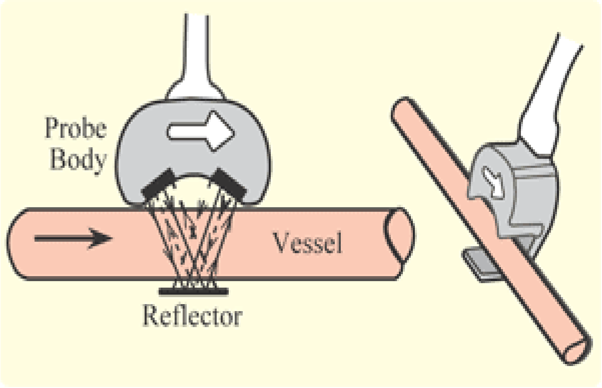


https://www.youtube.com/watch?v=f949gpKdCI4

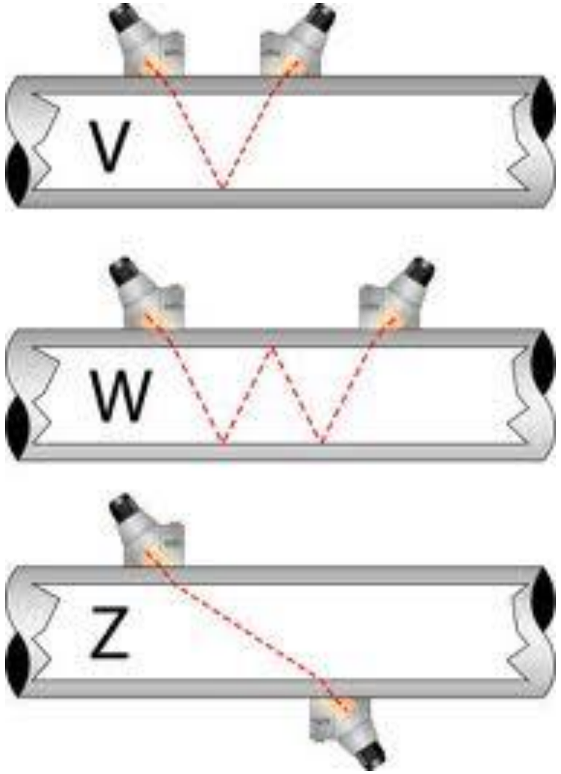
Ultrasonic Flow meters

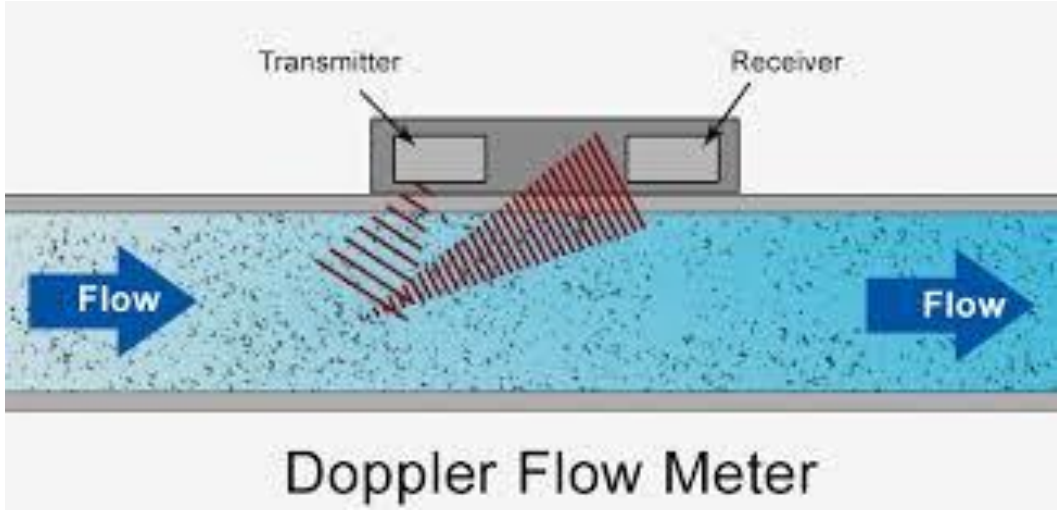
- There are two main types of Ultrasonic flow meters: Doppler and transit time.
- by averaging the difference in measured transit time between the pulses of ultrasound propagating into and against the direction of the flow
- by measuring the frequency shift from the Doppler effect

- https://www.youtube.com/watch?v=Bx2RnrfLkQg



Transit Time Vs Doppler





Flow meters

Sensor Type	Primary Use	Advantages	Disadvantages
Pitot Tube	Air	Inexpensive	clogging
Orifice Plate	Water , Steam	Inexpensive, many pipe size	Can erode, accuracy depend on diameter
Venturi Tubes	Water, Air	Lowest Head loss of insertion type	Large in size more costly
Hot Wire	Air	Measure mass flow, not contaminated	fragile
Turbine	Steam, Water	Good turndown ration	Wear , can damage
Vortex Shedding	Water	accurate	Complicated signal conditioning
Ultrasonic	Water	nonintrusive	Most expensive

Indoor Air Quality Sensor

- Sick building syndrome
- CO_2 Sensor

CO_2 Sensor

- Nondispersive infrared sensor
- 0 ~ 1000 ppm
- Above 0 ~ 1000 ppm is harmful

Other Sensor

- CO sensor
- VOC – Air Quality Sensor
- Light Level Sensor
- Water Level sensor
- BTU meters
- Enthalpy Meters
- Power Analyzers

Signal Conditioning

- Converting signal output for computers
- Conditioning ➔ Amplification, linearization, conversion to standard (0~ 10 Etc)
- A/D Conversion
  - Input Range (0~5V_{dc}, 0~10V_{dc}, 4 ~20mA)
  - Speed
  - Output Resolution (Numbers of Bits)

  N – Bit ➔ 2^N-1 outputs

Output Signal types in Analogues Sensors

4 ~ 20 mA	Analogue
0 ~ 20 mA	
0 ~ 10 Vdc	
0 ~ 5 Vdc	
Pt100	RTD
Pt1000	
Ni1000	

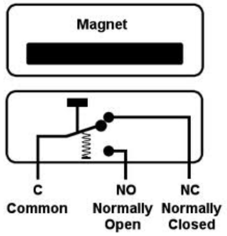
Special Parameters to check in sensor selection

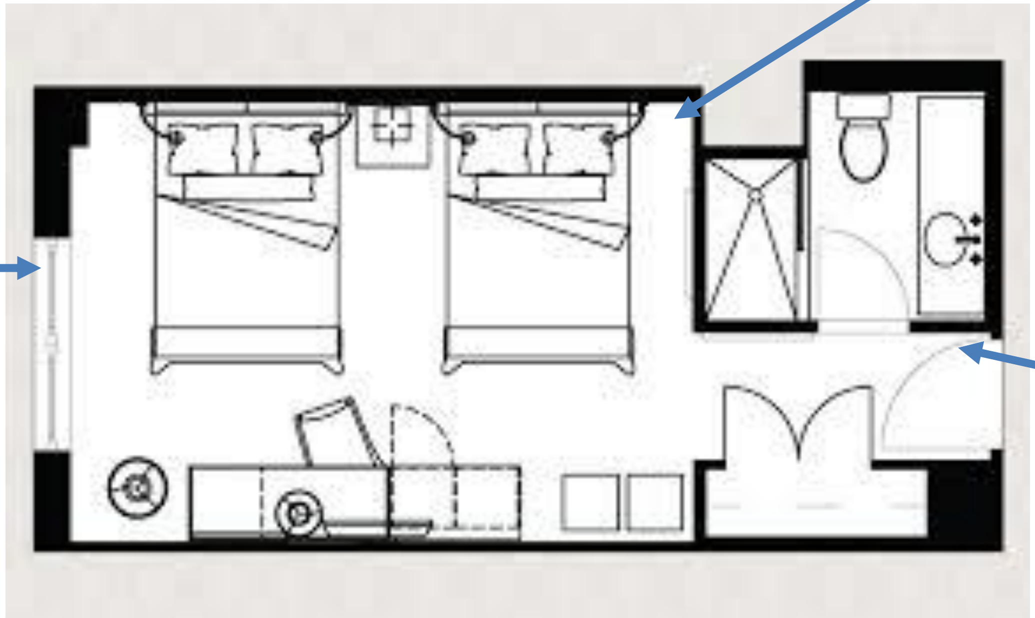
- Environmental Conditions – (IP Class)
- Operating Range
- Signal output type (RTD, 0 ~ 10 Vdc, 4 ~ 20 mA)
- Mounting method
- Linearity
- Sensitivity
- accuracy
- Measured medium
- Response time (too fast will not be good)

Sensor Switches

- Pressure Switches
- Thermostats
- Differential Pressure Switches (Air / Water/ Refrigerant)
- Flow Switches
- Duct Smoke Detector
- Relay / Contactors
- Level Switches/ Float Switches
- Leakage Detector
- Proximity Switches
- *Any of Above Analogue sensor can work as Switches*

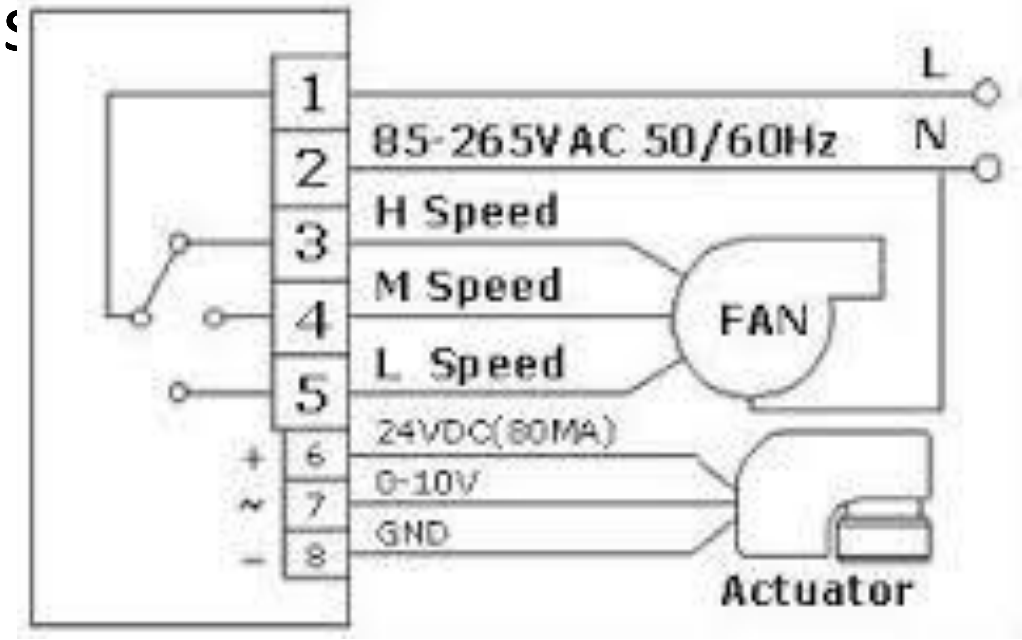
FCU Controlling





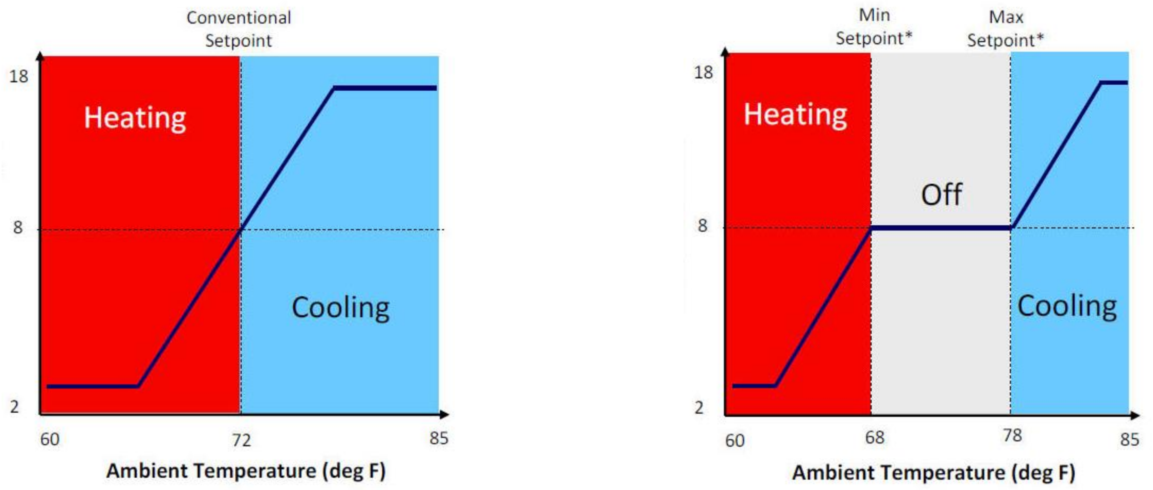
Thermostats

- Sensor & Controller combined
- Used for FCU controlling
- **Comfort, Economy and Protection mode operation**
- Coil Protection
- Very important items in the hotel Indus

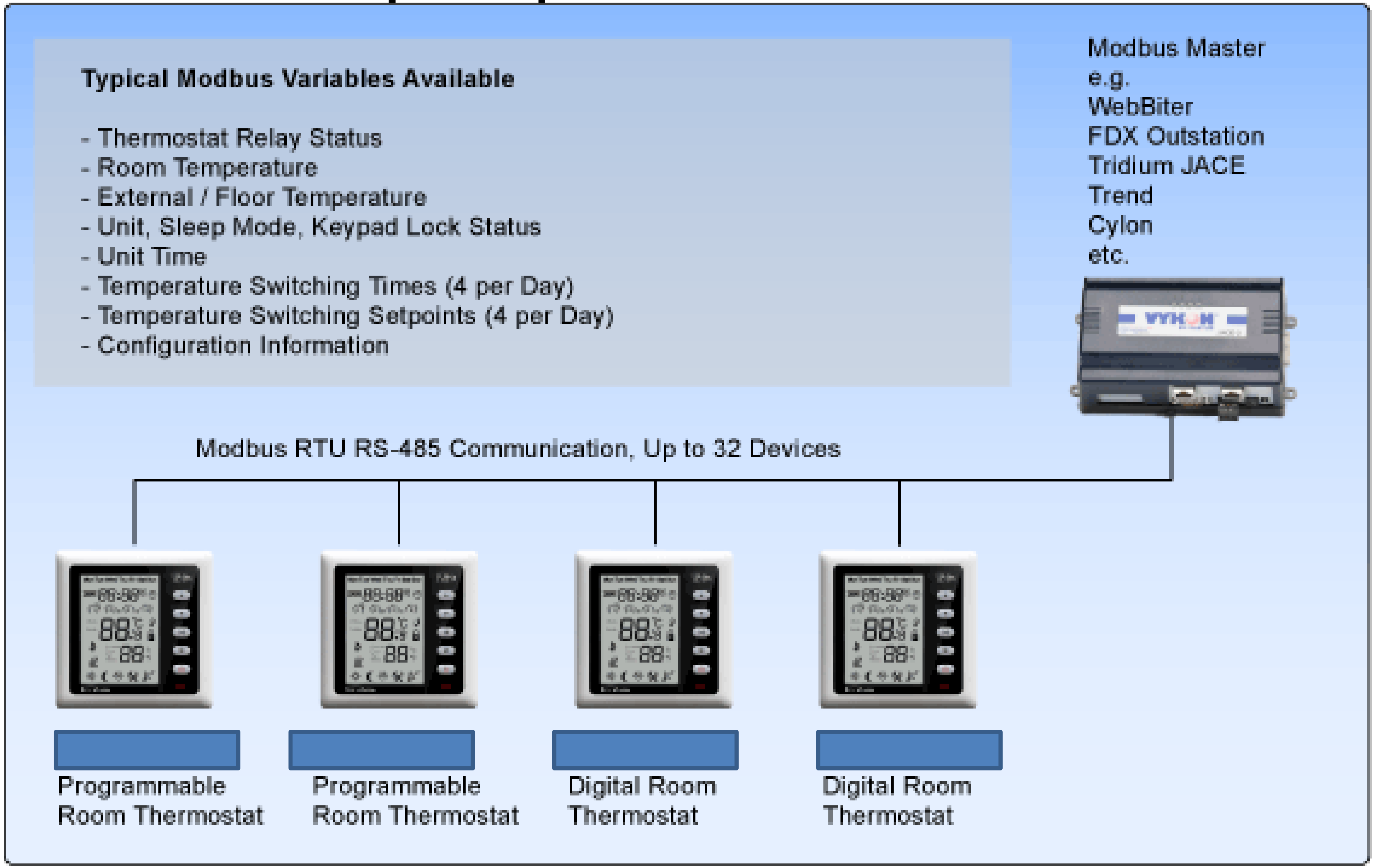


Types/Features

- Day/Night Function/ Night Setback- One set point day time, lower set point night time (to prevent too cold), Automatic or Manual changeover
- Combination Heat / Cool thermostats
- Dead band Thermostat



- Output Can be Modulating or On/OFF type

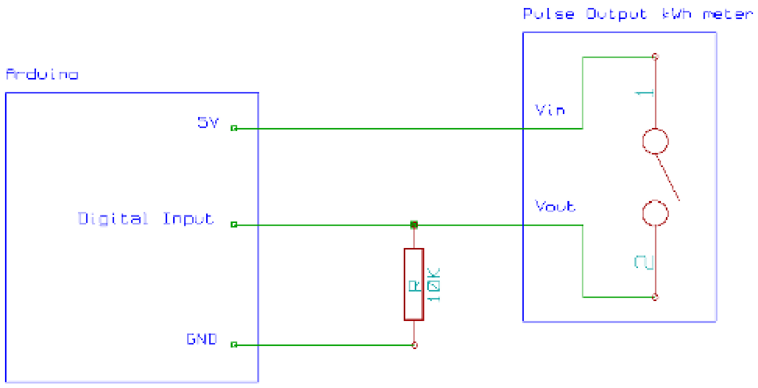

Typical Modbus Variables Available
- Thermostat Relay Status
- Room Temperature
- External / Floor Temperature
- Unit, Sleep Mode, Keypad Lock Status
- Unit Time
- Temperature Switching Times (4 per Day)
- Temperature Switching Setpoints (4 per Day)
- Configuration Information
Modbus Master
e.g.
WebBiter
FDX Outstation
Tridium JACE
Trend
Cylon
etc.
Modbus RTU RS-485 Communication, Up to 32 Devices
Programmable Room Thermostat
Programmable Room Thermostat
Digital Room Thermostat
Digital Room Thermostat

Discussion Topics

- Meters and metering

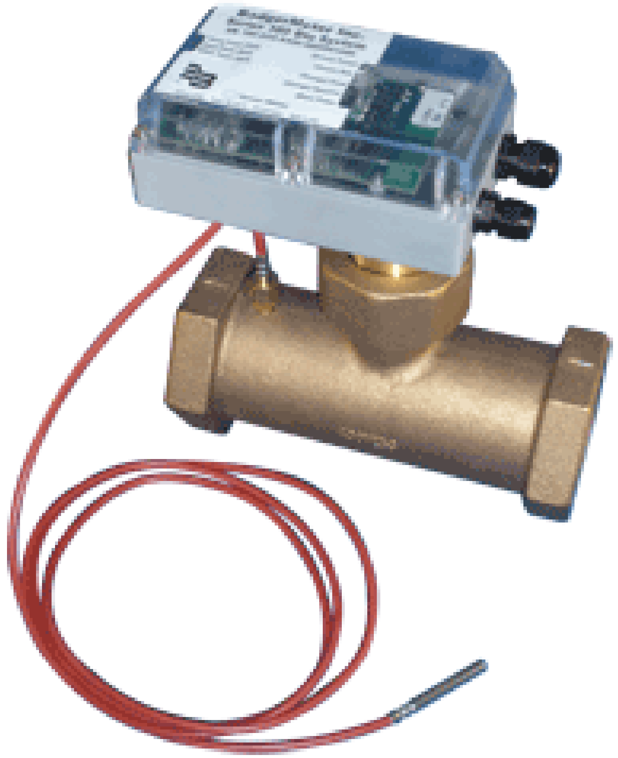
  Read the meters by Pulses (totalizing)

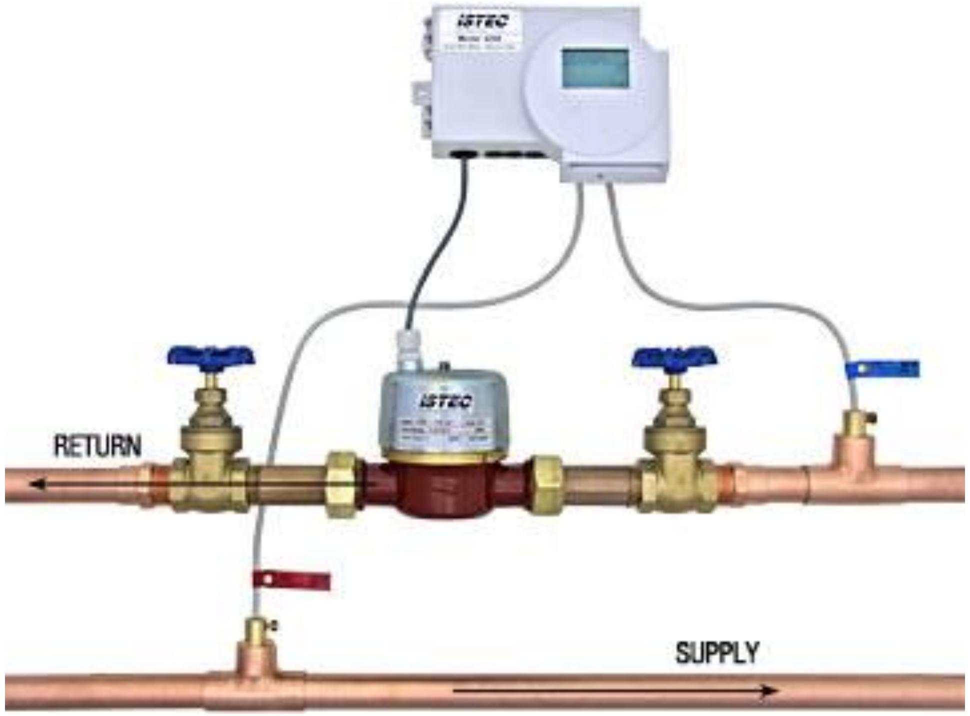
  - Water Meters
  - Fuel Meters
  - kWh meters
  - BTU meters



kWh meters

BTU Meters





Actuators…..

An actuator responds to the output signal from a controller and provides the mechanical action to operate the final control device, which is typically a **valve, damper or switch**. A wide range of actuators is available and the chosen actuator must address the following concerns:

1. • matching the mechanical requirements of the controlled device;
2. • matching the characteristics of the control system, especially the output signal of the controller;
3. • being suitable for its operating environment.

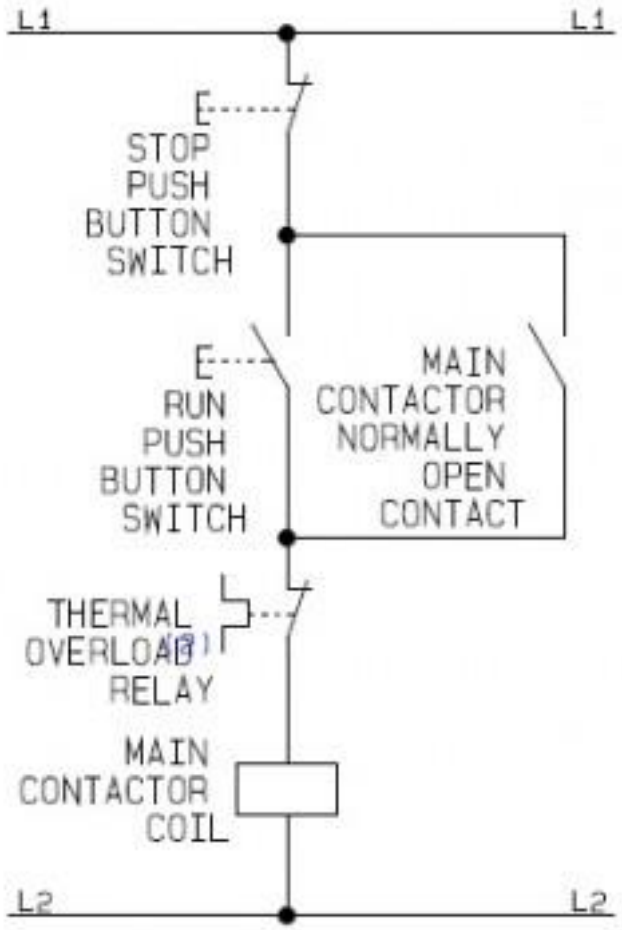
- Actuators (Analogue Actuators/ Digital Actuators)

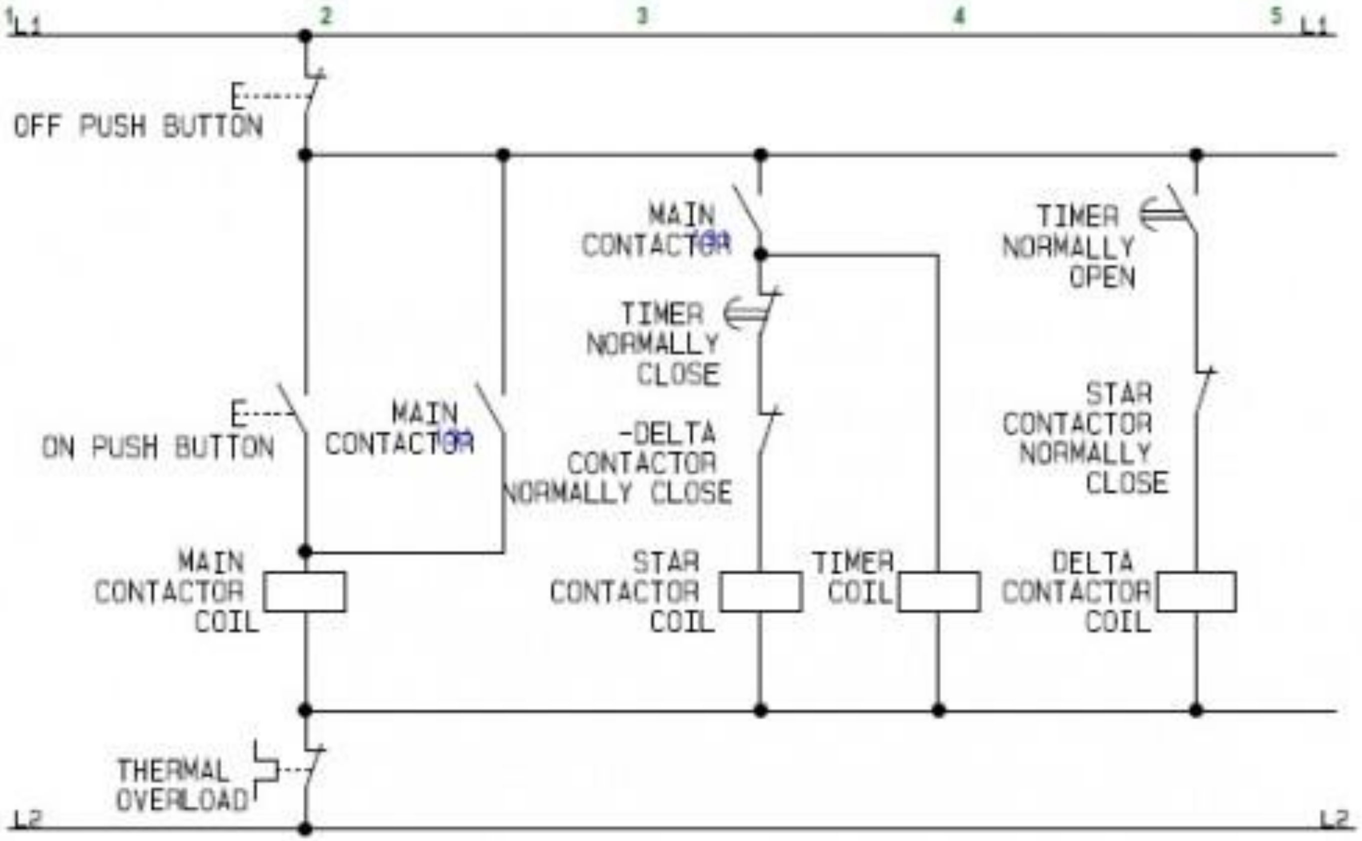
Actuators actuate the control action

- Motorized Valve Actuators
- Motorized Damper Actuators
- Speed Regulators (VSD)
- Relays/ Contactors
- Other type of Actuators

Valve Sizing & Actuator Sizing Will be discussed separately

Relays & Contactors – Digital Actuators





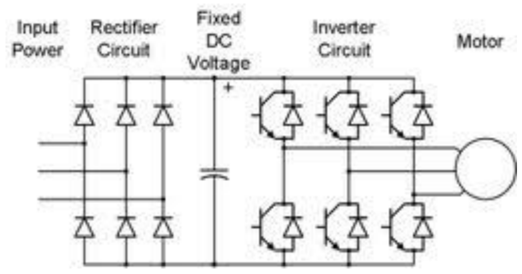
Variable Speed Drivers

- Used for speed regulation
- Analogue input 4 ~ 20 mA , 0~ 10 Vdc

- IP54/5 as standard/operation to 60°C
- B class filter installed as standard
- USB port for software tool and memory card slot
- 4 PID controllers
- Sizes from 0.37kW to 90kW
- Onboard communication protocols: Modbus RTU, Bac
  Profibus DP, CanOpen, USS
- HVAC functions: motor staging, hibernation, essential se
  Ni1000/PT1000 inputs

VSD

$$N_s = \frac{120f}{p}$$

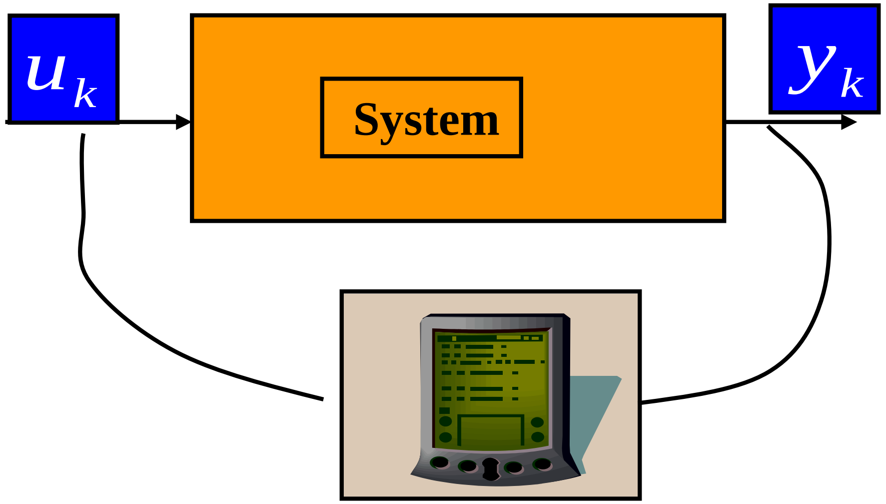


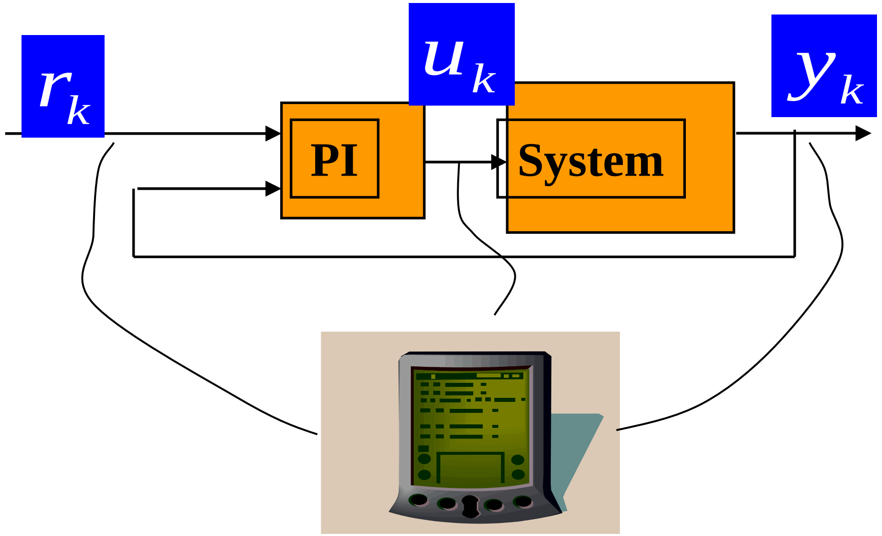
Other Type of Output Devices

- Buzzers
- Lamp Indicators

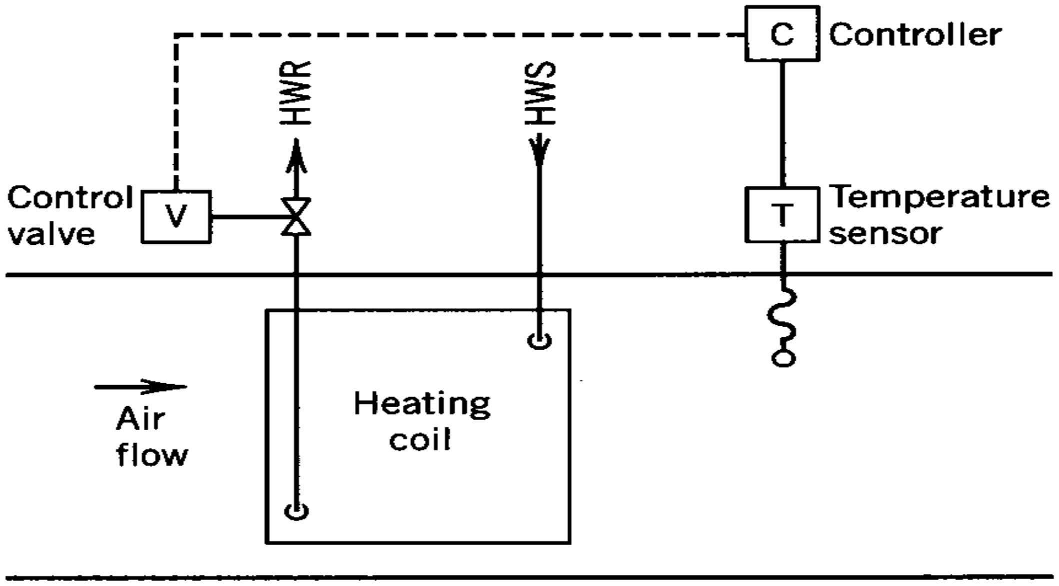
Testing Options

- Open loop
  - System only
- Closed loop
  - Control logic and system





DDC



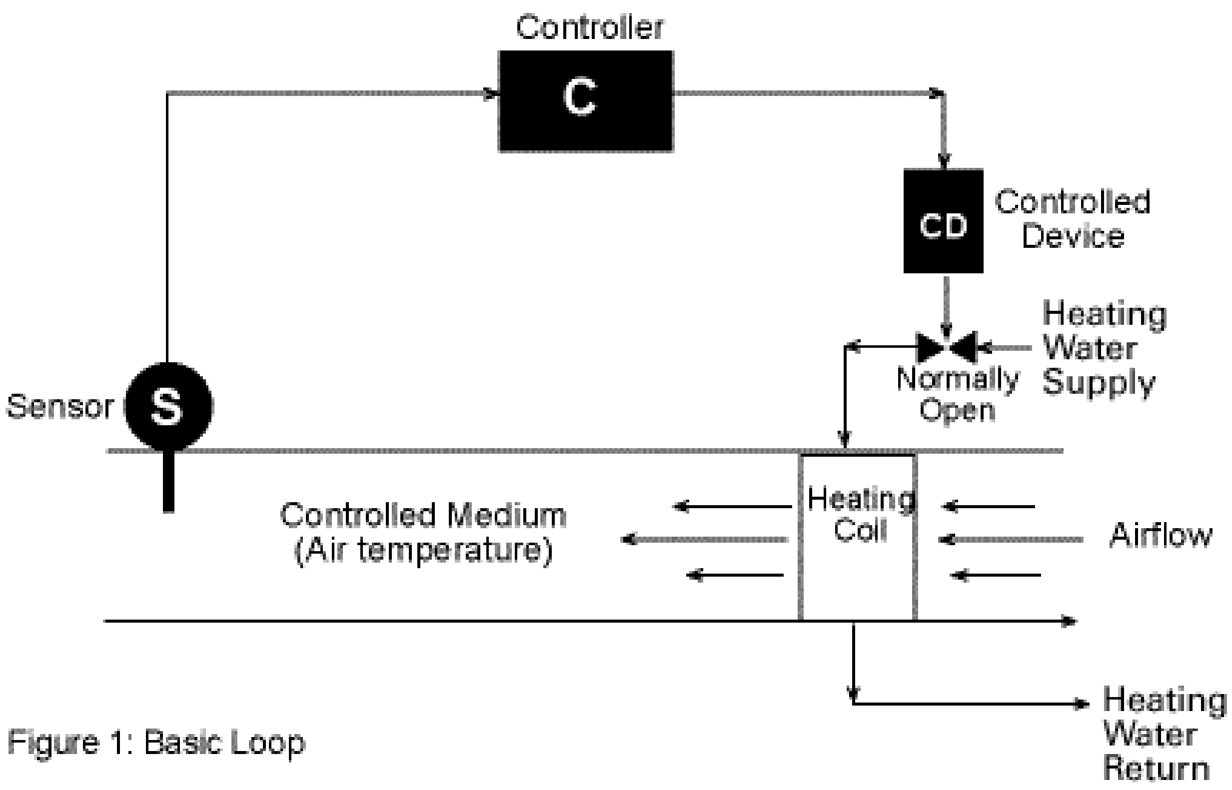
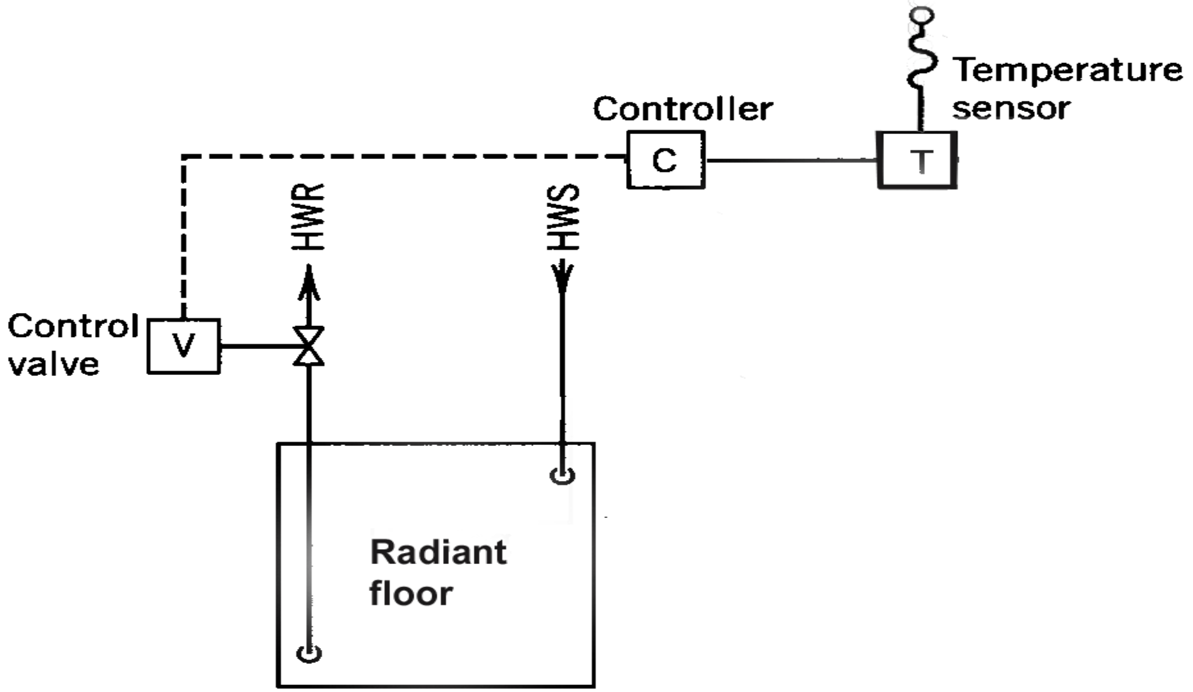


Figure 1: Basic Loop

Direct

Closed Loop or Feedback


Temperature sensor
Controller
C
T
HWR
HWS
Control valve
V
Radiant floor

Two-Position Control

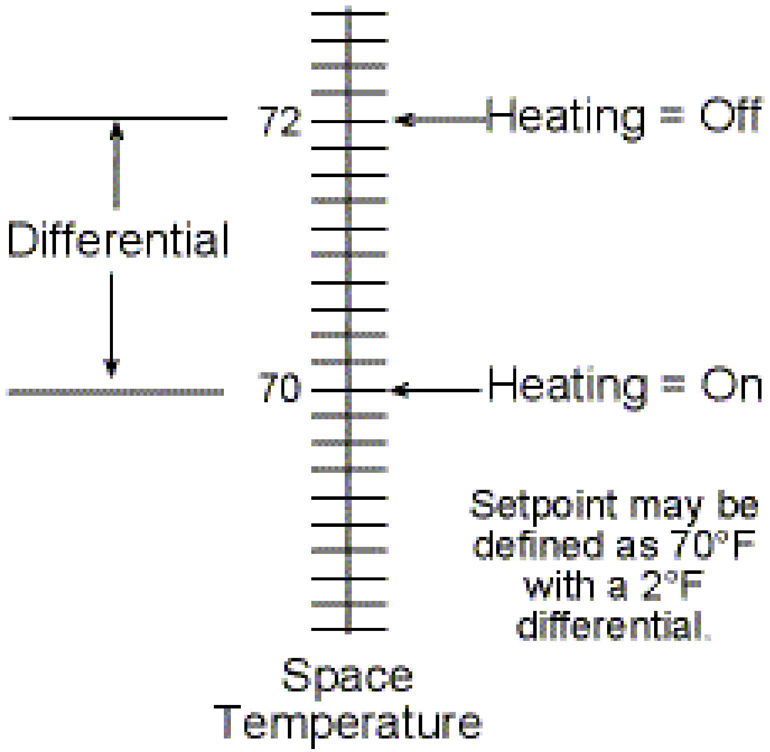


Figure 3: Two-Position Control Response

Floating Control

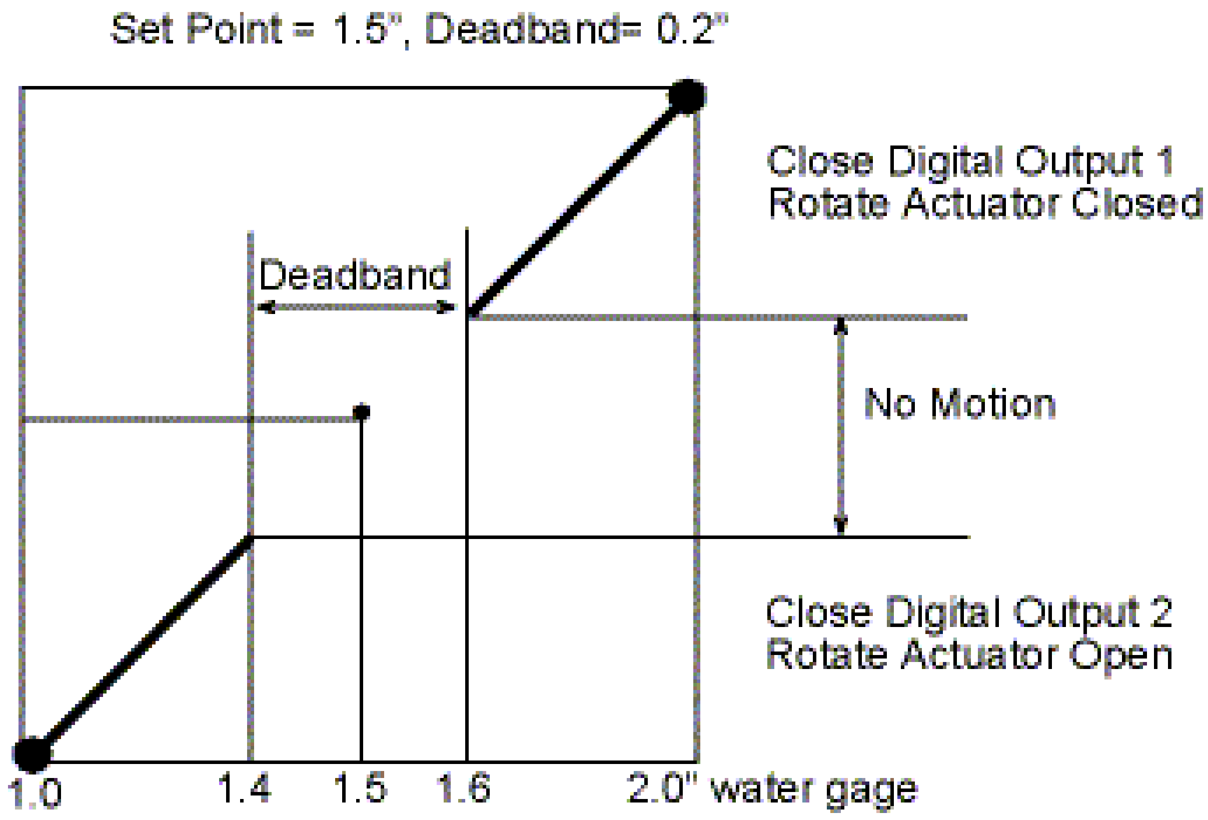


Figure 4: Floating Control Response

Proportional Control

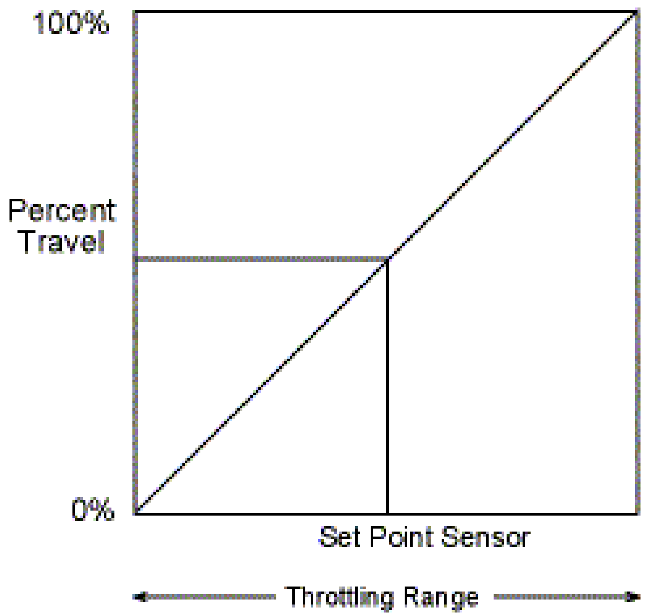


Figure 5: Proportional Control Response

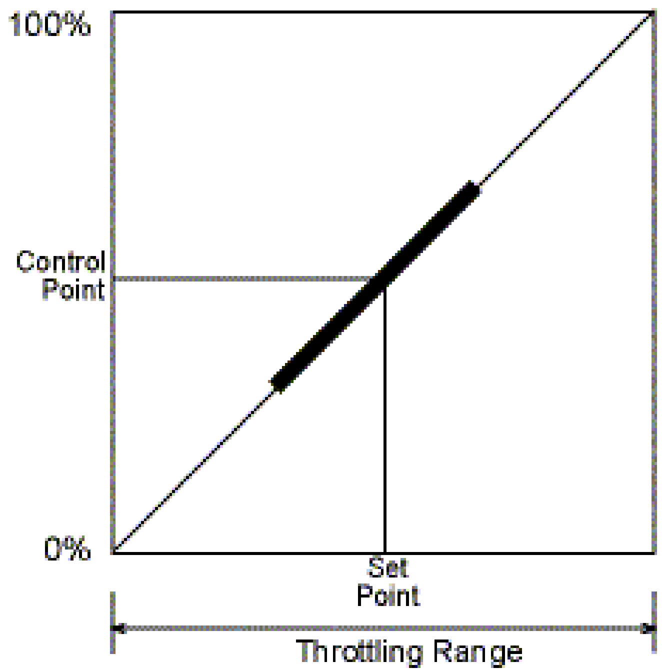


Figure 6: Proportional Integral Control Response

Modulating Control Systems

- Used in larger systems
- Output can be anywhere in operating range
- Three main types
  - Proportional
  - PI
  - PID

$$O = A + eK_P$$

O is controller output

A is controller output with no error

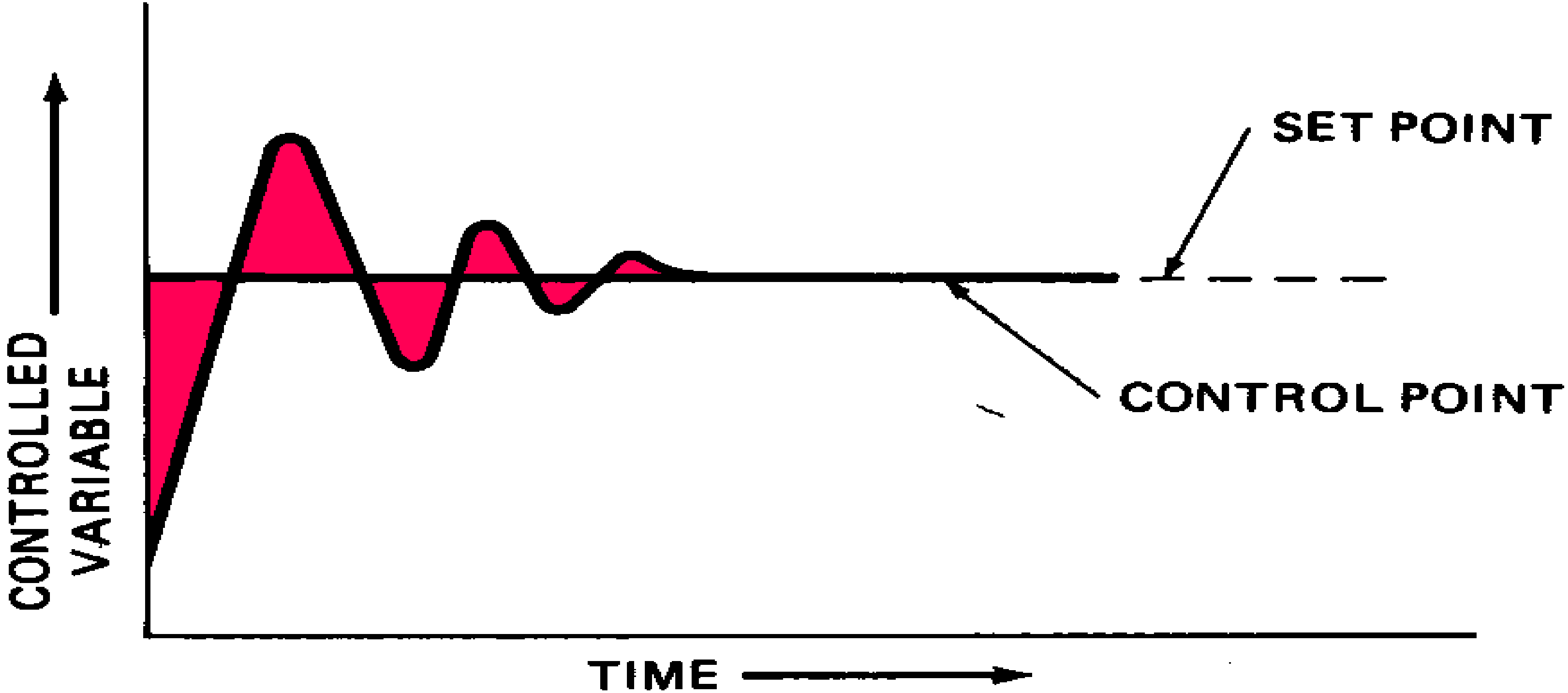
K_P is proportional **gain** constant

e is error (offset)

Proportional + Integral + Derivative (PID)

$$O = A + eK_P + K_i \int e\,dt + K_d \frac{de}{dt}$$

- Improvement over PI because of faster response and less deviation from offset
  - Increases rate of error correction as errors get larger
- But
  - HVAC controlled devices are too slow responding
  - Requires setting three different gains


SET POINT
CONTROL POINT
CONTROLLED VARIABLE
TIME

Controls for Protecting the Secure Facility

- Walls, Fencing, and Gates
- Guards
- Dogs, ID Cards, and Badges
- Locks and Keys
- Mantraps
- Electronic Monitoring
- Alarms and Alarm Systems
- Computer Rooms
- Walls and Doors

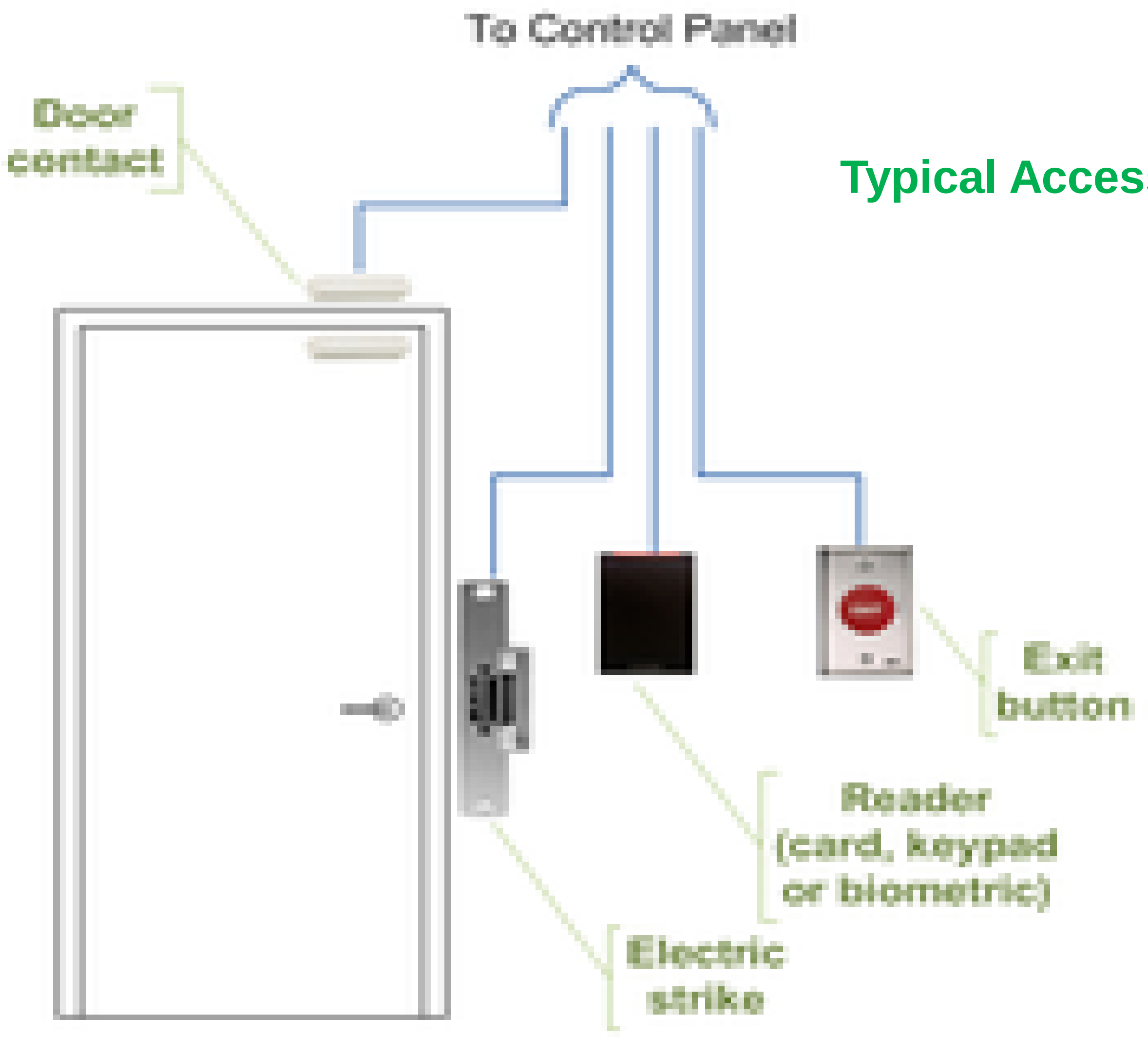
Access Control System

An **access control system** is a system which enables an authority to control access to areas and resources in a given physical facility or computer-based information system. An access control system, within the field of Physical Security is generally seen as the second layer in the security of a physical structure.

System Components

- **Access Controller**
- **Card Reader**
- **Electromagnetic locks**
- **Door Contacts**
- **Emergency Push Button**
- **Exit Push Button**
- **Access Cards**

Access Control Topology



Typical Access Control Door Wiring

Specification for Door Controller shall contain,

- No. of doors it can controlled
- No. of records it can stored
- Type of readers can connect
- No. of events it can record (Memory capacity)
- Power supply voltage
- No. of Inputs / Outputs available

Locks and Keys

- There are two types of locks
  - mechanical and electro-mechanical
- Locks can also be divided into four categories
  - manual, programmable, electronic, and biometric
- Locks fail and facilities need alternative procedures for access
- Locks fail in one of two ways:
  - when the lock of a door fails and the door becomes unlocked, that is a fail-safe lock
  - when the lock of a door fails and the door remains locked, this is a fail-secure lock

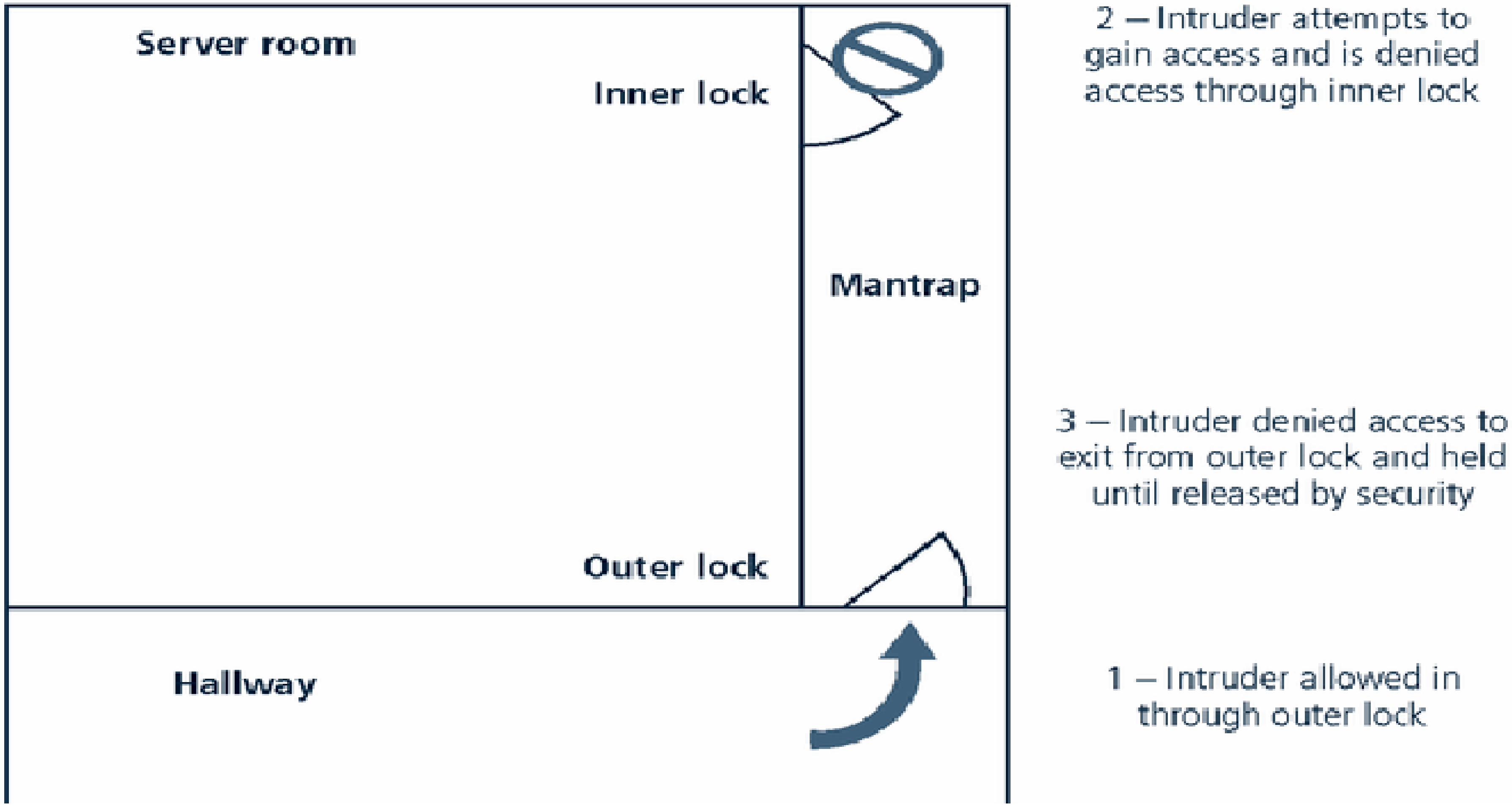
Programmable/mechanical

Biometric

Electronic

Mantraps

- An enclosure that has an entry point and a different exit point
- The individual enters the mantrap, requests access, and if verified, is allowed to exit the mantrap into the facility
- If the individual is denied entry, they are not allowed to exit until a security official overrides the automatic locks of the enclosure



Server room
Inner lock
Mantrap
Outer lock
Hallway
2 – Intruder attempts to gain access and is denied access through inner lock
3 – Intruder denied access to exit from outer lock and held until released by security
1 – Intruder allowed in through outer lock

Closed Circuit Television (CCTV)

Hidden CCTV cameras

post mounted CCTV

Fire Safety

- The most serious threat to the safety of the people who work in the organization is the possibility of fire
- Fires account for more property damage, personal injury, and death than any other threat
- It is imperative that physical security plans examine and implement strong measures to detect and respond to fires and fire hazards

Fire Detection and Response

- Fire suppression systems are devices installed and maintained to detect and respond to a fire
- They work to deny an environment of one of the three requirements for a fire to burn: heat, fuel, and oxygen
  - Water and water mist systems reduce the temperature and saturate some fuels to prevent ignition
  - Carbon dioxide systems rob fire of its oxygen
  - Soda acid systems deny fire its fuel, preventing spreading
  - Gas-based systems disrupt the fire's chemical reaction but leave enough oxygen for people to survive for a short time

Fire Detection

- Before a fire can be suppressed, it must be detected
- Fire detection systems fall into two general categories:
  - manual and automatic
- Part of a complete fire safety program includes individuals that monitor the chaos of a fire evacuation to prevent an attacker accessing offices
- There are three basic types of fire detection systems: thermal detection, smoke detection, and flame detection
  - Smoke detectors operate in one of three ways: photoelectric, ionization, and air-aspirating

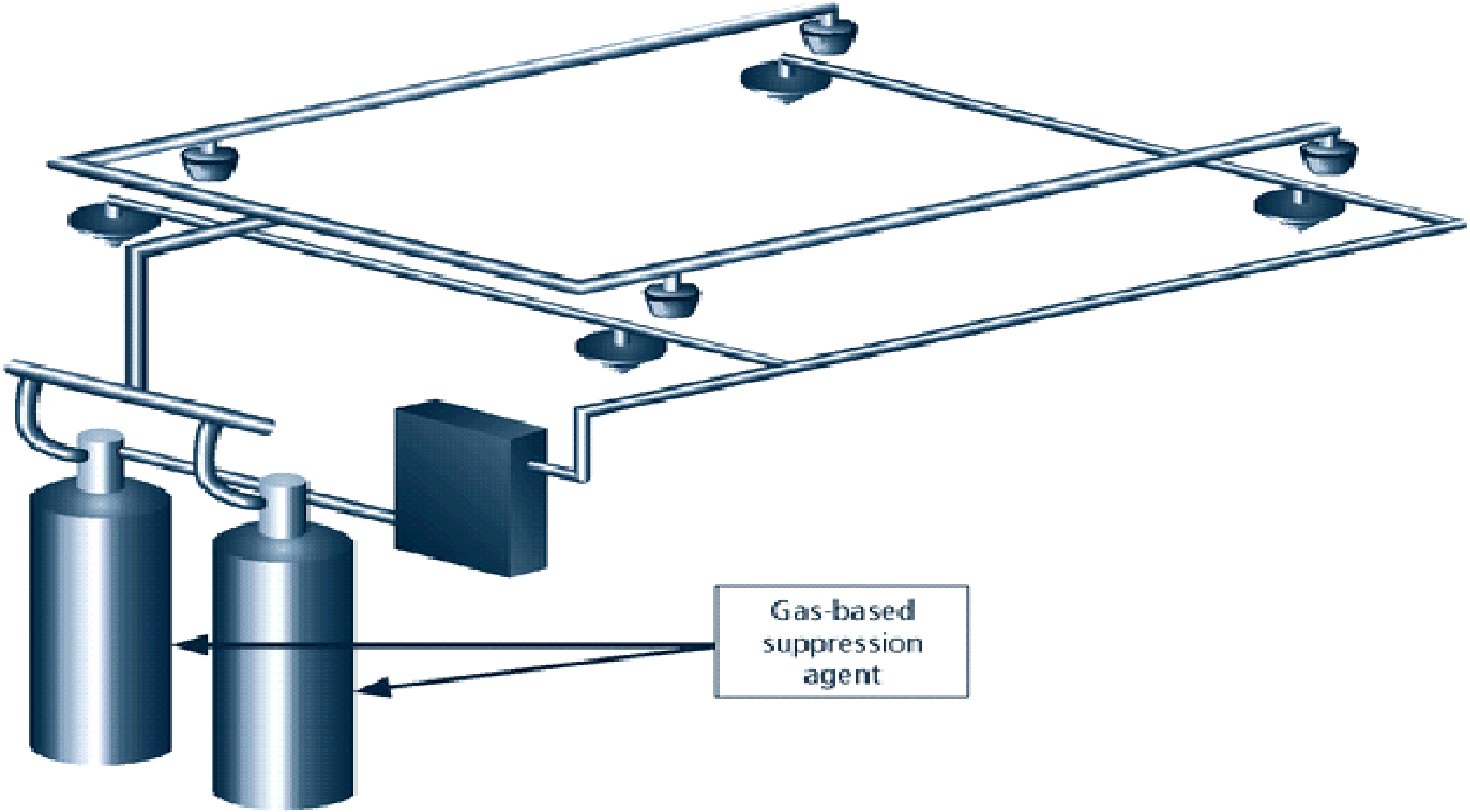
Fire Suppression

- Can be portable, manual, or automatic
- Portable extinguishers are rated by the type of fire:
  - Class A: fires of ordinary combustible fuels
  - Class B: fires fueled by combustible liquids or gases
  - Class C: fires with energized electrical equipment
  - Class D: fires fueled by combustible metals
- Installed systems apply suppressive agents, either sprinkler or gaseous systems
  - Sprinkler systems are designed to apply liquid, usually water
  - In sprinkler systems, the organization can implement wet-pipe, dry-pipe, or pre-action systems
  - Water mist sprinklers are the newest form of sprinkler systems and rely on microfine mists

When the ambient temperature reaches 140-150° F,
the plastic pin melts, releasing the stopper and allowing water
to hit the diffuser spraying water throughout the area

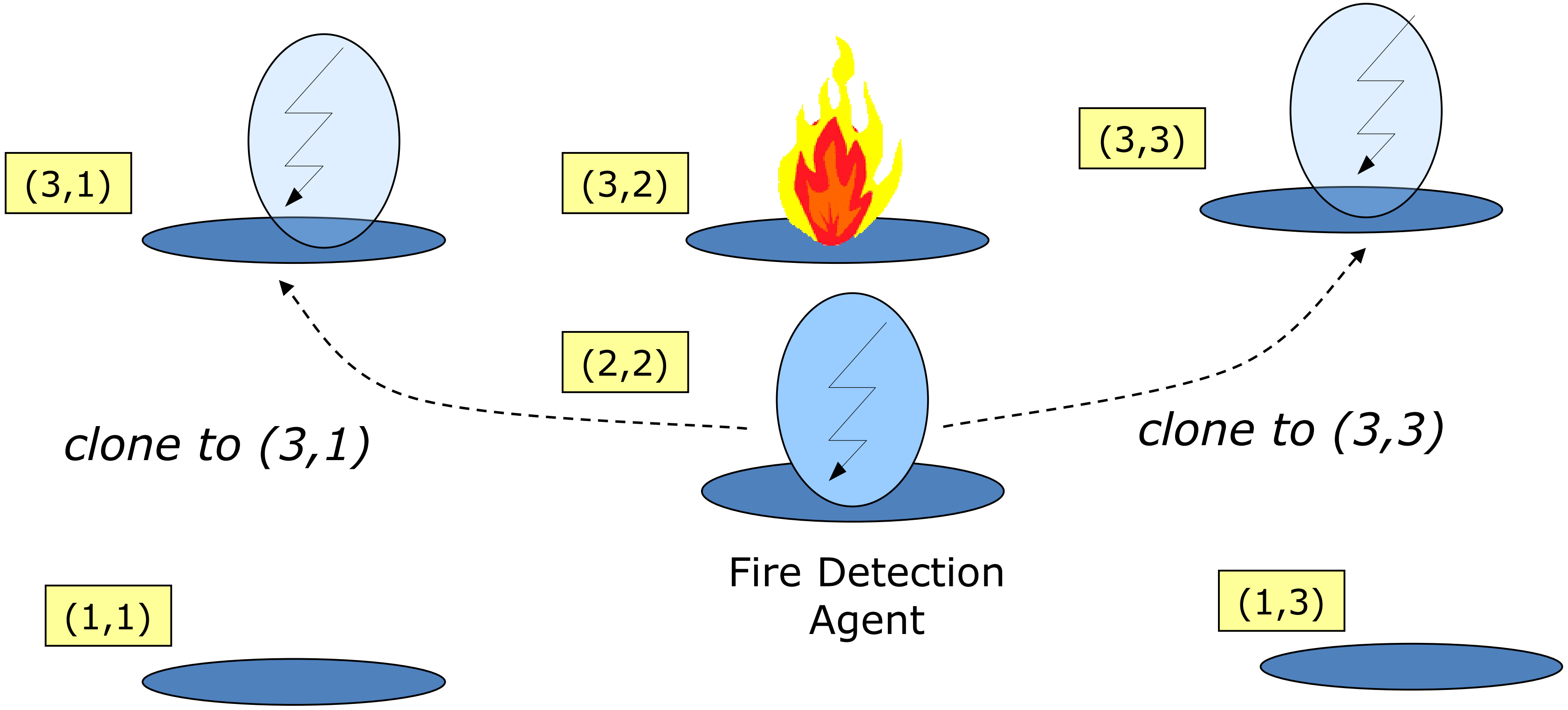
Gaseous Emission Systems

- Until recently there were only two types of systems
  - carbon dioxide and halon (compound containing carbon and halogen)
- Carbon dioxide clears a fire of its oxygen supply
- Halon is a clean agent but has been classified as an ozone-depleting substance, and new installations are prohibited
- Alternative clean agents include the following:
  - FM-200
  - Inergen
  - Carbon dioxide
  - FE-13 (trifluromethane)


Gas-based
suppression
agent

Location-Base Addressing

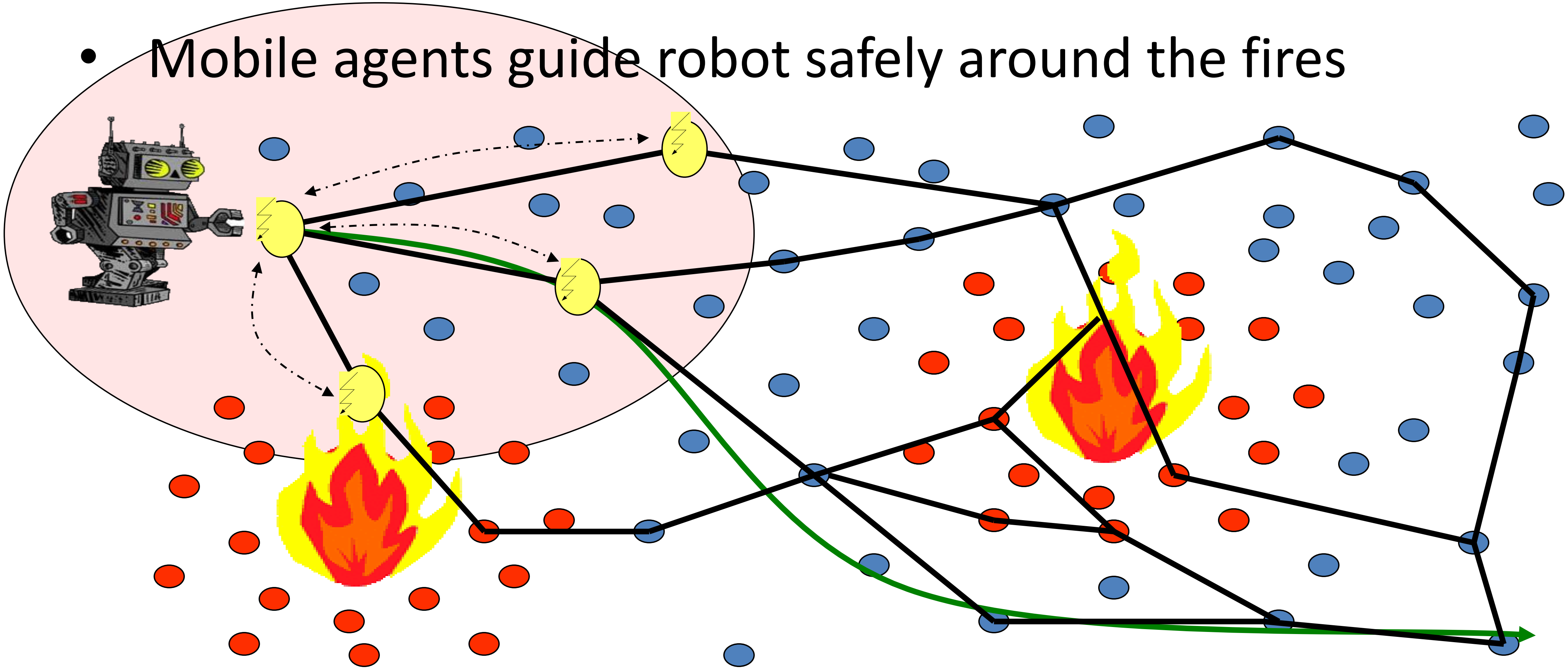
- Nodes are addressed by location



Research study: Chien-Liang Fok, Gruia-Catalin Roman, Chenyang Lu

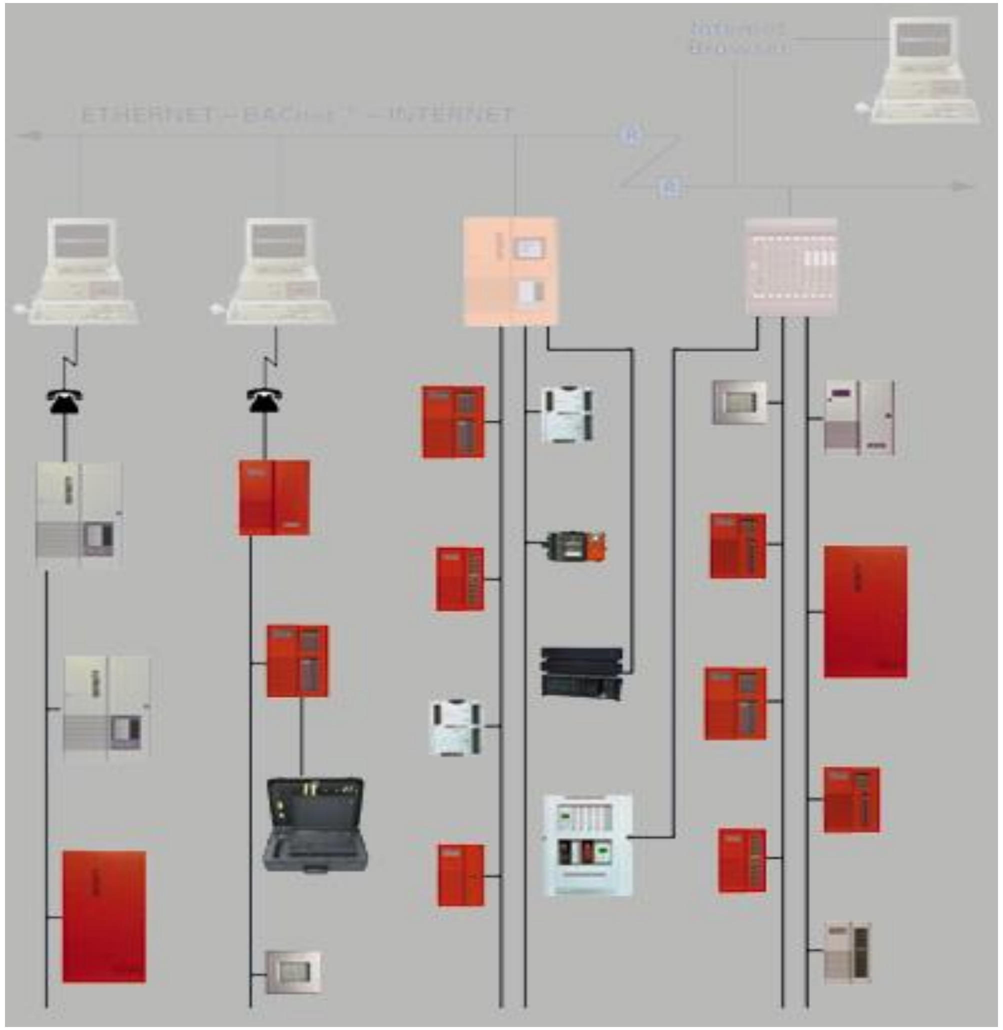
Robot Navigation

- Mobile agents guide robot safely around the fires



Case study-Monash University

Network- INFINET



- Connects Programmable Stand-Alone Controllers
  to the Network Controllers
- Up to Two Infinets
  per Network Controller
- RS 485—19,200 Baud
- Twisted Pair or Fiber Optic
- Peer-to-Peer Communications
- Token Passing Protocol
- 127 Application,
  31 Priority Controllers
  per Infinet Run

System Controllers

SCX 920

Chillers

Cooling Towers

Boilers

AHUs

LCX 810

Packaged HVAC Units

Heat Pumps

Fan Coil Units

- Universal Inputs and Outputs
- Form C Relays
- Manual Overrides
- I/O Expansion Ports
- Service Ports
- Optional Keypad Displays
- Peer-to-Peer Communications

Terminal Controllers

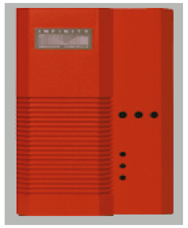
VAV Boxes

Fan Powered
Induction Units

Unit Ventilators

Rooftop Units

TCX 840



TCX 850

TCX 865

TCX 870

- Universal Inputs
- On-Board Airflow Sensors
- Tri-State and Analog Outputs
- Communications

Multi-agent system for building control

(Davidson and Boman 1998)

Personal comfort agent (PA):

Contains personal preferences and acts according to personal interests.

Room agents (RA):

Sets values of environmental conditions in order maximize energy savings

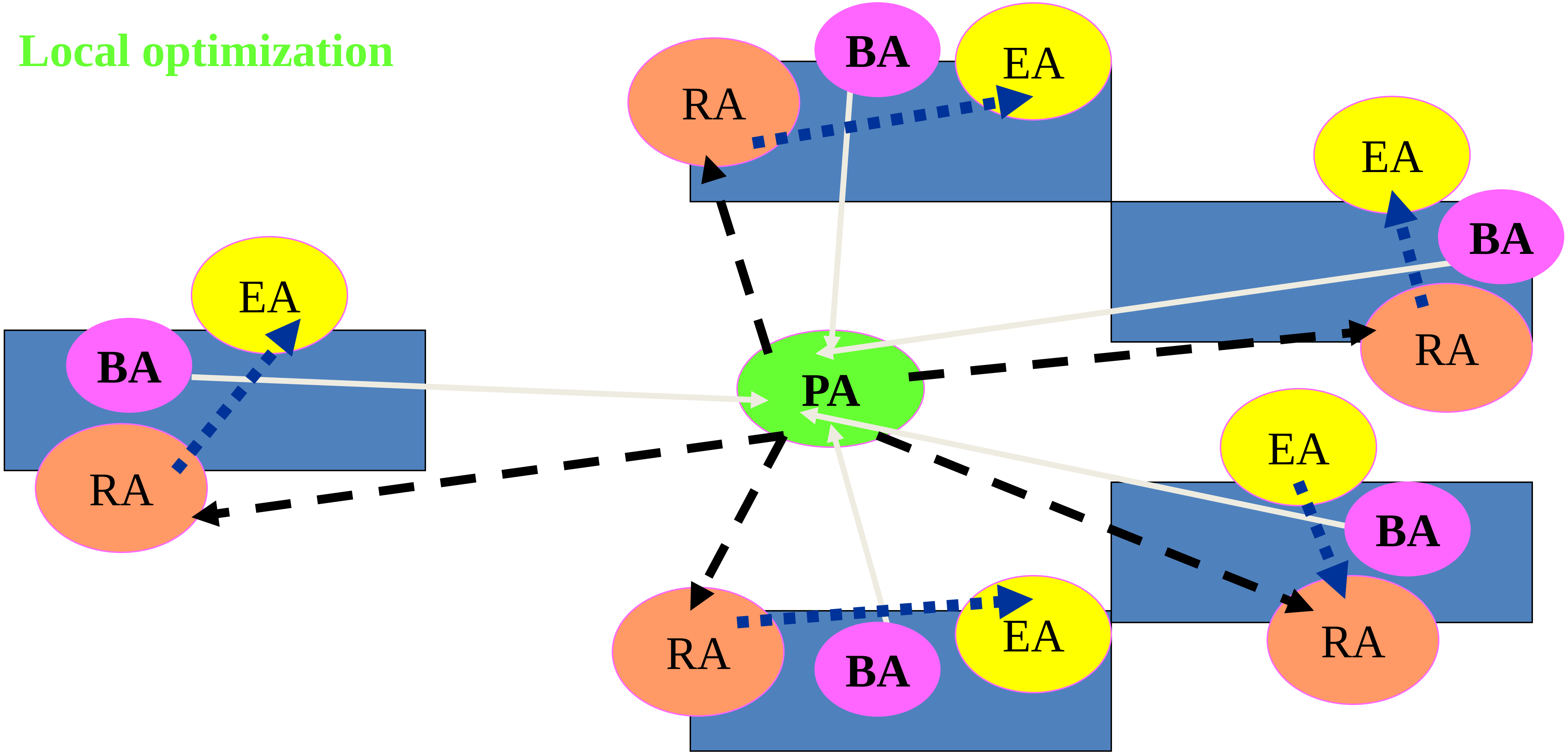
Environmental agents (EA):

Monitoring and control. Interface with sensors and devices

Badge system agent (BA): Tracks person’s presence

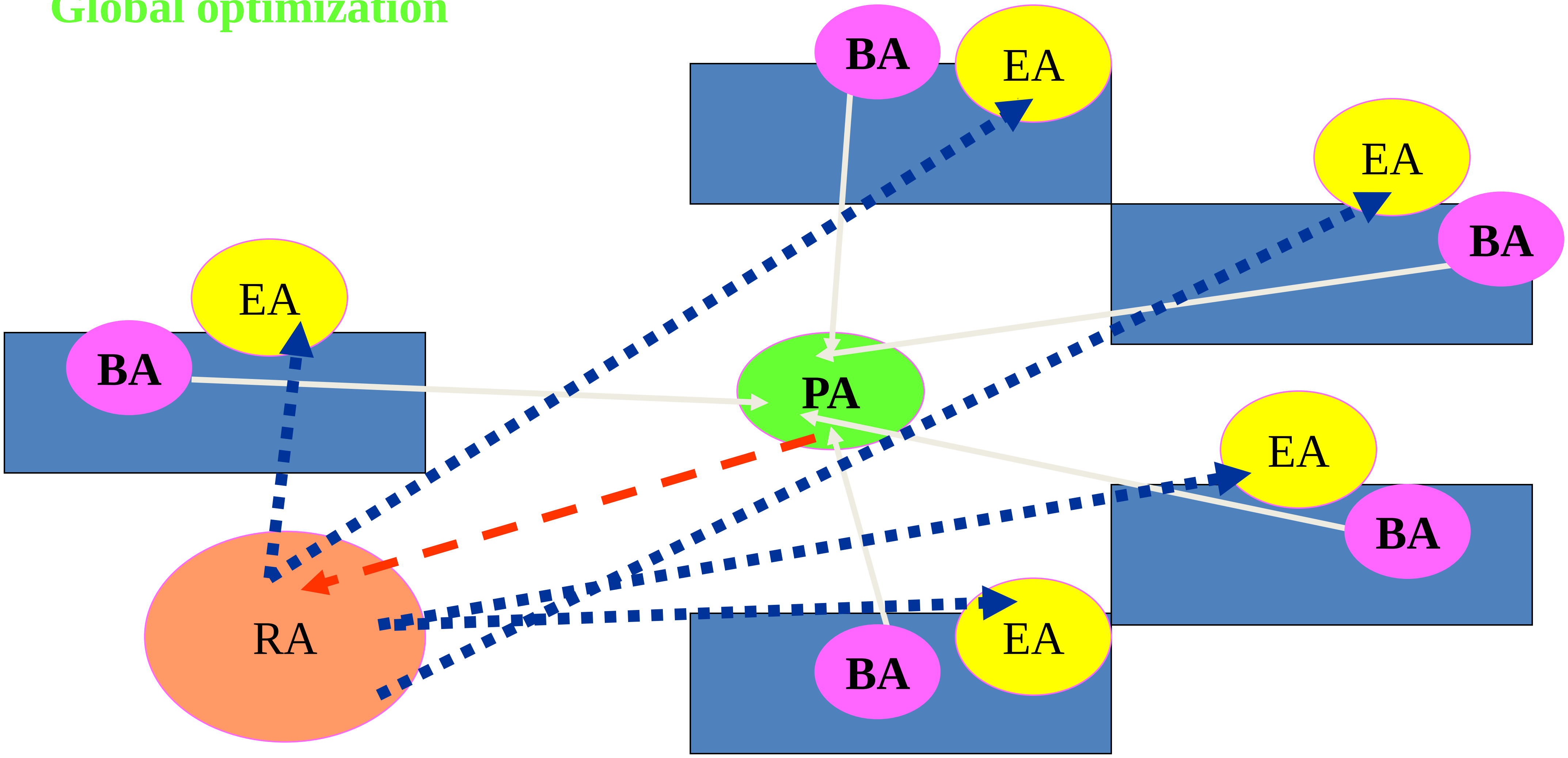
Multi-agent system for building control

Local optimization



Multi-agent system for building control

Global optimization



Market based zone control

(Cutkosky et. Al. 1993)

Goal:

Demand based control and better allocation of plant capacity

Method:

- Each thermostat receives a steady flow of funds
- Periodically thermostats bid against each other for access to the cooling or heating fluid

Market based zone control

(Cutkosky et. Al. 1993)

Logic:

- Thermostat offers to sell if it receives more than it needs
- Thermostat offers to buy if it receives less than it needs
- Bid is based on deviation from set point

Action:

- A central system aggregates the bids, calculates closing point and total volume
- Provides control signal to dampers based on closing point

Market based zone control

(Cutkosky et. Al. 1993)

Agents: Each thermostat

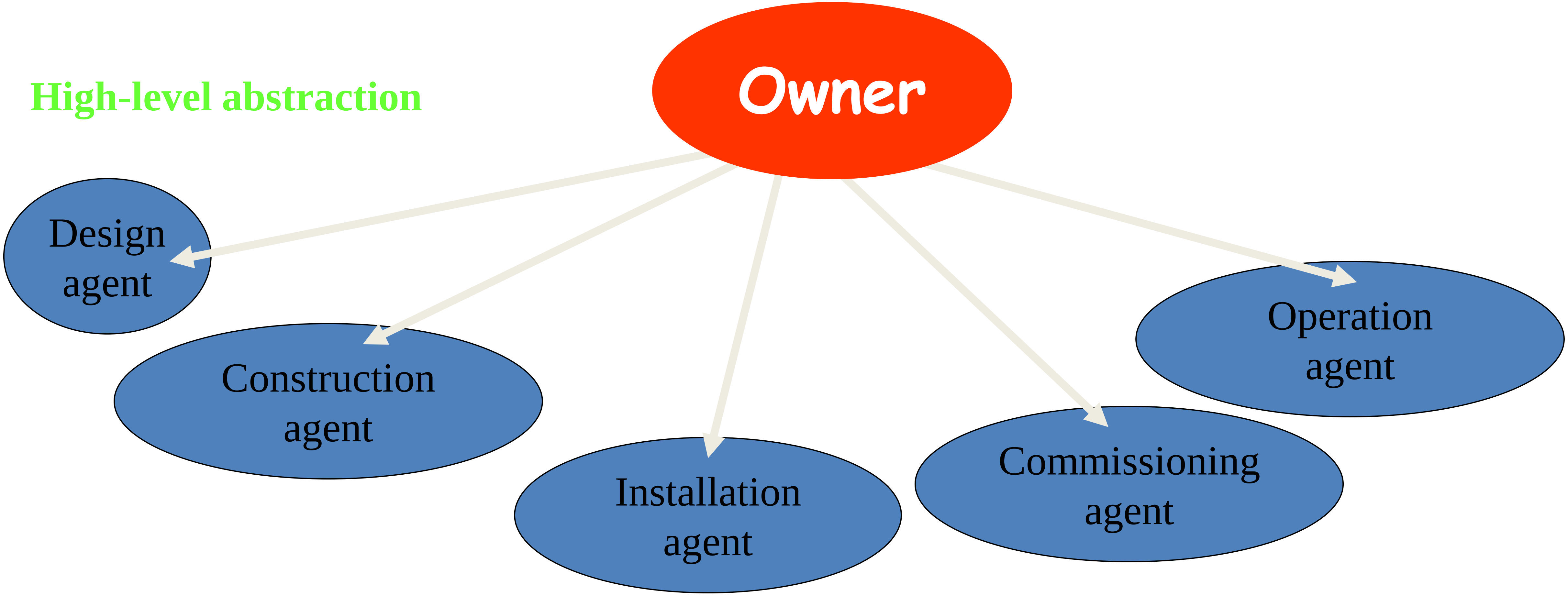
Agents model: Maintains goal for a specific environment based on thermostat setting

Agents structure: Identical except parameters

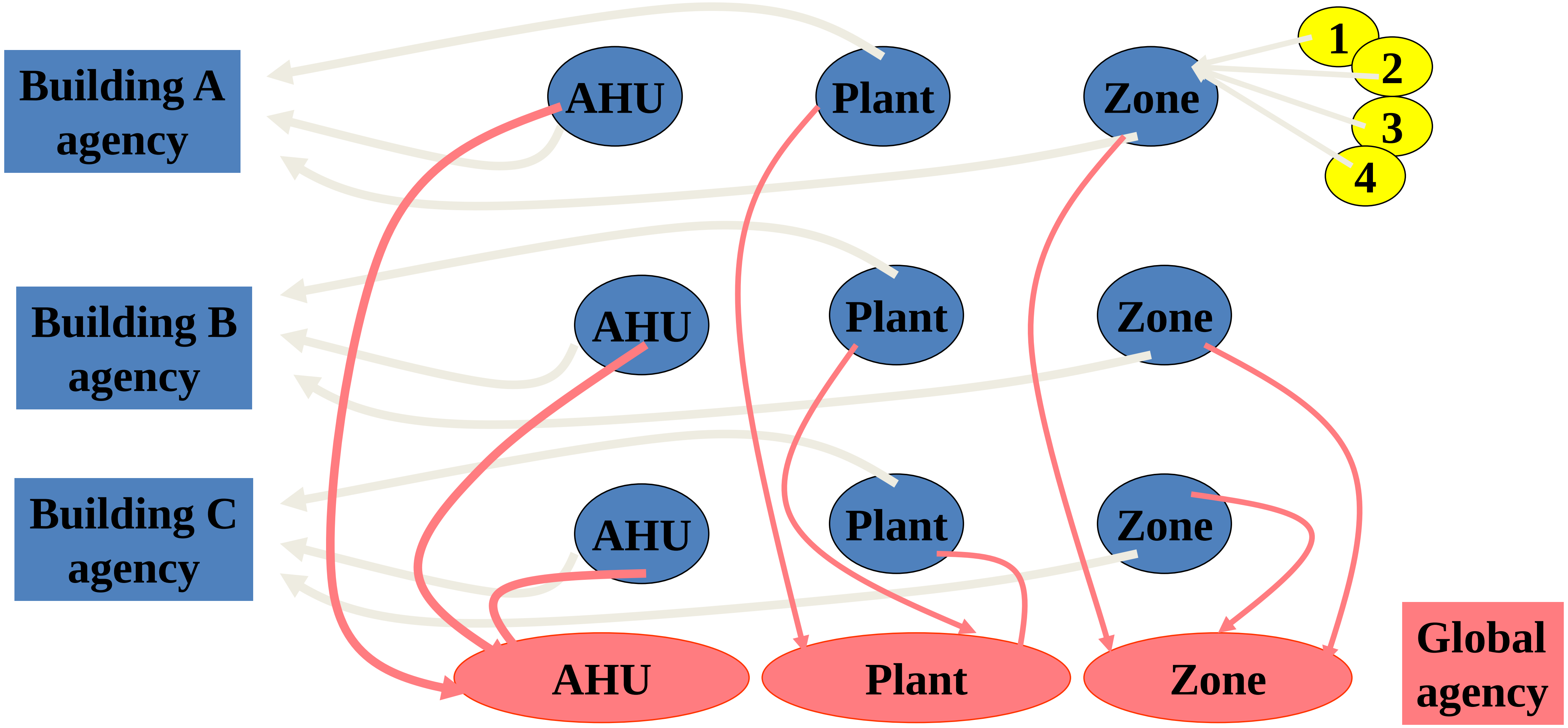
Population: 53 offices in 41 zones

Life-cycle building agency

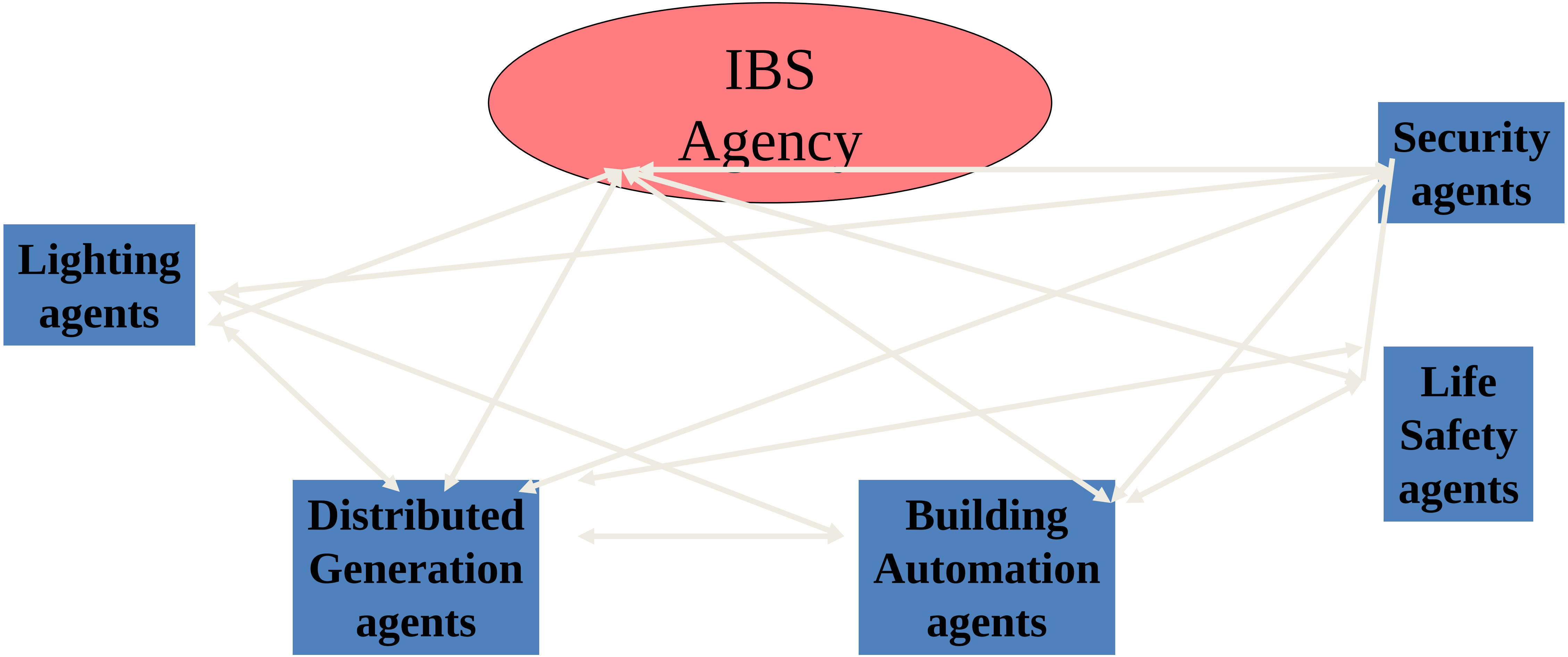
High-level abstraction



Collaborative global performance analysis agency

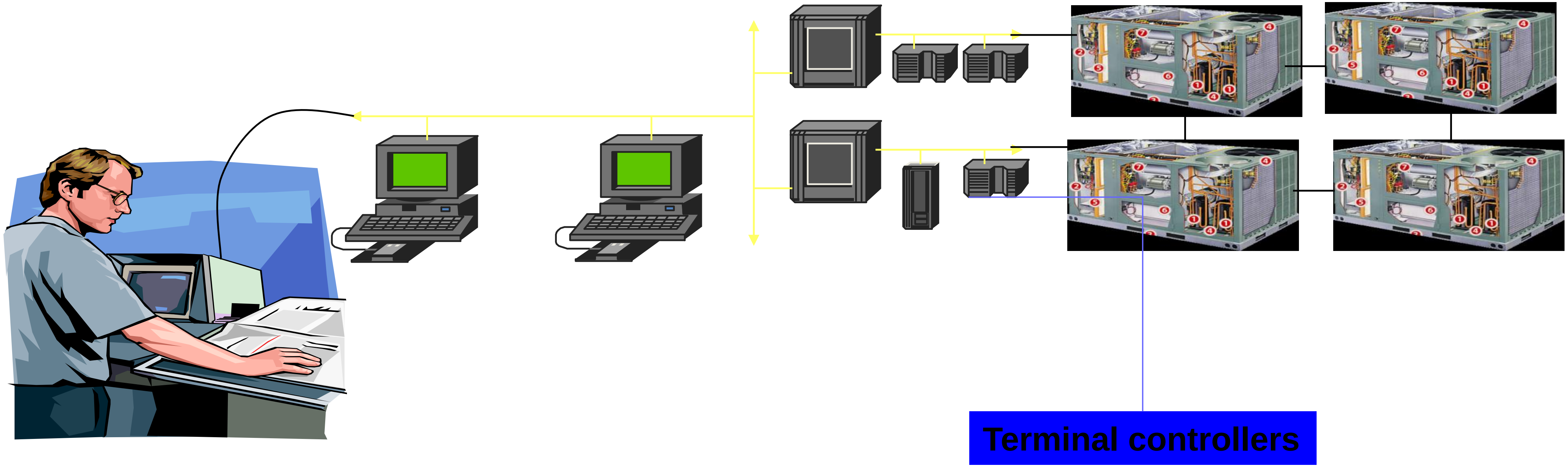


Agency for Integrated Building Services



Top Down Testing Approach

- Use the BMS to do the testing for installed equipment



Trends in Building Automation