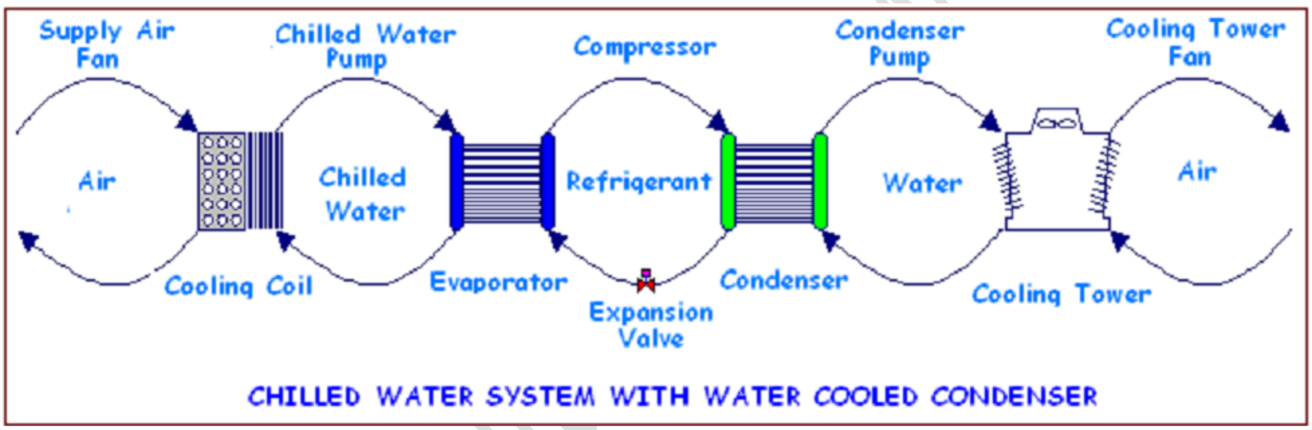
Chapter 1

Fundamentals of HVAC Controls

- The application of Heating, Ventilating, and Air-Conditioning (HVAC) controls starts with an understanding of the building and the use of the spaces to be conditioned and controlled.
- HVAC systems are classified as either self-contained unit packages or as central systems

Q: How does central air-conditioning system work?



CHILLED WATER SYSTEM WITH WATER COOLED CONDENSER

The main equipment used in the chilled water system is a chiller package that includes:
1- A refrigeration compressor (reciprocating, scroll, screw or centrifugal type),
2- Shell and tube heat exchanger (evaporator) for chilled water production
3- Shell and tube heat exchanger (condenser) for heat rejection in water cooled configuration
OR air cooled condenser can be used.
4- A cooling tower to reject the heat of condenser water
5- An expansion valve between condenser and the evaporator

The chilled water system is also called central A/C system. This is because the chilled water system can be networked to have multiple cooling coils distributed throughout a large or distributed buildings with the refrigeration equipment (chiller) placed at one base central location.

The heating cycle also follows the same cycle with a difference that the chilled water is replaced with hot water/steam and the chiller is replaced with boiler. The condenser and cooling tower circuit is not needed.

Q: What Parameters are controlled?

Proper environment is described with four variables: temperature, humidity, pressure and ventilation.

1- Temperature

ASHRAE suggests the following temperature ranges for overall thermal comfort.

Season	Clothing	Optimum Temperature	Temperature range
Winter	heavy slacks, long-sleeve shirts and sweaters	22°C 71°F	20-23.5°C 68-75°F
Summer	light slacks, and short sleeve shirt	24.5°C 76°F	23-26°C 73-79°F

2- Humidity

ASHRAE recommends the relative humidity (RH) to be maintained between 25 and 60%. Usually air is humidified to between 25 -45% during winter and dehumidified to below 60% during summer. Any figure outside this range shall produce discomfort and IAQ problems.

3- Ventilation

ASHRAE recommends minimum ventilation rates per person in the occupied spaces. In many situations, local building codes stipulate the amount of ventilation required for commercial buildings and work environments. The recommended value of outside air is typically 20 CFM for each occupant.

4- Pressure

Air moves from areas of higher pressure to areas of lower pressure through any available openings. A small crack or hole can admit significant amounts of air, if the pressure differentials are high enough (which may be very difficult to assess). The rooms and buildings typically have a slightly positive pressure to reduce outside air infiltration. This helps in keeping the building clean. Typically the stable positive pressure of .01-.05” is recommended.

5- Special Control Requirements

The special requirements pertain to the interlocking with fire protection systems, smoke removal systems, clean air systems, hazardous or noxious effluent control etc.

Q: Where are HVAC controls required?

The HVAC control system is typically distributed across three areas:

1- The HVAC equipment and their controls located in the main mechanical room.
2- The weather maker or the "Air Handling Units (AHUs)" may heat, cool, humidify, dehumidify, ventilate, or filter the air and then distribute that air.
3- The individual *room controls* depending on the HVAC system design. The equipment includes fan coil units, variable air volume systems, terminal reheat, unit ventilators, exhausters, zone temperature/humidistat devices etc.

Q: **What are the benefits (aims or purposes) of a Control System?**

Controls are required for one or more of the following reasons:

1- Maintain thermal comfort conditions
2- Maintain optimum indoor air quality
3- Reduce energy use, Efficient plant operation (economical operations)
4- Safe plant operation.
5- To reduce manpower costs and avoid the human error.
6- Identify maintenance problems
7- Monitoring system performance

O: What is Control?

In simplest term, the control is defined as the starting, stopping or regulation of heating, ventilating, and air conditioning system. Controlling an HVAC system involves three distinct steps:

1- Measure a variable and collect data
2- Process the data with other information
3- Cause a control action

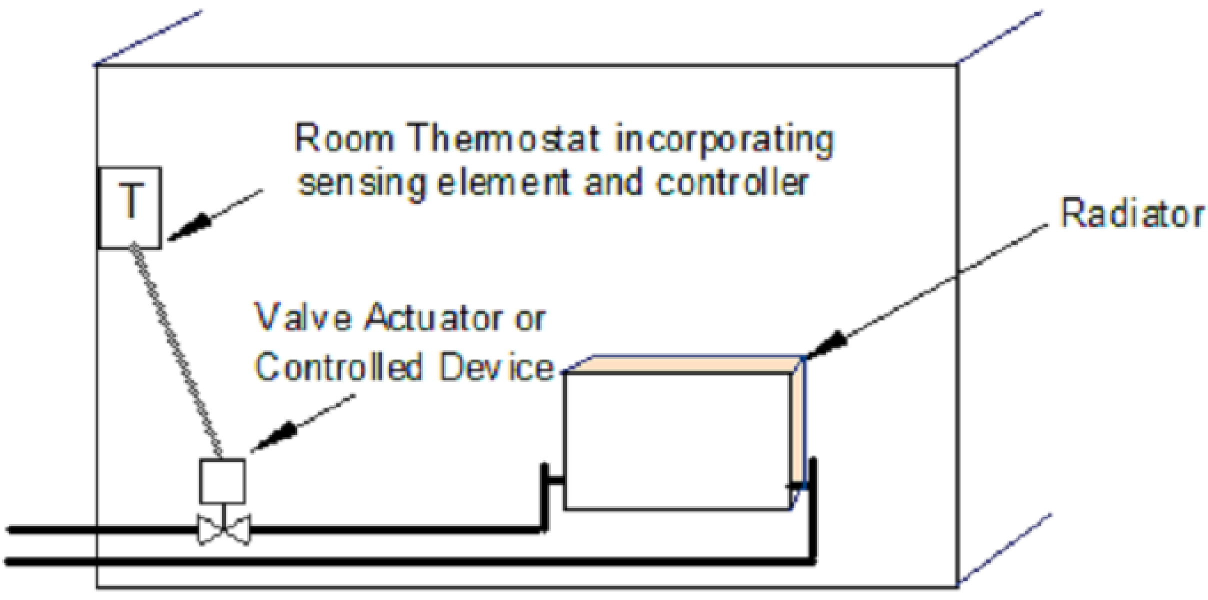
These functions are met through sensor, controller and the controlled device

Elements of a Control System

HVAC control system, from the simplest room thermostat to the most complicated computerized control, has **four** basic elements: sensor, controller, controlled device and source of energy.

1- Sensor measures actual value of ***controlled variable*** (the parameter that must be controlled) such as temperature, humidity and provides information to the controller.
2- Controller receives input from sensor, processes the input and then produces intelligent output signal for controlled device.
3- Controlled device acts to modify controlled variable as directed by controller.
4- Source of energy is needed to power the control system. Control systems use either a pneumatic or electric power supply.

Figure below illustrates a basic control loop for room heating. In this example the thermostat assembly contains both the sensor and the controller. The purpose of this control loop is to maintain the *controlled variable* (room air temperature) to some desired value, called a ***set point***. Heat energy necessary to accomplish the heating is provided by the radiator and the controlled device is the 2-way motorized or solenoid valve, which controls the flow of hot water to the radiator.



ROOM TEMPERATURE CONTROL

Theory of Controls:
Basically there are two types of controls, open loop control and closed loop control.

Open loop control

Open loop control is a system with no feedback i.e. there is no way to monitor if the *control system is working effectively.* Open loop control is also called feed forward control.

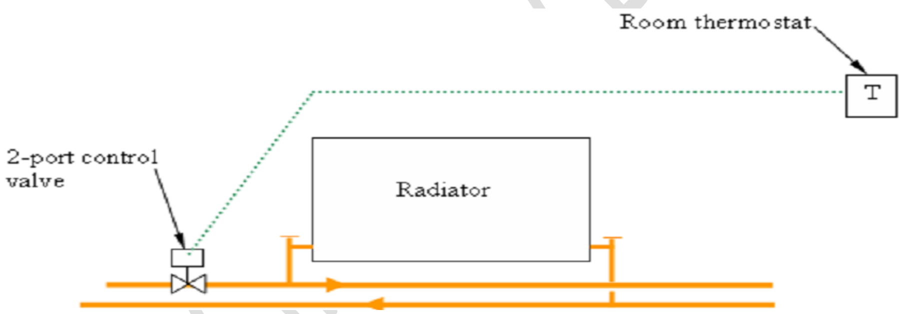
These types of controls are not suitable for air-conditioning and refrigeration system because it does not provide the facility of comparing the parameters to be controlled.

Closed Loop System:

If the oven in the example had (the difference between the actual value (controlled point) in controlled variable and its set point. A comparison of the sensed parameters is made with respect to the set parameters and accordingly the corresponding signals shall be generated. Closed loop control is also called *feedback control.*

In general ask a question, does sensor measure controlled variable? If yes the control system is closed loop, if not the system is open loop.

HVAC control systems are typically closed loops. Closed loop can be broadly classified into two categories viz. two position controls and continuous controls.



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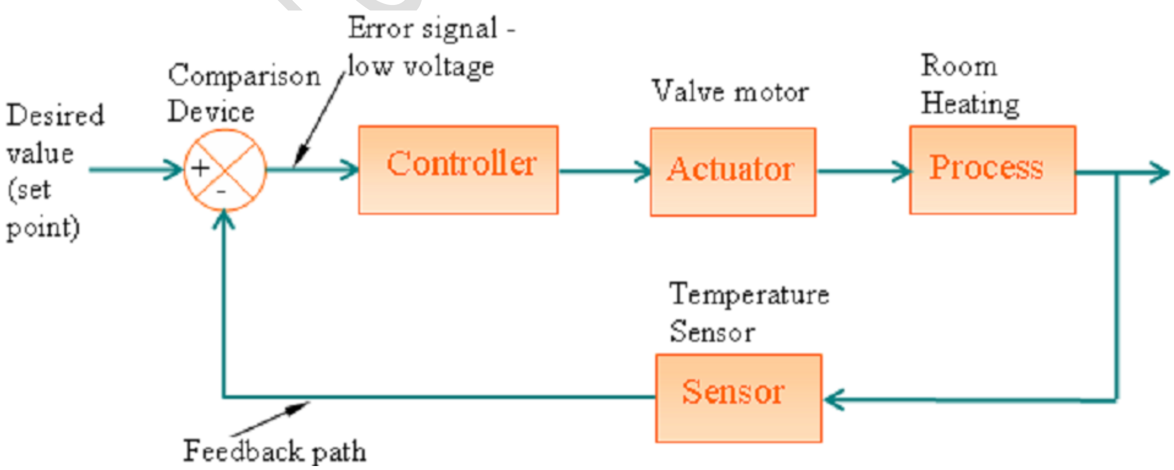

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Heating System Control Loop Diagram

The desired value or setpoint is adjusted at the knob on the front of the thermostat. (Note that the room thermostat contains the sensor, setpoint adjustment, comparison device and the controller, which are shown distinctly in the block diagram above). The temperature sensor measures the actual value and sends a signal back along the feedback path to the comparison device. The comparison device compares the value of temperature at the sensor to that of the desired value or setpoint on the controller. The difference between the desired value and the measured value is known as the error signal. The error signal is fed into the controller as a low voltage signal (e.g. 10 volts) to the actuator.

The controlled device, which is an actuator on 2-port valve reacts to the impulse received from the controller and varies the flow of the hot water. This in turn changes the condition of the space or process to the desired value. This type of control is called modulated control because the control elements are constantly changing the signal from the comparison device to maintain a near constant temperature in the room even though inside and outside conditions may vary.

Type of Control Systems according to the sources of energy:

1- Direct Acting Systems

The simplest form of controller is direct-acting, comprising a sensing element which transmits power to a valve through a capillary, bellows and diaphragm. The measuring system derives its energy from the process under control without amplification by any auxiliary source of power which makes it simple and easy to use. The most common example is the thermostatic radiator valve which adjusts the valve by liquid expansion or vapor pressure. Direct-acting thermostats have little power and have some disadvantages but the main advantage is individual and inexpensive emitter control. Direct acting thermostatic equipment gives gradual movement of the controlling device and may be said to modulate.

2- Electric / Electronic Systems

Electric controlled devices provide ON / OFF control. In residential and small commercial applications, low voltage electrical controls are most common. A transformer is used to reduce the 115 volt alternating current to a nominal 24 volts.

3- Pneumatic Systems

The most popular control system for large buildings historically has been pneumatics which can provide both On-Off and modulating control. Pneumatic actuators are described in terms of their spring range. Common spring ranges are 3 to 8 psig (21 to 56 kPa), 5 to 10 psig (35 to 70 kPa), and 8 to 13 psig (56 to 91 kPa).

4- Microprocessor Systems

Direct Digital Control (DDC) is the most common deployed control system today. The sensors and output devices (e.g., actuators, relays) used for electronic control systems are usually the same ones used on microprocessor-based systems. The distinction between electronic control systems and microprocessor-based systems is in the handling of the input signals. *In an electronic control system, the analog sensor signal is amplified, and then compared to a setpoint or override signal through voltage or current comparison and control circuits. In a microprocessor-based system, the sensor input is converted to a digital form, where discrete instructions (algorithms) perform the process of comparison and control.*

5-Mixed Systems

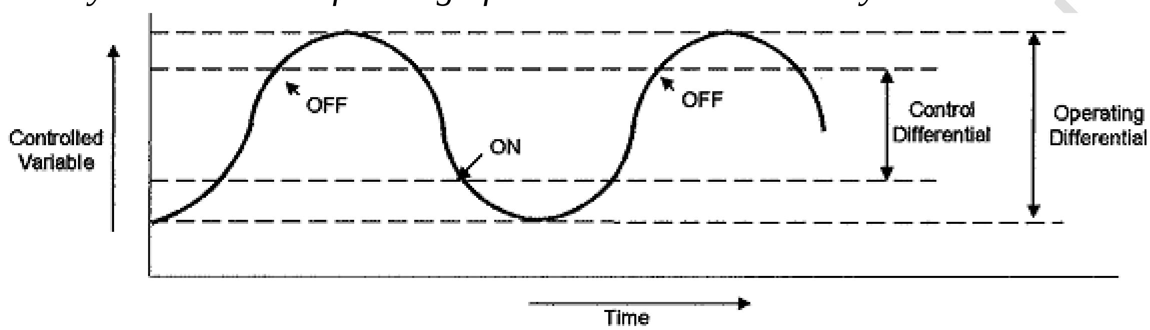
Combinations of controlled devices are possible. For example, electronic controllers can modulate a pneumatic actuator. Also, proportional electronic signals can be sent to a device called ***transducer***, which converts these signals into proportional air pressure signals used by the pneumatic actuators. These are known as electronic-to-pneumatic (E-P) transducers. For example, electronic-to-pneumatic (E/P) transducer converts a modulating 2 to 10V DC signal from the electronic controller to a pneumatic proportional modulating 3 to 13 psi signal for a pneumatic actuator. *A sensor-transducer assembly is* called a ***transmitter***.

CONTROL ACTION

To satisfy the need for various kinds of control response, several types of control actions are available. They may be broadly classified as follows.

1- Two-Position or On-Off Action

Any two-position controller needs a ***differential*** to prevent hunting, or too-rapid cycling. This differential is the difference between the setting at which the controller operates at one position and the setting at which it changes to the other. In a thermostat this is expressed in degrees of temperature. *The differential setting of any controller is usually somewhat less than the operating differential of the* ***HVAC*** *system because of the lag of the instrument and the system*.

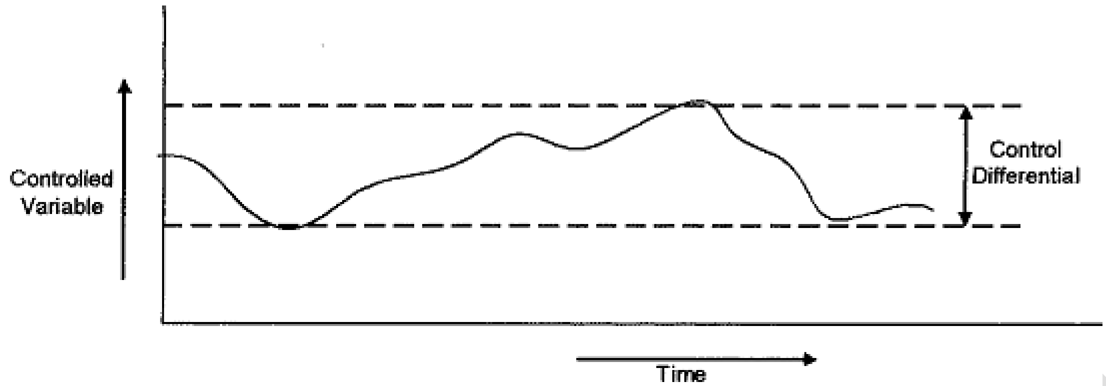


Two-position control

One way to reduce the operating differential is to shorten on or off time artificially in anticipation of system response. **A** heating thermostat may be provided with a small internal heater that is energized during on periods, thereby giving a false signal to the thermostat. *This is called heat anticipation.*

2- Floating Action:

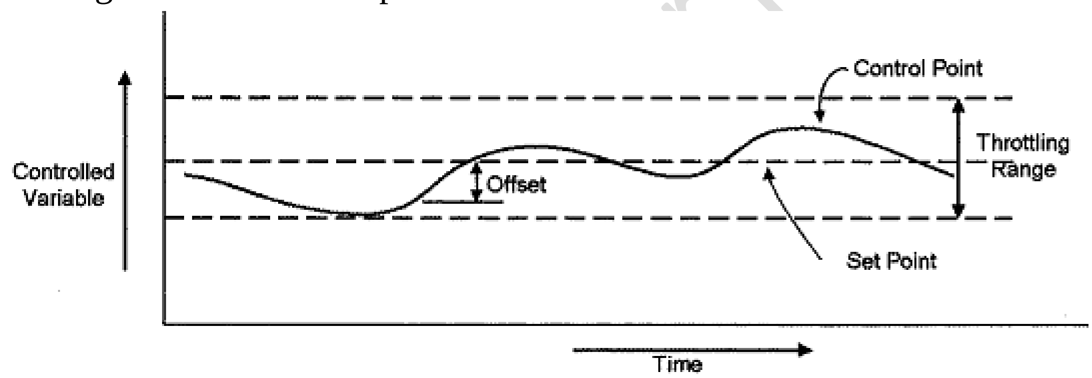
This term refers to a controlled device that modulates toward the on or off position any time appropriate contacts are closed but stops when the contacts open. For example, one set of contacts on a two-position thermostat might close when a room is too cold causing an electric motor to begin to open a steam valve on a heating coil. As the room temperature rises, the contacts open, stopping the motor in its new position. If the room temperature continues to rise, another set of contacts might close causing the motor to turn in the other direction, closing the steam valve. Note that the controller must have a dead spot or neutral zone in which neither set of contacts is closed. This allows the device to float in a partly open position. For good operation this system requires a rapid response in the controlled variable. Otherwise it will not stop at an intermediate point.



Floating Action

3-Modulating Control:

Modulating means that the output of the controller can vary infinitely over the range of the controller. In this situation the controlled device will seek a position corresponding the controller output.



Modulating control

Here are some terms encountered in discussing modulating control:

Throttling range: is the amount of change in the controlled variable required to run the controlled device from one extreme to the other.

Set point: is the controller setting and is the desired value of the controlled variable.

***Control point*:** is the actual value of the controlled variable. If the control point lies within the throttling range of the controller, it is said to be in control. When it exceeds the throttling range it is said to be out of control.

Offset or error: is the difference between the set point and the control point. This is sometimes called drift. droop, or deviation. The amount of offset theoretically possible is determined by the throttling range, but this value may be exceeded in out-of-control situations.

a- Control Modes-Proportional

There are three control modes encountered in modulating control. The first and simplest of these is proportional control. This is the control mode used in most pneumatic and older electric systems for HVAC. The mathematical expression for proportional control is:

$$Q = A + K_p e$$

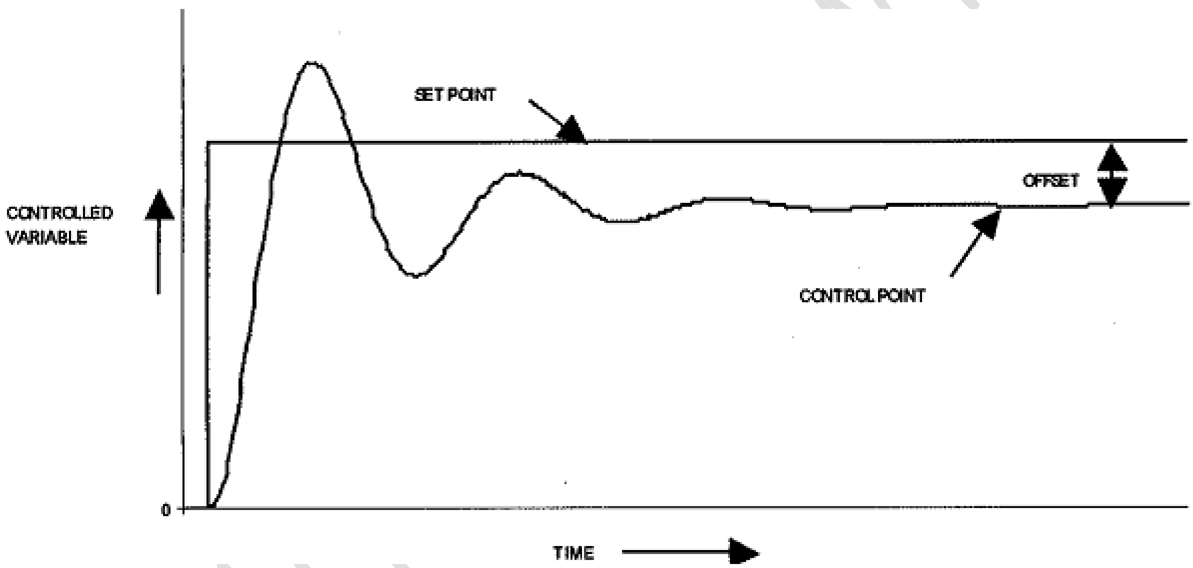
where:

Q =controller output

A is a constant equal to the value of the controller output with no error

e =the error, equal to the difference between the set point and value of the controlled point

K, = proportional gain constant



Proportional control—stable

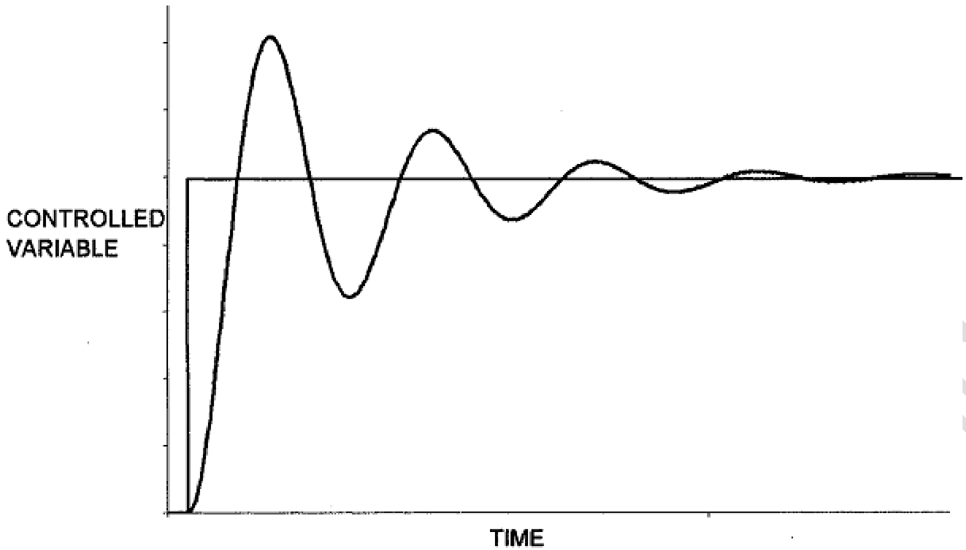
b- Control Modes-Proportional plus Integral

This designation is proportional plus integral, usually abbreviated PI. Mathematically, another term is added to the control equation:

$$Q = A + K_p e + K_i \int e\, dt$$

Where K_i is integral constant

The added term means that the output of the controller is now affected by the error signal integrated over time and multiplied by the integral gain constant. Note that the sign of the error may be positive or negative; therefore, the integral term may be plus or minus. The effect of this term is that the controller output will continue to change as long as any error persists, and the control offset will be eliminated



Proportional plus integral control

c- **Control Modes-Derivative**

For derivative control mode, still another term is added to the control equation:

$$Q = A + K_p e + K_i \int e\,dt + K_d \frac{de}{dt}$$

Where:

K_d = derivative gain constant

The derivative term provides additional controller output related to the rate of change of the controlled variable. A rapid rate of change in the error will increase the absolute value of the derivative term. **A** small rate of change will decrease the value.

Derivative control is used to reduce overshoot when a rapid response is desired (requiring a high proportional gain).

Measurements:

All the control actions described above depend first on the measurement of a controlled variable. Accurate and rapid measurement is a serious challenge to engineers in the control industry. Although it is essential for proper control, it is very difficult to obtain an accurate and instantaneous reading, especially if the property being measured is fluctuating or changing very rapidly. Control system designers must be aware of the practical limitations of the accuracy and the response of available sensing devices. Thermostats will be affected by the presence or the absence of air motion (drafts), the temperature of the surfaces on which they are mounted (if greatly different from the air temperature), the mass of the sensing element and the presence of radiant effects from windows or hot surfaces. For a residence or an office a variation of one or two degrees Fahrenheit on either side of the set point may be acceptable. For a standards laboratory a variation of ± 0.50 degrees may be unacceptable.

A pressure sensor that is located at a point of turbulence (such as a turn or change of pipe size) in the fluid can never provide accurate or consistent readings. For this purpose a long straight run of duct or pipe generally is required. Straightening vanes can be used where long straightaways are not possible.

Quations:

1- What are the parameters in HVAC systems that must be controlled to provide a proper environment?
2- Why Automatic Controls in HVAC systems? Or what are the reasons of a Control in HVAC System? Or (**benefits ,aims ,purposes)**
3- Where are HVAC controls required**?**
4- What is the meaning of Control in HVAC systems and there controlling steps?
5- What are the main elements of a Control System?
6- Draw a diagram showing a room heated by a hot water radiator and then represents the control sequence on a block diagram?
7- List five types of control systems according to their source of energy?
8- Define the following terms: Control variable, sensor, controller, control device, Controlled agent, control loop, open loop, close loop. control reset, set point, control point, final control element, *Throttling range, Offset*, *error*, drift, droop, deviation, Differential of ON/OFF controller, heat anticipation?
9- Rationalize the following:
   a- *The differential setting of any controller is usually somewhat less than the operating differential of the HVAC system?*
   b- Any two-position controller needs a *differential?*
   c- For good operation the floating action control system requires a rapid response in the controlled variable? .
   d- There is distinction between electronic and microprocessor-based control systems?
   e- The control offset will be eliminated in proportional and integral modulating control action?
   f- The use of derivative control?