Fundamentals of DDC

Introduction to Direct Digital Controls

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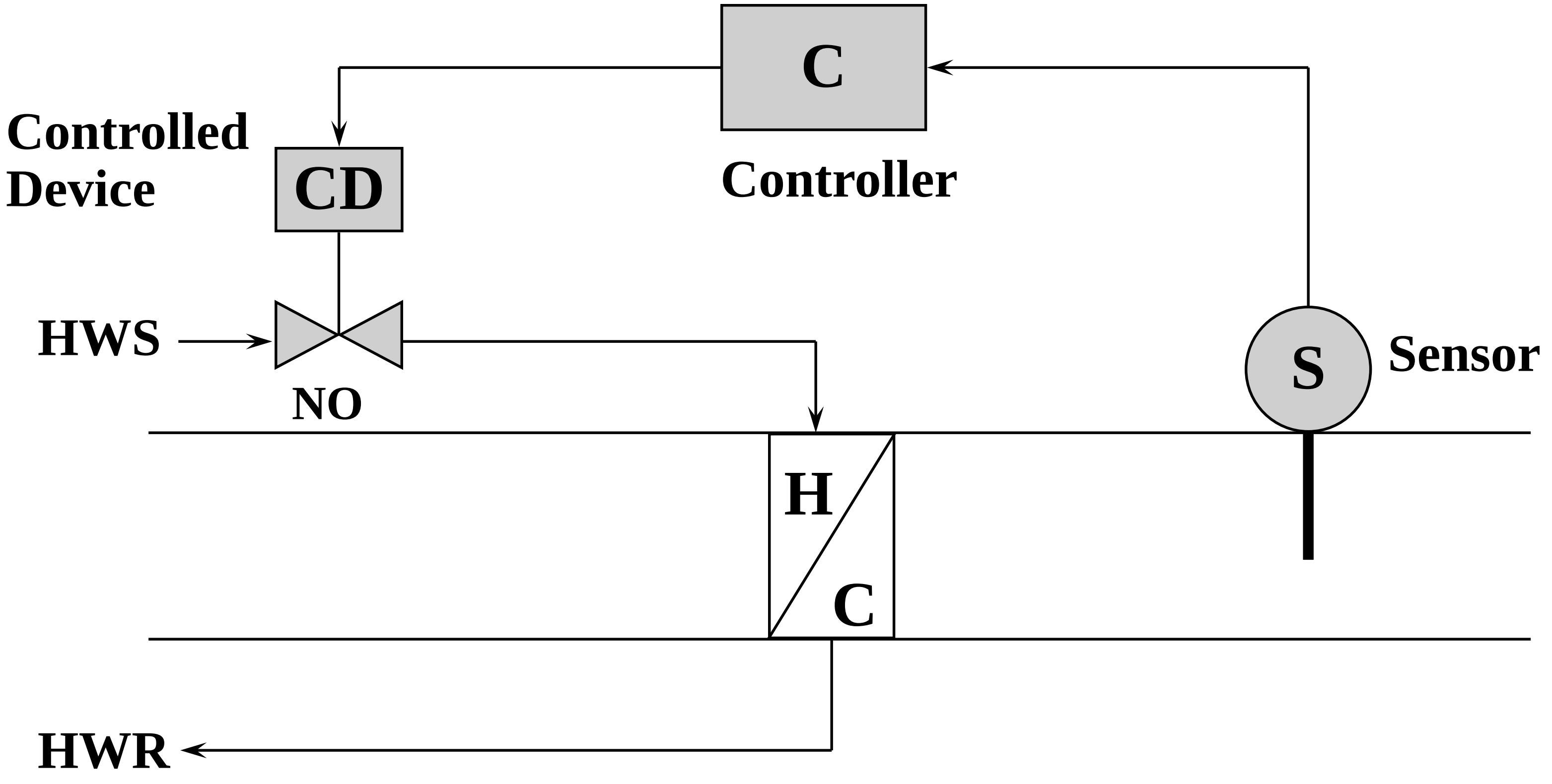
Block Objective

The goal of this introduction block is familiarize the student with the basic components of a control loop. The various types of control loop response will be introduced. The choices that are available for set point selection will be reviewed. The different types of control hardware that are available for HVAC control systems will be discussed along with their advantages and disadvantages. Input and outputs point types will be covered briefly. The user software types that are employed in the DDC systems will be reviewed and discussed.

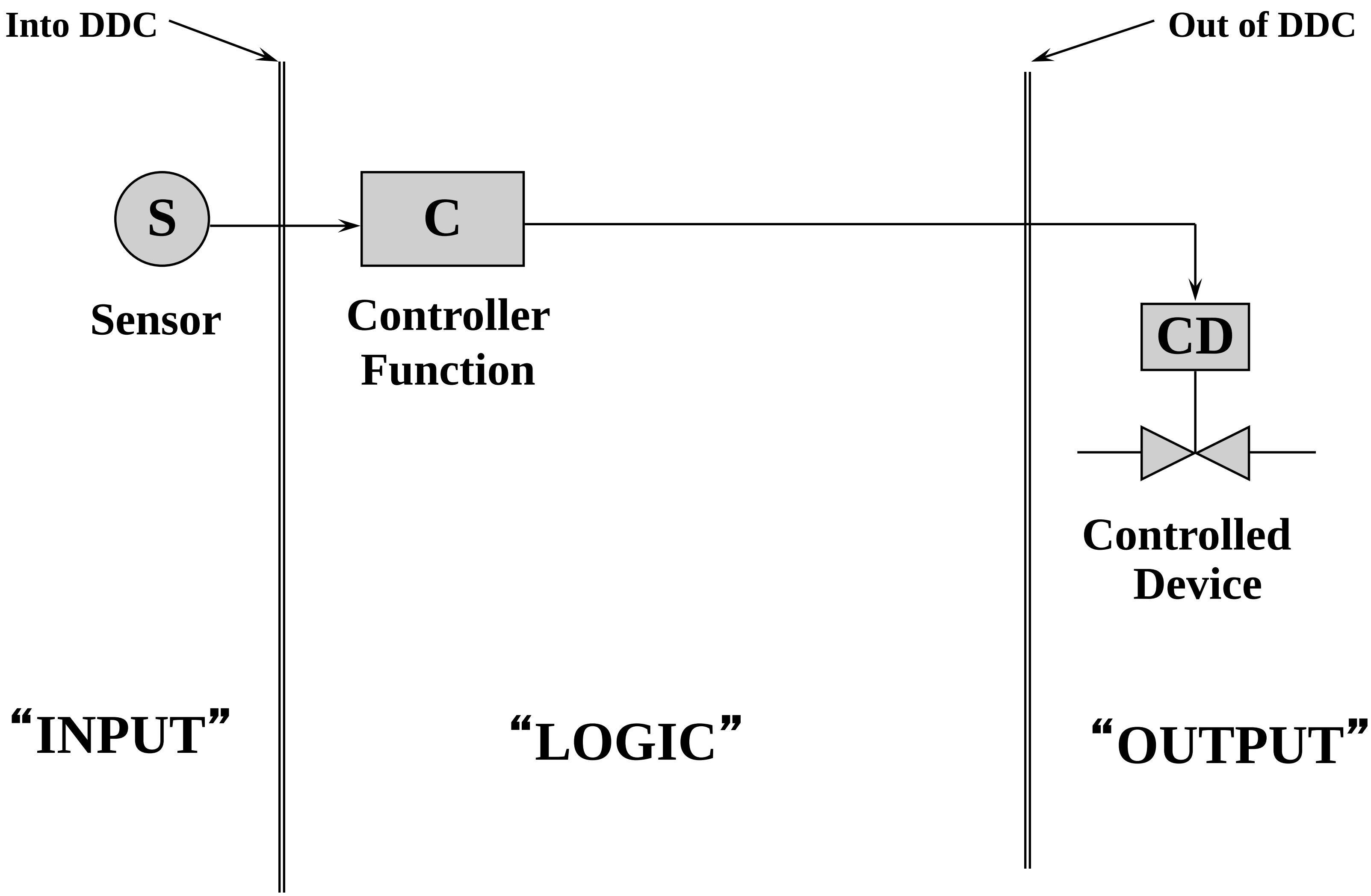
What Is Control?

- Measuring Data
  - Most importantly, we must measure what we wish to control
    - Temperature, Humidity, Pressure, CFM, CO_2
  - We may also measure other variables that indirectly have an impact on what we wish to control
    - Other Temperatures
    - Time of Day
    - Demand Condition
- Processing Data
  - The logic of control
- Causing an Action
  - Valves, dampers, fans, pumps, boilers, etc.

Basic Control Loop(Pneumatics)



Basic Control Loop (DDC)



The Sensor

- The function of the sensor is to measure the controlling variable or other control input in an accurate and repeatable manner.
- The controlling variable may be:
  - Temperature, Relative humidity, Pressure, CO_2
  - Status: Airflow, Water Flow, Current
  - Safety: Fire, Smoke, High/Low Temperature Limit
  - A number of other physical parameters
- Sensors can be the first and a major weak link in the chain of control.

The Controller Function

- The controller’s function is to compare it’s input (from the sensor) with a set of instructions such as setpoint, throttling range, action, etc., and to produce the appropriate output signal.
- How the controller functions is referred to as “The Control Response”.
  - Two Position
  - Floating
  - Proportional (P only)
  - Proportional plus Integral (PI)
  - Proportional plus Integral plus Derivative (PID)

Two Position

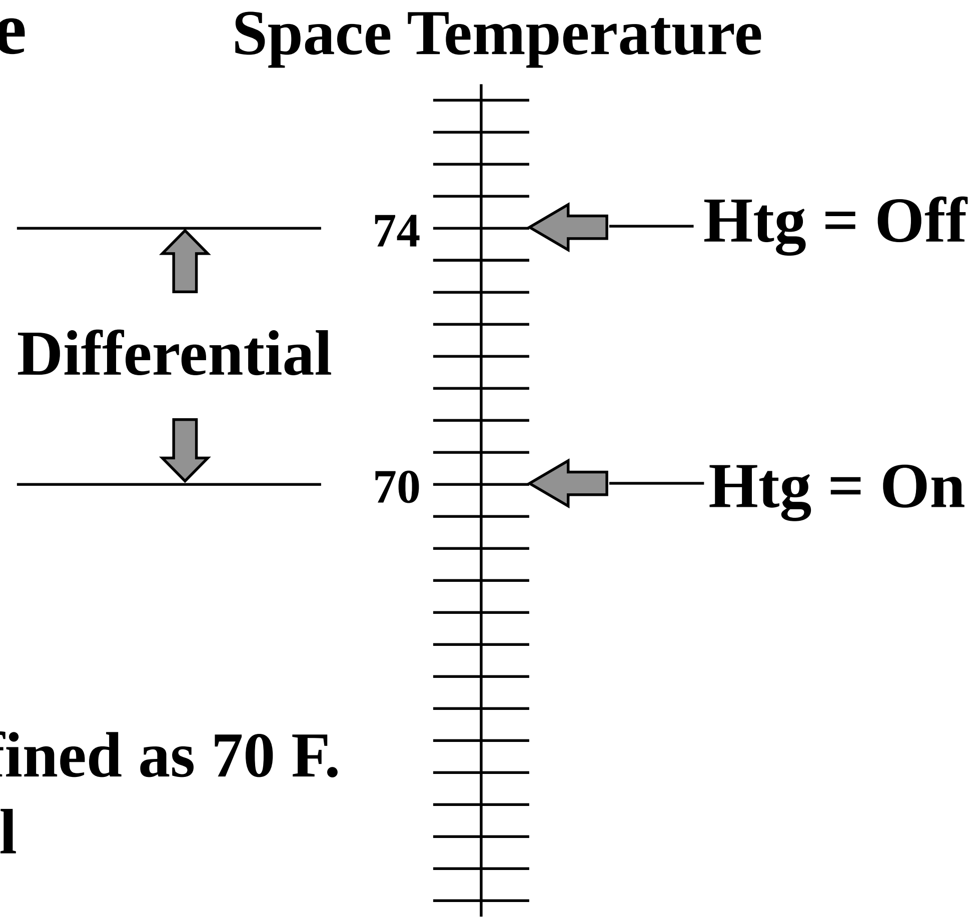
- Digital (Two position) Output
- Variable Input
- Upper Limit and Lower Limit
  - Change of output based on analog input crossing limits
  - There is no standard for defining these limits
  - Most often a setpoint and differential, but even these terms do not have a universal relationship
- Applications
  - Primary Control Loop (i.e. temperature control)
  - Limit Control (i.e. freezestats, OA temperature limits)
  - Moderate to slow responding control loops

Types of Two Position Controllers

- Analog Variables
  - Temperature
  - Relative Humidity
  - Pressure
  - Current
  - Levels
- Time Based
  - Time clock with “pins”.
  - Software schedule is the “setpoint”.
  - Input is time

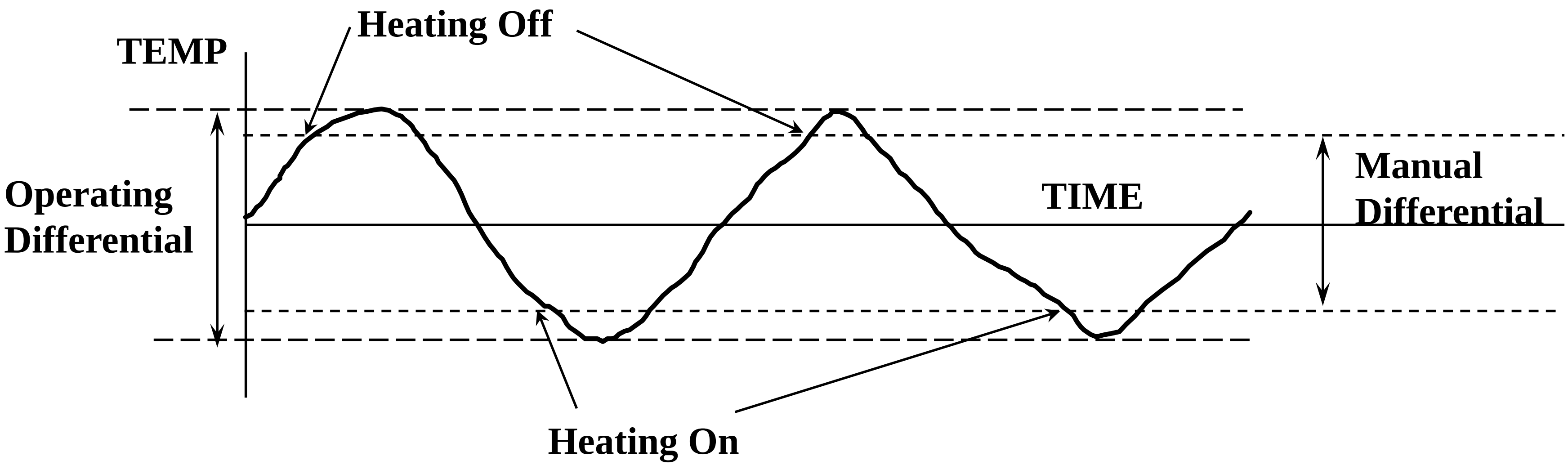
Primary Control Example

- Home heating system
- Desired Performance
  - Enable at 70 F.
  - Disable at 74 F.



Setpoint may be defined as 70 F.
with 4 F. differential

Primary Control Example

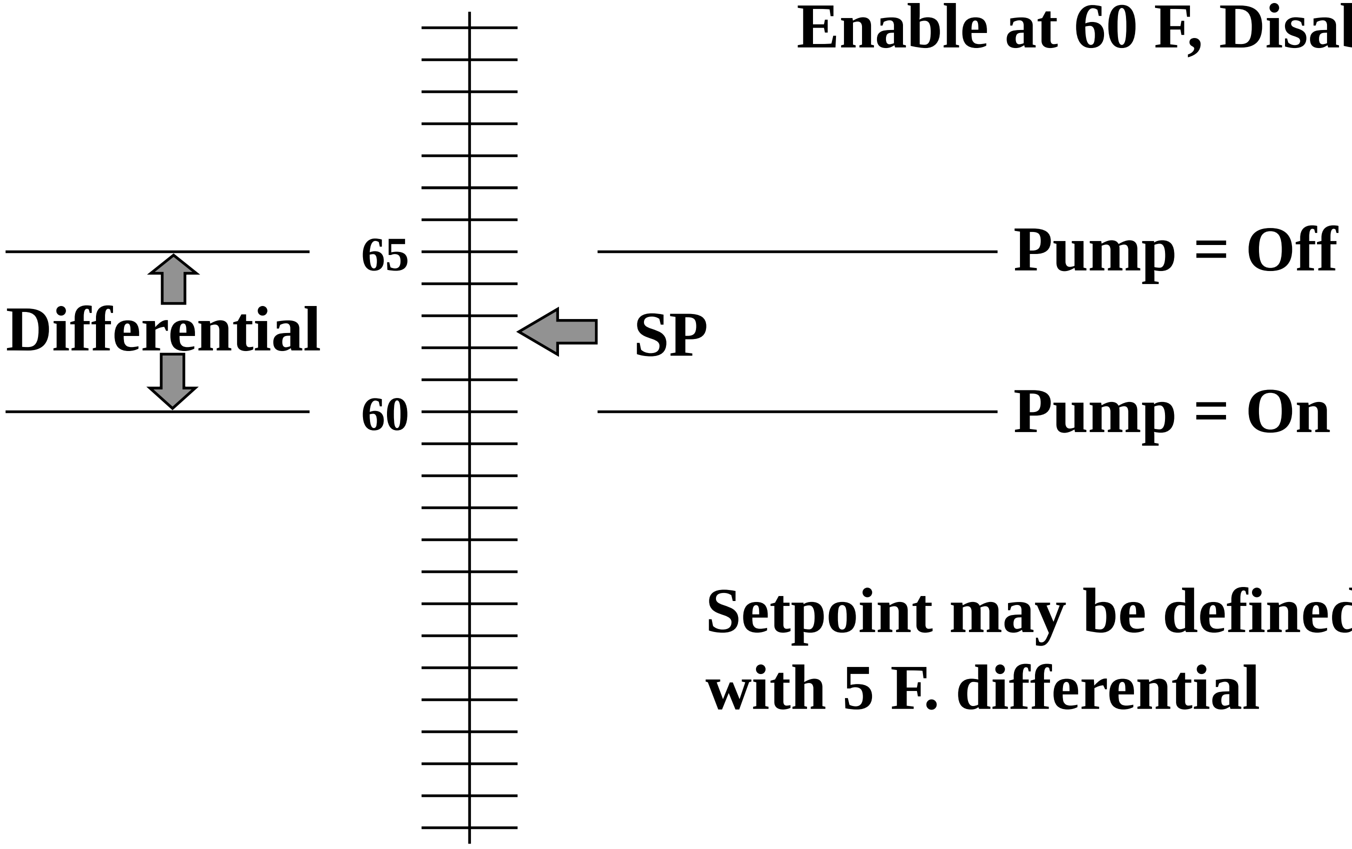


- **Manual Differential - Difference in controlled variable that causes the controlled device to turn on and off**
- **Operating Differential - Resulting difference in controlled variable due to the controlled device cycling**

Two Position Limit Control

OA Limit on HW Pump

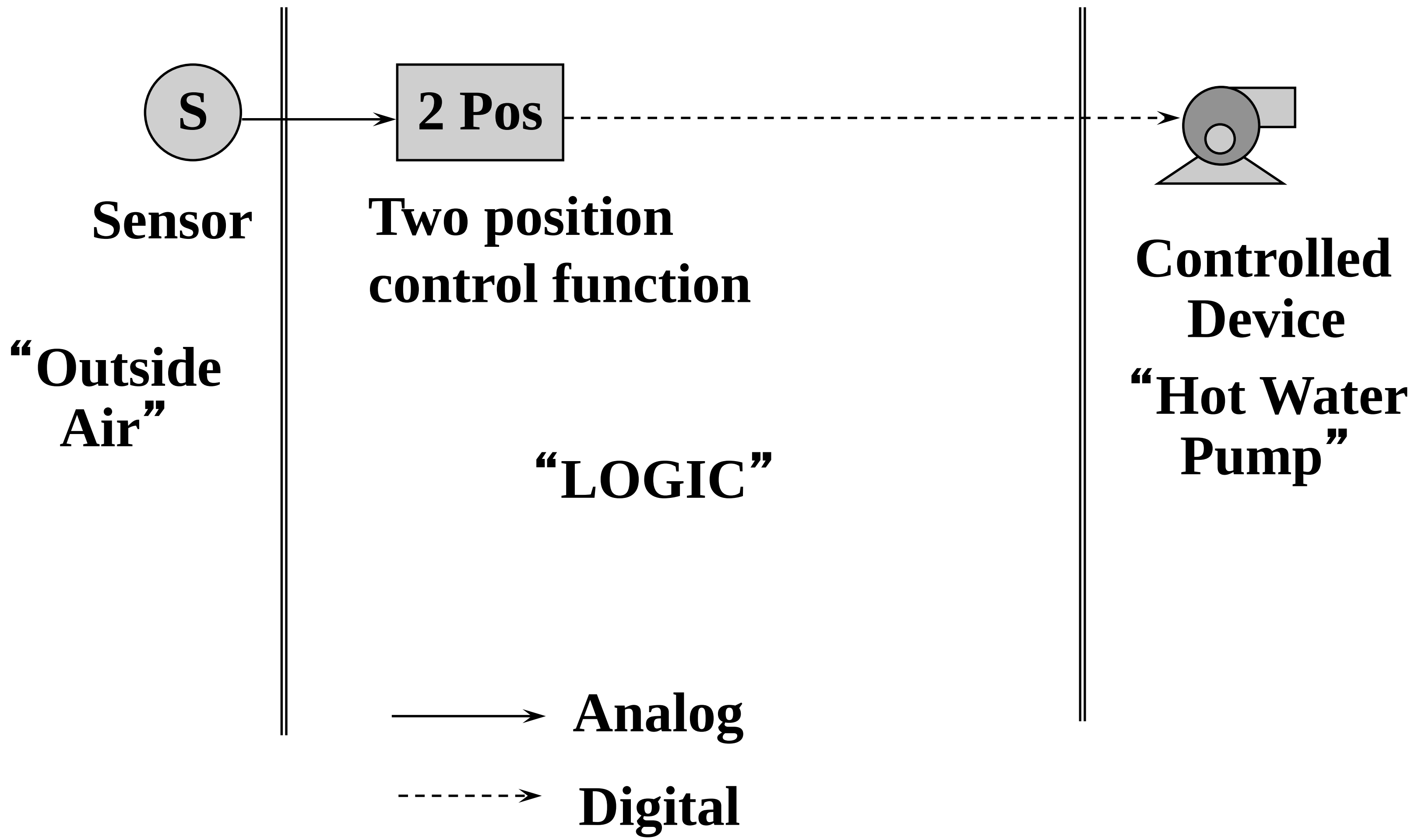
Desired Performance
Enable at 60 F, Disable at 65 F.



Setpoint may be defined as 62.5 F. with 5 F. differential

OA Temperature

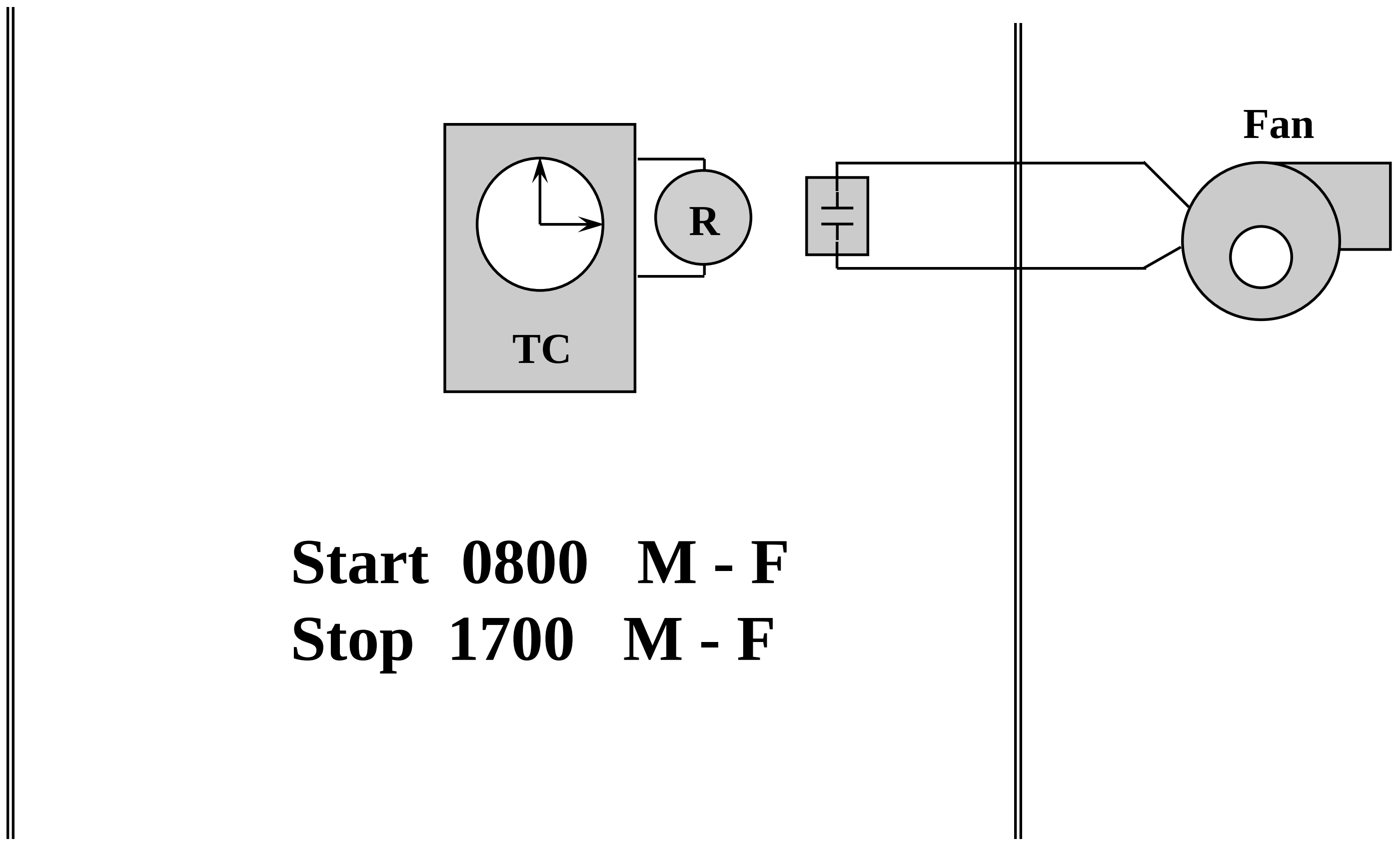
Two Position - Logic



Setpoint / Differential

- Setpoint
  - May be defined as middle, top or bottom of differential
  - Be careful!
- Differential
  - If the input changes quickly the differential will be larger
  - Important for stability.

Two Position - Time Based

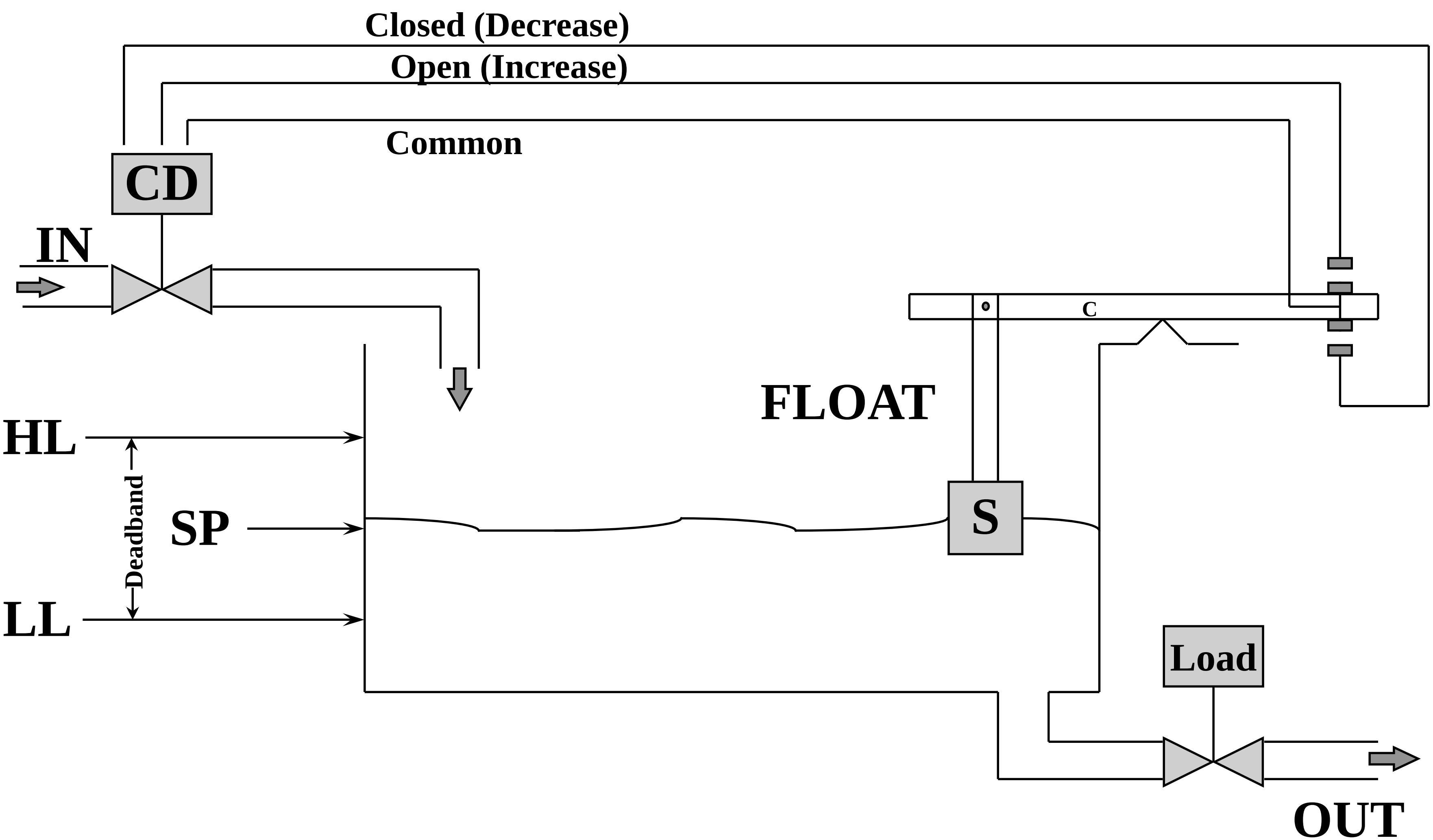


Start 0800 M - F
Stop 1700 M - F

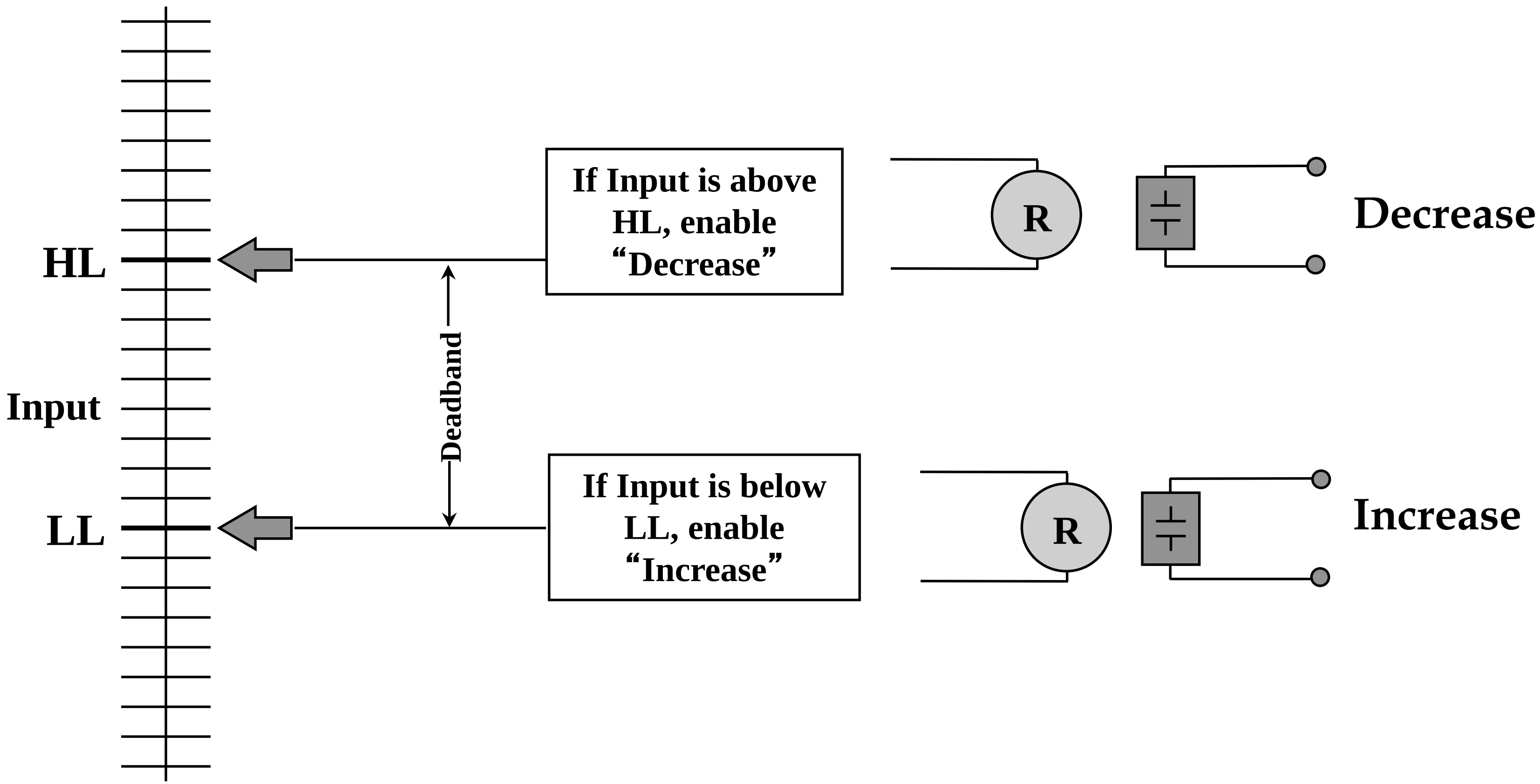
Floating Control

- Two Digital (Two position) Outputs
  - Increase
  - Decrease
- Variable Input
- Upper Limit and Lower Limit
  - Change of outputs based on analog input crossing limits
  - There is no standard for defining these limits
  - Setpoint and "deadband" establish limits
- Applications
  - Primary Control Loop (i.e. static pressure control)
  - Fast Control Loops

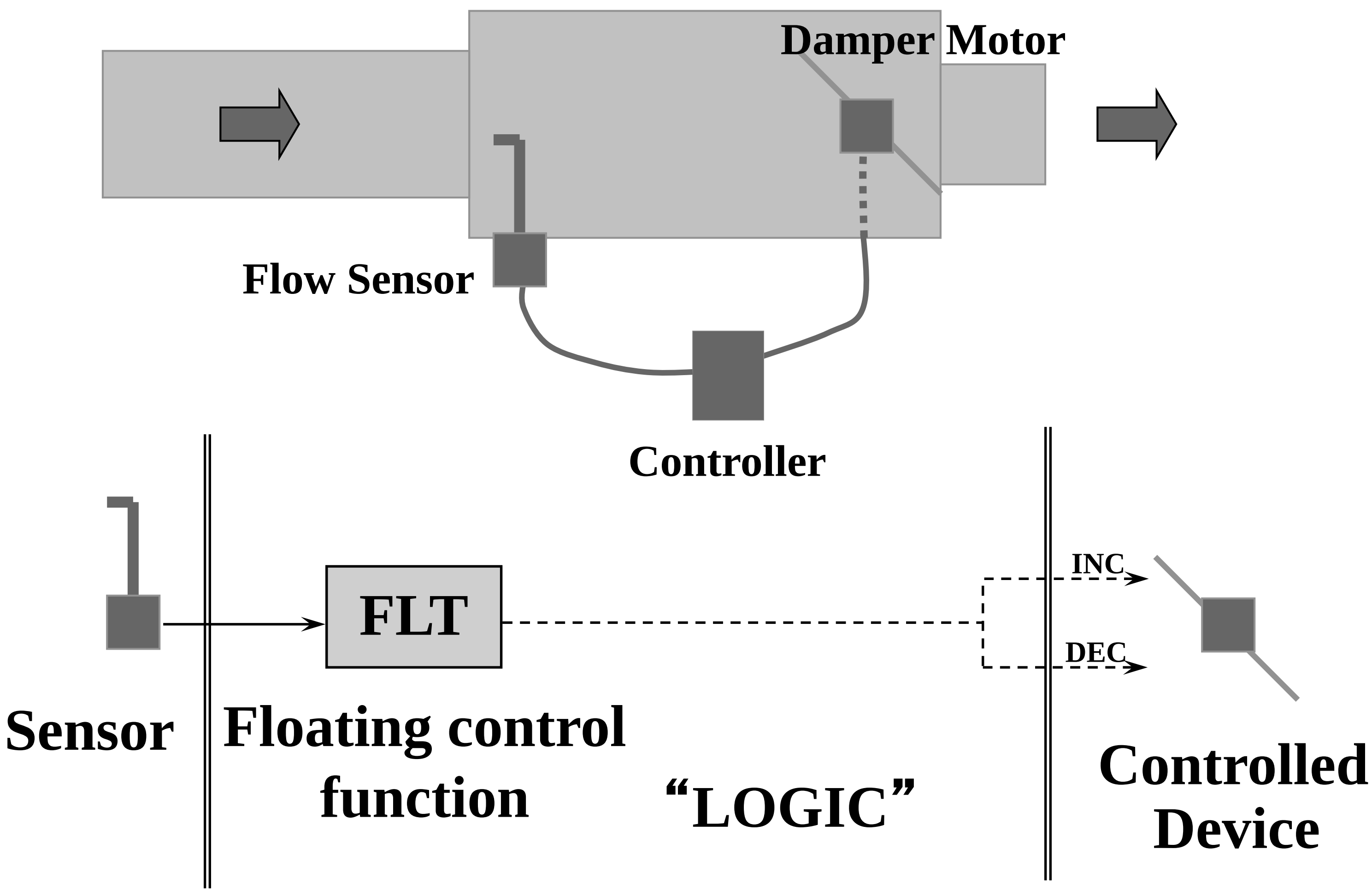
Floating Control



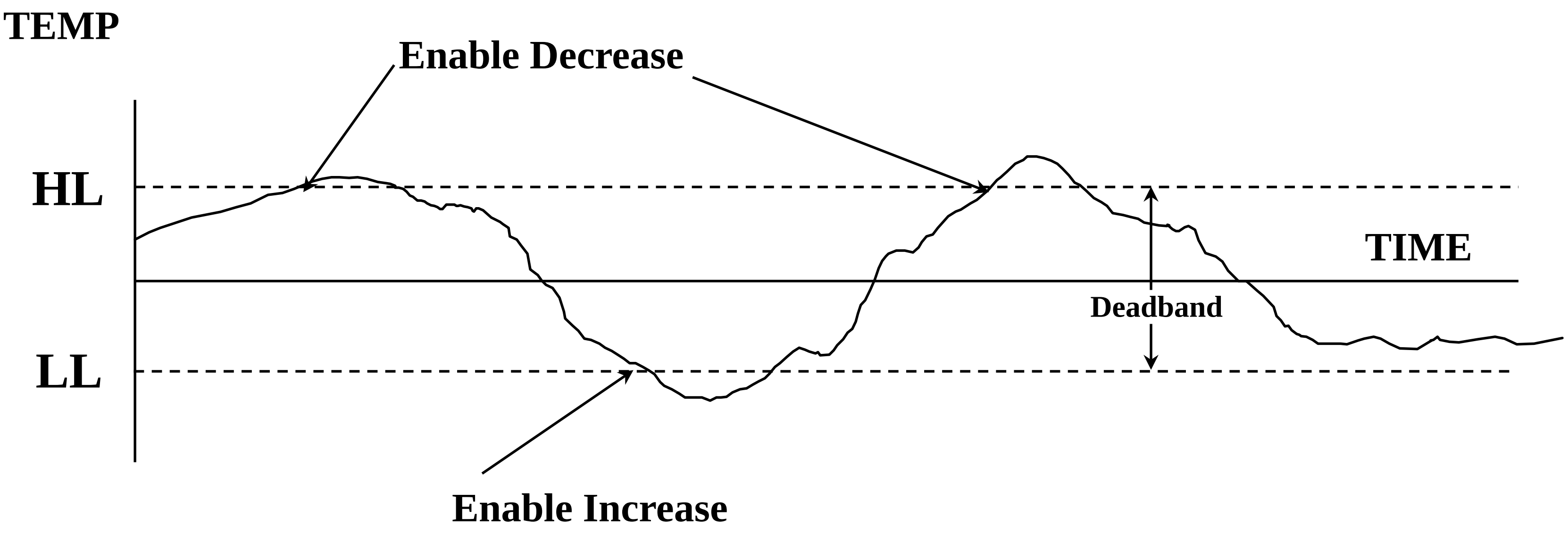
Floating Control



Floating Control



Floating Control

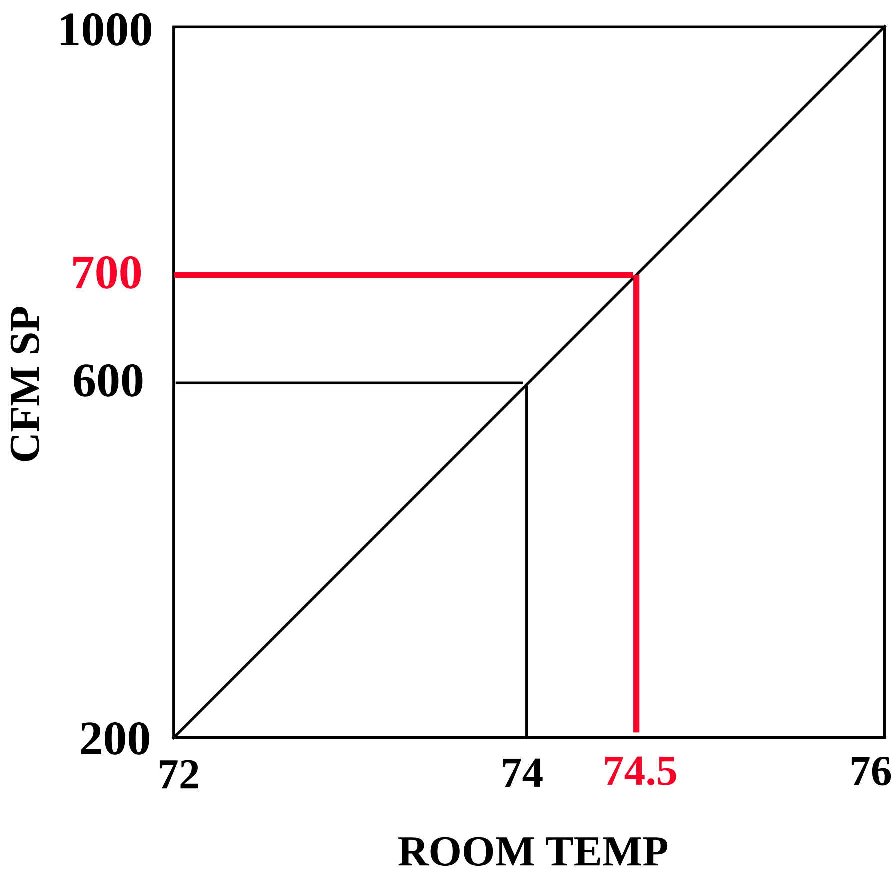


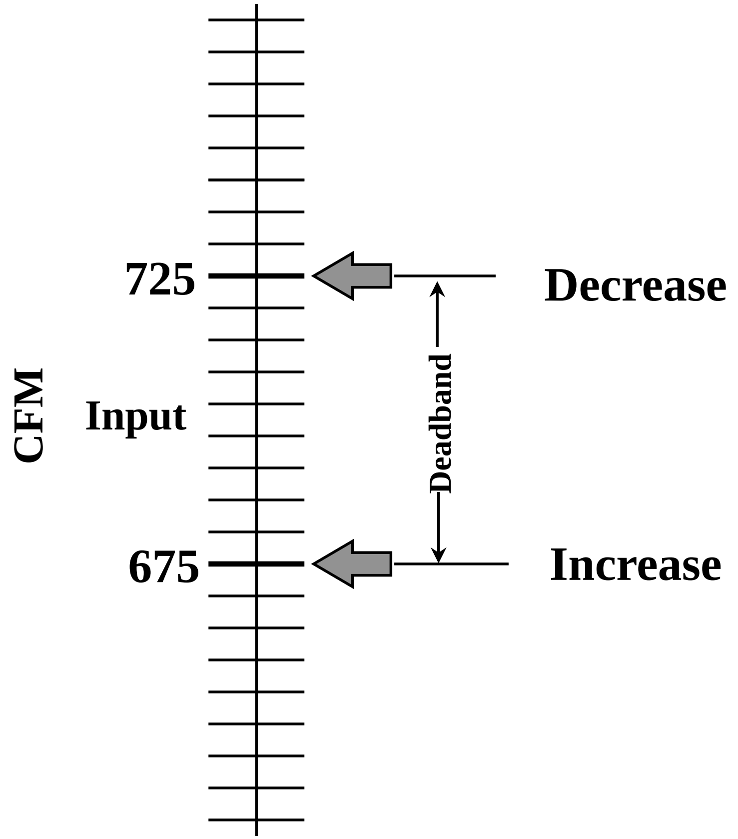
Floating Control

- In true floating control there is a deadband or neutral zone, defined by a high and a low limit.
- As long as the sensor is in this neutral zone, there will not be any activity by the controlled device. It will remain stationary.
- For floating control to be stable, the sensor must sense the effect of the controlled device movement very rapidly.
- Floating control does not function well where thermodynamic lag exists.
- Fast airside control loops respond well to true floating control.

Floating Control Example

VAV Terminal Unit Control

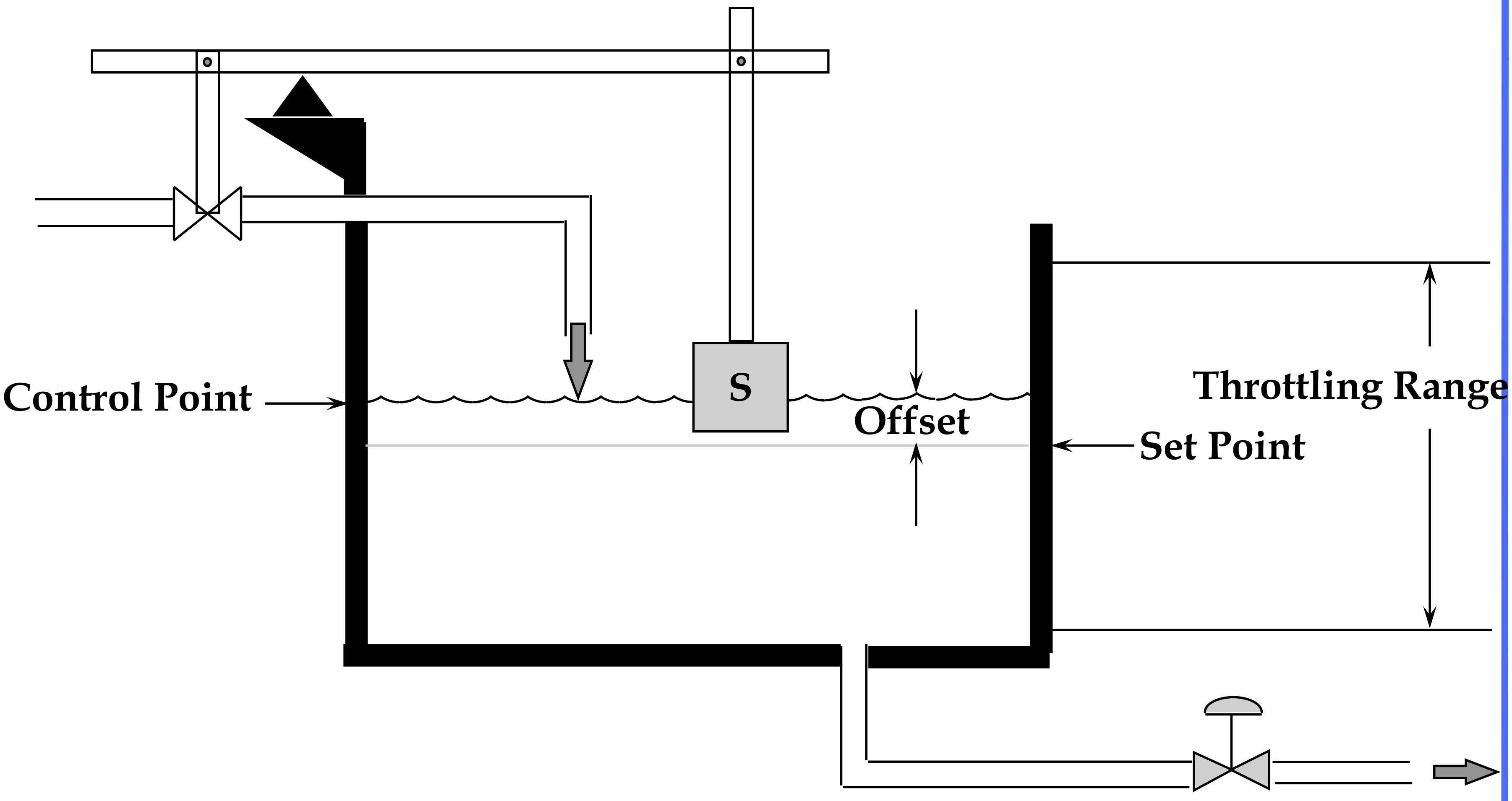




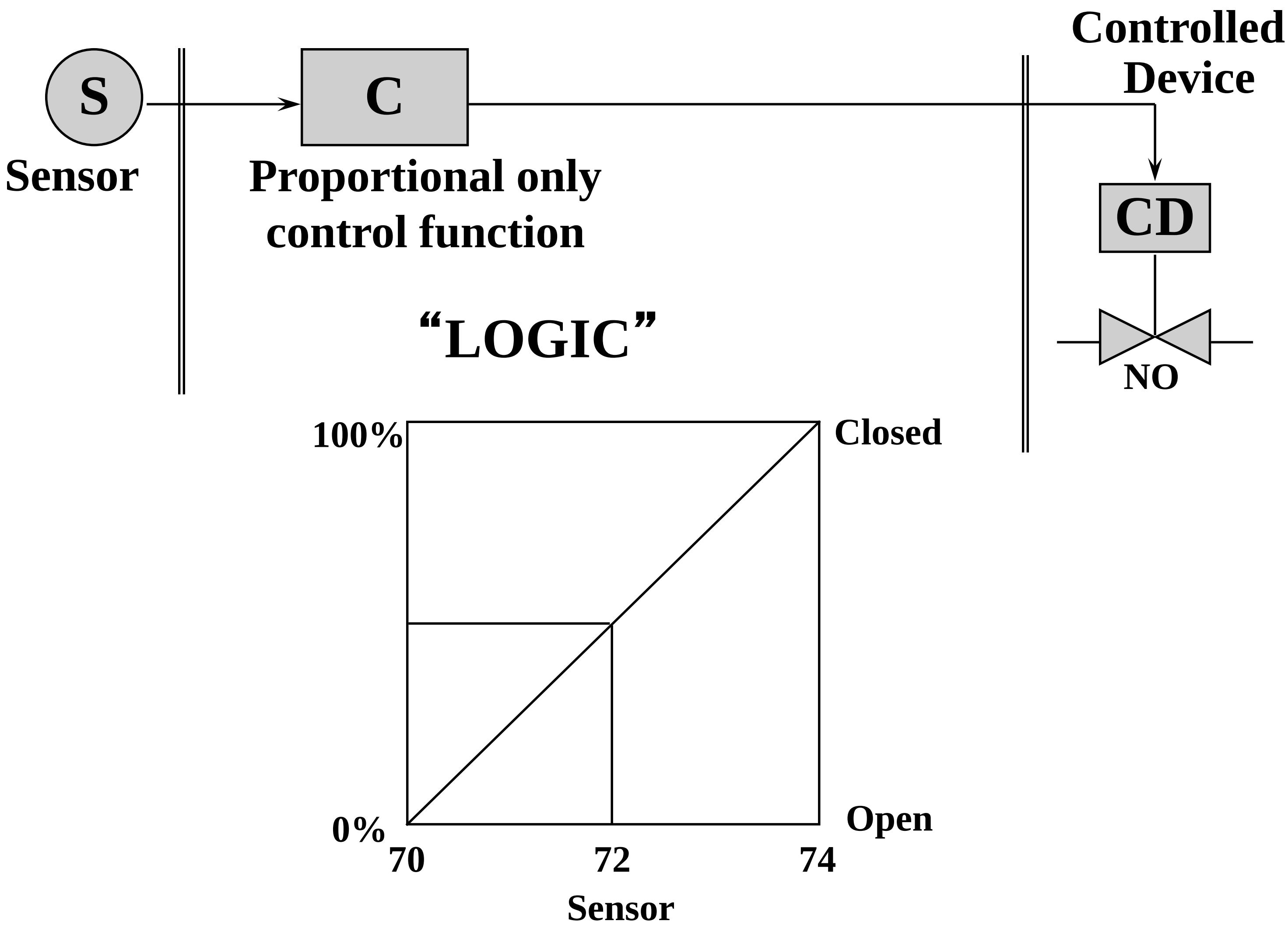
Proportional Control

- Analog Output
- Variable Input
- Linear Relationship between input and output
  - Typically defined by setpoint and throttling range
  - Action defines slope of linear relationship
    - Direct Acting: Increase in control variable causes increase in output
    - Reverse Acting: Increase in control variable causes decrease in output
- Applications
  - Primary Control Loop
  - Moderate to slow control loops

Proportional Control



Proportional Control



Proportional Control

- There is a unique value of the controlled variable that corresponds to full travel (100%) of the controlled device.
- There is a unique value of the controlled variable that corresponds to zero travel (0%) of the controlled device.
- The change in the controlled variable which causes the controlled device to move from fully open to fully closed is called throttling range.
- It is within this range of values that the control loop will control, provided the system has the capacity to meet the requirements.

Proportional Control

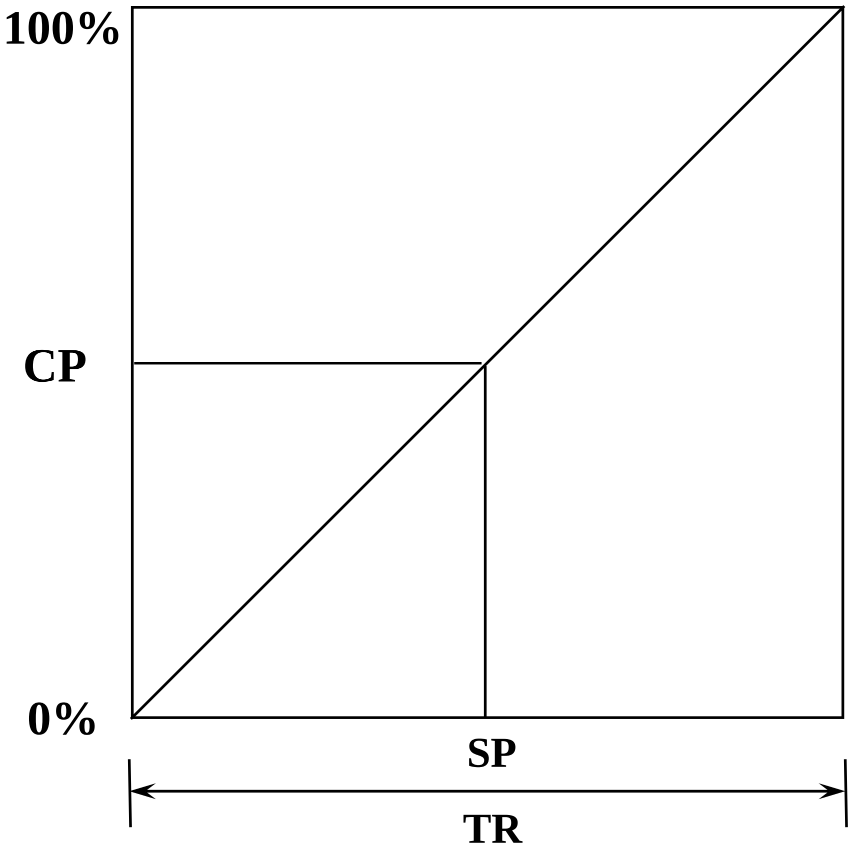
- The more dynamic (subject to rapid change) the controlling variable is, the larger the throttling range must be for stable control.
- Stable control is where the controlled device is periodically repositioned but it is not constantly in motion.
- In closed loop proportional control the desired condition of the controlled variable corresponds to half travel (50%) of the controlled device.
- In closed loop control, the controlled variable will vary within the throttling range. Its value at any given moment is called the <u>control point</u>.

Proportional Control

- **The difference between the control point and the desired condition of the controlled variable is called <u>offset</u> (error). The offset will vary from plus 1/2 throttling range to minus 1/2 throttling range from the desired condition.**
- **In closed loop proportional control, reducing the size of the throttling range to reduce offset (tighter control) may cause the control loop to become unstable.**
- **Instability is represented by a controlled device that is always in motion ("hunting").**

Proportional Control

- Proportional Control
  - Setpoint
  - Calibration Point
  - Throttling Range
  - Action



Proportional Control "Only"

$$y = mx + b$$

$$y = \%Travel$$

$$m = Slope = \frac{Rise}{Run} = \frac{\%Travel}{Temp} = \frac{100\%}{TR}$$

$$x = Error\ or\ (T - SP)$$

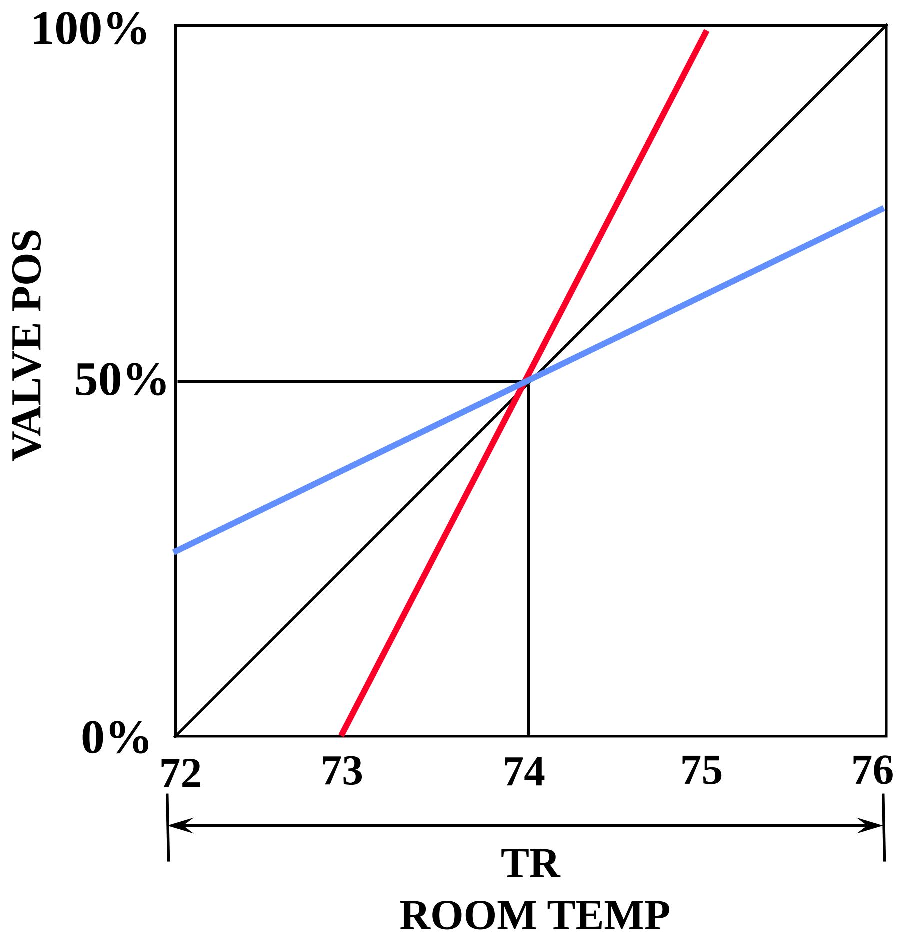
$$b = CP$$

$$\%Travel = CP + \frac{(T - SP)}{TR} \times 100\%$$

$$SLOPE = \frac{100\%}{TR} = Proportional\ Gain\ (PG)$$

$$PG = \frac{\%Travel}{{}^{o}F.}$$

Proportional Gain Example



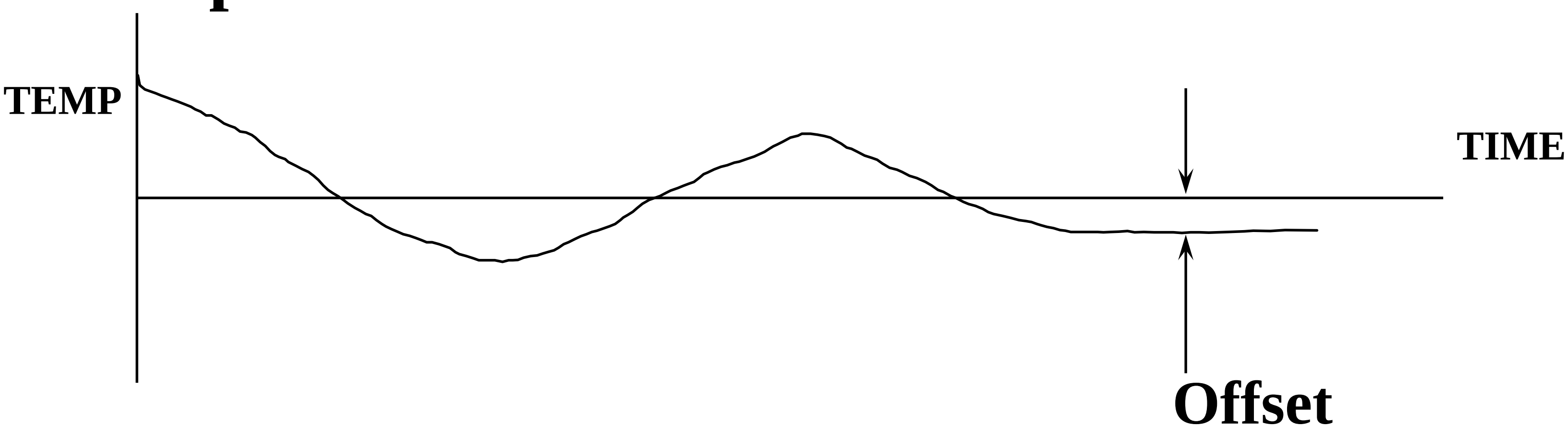
PG = 100/4 = 25%/F

PG = 100/2 = 50%/F

PG = 100/8 =12.5%/F

Proportional Control

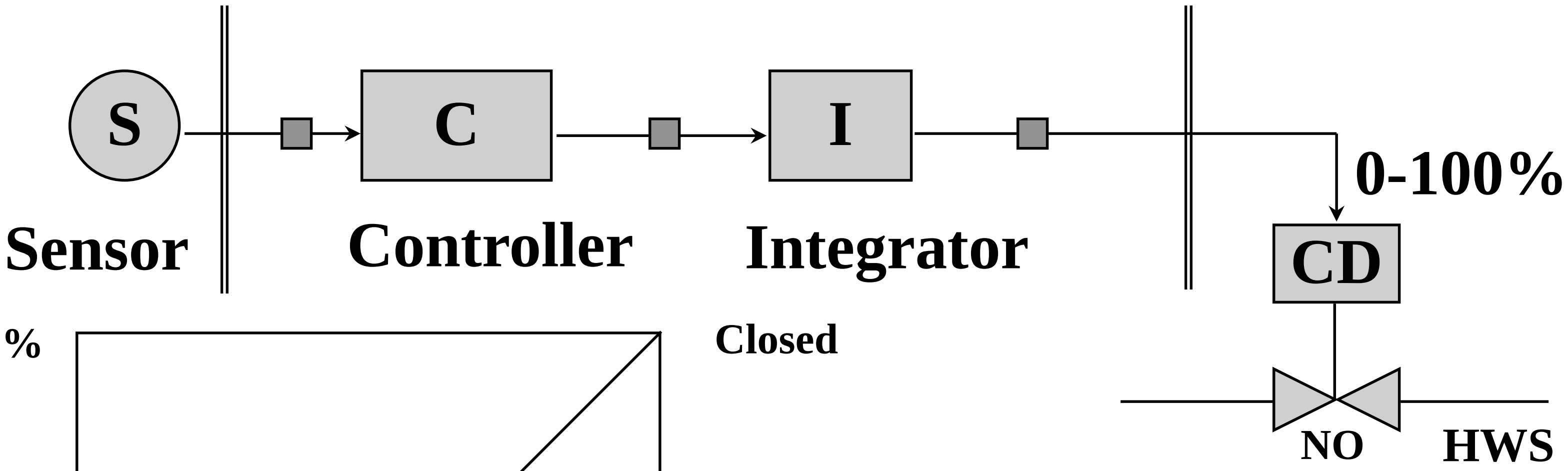
- The more quickly the sensor feels the effect of controlled device movement, the larger the throttling range must be to produce stable control.
- To obtain both stable control and very small offsets, proportional plus integral (PI) control loops must be used.

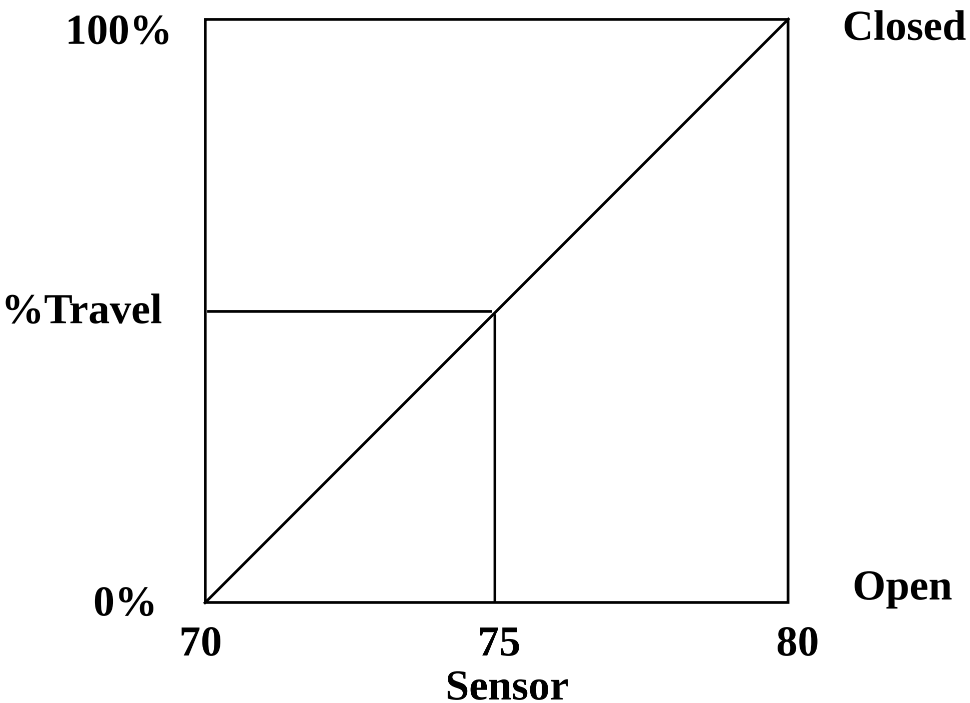


Proportional Integral Control (PI)

- **Analog Output**
- **Variable Input**
- **Modification to Proportional Control Response**
  - **Offset is measured over time**
- **Applications**
  - **Moderately fast control loops such as mixed air dampers, central station coils controlled by discharge air temperature.**
- **Control Objective**
  - **To have stable control with minimum offset**

Proportional Plus Integral





Desired condition is 75 ºF.

The throttling range is 10 ºF.

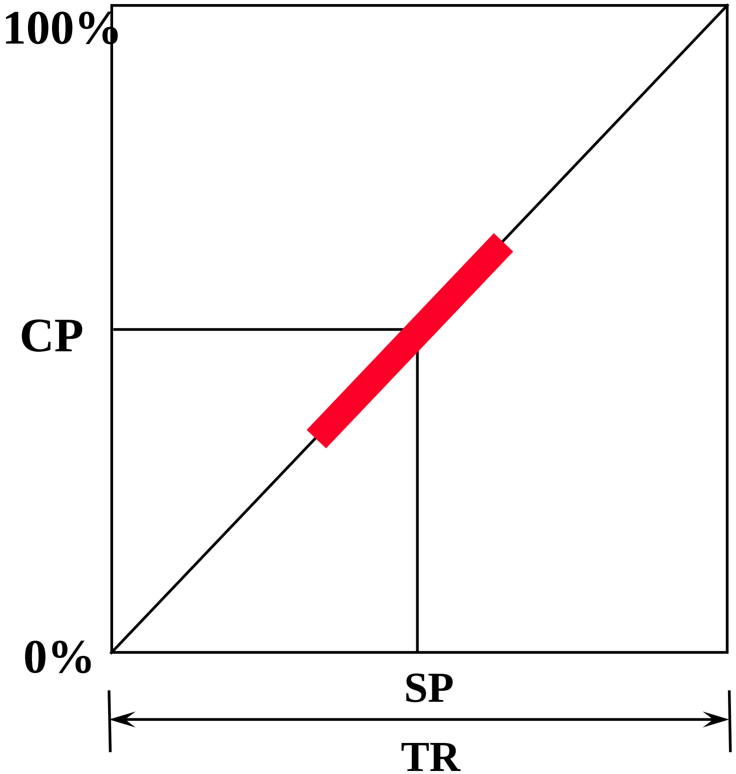
The integrator is programmed to look for 50% which corresponds to the desired condition of 75 ºF.

Proportional Plus Integral

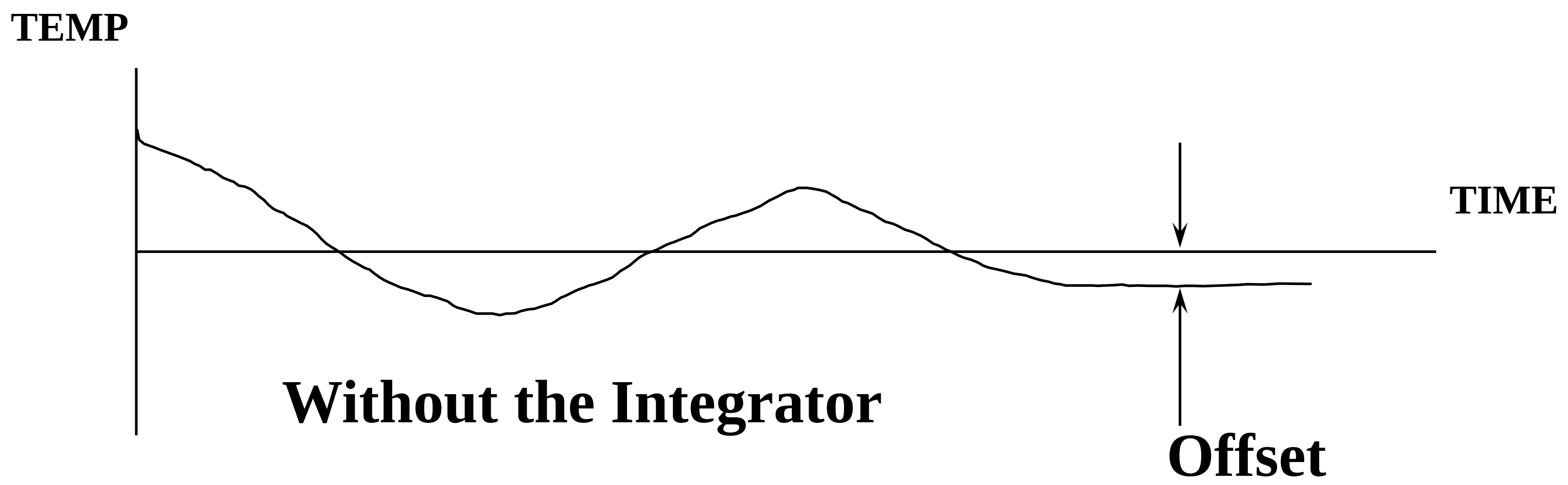
- If the integrator receives a value of 60%, it recognizes that the temperature is too high.
- It will increase the control signal to 70% (example only) to close the heating valve an extra 10%.
  - The amount of the increase will depend on the integral time constant that is programmed.
- This will put less heat into the system and cause the temperature to drop moving the system toward set point.

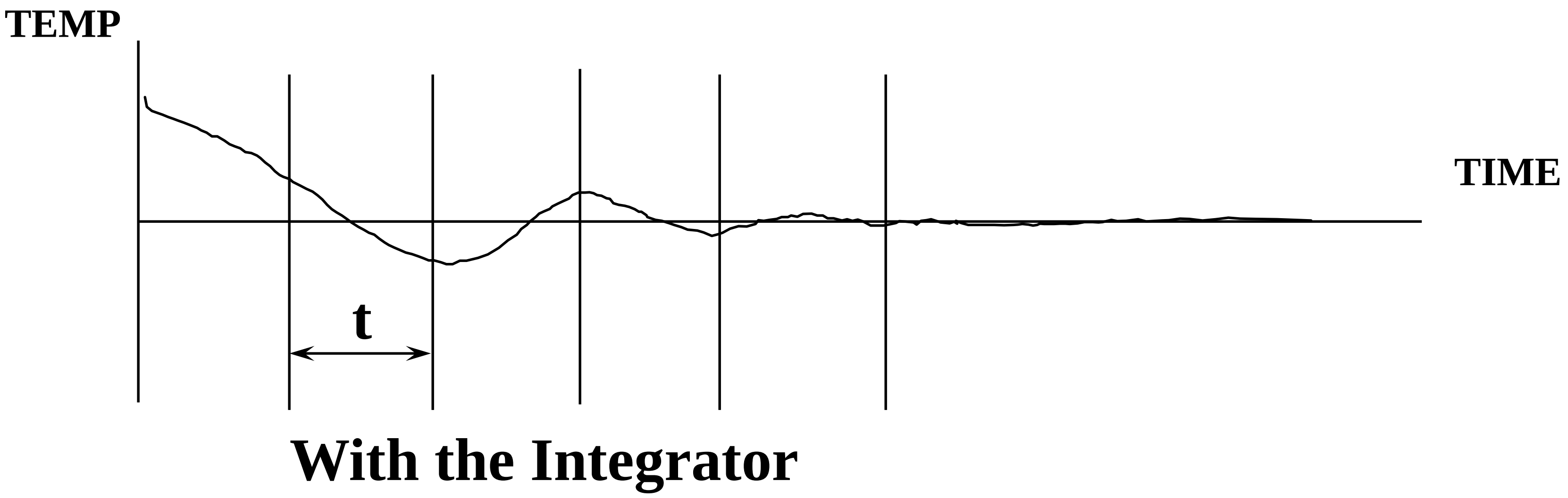
PI Control

- A good PI loop will operate in a narrow band close to the setpoint.
- It will not use the entire throttling range.
- PI control loops do not perform well when:
  - Setpoints are dynamic
  - Sudden large load changes occur
  - The throttling range is very small



Proportional Plus Integral





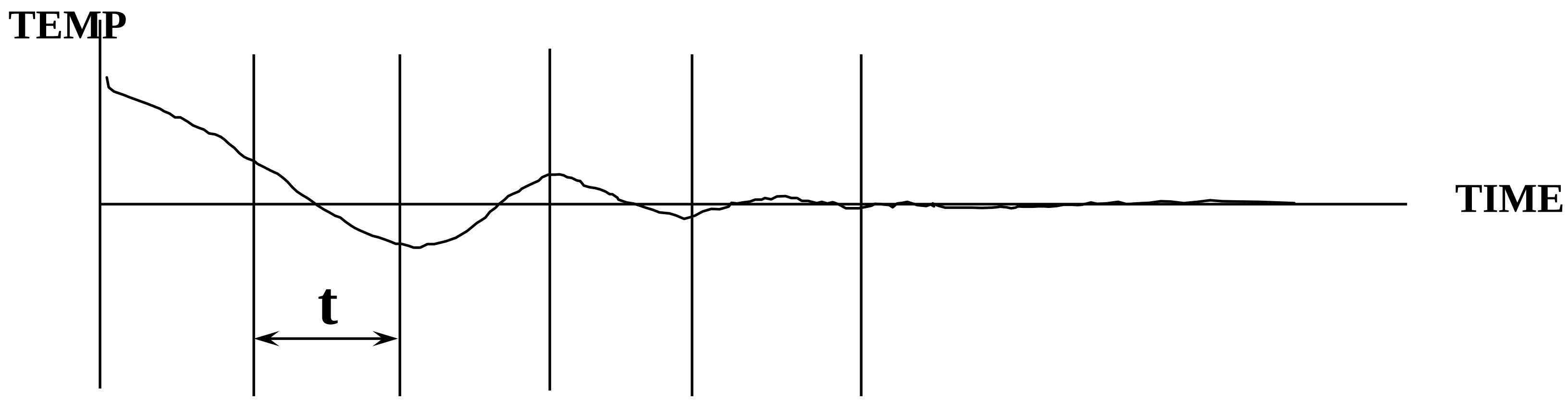
Proportional Integral Derivative Control (PID)

- Analog Output
- Variable Input
- Modification to Proportional Integral Control Response
  - Adds "predictive" element to the control response
- Applications
  - Primary Control Loop
  - Need to return to set point quickly after a set point change or sudden change in load.

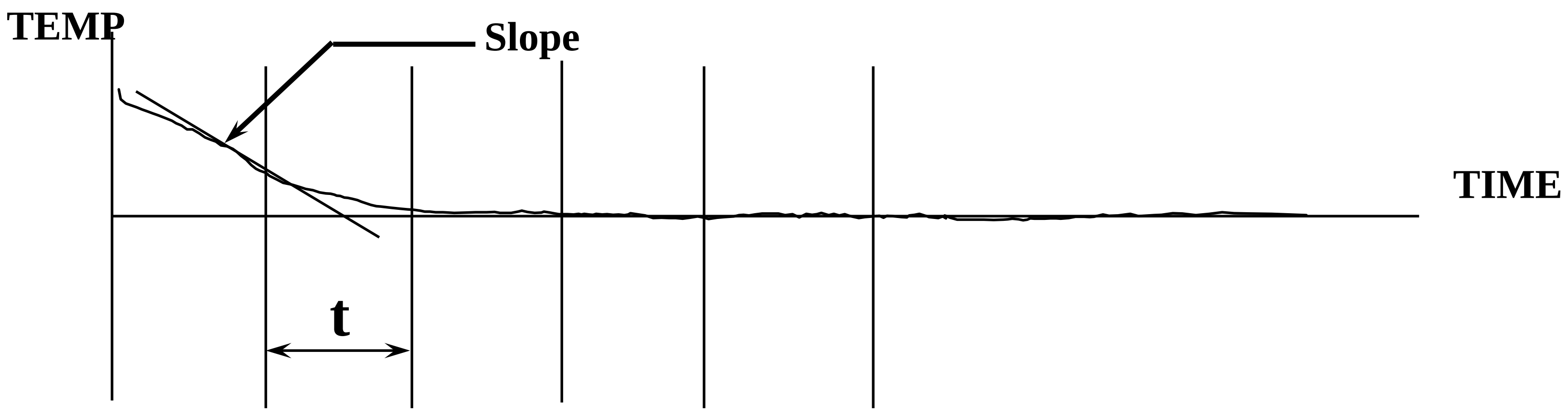
Proportional/Integral/Derivative

- PID is precision process control and not always required for HVAC applications.
- The routine application of PID to every control loop is labor intensive, can lead to instability with non-linear controlled devices and may increase energy costs.
- Its application should be selective.
  - P or PI does not provide adequate control
- Many facility managers and engineers have been oversold on the benefits of PID.

Proportional/Integral/Derivative



With the Integrator



With the Integrator and Derivative

PID Control Model

- **Proportional Only**

$$\%\text{Travel} = \text{CP} + \underbrace{[\text{PG} \times \text{E}]}_{\textbf{P Term}} + \underbrace{\cancelto{0}{\left[\text{IG}\int \text{Edt}\right]}}_{\textbf{I Term}} + \underbrace{\cancelto{0}{\text{DG} \times \frac{\text{dE}}{\text{dt}}}}_{\textbf{D Term}}$$

$$\text{CP} = \text{Calibration Point}$$

$$\text{PG} = \text{Proportional Gain}$$

$$\text{E} = \text{Error}$$

$$\text{IG} = \text{Integral Gain}$$

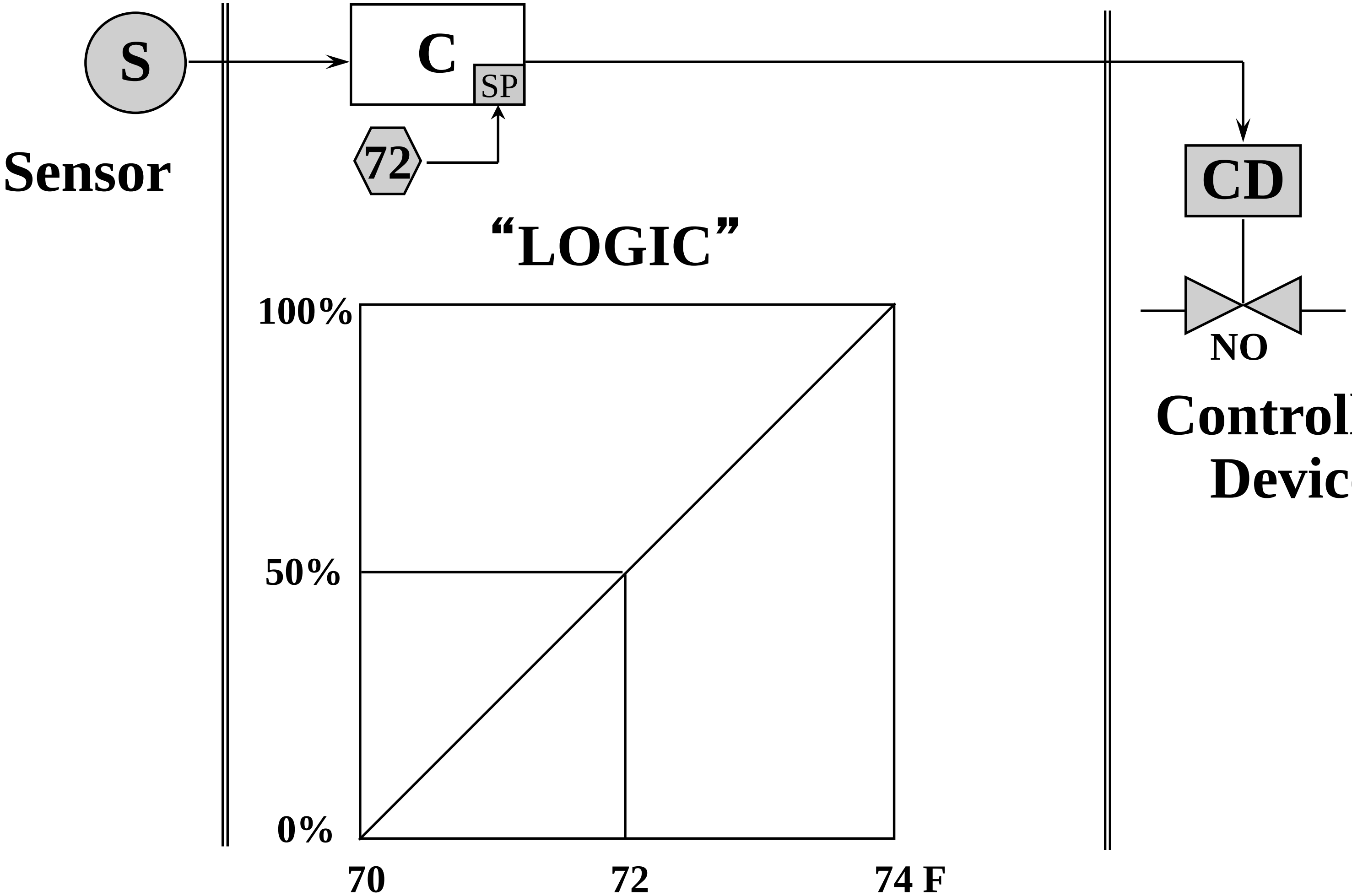
$$\text{DG} = \text{Derivative Gain}$$

$$\%\text{Travel} = \text{P} + \text{I} + \text{D}$$

Setpoints

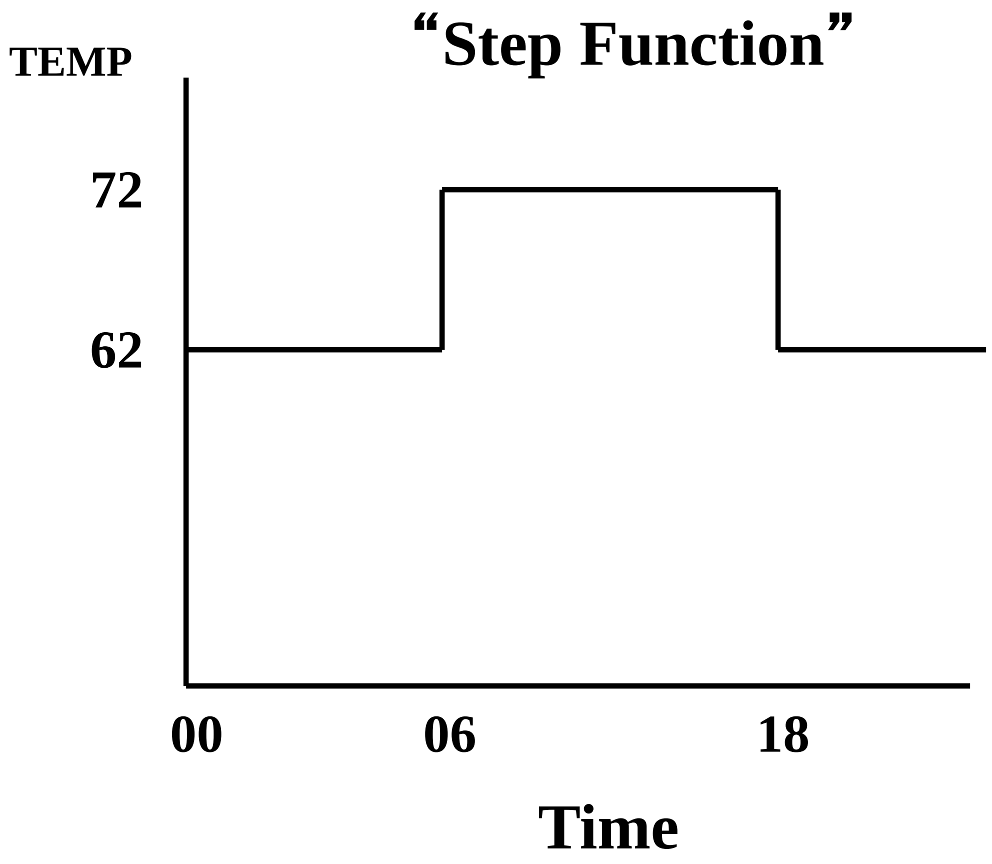
- The purpose of the controller is to compare the input variable with a setpoint (or time schedule) and produce a control signal.
- What is the value of the setpoint and does it remain constant?
- Options
  - Control Loop w/ fixed set point
  - Control Loop w/ variable set point
    - Set point Table
    - Set point Schedule

Loop With Fixed Setpoint

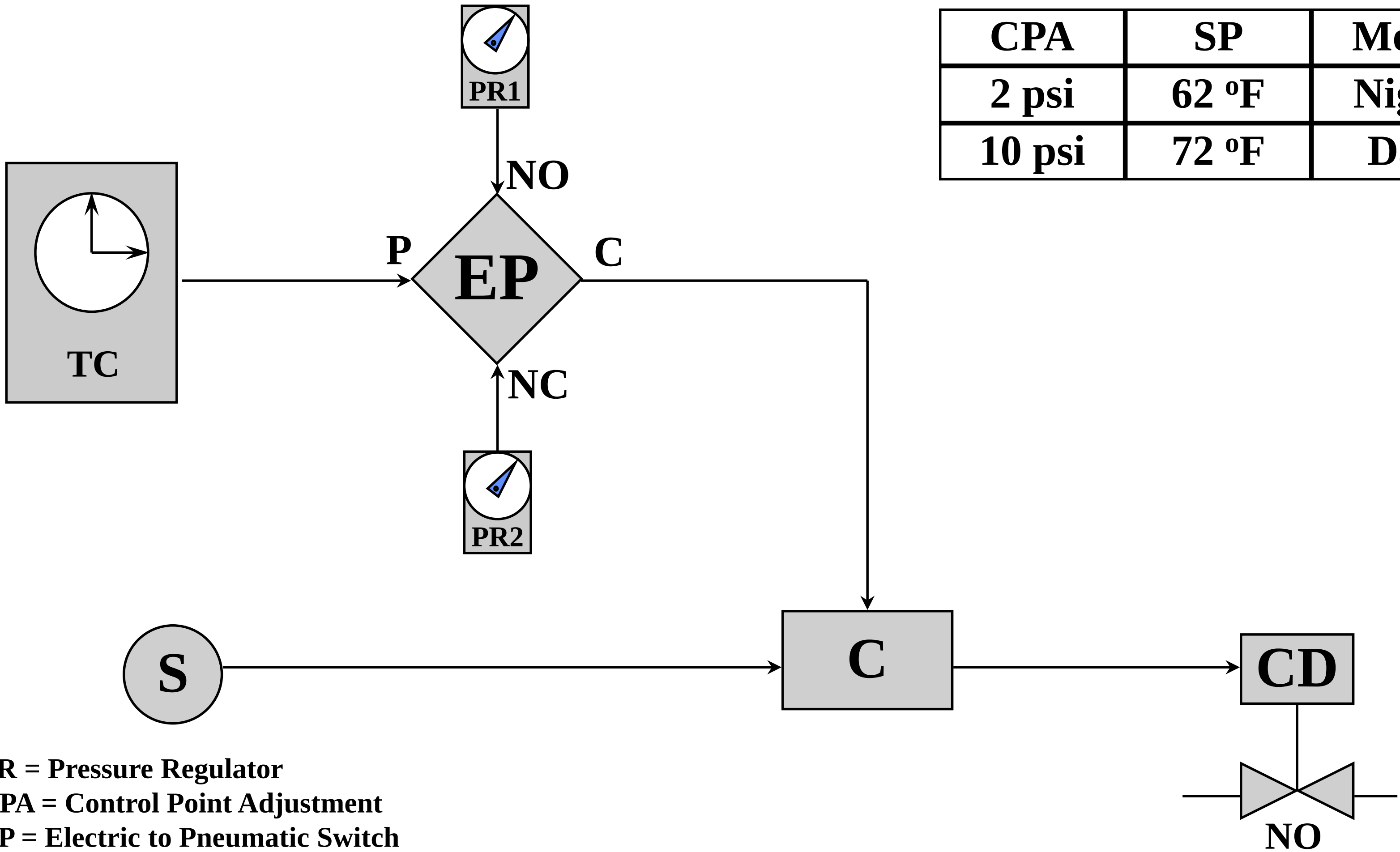


Variable Set Point - Table

Time	SP
Day	72 ºF
Night	62 ºF



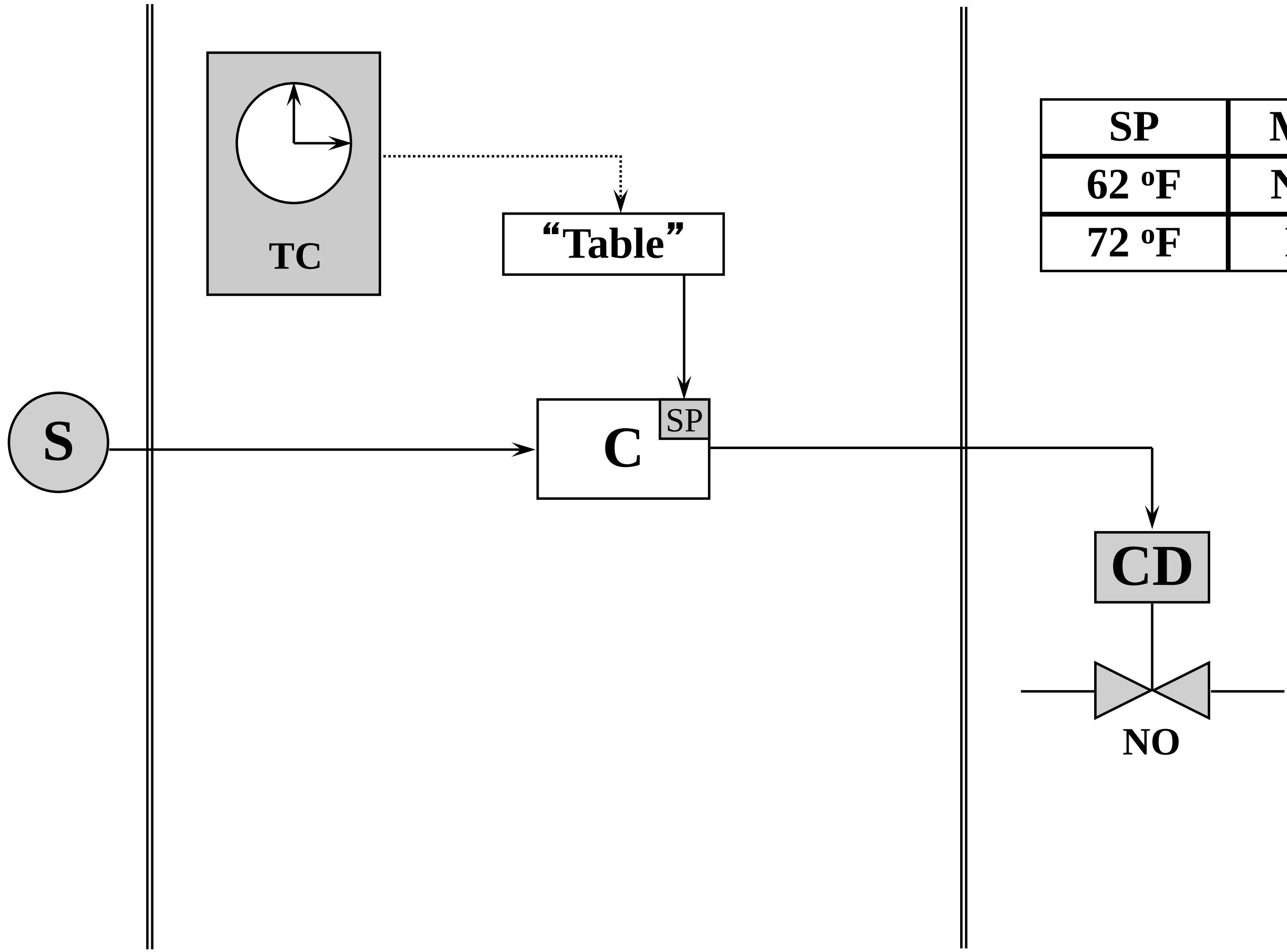
Set Point Table - Pneumatic



CPA	SP	Mode
2 psi	62 ºF	Night
10 psi	72 ºF	Day

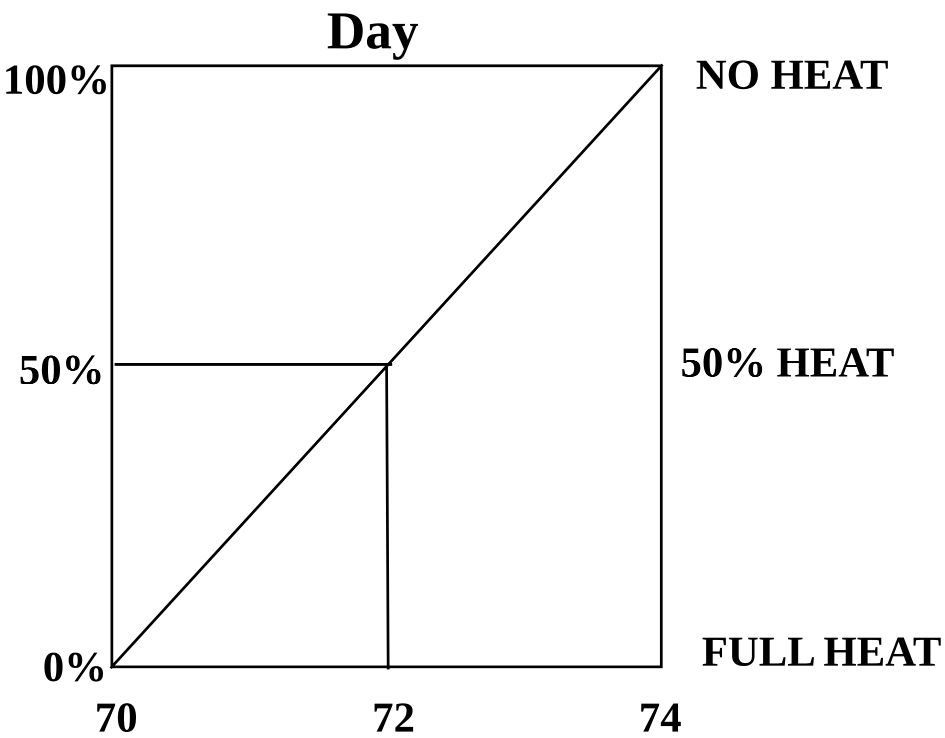
PR = Pressure Regulator
CPA = Control Point Adjustment
EP = Electric to Pneumatic Switch

Set Point Table - DDC

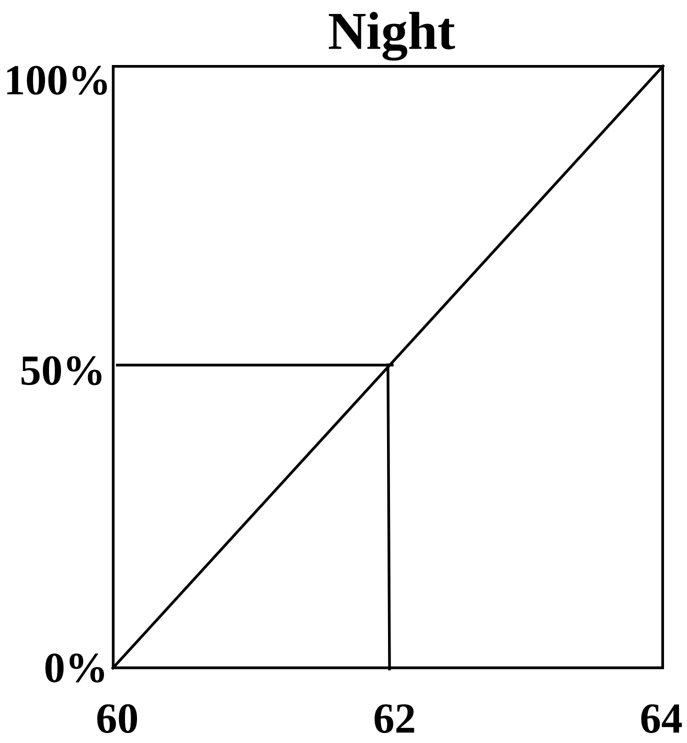


SP	Mode
62 ºF	Night
72 ºF	Day

Day - Night



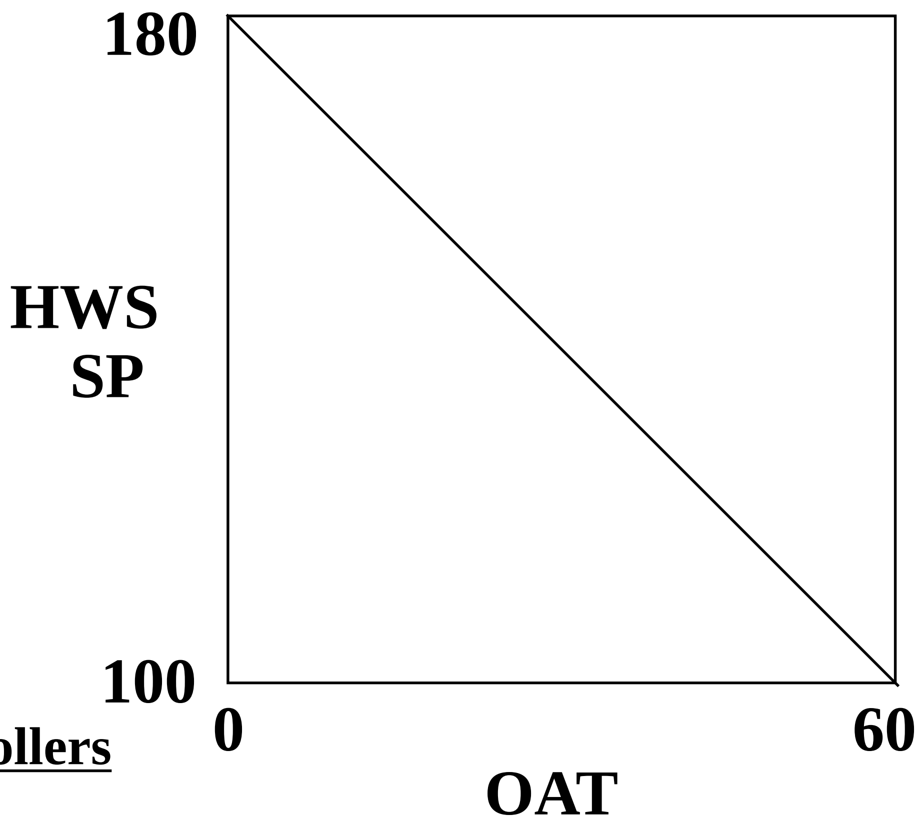
Day
100%
50%
0%
70
72
74
NO HEAT
50% HEAT
FULL HEAT



Night
100%
50%
0%
60
62
64

Variable Set Point - Schedule

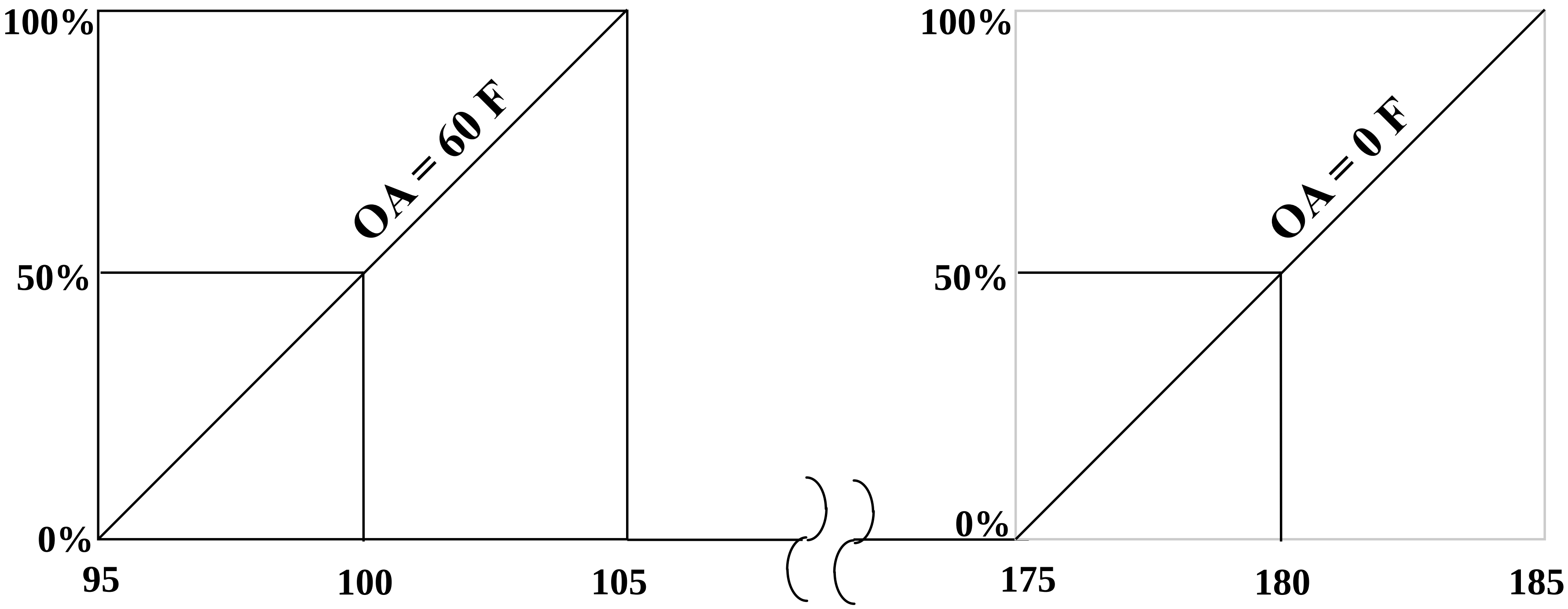
OA	HWS SP
0 ^{o}F	180 ^{o}F
60 ^{o}F	100 ^{o}F



<u>**Pneumatics – Dual Input Controllers**</u>

Two sensors

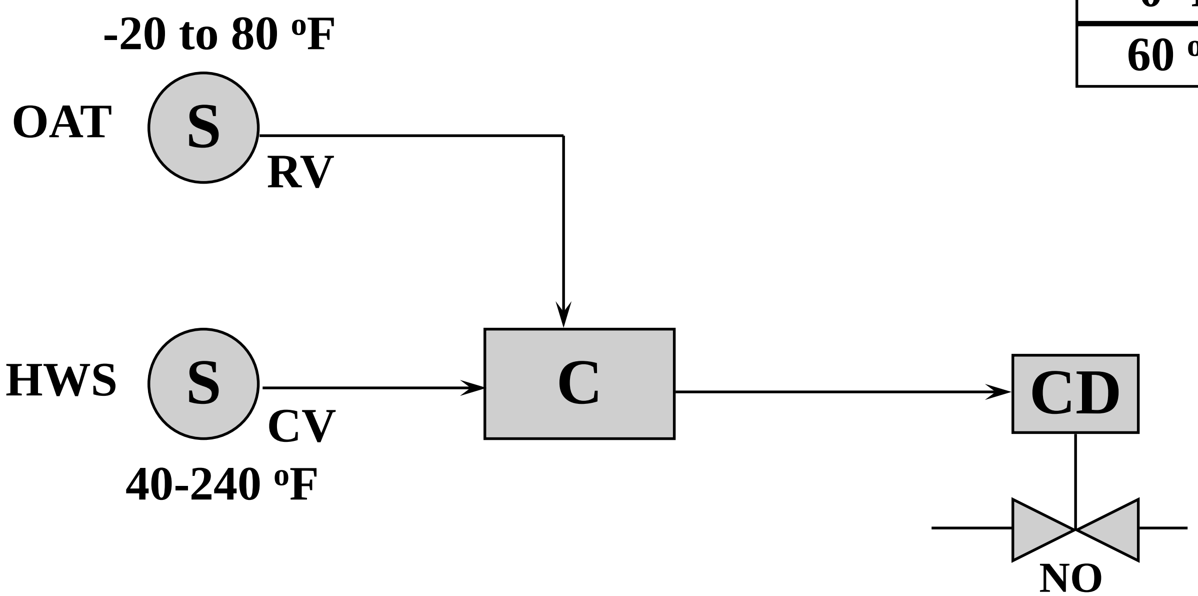
Variable Set Point - Schedule



Set Point Schedule - Pneumatic

Dual Input

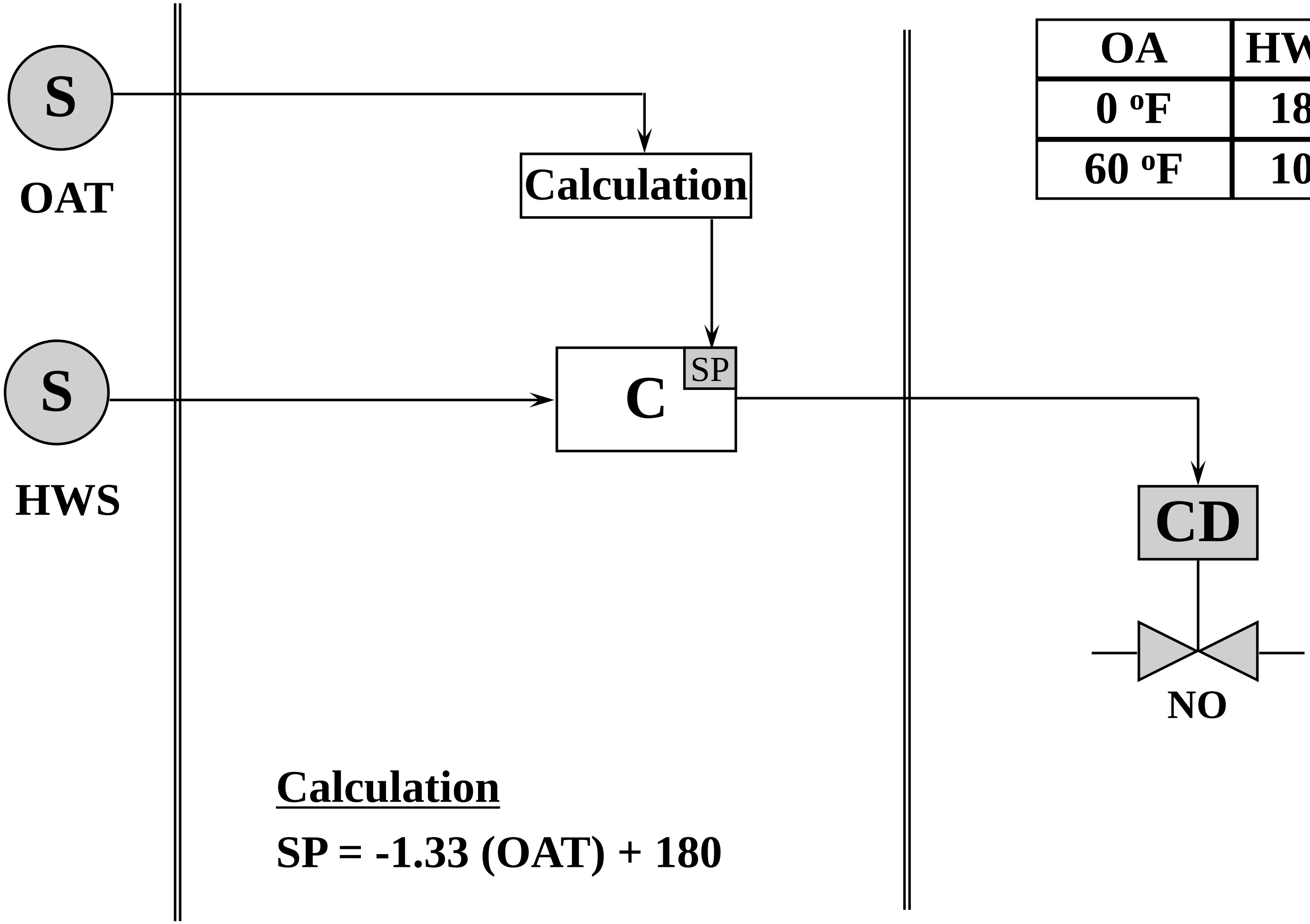
OA	HWS SP
0 ^oF	180 ^oF
60 ^oF	100 ^oF



RV: Reset Variable

CV: Control Variable

Set Point Schedule - DDC

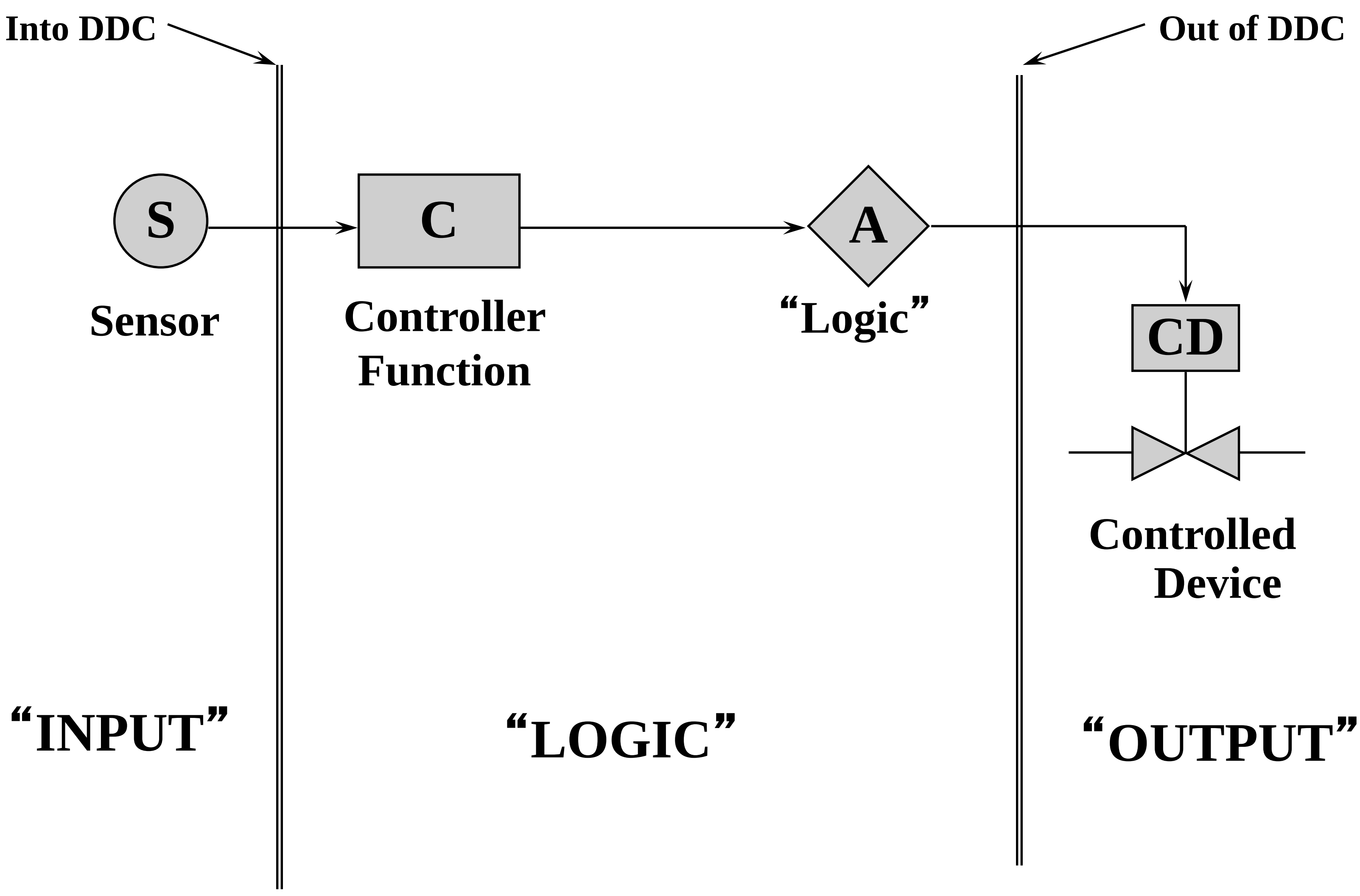


OA	HWS SP
0 ºF	180 ºF
60 ºF	100 ºF

Calculation

SP = -1.33 (OAT) + 180

Other Software Logic



Other Logic

- Software “modules” in DDC perform this same function
- From Pneumatics
  - Adapters are hardware components that perform well defined simple functions used to create specific control strategies.
  - Other terms used to describe adapters include:
    - Relays
    - Cumulators
- Symbols will be assigned to these “functions” in Programming Tools discussion

Typical Adapters (Pneumatic)

- Minimum Position
- Signal Averaging
- Input/Output Ratio
- High Signal Selector
- Square Root Extractor
- Maximum Position
- Signal Reversing
- Switching
- Low Signal Selector

Typical Software Modules (DDC)

- Signal Averaging
- Input/Output Ratio
- High Signal Selector
- Low Signal Selector
- Math Functions
- Switching
- Latching
- Proof

The Controlled Device

- A Device that responds to the signal from the controller or adapter and changes the condition of the controlled medium or the state of the end device.
  - Valve Operators
  - Damper Operators
  - Electric Relay
    - Fans/Pumps
    - Compressors
  - Variable Speed Drives - Fans/Pumps

Types of Control - Pneumatics

- Mainstay of the commercial HVAC controls industry for decades
- Can support the most complex strategies
- Very strong actuation capabilities
- Applicable for use in difficult environments
- Maintaining a quality air supply has always been a liability
- Periodic labor intensive calibration is essential for accurate control

Types of Control - Direct Digital

- Microprocessor based with the controllers and most of the adapters replaced by software
- Analog sensors can be resistance, voltage, or current generators
- Most systems have distributed the software to remote controllers to eliminate the need for continuous communication capability (stand alone).
- The PC is primarily used to monitor status and store data and programs.
- Complex strategies and energy management readily available at the lowest level

Direct Digital Controls

- Pneumatic actuation accomplished with electronic to pneumatic transducers
- Calibration of sensors is mathematical
- Total man-hours for calibration - greatly reduced
- Central diagnostic capabilities are a significant asset
- Software and programming is becoming more user friendly with each update but a degree of computer literacy will always be required.
- Diverse skills required: HVAC Systems, HVAC Controls, electrical, computer, networking

Potential Benefits of DDC

- Effectiveness
  - Flexibility
  - Accuracy
  - System Performance Feedback
  - Integration
    - Third Party HVAC Equipment
    - Fire
    - Access Control Systems
    - Security Systems
    - Time Management Systems
    - Lighting Control Systems
    - Maintenance Management Systems

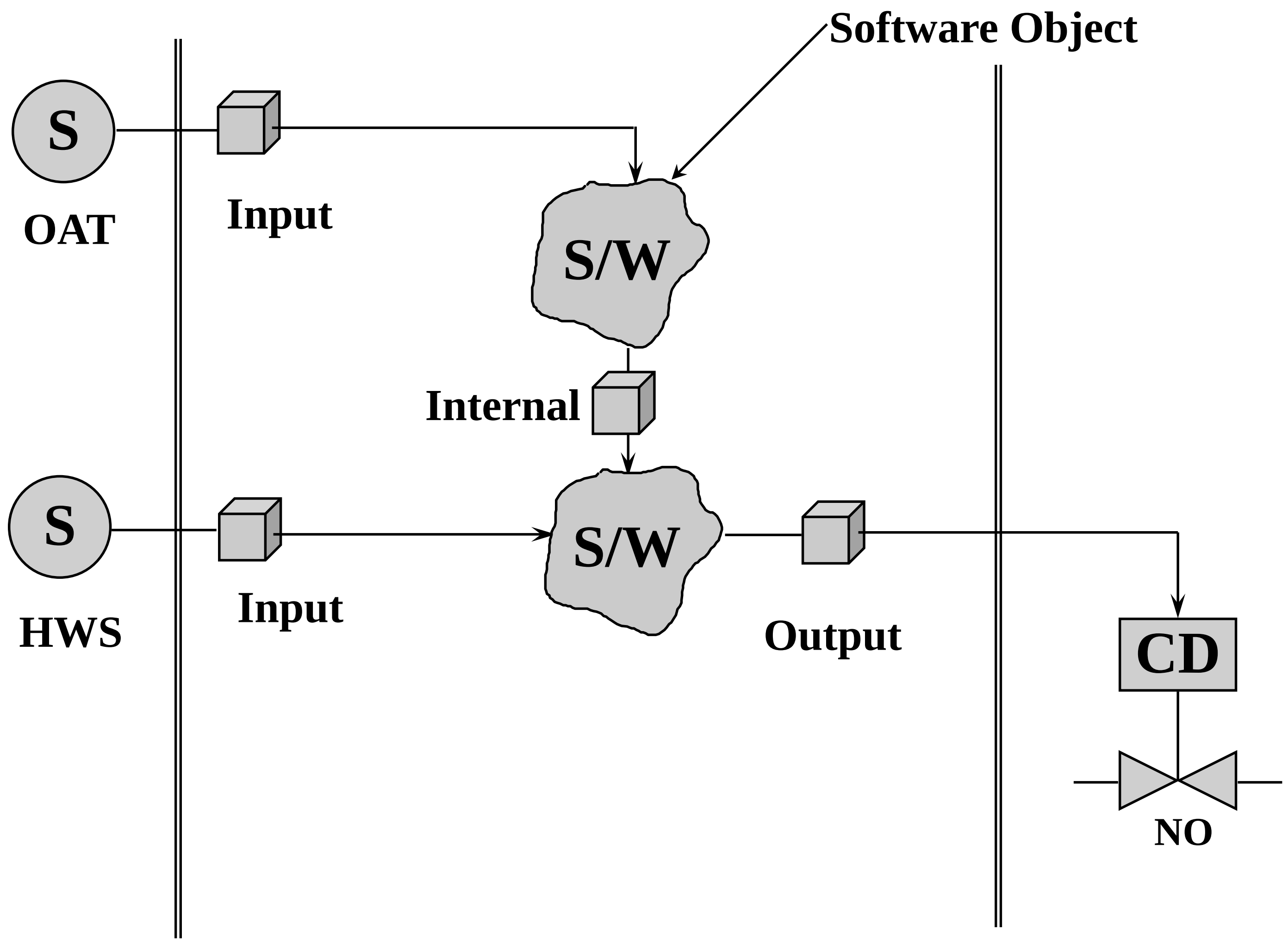
Potential Benefits of DDC

- Efficiency - Operations
  - Alarms
  - Centralized Data For Troubleshooting
  - Trending
  - Run - Time
  - Off - site access / communication (security issues)
  - Software based calibration of external devices
- Efficiency - Energy
  - Demand Monitoring and Control
  - Energy Consumption Monitoring
  - Central Scheduling of Equipment
  - Centralized data
  - More Complex Sequences

Points

- Data storage locations
  - Receive data from sensors or software
  - Send data to controlled devices or software
  - Store data internal to the program
- Input, Output or Internal
  - Input: Receive data from sensors
  - Output: Send data to controlled devices
  - Internal: Store data within the application program
- Type
  - Analog
  - Digital
  - Pulse

Point Software Concept



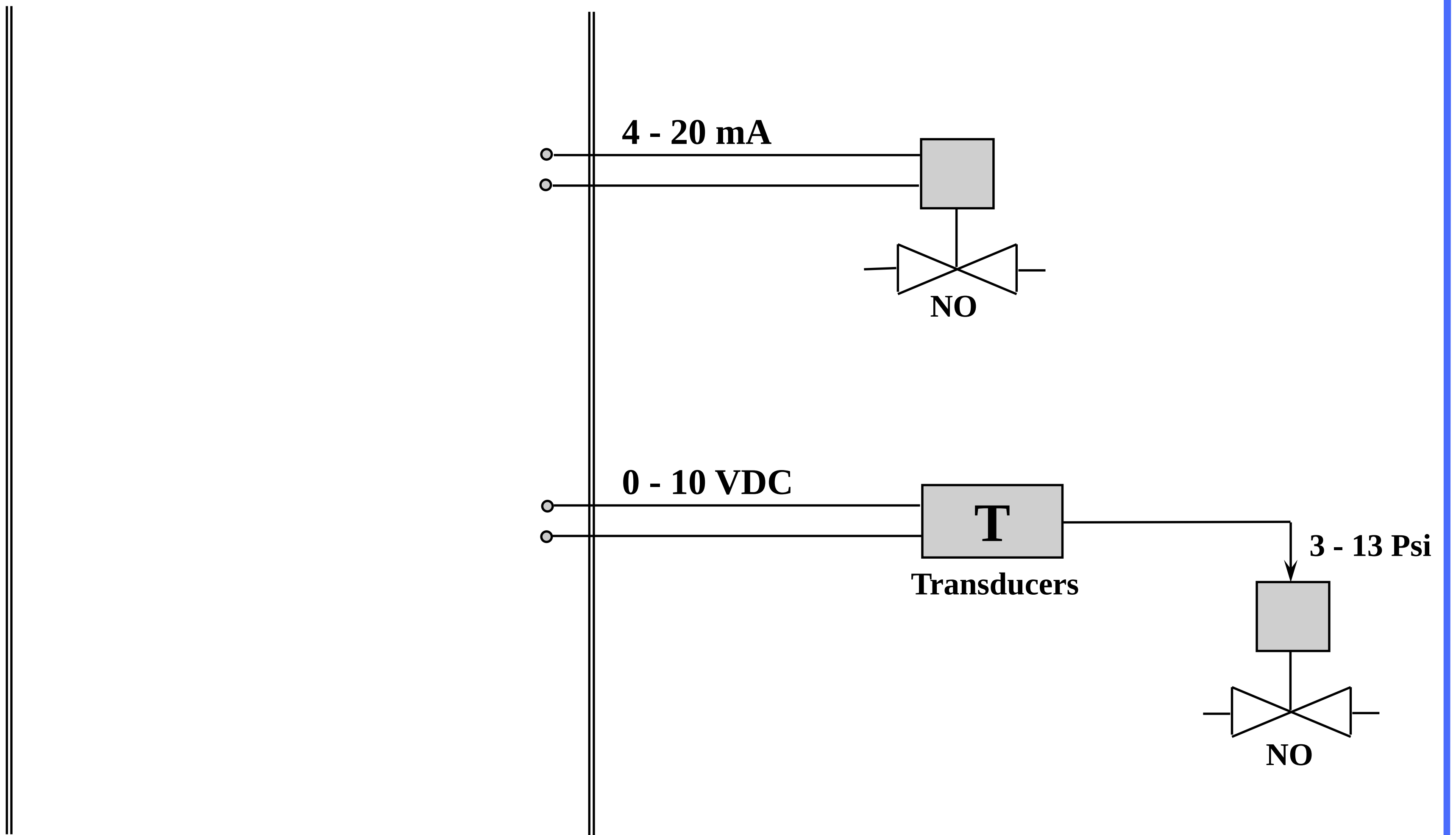
Inputs to DDC

- **<u>Analog Sensors (AI):</u> A varying input in DC Volts or milliamps or ohms converted to DC Volts, where the input is a function of temperature, relative humidity, pressure, etc.**
- **<u>Digital Sensors (DI):</u> A two position input, a dc voltage or no voltage, where the input represents the status or state of a set of contacts.**
- **<u>Pulses (PI):</u> A digital input that "makes and breaks" repeatedly over a period of time.**
  - **The number of pulses equates to a quantity of the measured variable.**
  - **Quantity is "accumulated" in software**

Outputs from DDC

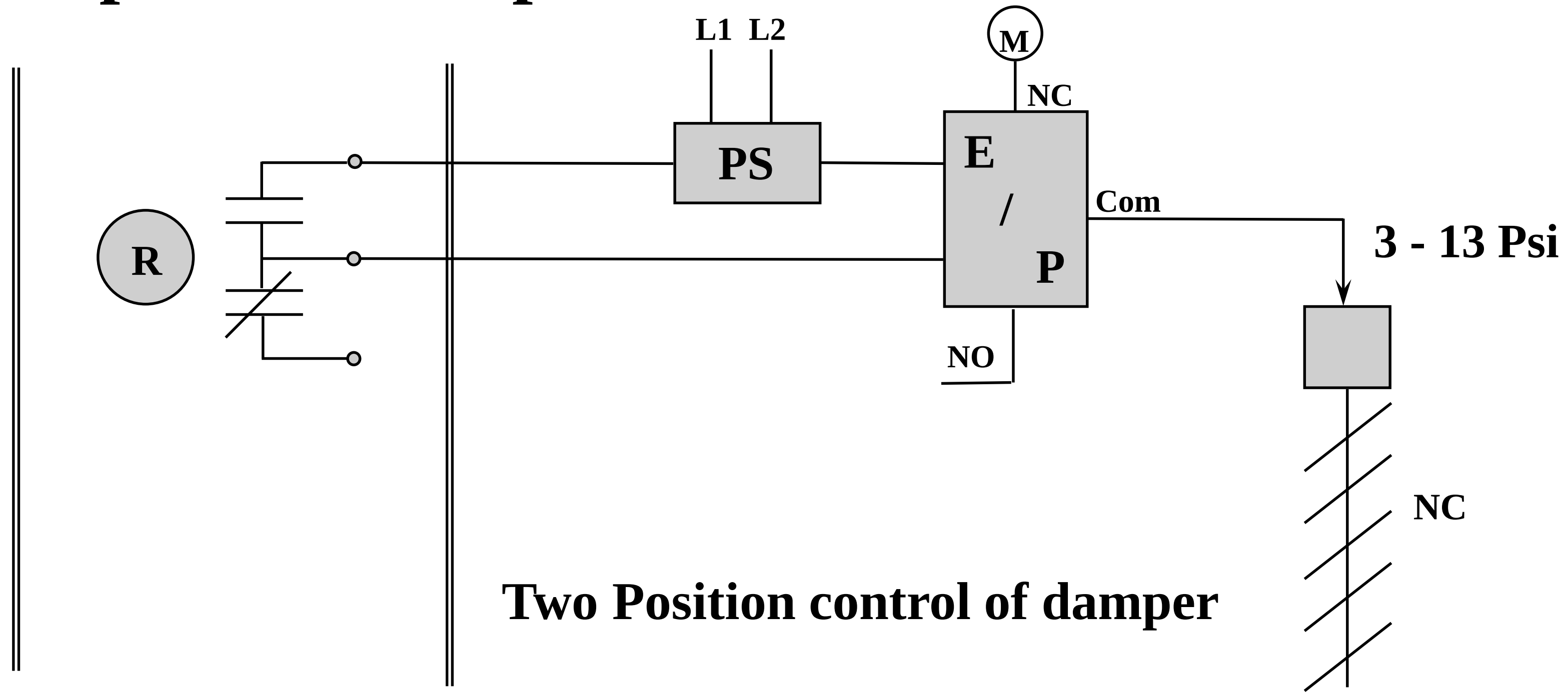
- **<u>Analog Voltage or Current (AO):</u> A varying dc voltage or milliamp signal that is used to drive a transducer or controlled device.**

Analog Outputs



Outputs from DDC

- **<u>Digital Outputs - A Controlled Relay (DO):</u> A relay that is either energized or de-energized. This relay can open and close a set of contacts to operate a two position device.**



Two Position control of damper

Software Concepts

- Software characteristics
  - Compiled
  - Interpreted
- Programming methods
  - Line
  - Menu or template
  - Graphical

Programming Methods

- Line Programming
  - Basic or FORTRAN like language with HVAC "subroutines"
  - Strong computer programming background required
  - Totally flexible
  - Requires extensive external documentation (logic flow charts, etc.) to understand control logic
  - Wide variance in programming common HVAC applications

Line Programming Example

```
920    IF(MO.GT.4.AND.MO.LT.10)GOTO 960
930    HWSP=140-(OA-10)*(80/50)
940    LOOP(HW,HWSP,DA,10%/ºF.,50%)
950    GOTO 970
960    HW=100%
970    CONTINUE
```

Programming Methods

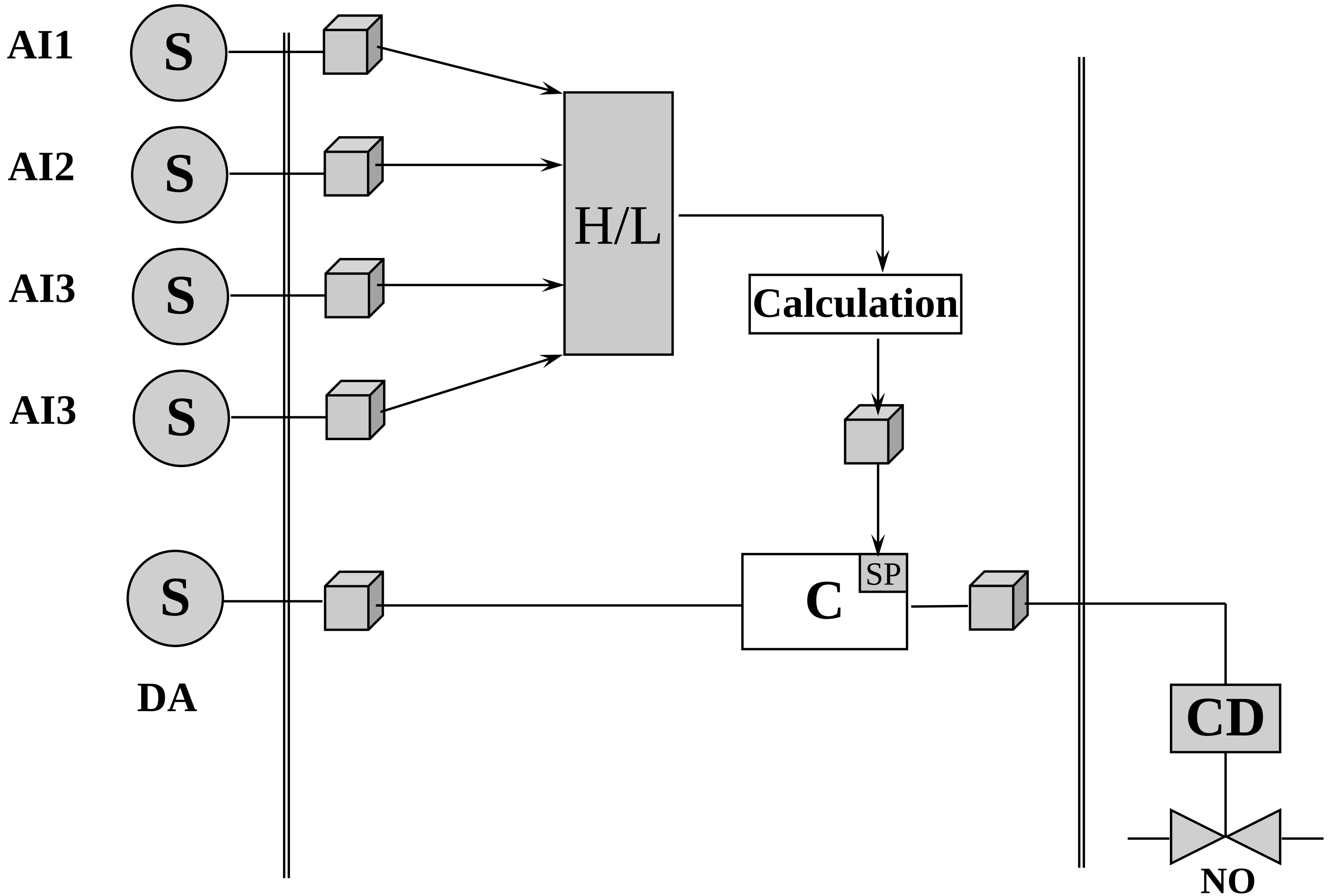
- Menu driven
  - Template/tabular programming
  - No computer language required
  - Requires a control logic diagram prior to programming to establish data flow
  - Data flow must be programmed within each template
    - where is data coming from
    - where is data going to

Menu/Template Example

- HIGH/LOW Signal Selector

Module Name:	MAX Temp
Scan Rate (sec):	60 Sec
Input No. 1 (point or line):	Room 1 Temp
Input No. 2: (point or line):	Room 2 Temp
Input No. 3: (point or line):	Room 3 Temp
Input No. 4: (point or line):	Room 4 Temp
High Output: (point or line):	Warm Room
Low Output: (point or line):	Cold Room

Logic Diagram



Programming Methods

- Graphical Programming
  - Control logic is depicted using graphical symbols connected by “data flow” lines
  - Process is depicted with symbols as on electrical schematics and pneumatic control diagrams
  - Graphical diagrams are created and the detailed data is entered in background menus or screens
  - Self documenting
  - Complexity is easy to achieve
  - Programming tools resemble ladder logic diagrams
  - Compile step required

Graphical Programming Example