CAE 438/538 Control of Building Environmental Systems

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Instrumentation (1)

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INTRODUCTION TO MEASUREMENTS

Introduction to Measurements

There are two types of measurements:

- Primary measurements
  - ❑ One that is obtained directly from the measurement sensor
  - ❑ It is a single item from a specific measurement device
  - ❑ Examples: ??

- Derived measurements
  - ❑ One that is calculated using one or more measurements
  - ❑ The calculation can occur at the sensor level, or by a data logger, or during data processing
  - ❑ Derived measurements can use both primary and other derived measurements
  - ❑ Examples: ??

Introduction to Measurements

There are two categories of data:

- Type (i.e., the measured value)
  - ❑ Stationary
    - ❖ Data do not change in time
    - ❖ Examples: ??
  - ❑ Time-dependent
    - ❖ Data do change in time
    - ❖ Examples: ??

- Sample (i.e., how you measure it)
  - ❑ Single-sample
    - ❖ One or more readings taken under identical conditions at the same or different times
    - ❖ Example: repeated measurements using the same instrument
  - ❑ Multi-sample
    - ❖ Repeated measurement of a fixed quantity using different instruments
    - ❖ Example: repeated measurements using different instruments

Introduction to Measurements

- A detailed experimental plan and measurement methodology must be developed to obtain the results you need
- The experimental process:
  1. Identify experimental goals and acceptable accuracy
  2. Identify the important variables and appropriate relationships
  3. Establish the quantities that must be measured and their expected range of variation
  4. Tentatively select sensors/instrumentation appropriate for the task
  5. Document uncertainty of each measured variable
  6. Perform a preliminary uncertainty analysis
  7. Study uncertainty results and reassess the ability of the measurement methods and instrumentation to meet acceptable accuracy
  8. Install selected instrumentation in accord with standards/best practices
  9. Collect experimental data and subject data to ongoing quality control criteria
  10. Reduce/analyze data, perform final uncertainty analysis, and report results

Introduction to Measurements

- (some) real work concerns are:
  - ❑ First cost and operating cost
  - ❑ Ease of use
  - ❑ Safety of use
  - ❑ Durability
  - ❑ Flexibility
  - ❑ Reliability
  - ❑ Power requirements
  - ❑ Environmental conditions requirements

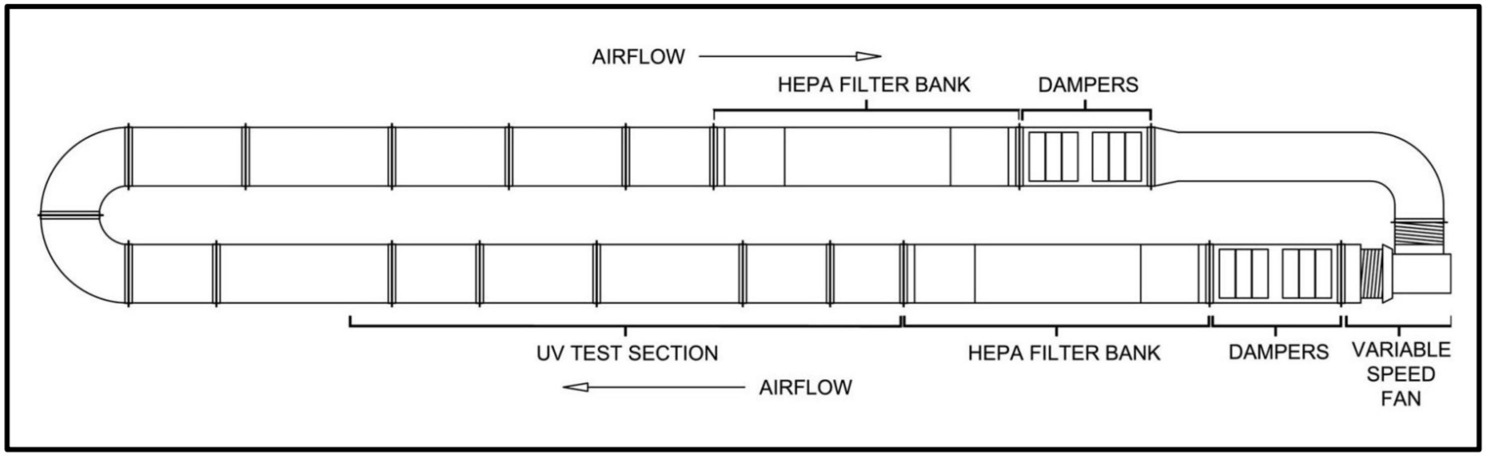
Introduction to Measurements

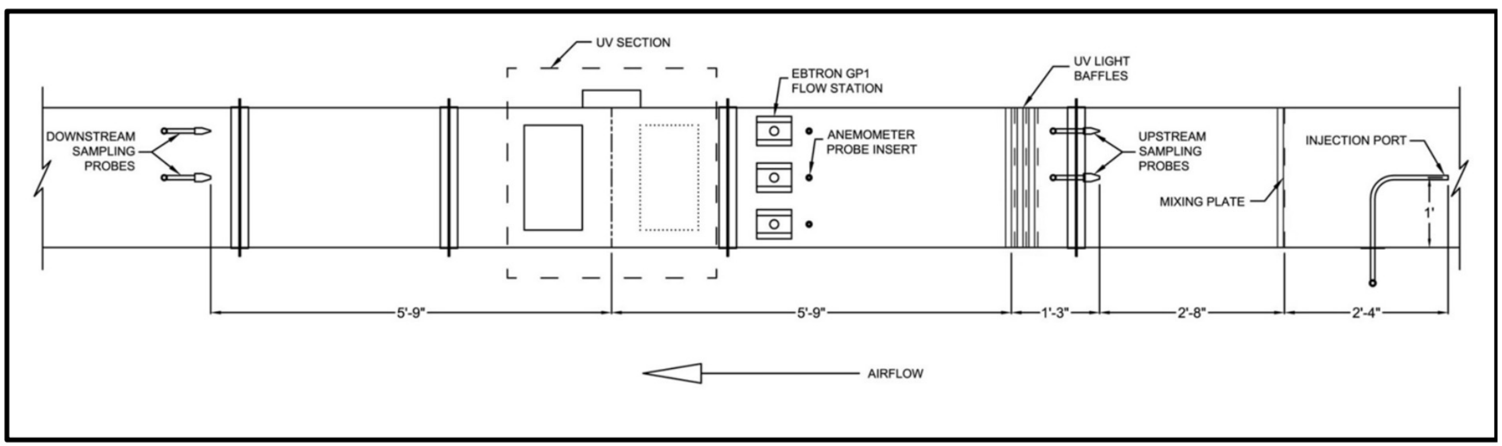
- Some examples:

Stephen Martin, PSU Dissertation 2014

Introduction to Measurements

- Some examples:





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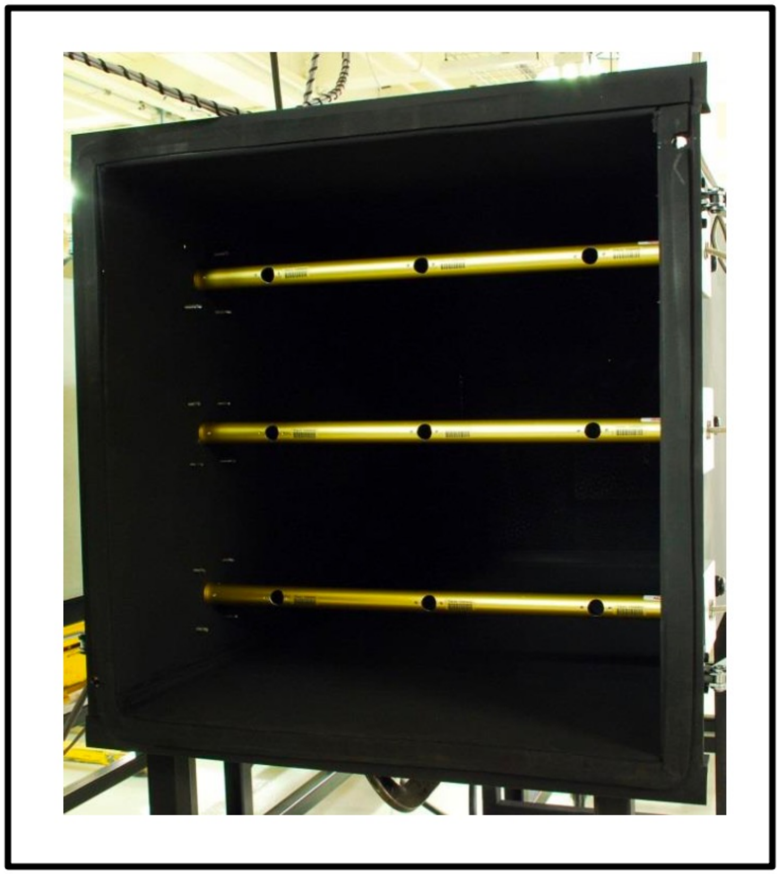
Introduction to Measurements

- Some examples:



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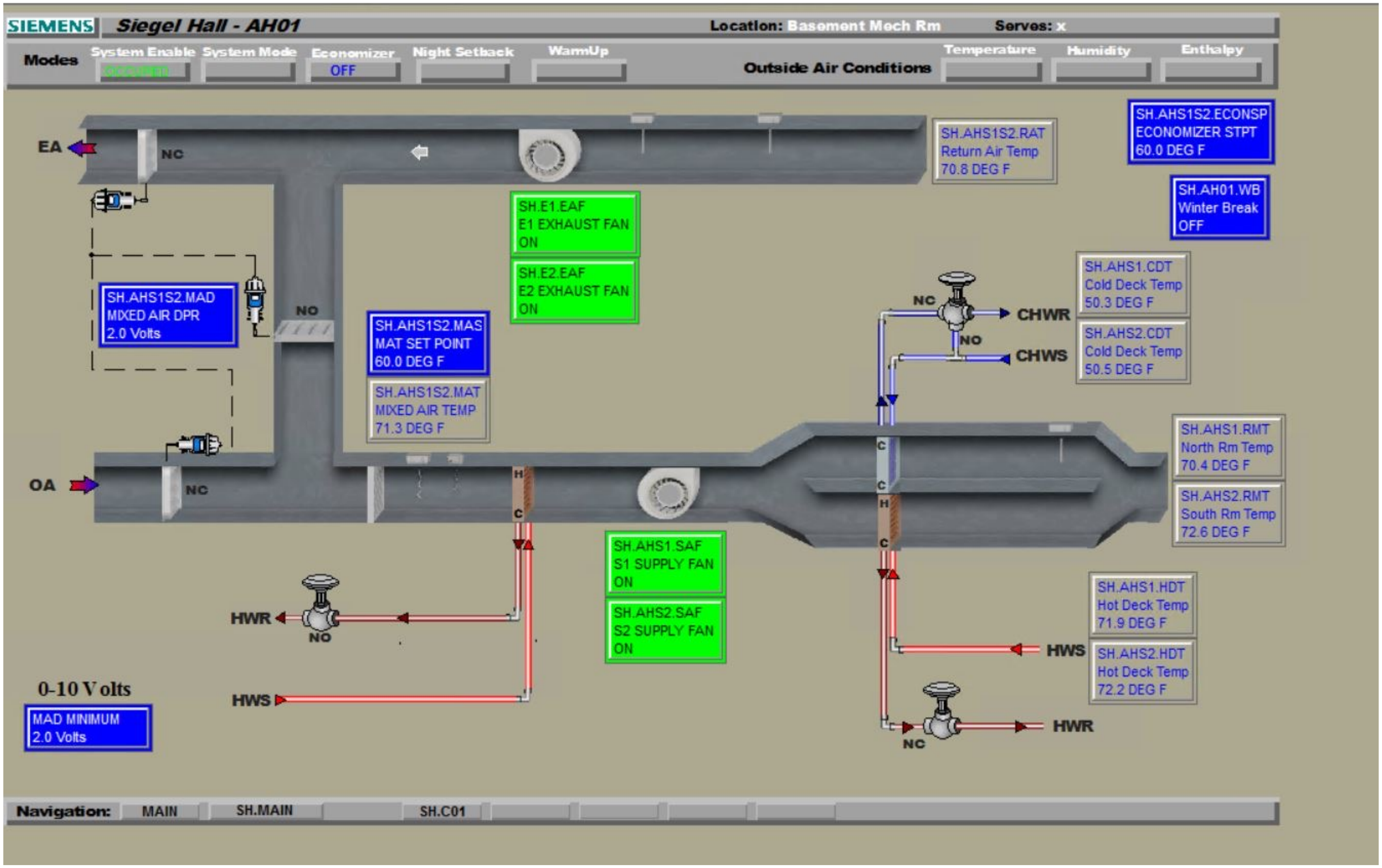
Class Activity

- What sensors (or variables) do we usually consider in an air handling unit?

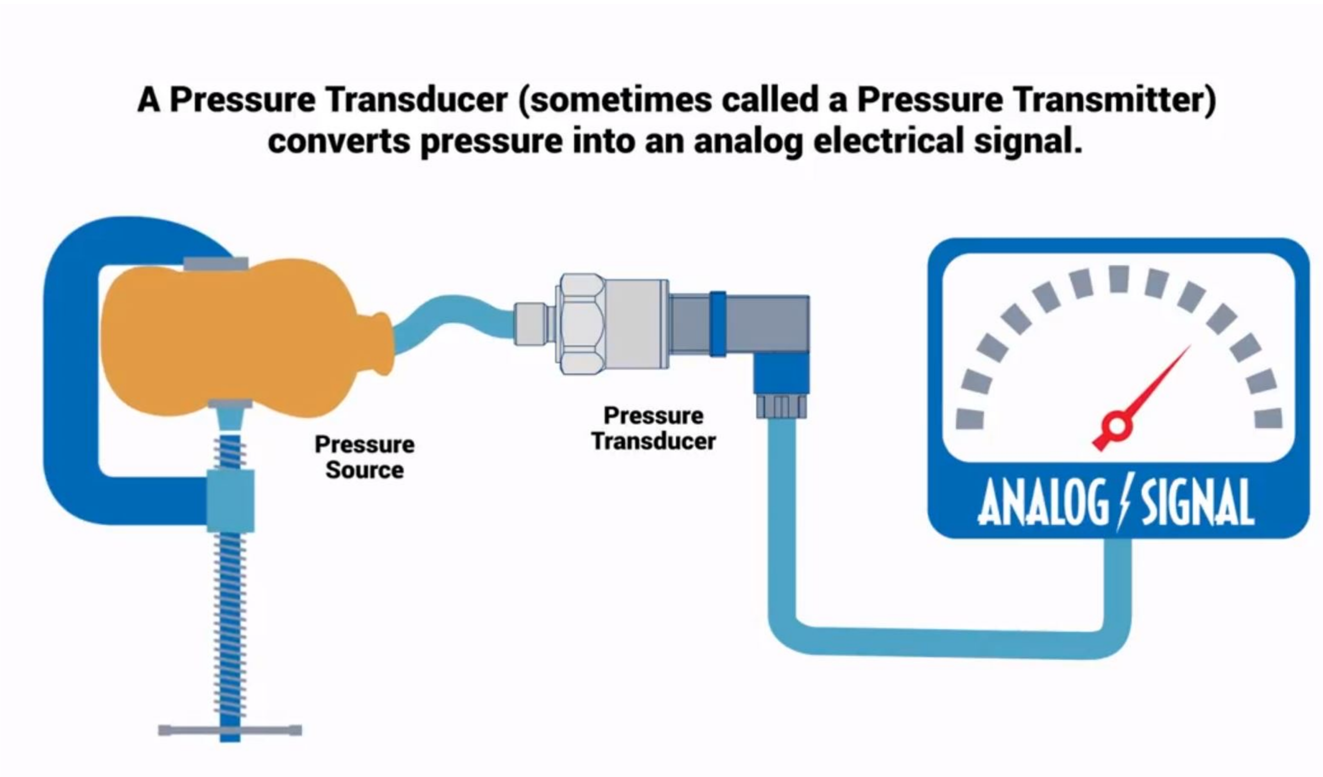


INSTRUMENTATION CONTROL TERMINOLOGY

Instrumentation Control Terminology

- Sensor
  - ❑ A device that responds to a change in the controlled variable and sense something (e.g., temperature sensor)
- Transducer
  - ❑ A device that changes one energy from another form
  - ❑ Mostly have a voltage output vary from a magnitude of a few millivolts to several volts (e.g., pressure transducer, speaker)
- Transmitter
  - ❑ A device that is used to transmit energy from one device to other
  - ❑ Mostly have a current output in the range of 4-20mA

Instrumentation Control Terminology



Deform with the pressure change (e.g., thin flexible membrane)

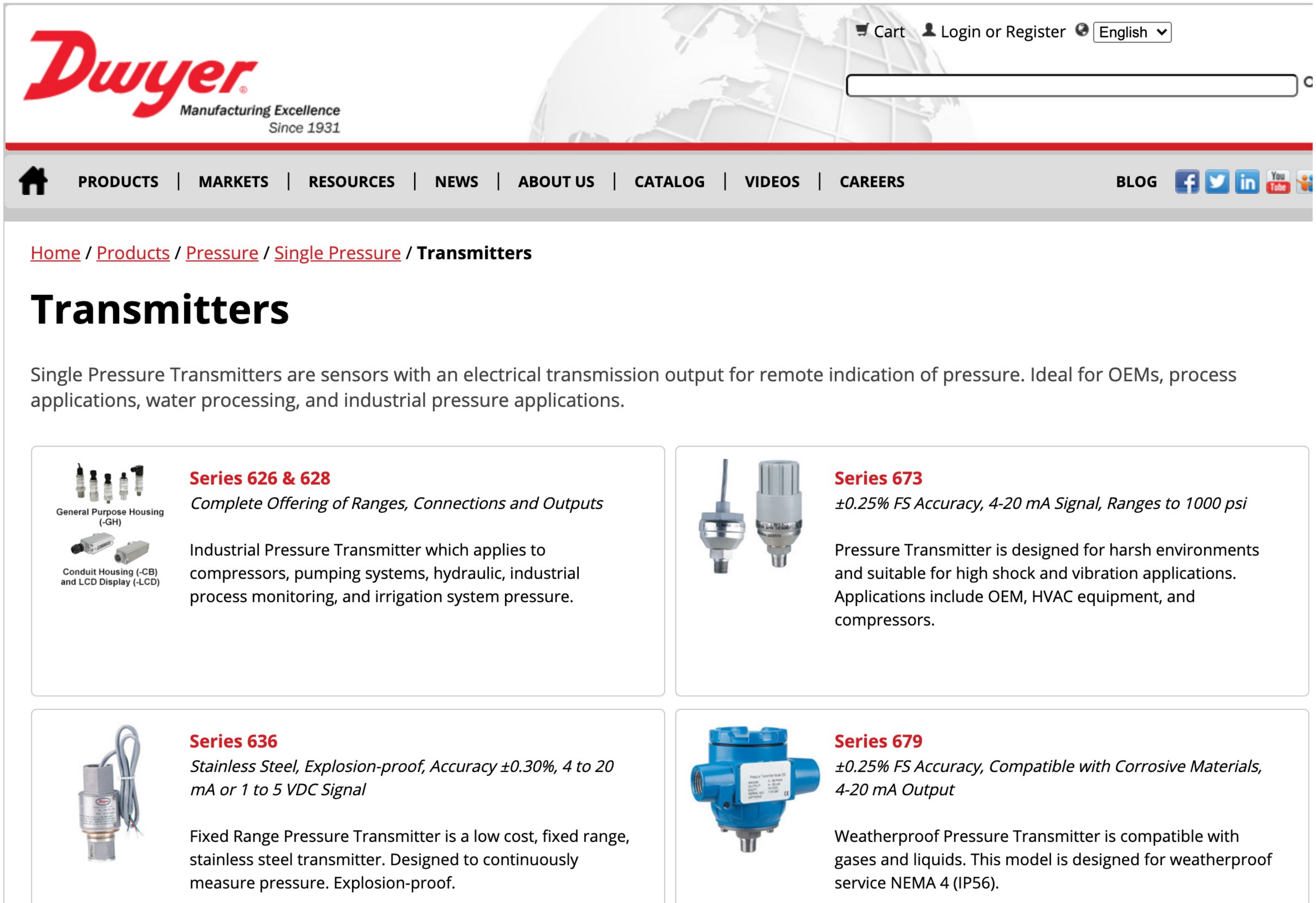
Detect the deformation and covert into an electrical signal (e.g., capacitator, resistor, inductor)

https://www.omega.com/en-us/resources/pressure-transducers-how-it-works

https://www.sensorsone.com/pressure-transducers/

Instrumentation Control Terminology

- Examples of pressure transmitters are:



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Home / Products / Pressure / Single Pressure / **Transmitters**

Transmitters

Single Pressure Transmitters are sensors with an electrical transmission output for remote indication of pressure. Ideal for OEMs, process applications, water processing, and industrial pressure applications.

General Purpose Housing (-GH)
Conduit Housing (-CB) and LCD Display (-LCD)

Series 626 & 628
Complete Offering of Ranges, Connections and Outputs

Industrial Pressure Transmitter which applies to compressors, pumping systems, hydraulic, industrial process monitoring, and irrigation system pressure.

Series 673
±0.25% FS Accuracy, 4-20 mA Signal, Ranges to 1000 psi

Pressure Transmitter is designed for harsh environments and suitable for high shock and vibration applications. Applications include OEM, HVAC equipment, and compressors.

Series 636
Stainless Steel, Explosion-proof, Accuracy ±0.30%, 4 to 20 mA or 1 to 5 VDC Signal

Fixed Range Pressure Transmitter is a low cost, fixed range, stainless steel transmitter. Designed to continuously measure pressure. Explosion-proof.

Series 679
±0.25% FS Accuracy, Compatible with Corrosive Materials, 4-20 mA Output

Weatherproof Pressure Transmitter is compatible with gases and liquids. This model is designed for weatherproof service NEMA 4 (IP56).

https://www.dwyer-inst.com/Product/Pressure/SinglePressure/Transmitters/

Instrumentation Control Terminology

- Examples of pressure transmitters are:

Series 636 Fixed Range Pressure Transmitter

Stainless Steel, Explosion-proof, Accuracy ±0.30%, 4 to 20 mA or 1 to 5 VDC Signal

View All Product Images

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The **Series 636 Pressure Transmitter** is a low cost, fixed range, stainless steel transmitter with ±0.30% accu
is designed to continuously measure pressure for years in even the toughest environmental and media cond
Transmitters are explosion-proof, (FM approved) and meet NACE standards for off-shore applications.

Product Applications

- Off-shore
- Process applications

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Specifications

Service:	Liquid, gas or vapor.
Wetted Materials:	316 L SS.
Fill Fluid:	DC 200 Silicone (standard).
Accuracy:	±0.30% of calibrated span.
Stability:	±0.5% of upper range limit for six months.
Temperature Limits:	Electronics (ambient): -40 to 140°F (-40 to 60°C); Process interface: -40 to 212°F (-40 to 100°C).
Pressure Limits:	300% upper range limit.
Compensated Temperature Range:	-20 to 180°F (-29 to 82°C).
Thermal Effect (includes zero and span):	Between -20 and 180°F (-29 and 82°C). ±2.0% per 50°F (28°C).
Power Requirements:	12 to 30 VDC (636), 8 to 14 VDC (636LP), reverse polarity protection.
Output Signal:	4 to 20 mA DC, limited to 30 mA DC (636), 1 to 5 VDC (636LP).
Zero and Span Adjustments:	Null: 4.0 mA ±2% span (636), 1 VDC ±1% span (636LP); Span: 16.0 mA ±1% span (636), 4

https://www.dwyer-inst.com/Product/Pressure/SinglePressure/Transmitters/Series636#specs

Instrumentation Control Terminology

- Examples of pressure transmitters are:

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Home / Products / Valves / Current to Pressure Transducers / **Series EPTA**

Series EPTA Electro-Pneumatic Transducers

Low Cost, Selectable Input/Output, Manual Override

SHARE

The **Series EPTA Electro-Pneumatic Transducers** convert an analog input signal to a linearly proportionate pneumatic output by modulating its control valves to regulate branch line pressure to the set point determined by the input signal. All models incorporate two low voltage valves, an integral in-barb filter, a 0 to 30 psi analog gage, an anodized aluminum manifold, and brass barbed fittings. The EPTA offers adjustable span and offset as well as manual override. This unit has no air consumption and is immune to mounting orientation. Output pressure ranges include field-selectable 0 to 10, 0 to 15, and 0 to 20 psig. Also included is an analog 0 to 5 VDC feedback signal indicating the resultant branch line pressure. Universal 24 VAC/24 VDC supply voltage and field-selectable 4 to 20 mA, 0 to 5 VDC, 0 to 10 VDC, or 0 to 15 VDC inputs ensure single unit compatibility with most systems. The standard models maintain branch pressure on power loss while the Fail-Safe models will drop the branch pressure to 0 psi on power loss. Mounting configurations include a metal bracket mount in the EPTA-B models and a snap-track mount in the EPTA-S models. The A-400 accessory kit will allow the EPTA-S models to be mounted on a standard DIN rail.

California Residents: Click Here for Proposition 65 WARNING.

Product Applications

- Operation of valve actuators, positioners, damper and louver actuators.

Ordering | Specifications | Features | Support Library | Drawings | Accessories | Related Products | Photo Downloads | Reviews

Specifications

Service:	Clean dry air or any inert gas.
Input Signal:	DC Current (4-20 mA) or DC Voltage (0-5/0-10/0-15).
Input Impedance:	Current: 250 ohms; Voltage: Infinite.
Output Signal:	Jumper selectable 0-10 psig (0-69 kPa), 0-15 psig (0-103 kPa), or 0-20 psig (0-138 kPa).
Feedback Output:	0 to 5 VDC.

https://www.dwyer-inst.com/Product/Valves/CurrenttoPressureTransducers/SeriesEPTA

BASIC SENSOR INPUT/OUTPUTS

Basic Sensor Inputs and Outputs

- Signal Types:
  - ❑ Analog (current or voltage)
  - ❑ Binary: On/Off (i.e., switch position)
  - ❑ Digital (e.g., binary or discrete)

Basic Sensor Inputs and Outputs

- Hard wired:
  - ❑ Thermistors of type specs for temperature
  - ❑ Other with transducers to produce the 0-5 v or 4-20 mA signal

- BACnet (other communication protocols) communications

- Wireless communication:
  - ❑ Power supply and transmitter
  - ❑ Network that receives the signal need to be able to communicate with the controller or BACnet

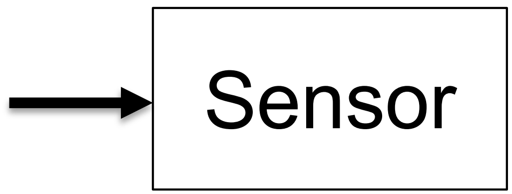
Basic Sensor Inputs and Outputs

- 4 to 20 mA current output signal:
  - ❑ Mostly is used in a series circuit for a robust measurement signal
  - ❑ Act like a current source
  - ❑ Create a constant current output for a given measurement independent of the supply voltage or impedance
  - ❑ Produce the same current output at any particular point in the circuit (Unlike a voltage output)
  - ❑ Is a relatively high-power analogue output which can be used in measurement circuits over long distances

https://www.sensorsone.com/4-to-20-ma-current-loop-output-signal/

Basic Sensor Inputs and Outputs

- Power voltage inputs are (Most common types):
  - ❑ 24 ADC (volts + alternating current)
  - ❑ 24 VDC (volts + direct current)
  - ❑ 120 VAC (volts + alternating current)



SENSOR POWER INPUT

Sensor Power Input

- Voltage inputs are:
  - Most common types are:
    - 12 VAC
    - 12 VDC
    - 24 VAC
    - 24 VDC
    - 120 VAC

V: Volts

AC: Alternating Current

DC: Direct Current

Sensor Power Input

- 120 VAC voltage input:
  - ❑ Advantages:
    - It is robust, reliable, and has a very broad existing installation base
    - Due to the high potential voltage: (i) Voltage drop over long distances is not an issue and (ii) Current requirements are smaller than lower voltage systems
  - ❑ Disadvantages
    - Can be dangerous and potentially lethal (high voltage)
    - Technicians require to wear proper shock resistant PPE

Sensor Power Input

- 24 VDC (or 12 VDC) voltage input:
  - ❑ Advantages:
    - Safety is the main advantage
    - Technicians can work without any additional electrical PPE equipment
    - Has limiting circuits to protect against short circuits (eliminate the need for fuses)
  - ❑ Disadvantages
    - Suffer from voltage drop issues much sooner over shorter distances
      - Using larger wire
      - If possible, increase the voltage generated by the power supply (many DC control systems are rated from 10-30V)
    - A lower voltage leads to more current (e.g., solenoids with high power requirements - large motor starters and more expensive)

Sensor Power Input

- 24 VAC voltage input:
  - Advantages:
    - Safety is the main advantage
    - Technicians can work without any additional electrical PPE equipment
    - It requires only a transformer to change the voltage (e.g., thermostats, doorbells, and security cameras)
    - Motors and solenoids used to be low cost
  - Disadvantages
    - Suffer from voltage drop issues much sooner over shorter distances

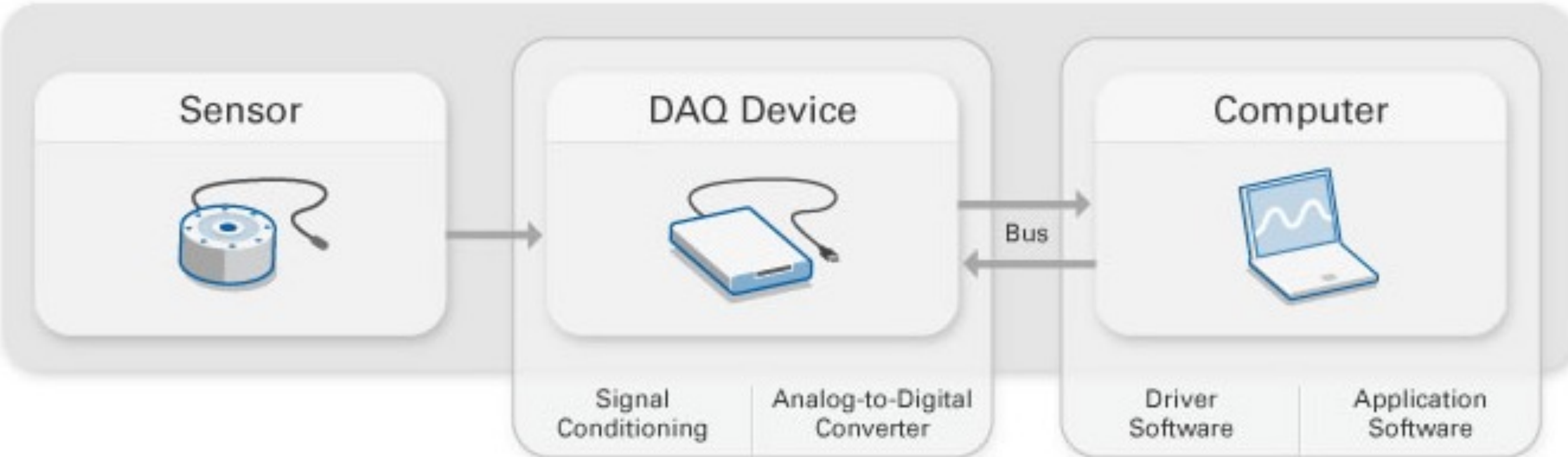
Sensor Power Input

- 24 VAC voltage input:

https://www.grainger.com/category/hvac-and-refrigeration/hvac-controls-and-thermostats/low-voltage-thermostats/low-voltage-mechanical-thermostats?attrs=Voltage%7C24VAC&filters=attrs

Sensor Power Input

- Be careful of mixing different voltages:
  - Consider using one control voltage for all sensors and devices
  - It creates new points of failure, mixing and matching control voltages creates
  - Maintenance issue for technicians



INTRODUCTION TO DATA ACQUISITION

http://www.ni.com/data-acquisition/what-is/

Data Acquisition

- The interface system makes every transducer and sensor computer-compatible

- Integration of the transducer to the system leads to lose its identity

- A data acquisition system usually consists of:
  - ❑ Sensors
  - ❑ Data acquisition measurement hardware
  - ❑ A computer with programmable software

Data Acquisition

- The transducer follows the linearization, offset correction, self-calibration, and so forth of the system

- Currently computers are integrated into every aspect of data recording allows:
  - ❑ Sophisticated graphics
  - ❑ Data acquisition hardware
  - ❑ Control
  - ❑ Data analysis
  - ❑ Additional processing power
  - ❑ Additional flexibility and connectivity capabilities

Data Acquisition

- A digital data acquisition system contains an interface:
  - ❑ Involve one or several analog-to-digital converters
  - ❑ In the case of multichannel inputs (Multiplexers)
  - ❑ The interface may also provide excitation for transducers, calibration, and conversion of units
  - ❑ Once the input signals have been digitized, the digital data are essentially immune to noise and can be transmitted over great distances

- The digital data are arranged into one or several standard digital bus formats

Data Acquisition

- Examples of existing data acquisition systems: “National Instruments”:

- Limited channel count
- Applicable for single data acquisition devices

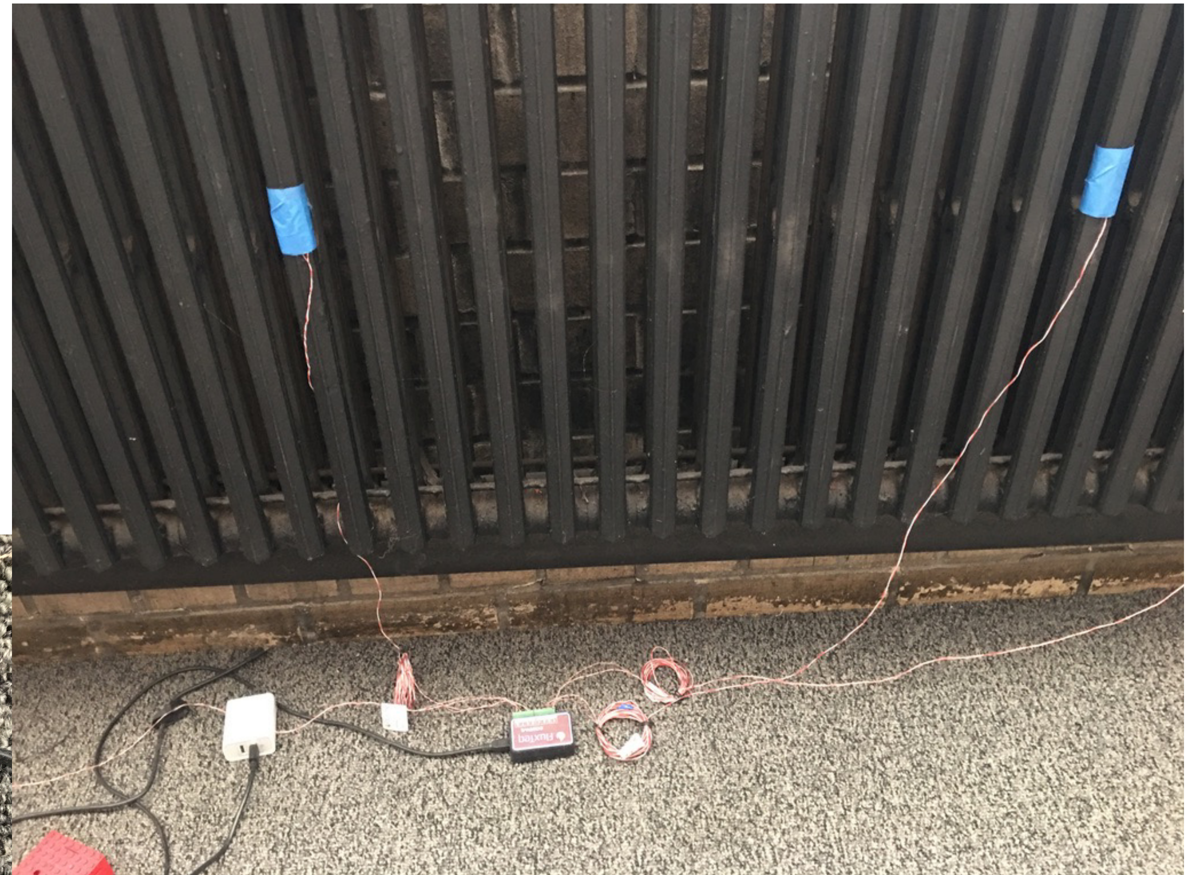
- Medium channel count
- Modular data acquisition system
- USB, Ethernet, and Wi-Fi connectivity

- High channel count
- Applicable for single data acquisition devices
- Synchronization and stand-alone operation or remote control

http://www.ni.com/data-acquisition/

Data Acquisition

- An example for the heat flux sensors:



DATA LOGGERS

Data Loggers

- Data loggers digitally store signals (analog or digital):
  - Store data at different intervals
  - May store data based on an event (e.g., button push)
  - May perform linearization or other signal conditioning
  - Assign the time/date with transducer signal information
  - Have different channel configurations (from single channel input to 256 or more).
  - Can work for general-purpose devices that accept a multitude of analog and/or digital inputs
  - May be more specialized to a specific measurement (e.g., a portable anemometer with built-in data- logging capability) or application (e.g., a temperature, relative humidity, CO_2, and CO monitor with data logging for IAQ applications)
  - Download the stored data using a serial interface with a temporary direct connection to a personal computer

Data Loggers

- Examples of using data loggers:

Telaire 7001

HOBO U12

CHAPTER 14

MEASUREMENT AND INSTRUMENTS

HVAC engineers and technicians require instruments for both laboratory work and fieldwork. Precision is more essential in the laboratory, where research and development are undertaken, than in the field, where acceptance and adjustment tests are conducted. This chapter describes the characteristics and uses of some of these instruments.

TERMINOLOGY

The following definitions are generally accepted.

Deviation, standard. Square root of the average of the squares of the deviations from the mean (root mean square deviation). A measure of dispersion of a population.

Distortion. Unwanted change in wave form. Principal forms of distortion are inherent nonlinearity of the device, nonuniform response at different frequencies, and lack of constant proportionality between phase-shift and frequency. (A wanted or intentional change might be identical, but it is called **modulation**.)

Drift. Gradual, undesired change in output over a period of time that is unrelated to input, environment, or load. Drift is gradual; if variation is rapid and recurrent, with elements of both increasing

TERMINOLOGY

Uncertainty Analysis

- No measurement is accurate
- The inaccuracy can be expressed in uncertainty
- Uncertainty is NOT the same as an error
  - An error in a measurement is the difference between the correct value and the measured value
  - An error is fixed and not a statistical variable
- Uncertainty is a possible value that the error might take on in a given measurement

Uncertainty Analysis

- Uncertainty:
  - ❑ Is a statistical variable
  - ❑ Can be represented as a histogram of values

- Similarity of uncertainty with statistical analysis:
  - ❑ Measured value describes a central tendency (similar to Mean)
  - ❑ Uncertainty represents dispersion usually in terms of probability (similar to standard division)

Uncertainty Analysis

- Source of uncertainties:
  - ❑ Inaccuracy in the mathematical model
  - ❑ Inherent stochastic variability of the measurement process
  - ❑ Uncertainties in measurement standards and calibrated instrumentation
  - ❑ Time-dependent instabilities caused by gradual changes in standards and instrumentation
  - ❑ Effects of environmental factors such as temperature, humidity, and pressure
  - ❑ Values of constants and other parameters obtained from outside sources
  - ❑ Uncertainties arising from interferences, impurities, inhomogeneity, inadequate resolution, and incomplete discrimination
  - ❑ Computational uncertainties and data analysis
  - ❑ Incorrect specifications and procedural errors

Uncertainty Analysis

- Accuracy is usually reported as the following examples:
  - ❑ Onset HOBO U12 internal temperature sensor
    - ❖ ± 0.35°C from 0 to 50°C (± 0.63°F from 32° to 122°F)
  - ❑ Onset HOBO U12 internal relative humidity sensor
    - ❖ ± 2.5% RH from 10% to 90% over the range 10° to 50°C (50° to 122°F) typical; ± 3% RH from 5% to 95%; conditions above 80% RH and 60°C (140°F) may cause additional error
  - ❑ Telaire 7001 CO2 sensor
    - ❖ ±50 parts per million (ppm) or ±5% of reading, whichever is greater
  - ❑ Setra differential air pressure sensor
    - ❖ ±1% FS (Root Sum Squares of Non-Linearity, Non-Repeatability, Hysteresis)

Precision vs. Accuracy

- Precision vs. Accuracy:
  - These terms are often confused and conflated with other terms

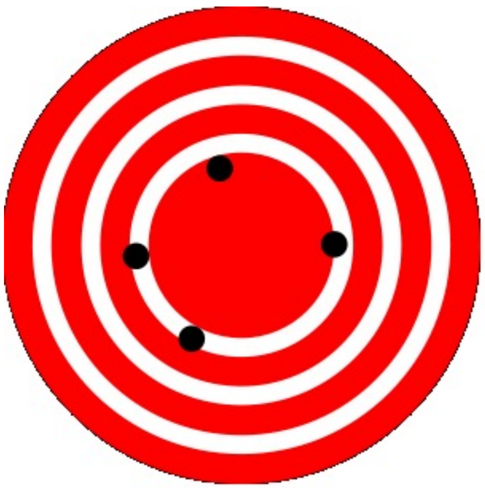
- Accuracy is "*Capability of an instrument to indicate the true value of a measured quantity*"

- Precision is "*Repeatability of measurements of the same quantity under the same conditions; not a measure of absolute accuracy*"
  - Precision not often reported

Reference ASHRAE Guideline 2

Precision vs. Accuracy

- Example of accuracy and precision:



High **accuracy**,
low **precision**

Low **accuracy**,
High **precision**

- A good measurement result is both accurate and precise

Uncertainty Analysis

- Some popular terms used in uncertainty analysis

Current	Earlier Version
Precision	Repeatability Random error Random component of uncertainty Probable error
Bias	Fixed error Fixed component of uncertainty Systematic error

Type of Errors

- Errors in the measurements are in two forms of:
  - Fixed or systematic error (*Bias*)
    - It is the same amount for each trial
    - It is the same for each reading
    - Can be removed by calibration or correction
  - Random of non-repeatable error (*Uncertainty*)
    - It is random by nature
    - It is different for every reading
    - Cannot be removed by calibration or correction

Uncertainty Analysis

- The quantification of uncertainty for a measurement requires considering influence of the all variables
- Example: Imagine a pressure measurement use pressure transductors of diaphragm type

$$\frac{\Delta \mathrm{R}}{\Delta \delta} = \mathrm{a}(1 \pm \epsilon_a)$$

$$\frac{\Delta \mathrm{V_{in}}}{\Delta R} = \mathrm{b}(1 \pm \epsilon_b)$$

$$\frac{\Delta \mathrm{V_{out}}}{\Delta V_{in}} = \mathrm{c}(1 \pm \epsilon_c)$$

$$\frac{\Delta \mathrm{y}}{\Delta V_{out}} = \mathrm{d}(1 \pm \epsilon_d)$$

  - ϵ_a to ϵ_d :Proportional error for each step
  - R: Resistance
  - V_{in} and $\mathrm{V_{out}}$: Input and output voltage
  - δ: Diaphragm displacement
  - "a" to "d": measurement of each step

Uncertainty Analysis

- Final measurement:

$$X = \frac{\Delta y}{\Delta \delta} = abcd(1 \pm \epsilon_a)(1 \pm \epsilon_b)(1 \pm \epsilon_c)(1 \pm \epsilon_d)$$

- Assume all errors are very small compared to unity:

$$\epsilon = \epsilon_a + \epsilon_b + \epsilon_c + \epsilon_d$$

- In general:

$$X = F(a, b, c, d)$$

$$dX = \sum_{n=a}^{d} \left(\frac{\partial F}{\partial n}\right) dn$$

$$\epsilon = \sqrt{\epsilon_a^2 + \epsilon_b^2 + \epsilon_c^2 + \epsilon_d^2}$$

Example

- Temperature difference ($\Delta T = T_2 - T_1$) is an important factor especially in the heat flux and transfer calculations.
- In expensive sensors typically have +/-2 ºF as their accuracy.
- Calculate absolute and relative uncertainty in ΔT when:
  - ΔT is 8 ºF
  - ΔT is 20 ºF

Example

$$E = \sqrt{\left(\Delta T_1 \frac{\partial \Delta T}{\partial T_1}\right)^2 + \left(\Delta T_2 \frac{\partial \Delta T}{\partial T_2}\right)^2}$$

$$\frac{\partial \Delta T}{\partial T_1} = \frac{\partial}{\partial T_1}(T_2 - T_1) = -1$$

$$\frac{\partial \Delta T}{\partial T_2} = \frac{\partial}{\partial T_2}(T_2 - T_1) = 1$$

$$E = \sqrt{(-\Delta T_1)^2 + (\Delta T_2)^2} = \sqrt{\Delta T_1^2 + \Delta T_2^2}$$

Example

- The absolute error is 1.4 F in both Part (a) and (b)
- Relative error in ΔT.
  - ΔT is 8 F: $\frac{1.4}{8}$ =17.5 %
  - ΔT is 20 F: $\frac{1.4}{20}$ =7.0 %

$$E = \sqrt{(-\Delta T_1)^2 + (\Delta T_2)^2} = \sqrt{\Delta T_1^2 + \Delta T_2^2}$$

$$E = \sqrt{\left(\Delta T_1 \frac{\partial \Delta T}{\partial T_1}\right)^2 + \left(\Delta T_2 \frac{\partial \Delta T}{\partial T_2}\right)^2}$$

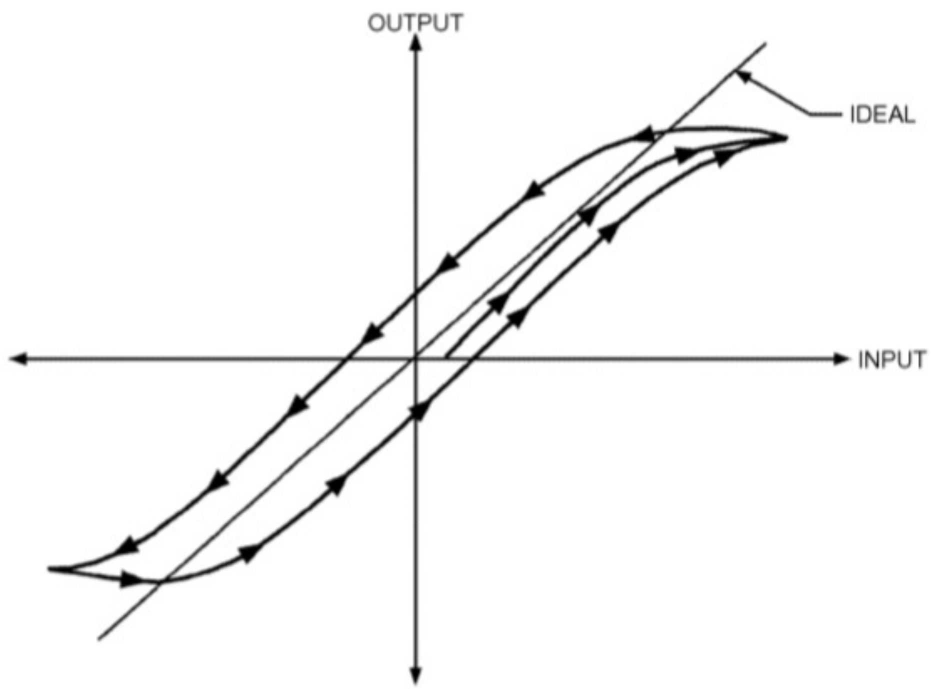
Inaccuracy

- Do not confuse inaccuracy with accuracy
- Inaccuracy defines as “departure from the true value due all causes of error such as:
  - Hysteresis
  - Nonlinearity
  - Drift
  - Temperature effects
  - Other sources

Reference ASHRAE Guideline 2

Hysteresis

- Hysteresis is defined as “summation of all effects, under constant environmental conditions, that cause an instrument’s output to assume different values at a given stimulus point when that point is approached with increasing or decreasing stimulus



B. HYSTERESIS

ASHRAE Fundamentals, Chapter 14

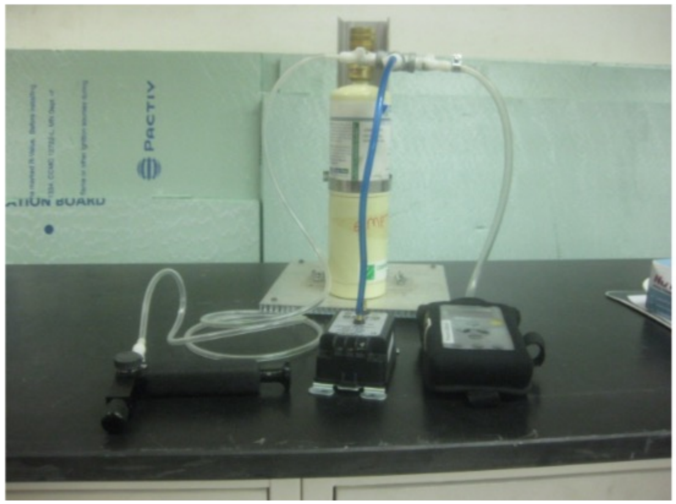
Calibration

- Calibration is defined as:
  - Process of comparing a set of discrete magnitudes or the characteristic curve of a continuously varying magnitude with another set or curve previously established as a standard
  - Process of adjusting an instrument to fix, reduce, or eliminate the deviation defined due to the comparisons with the references curve

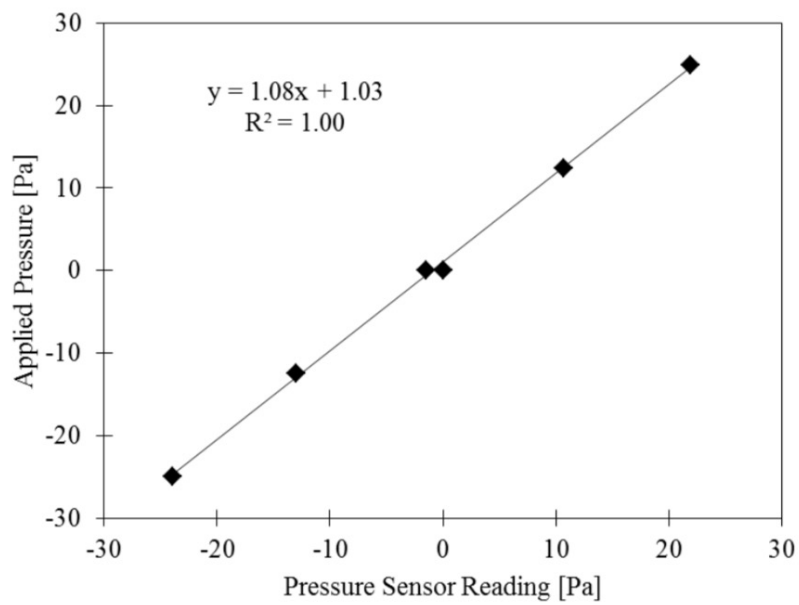
- Calibration process usually aims to provide calibration curves:
  - Path or locus of a point that moves so that its graphed coordinates correspond to values of input signals and output deflections
  - Plot of error versus input (or output)

Calibration

- Example of calibration:
  - Setup:

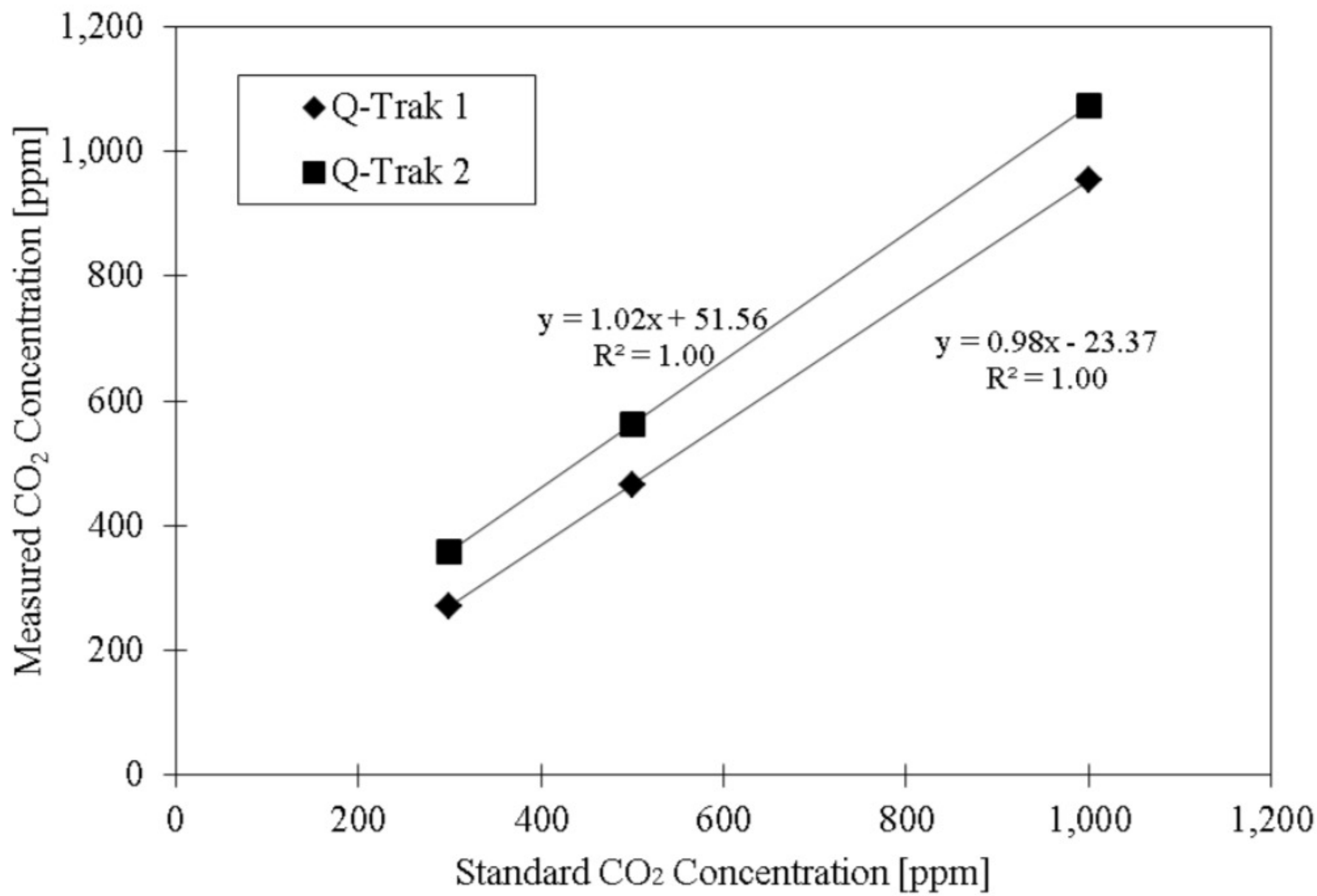


  - Calibration curve:



Calibration

- Example of calibration:
  - Calibration curve:



Calibration

Resolution

- Resolution is “the smallest detectable incremental change of input parameter that can be detected in the output signal”

- Resolution unlike precision is a psychological term For example:
  - A CO_2 sensor has a resolution of one part per million (ppm) of full scale
  - The Accuracy is no better than 25 ppm (0.0025%)

- An instrument cannot be any better than the resolution of the indicator or detector

Range

- Range is a statement of upper and lower limits between which an instrument's input can be received and for which the instrument is calibrated

- Accuracy is rarely constant over a range

- Consider frequent calibration
  - Using standards
  - Calibrate over range of interest
  - Don't use complicated calibration curves
    - Anything other than linear requires justification

- Consider arrangement with multiple sensors

Examples

HOBO® MX CO_2 Logger (MX1102) Manual

HOBO Data Loggers

The HOBO MX CO_2 data logger records carbon dioxide, temperature, and relative humidity (RH) data in indoor environments using non-dispersive infrared (NDIR) self-calibrating CO_2 sensor technology and integrated temperature and RH sensors. This Bluetooth® Low Energy-enabled logger is designed for wireless communication with a mobile device and also supports a USB connection. Using the HOBOmobile® app on your phone or tablet or HOBOware software on your computer, you can easily configure the logger, read it out, and view plotted data. The logger can calculate minimum, maximum, average, and standard deviation statistics and can be configured to trip audible or visual alarms at thresholds you specify. In addition, it supports burst logging in which data is logged at a different interval when sensor readings are above or below certain limits. This logger also has a built-in LCD screen to display the current CO_2 level, temperature, RH, logging status, battery use, memory consumption, and more.

HOBO MX CO_2 Logger

MX1102

Included Items:

- Four AA 1.5 V alkaline batteries

Required Items:

- HOBOmobile app and Device with iOS or Android™ and Bluetooth

OR

- HOBOware 3.7.3 or later and USB cable

Accessories:

Specifications

Temperature Sensor

Range	0° to 50°C (32° to 122°F)
Accuracy	±0.21°C from 0° to 50°C (±0.38°F from 32° to 122°F), see Plot A
Resolution	0.024°C at 25°C (0.04°F at 77°F), see Plot A
Drift	<0.1°C (0.18°F) per year

RH Sensor*

Range	1% to 70% RH when CO_2 sensor is enabled (non-condensing) 1% to 90% RH when CO_2 sensor is disabled (non-condensing)
Accuracy	±2% from 20% to 80% typical to a maximum of ±4.5% including hysteresis at 25°C (77°F); below 20% and above 80% ±6% typical
Resolution	0.01%
Drift	<1% per year typical

CO_2 Sensor

Range	0 to 5,000 ppm
Accuracy	±50 ppm ±5% of reading at 25°C (77°F), less than 70% RH and 1,013 mbar

Onset

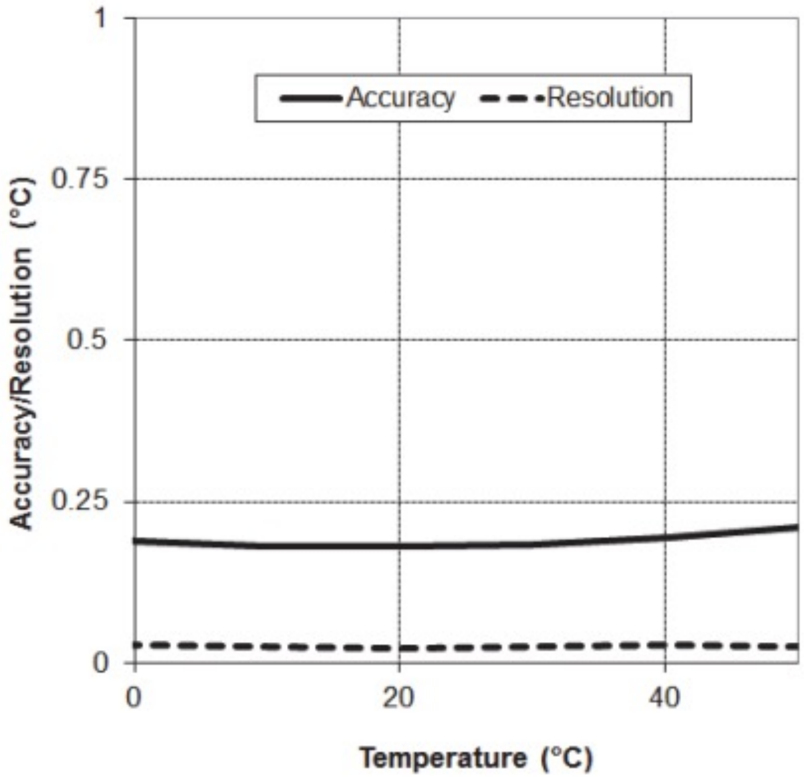
Examples

Warm-up Time	15 seconds
Calibration	Auto or manual to 400 ppm
Non-linearity	<1% of FS
Pressure Dependence	0.13% of reading per mm Hg (corrected via user input for elevation/altitude)
Operating Pressure Range	950 to 1,050 mbar (use Altitude Compensation for outside of this range)
Compensated Pressure Range	-305 to 5,486 m (-1,000 to 18,000 ft)
Sensing Method	Non-dispersive infrared (NDIR) absorption
Response Time	
Temperature	12 minutes to 90% in airflow of 1 m/s (2.2 mph)
RH	1 minute to 90% in airflow of 1 m/s (2.2 mph)
CO_2	1 minute to 90% in airflow of 1 m/s (2.2 mph)
Logger	
Radio Power	1 mW (0 dBm)
Transmission Range	Approximately 30.5 m (100 ft) line-of-sight
Wireless Data Standard	Bluetooth Low Energy (Bluetooth Smart)
Logger Operating Range	0° to 50°C (32° to 122°F); 0 to 95% RH (non-condensing)

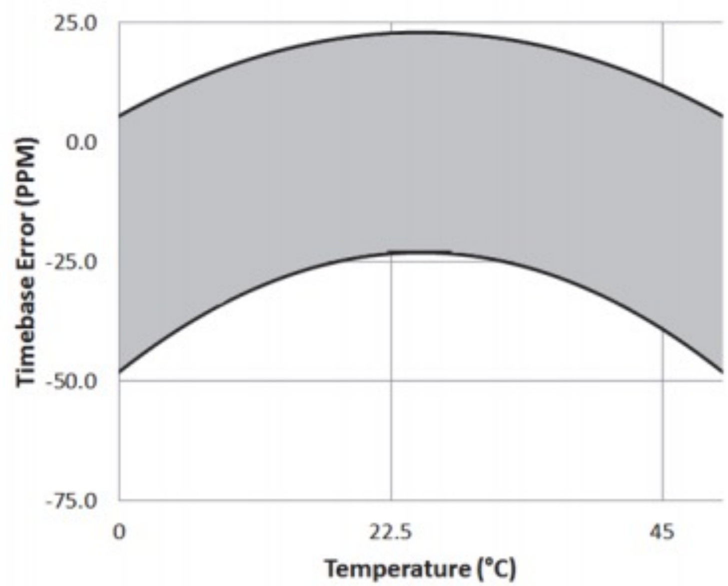
*Per RH sensor manufacturer data sheet

Note: The HOBO U-Shuttle (U-DT-1) is not compatible with this logger.

Examples



Plot A: Temperature Accuracy and Resolution



Plot B: Time Accuracy

TEMPERATURE SENSORS

Common Temperature Measurement Techniques

- These techniques work based on:
  - Increase or decrease in size (e.g. expansion or contraction)
  - Increase in pressure
  - Change of color
  - Change of state
  - Change of surface radiation
  - Change of electrical resistance
  - Generation of electromotive force

- What factors influence the selection of measurement technique?

Common Temperature Measurement Techniques

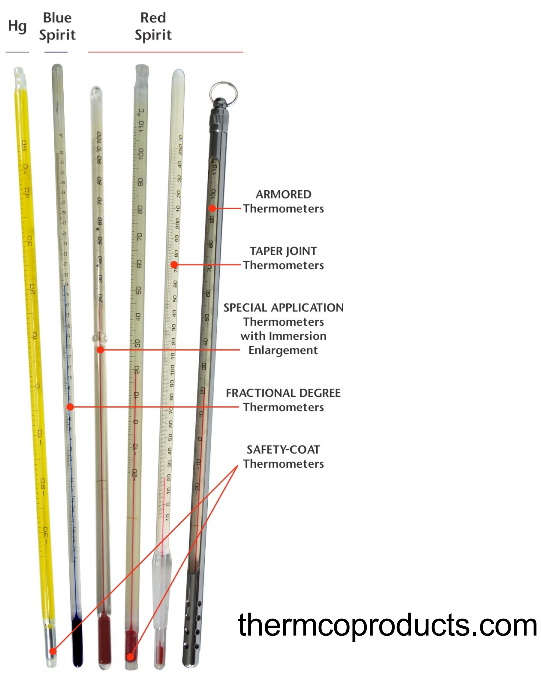
Measurement Means	Application	Approximate Range, °F	Uncertainty, °F	Limitations
Liquid-in-glass thermometers				
Mercury-in-glass	Temperature of gases and liquids by contact	–36/1000	0.05 to 3.6	In gases, accuracy affected by radiation
Organic fluid	Temperature of gases and liquids by contact	–330/400	0.05 to 3.6	In gases, accuracy affected by radiation
Resistance thermometers				
Platinum	Precision; remote readings; temperature of fluids or solids by contact	–430/1800	Less than 0.0002 to 0.2	High cost; accuracy affected by radiation in gases
Rhodium-iron	Transfer standard for cryogenic applications	–460/–400	0.0002 to 0.2	High cost
Nickel	Remote readings; temperature by contact	–420/400	0.02 to 2	Accuracy affected by radiation in gases
Germanium	Remote readings; temperature by contact	–460/–400	0.0002 to 0.2	
Thermistors	Remote readings; temperature by contact	Up to 400	0.0002 to 0.2	
Thermocouples				
Pt-Rh/Pt (type S)	Standard for thermocouples on IPTS-68, not on ITS-90	32/2650	0.2 to 5	High cost
Au/Pt	Highly accurate reference thermometer for laboratory applications	–60/1800	0.1 to 2	High cost
Types K and N	General testing of high temperature; remote rapid readings by direct contact	Up to 2300	0.2 to 18	Less accurate than Pt-Rh/Pt or Au/Pt thermocouples
Iron/Constantan (type J)	Same as above	Up to 1400	0.2 to 10	Subject to oxidation
Copper/Constantan (type T)	Same as above; especially suited for low temperature	Up to 660	0.2 to 5	
Ni-Cr/Constantan (type E)	Same as above; especially suited for low temperature	Up to 1650	0.2 to 13	
Bimetallic thermometers	For approximate temperature	–4/1200	2, usually much more	Time lag; unsuitable for remote use
Pressure-bulb thermometers				
Gas-filled bulb	Remote reading	–100/1200	4	Use caution to ensure installation is correct
Vapor-filled bulb	Remote testing	–25/500	4	Use caution to ensure installation is correct
Liquid-filled bulb	Remote testing	–60/2100	4	Use caution to ensure installation is correct
Optical pyrometers	For intensity of narrow spectral band of high-temperature radiation (remote)	1500 and up	30	Generally requires knowledge of surface emissivity
Infrared (IR) radiometers	For intensity of total high-temperature radiation (remote)	Any range		
IR thermography	Infrared imaging	Any range		Generally requires knowledge of surface emissivity
Seger cones (fusion pyrometers)	Approximate temperature (within temperature source)	1200/3600	90	

Common Temperature Measurement Techniques

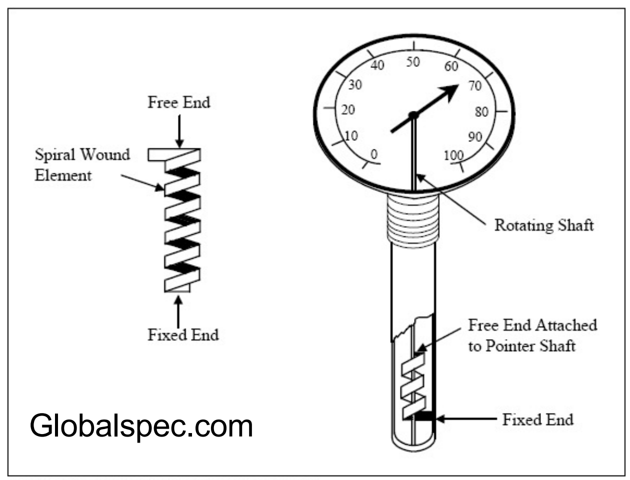
Liquid-in-Glass Mercy
(Discontunied as of March 2011)

Resistance thermometers

Thermocouple



Liquid-in-Glass



Bimetallic Thermometers

Common Temperature Measurement Techniques

Measurement Means	Application	Approximate Range, °F	Uncertainty, °F	Limitations
Liquid-in-glass thermometers				
Mercury-in-glass	Temperature of gases and liquids by contact	–36/1000	0.05 to 3.6	In gases, accuracy affected by radiation
Organic fluid	Temperature of gases and liquids by contact	–330/400	0.05 to 3.6	In gases, accuracy affected by radiation
Resistance thermometers				
Platinum	Precision; remote readings; temperature of fluids or solids by contact	–430/1800	Less than 0.0002 to 0.2	High cost; accuracy affected by radiation in gases
Rhodium-iron	Transfer standard for cryogenic applications	–460/–400	0.0002 to 0.2	High cost
Nickel	Remote readings; temperature by contact	–420/400	0.02 to 2	Accuracy affected by radiation in gases
Germanium	Remote readings; temperature by contact	–460/–400	0.0002 to 0.2	
Thermistors	Remote readings; temperature by contact	Up to 400	0.0002 to 0.2	

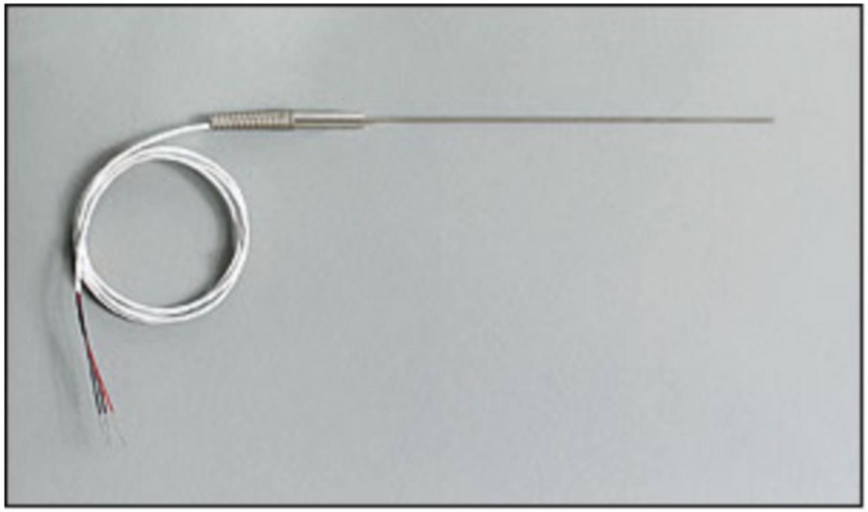
Resistance Temperature Devices

- Categorized by the material:
  - Platinum
  - Rhodium-iron
  - Nickel
  - Nickel-iron
  - Tungsten
  - Copper
- Also by:
  - Simple circuit designs
  - High degree of linearity
  - Good sensitivity
  - Excellent stability
- What's the selection criteria?

Resistance Temperature Devices

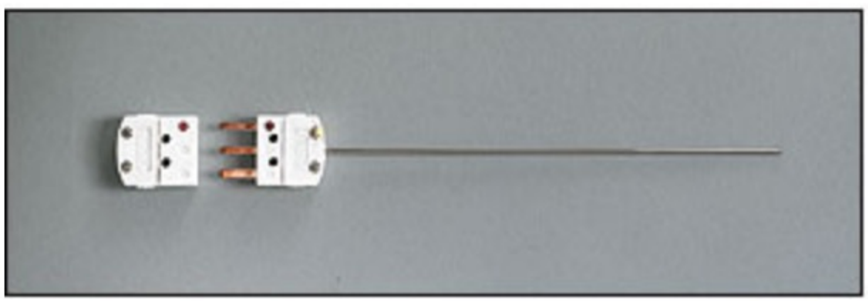
- Platinum RTDs:
  - Widely used for HVAC applications
  - Are extremely stable and corrosion-resistant
  - Are highly malleable and can thus be drawn into fine wires
  - Can be manufactured inexpensively as thin films
  - Have wide range of applications from 13.8033 K (triple point of equilibrium hydrogen) to 1234.93 K (freezing point of silver)
  - Have one of the most linear relationships
  - Designed with a resistance of 100 Ω at 32 °F

Resistance Temperature Devices

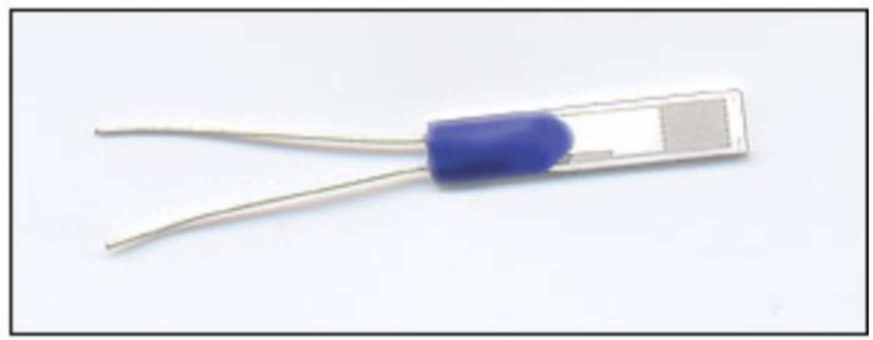


Thick Film Omega Film Element

Glass sealed Biflar Winding



Typical RTD Probes



Thin Film Omega TFD Element

Omega.com

Thermocouples

- When two wires of dissimilar metals are joined by soldering, welding, or twisting, they form a thermocouple junction or "thermo-junction"
- An electromotive force (emf) that depends on the wire materials and the junction temperature exists between the wires. This is known as the Seebeck voltage
- The most common instruments of temperature measurement for the range of 32 to 1800°F (except platinum resistance thermometers)
- Because of their low cost, moderate reliability, and ease of use, thermocouples are widely accepted

Thermocouples

Table 2 Thermocouple Tolerances on Initial Values of Electromotive Force Versus Temperature

Thermocouple Type	Material Identification	Temperature Range, °F	Reference Junction Tolerance at 32°F[a] Standard Tolerance (whichever is greater)	Reference Junction Tolerance at 32°F[a] Special Tolerance (whichever is greater)
T	Copper versus Constantan	32 to 700	±1.8°F or ±0.75%	±0.9°F or ±0.4%
J	Iron versus Constantan	32 to 1400	±4°F or ±0.75%	±2°F or ±0.4%
E	Nickel-10% Chromium versus Constantan	32 to 1600	±3.1°F or ±0.5%	±1.8°F or ±0.4%
K	Nickel-10% Chromium versus 5% Aluminum, Silicon	32 to 2300	±4°F or ±0.75%	±2°F or ±0.4%
N	Nickel-14% Chromium, 1.5% Silicon versus Nickel-4.5% Silicon, 0.1% Magnesium	32 to 2300	±4°F or ±0.75%	±2°F or ±0.4%
R	Platinum-13% Rhodium versus Platinum	32 to 2700	±2.7°F or ±0.25%	±1.1°F or ±0.1%
S	Platinum-10% Rhodium versus Platinum	32 to 2700	±2.7°F or ±0.25%	±1.1°F or ±0.1%
B	Platinum-30% Rhodium versus Platinum-6% Rhodium	1600 to 3100	±0.5%	±0.25%
T[b]	Copper versus Constantan	−328 to 32	±1.8°F or ±1.5%	c
E[b]	Nickel-10% Chromium versus Constantan	−328 to 32	±3.1°F or ±1%	c
K[b]	Nickel-10% Chromium versus 5% Aluminum, Silicon	−328 to 32	±4°F or ±2%	c

Source: ASTM *Standard* E230, Temperature-Electromotive Force (EMF) Tables for Standardized Thermocouples.

[a]Tolerances in this table apply to new thermocouple wire, normally in the size range of 0.01 to 0.1 in. diameter and used at temperatures not exceeding the recommended limits. Thermocouple wire is available in two grades: standard and special.

[b]Thermocouples and thermocouple materials are normally supplied to meet the tolerance specified in the table for temperatures above 32°F. The same materials, however, may not fall within the tolerances given in the second section of the table when operated below freezing (32°F). If materials are required to meet tolerances at subfreezing temperatures, the purchase order must state so.

[c]Little information is available to justify establishing special tolerances for below-freezing temperatures. Limited experience suggests the following special tolerances for types E and T thermocouples:

Type E −328 to 32°F; ±2°F or ±0.5% (whichever is greater)

Type T −328 to 32°F; ±1°F or ±0.8% (whichever is greater)

These tolerances are given only as a guide for discussion between purchaser and supplier.

CLASS ACTIVITY

Class Activity

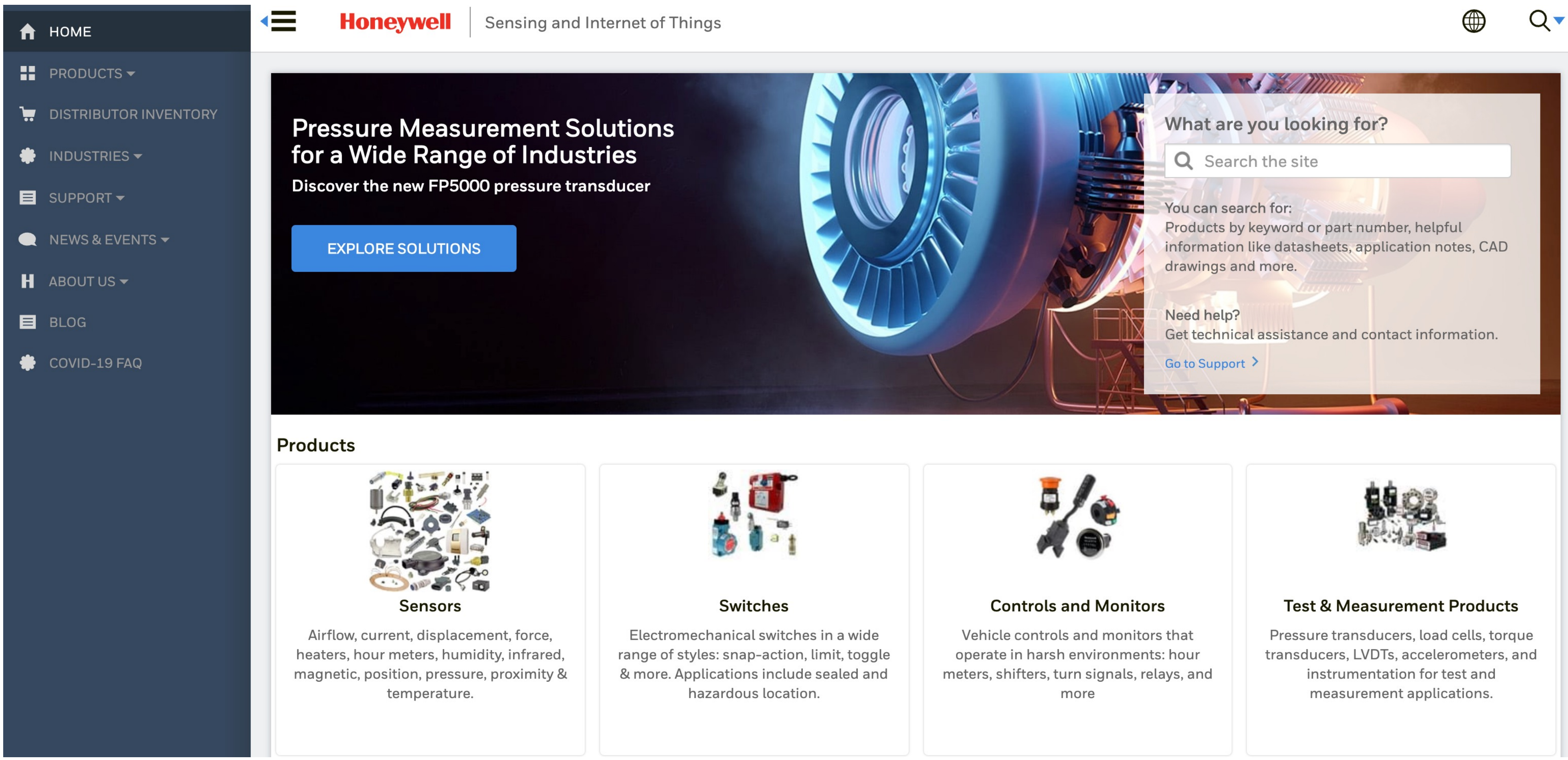
- Form 2-3 groups

- Fill in the spreadsheet (at least 10 sensors and 4 variables):
- https://docs.google.com/spreadsheets/d/1duxKfuy1kpYNJxXT6e9bHjVBBqUXnwBSBuR8Dkz4f7c/edit#gid=0

- You can use the materials in the next slides

Class Activity

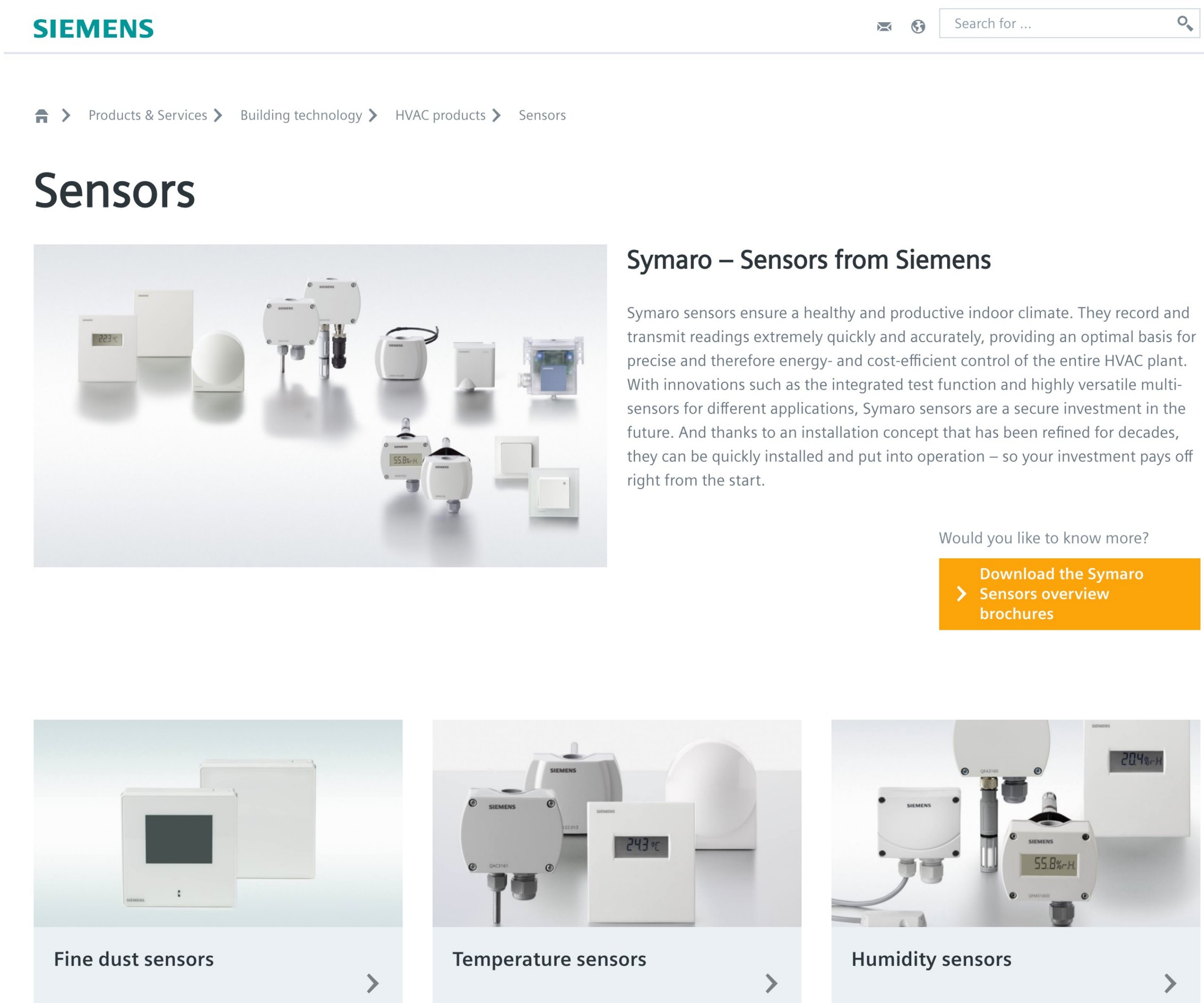
- Some sources



https://sensing.honeywell.com/2

Class Activity

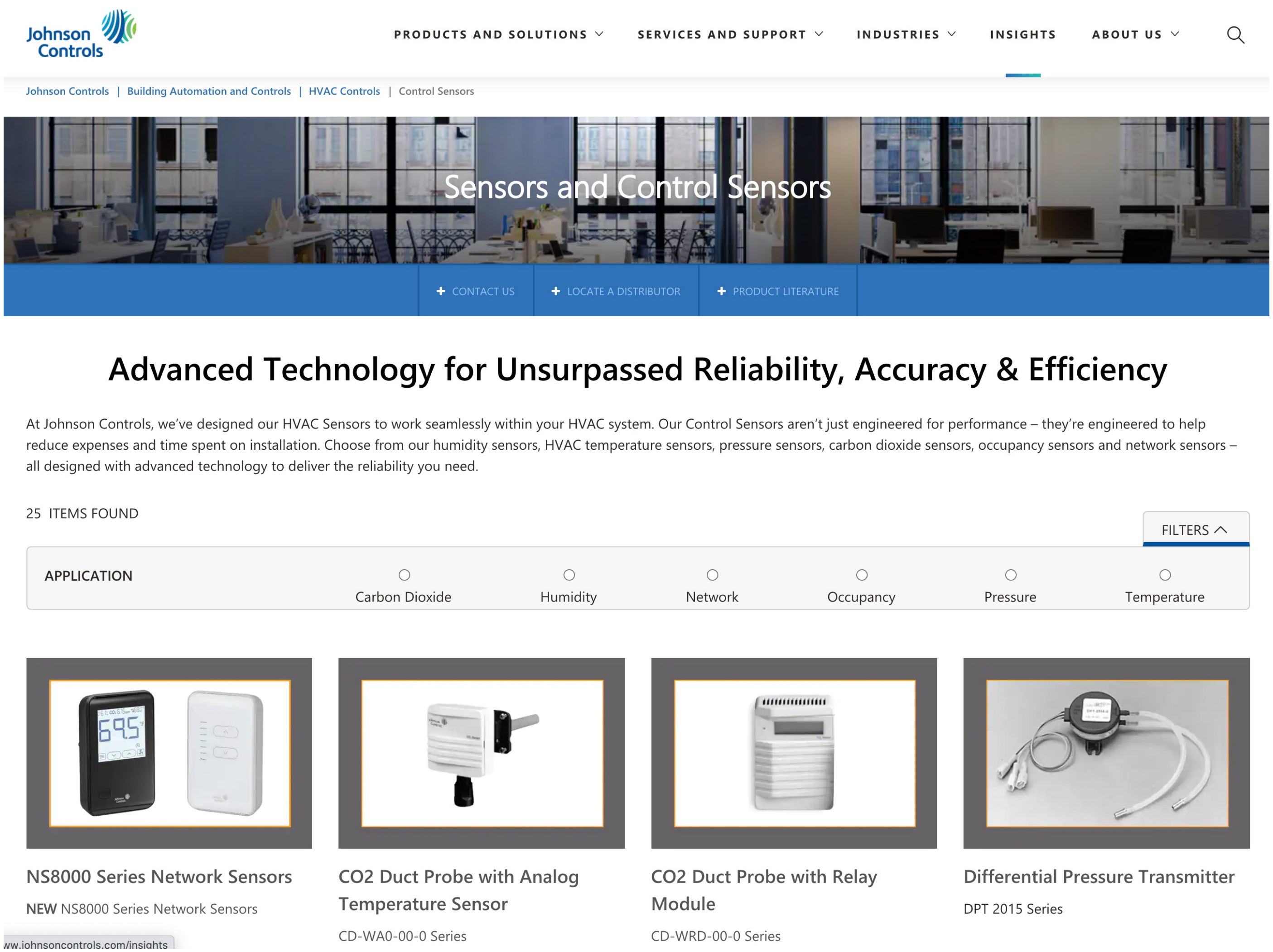
- Some sources



https://new.siemens.com/global/en/products/buildings/hvac/sensors.html

Class Activity

- Some sources

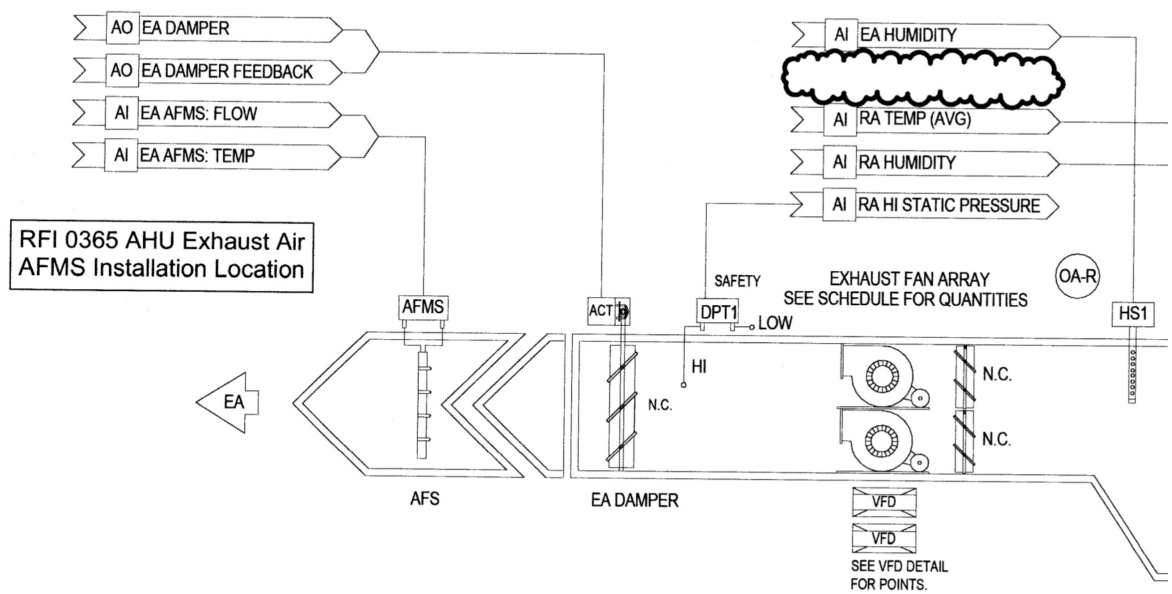


https://www.johnsoncontrols.com/building-automation-and-controls/hvac-controls/control-sensors

SIGNAL TYPES

Signal Types

- Signal Types:
  - ❑ Analog (mostly current or voltage)
    - ❖ Analog Input (AI)
    - ❖ Analog Output (AO)
  - ❑ Digital (discrete signals)
    - ❖ Digital Input (DI)
    - ❖ Digital Output (DO)



Signal Types

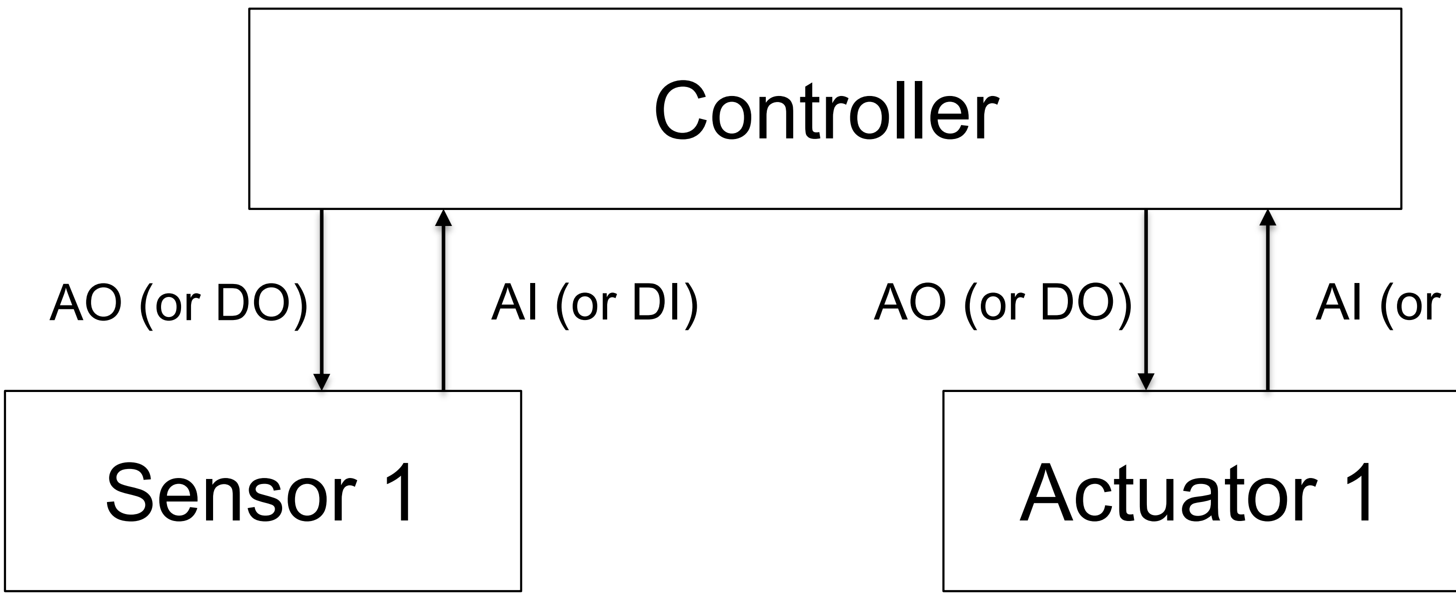
- The consideration of inputs and outputs are relative to the context. For example:

  - ❑ Power input to the sensor and output of the sensor
    - ❖ Sensor power input (e.g., 12 VDC)
    - ❖ Sensor output (e.g., 4-20 mA)

  - ❑ For the integration with building automation system, we consider the output of the sensor as the input of the controller:
    - ❖ Analog input: such as a signal from a temperature sensor to a controller
    - ❖ Analog output: such as a signal from a controller to a damper

Class Activity

- In the context of building automation system (meaning the inputs/outputs to the controller is the reference), let's look at some examples:



https://docs.google.com/spreadsheets/d/1duxKfuy1kpYNJxXT6e9bHjVBBqUXnwBSBuR8Dkz4f7c/edit#gid=991645145

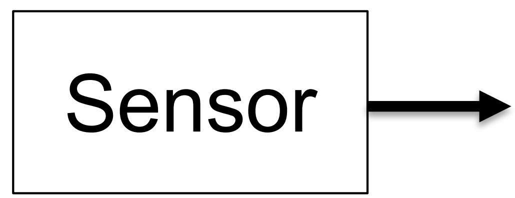
Class Activity

- The completed table is as follow:

Point Description	Output		Input	
	Digital	Analog	Digital	Analog
Supply air temperature				x
Compressor stage (e.g., 1, 2, 3)	x			
Lighting fixtures (on/off)	x			
VFD (start/stop)	x			
Return air temperature				x
Duct static pressure				x
Humidity				x
Supply fan status (on/off)			x	
VFD (speed)		x		
Smoke detector			x	
Damper position		x		

Class Activity

- Summary:
  - AI: Can be used to send a sensor measurement (e.g., supply air temperature)
  - DI: Can be used to indicate if a device is turned on or not (e.g., status)
  - AO: Control the speed or position of a device, (e.g., VFD)
  - DO: Open and close relays and switches (e.g., turn on lights)



SENSOR OUTPUT SIGNAL

Sensor Output Signal

- Analog output:
  - ❑ Can be used to read a variable measurement
  - ❑ Examples are temperature, humidity and pressure sensor (e.g., 4-20 mA, 0-10 volt)

Sensor Output Signal

- 0-10 Volt analog outputs:
  - Advantages:
    - Ease of verification of the output signal on sites with connecting a voltmeter in series
    - Correlate the voltage reading reading to the range on the sensor
  - Disadvantages:
    - Signals are also more susceptible to electrical interference from devices such as motors or relays leading to inaccurate output signals

Sensor Output Signal

- 4-20 mA analog outputs:
  - ❑ Advantages:
    - ❖ Reading a corresponding output signal can be more cumbersome
    - ❖ Require a precision resistor in conjunction with the sensor to convert the analog signal to a voltage signal using a voltmeter
    - ❖ The output signal offers increased immunity in a noisy environment
  - ❑ Disadvantages:
    - ❖ Ease of validation and verification during installation and operation

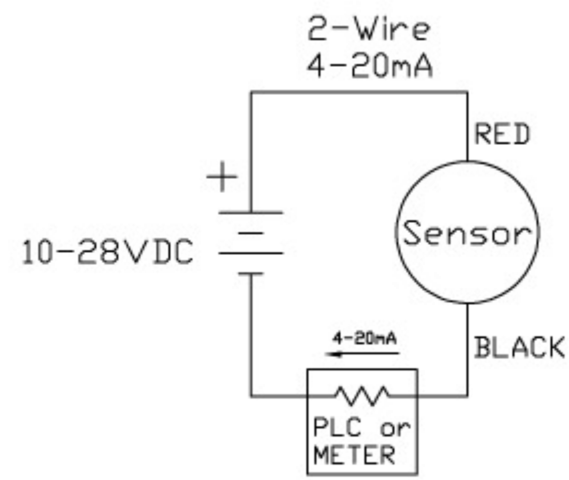
Sensor Output Signal

- 4 to 20 mA current output signal:
  - ❑ It is mostly used in a series circuit for a robust measurement signal
  - ❑ It acts like a current source
  - ❑ It create a constant current output for a given measurement independent of the supply voltage or impedance
  - ❑ It can produce the same current output at any particular point in the circuit (Unlike a voltage output)
  - ❑ It is a relatively high-power analog output which can be used in measurement circuits over long distances

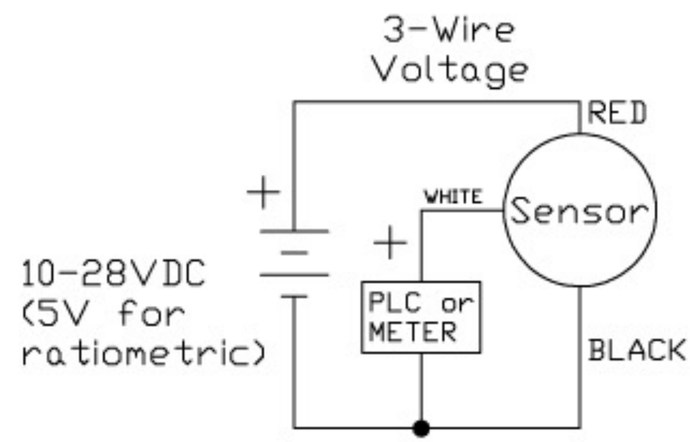
https://www.sensorsone.com/4-to-20-ma-current-loop-output-signal/

Sensor Output Signal

- 4 to 20 mA current output signal:
  - Exist different configurations:
    - A 2-wire configuration (common)



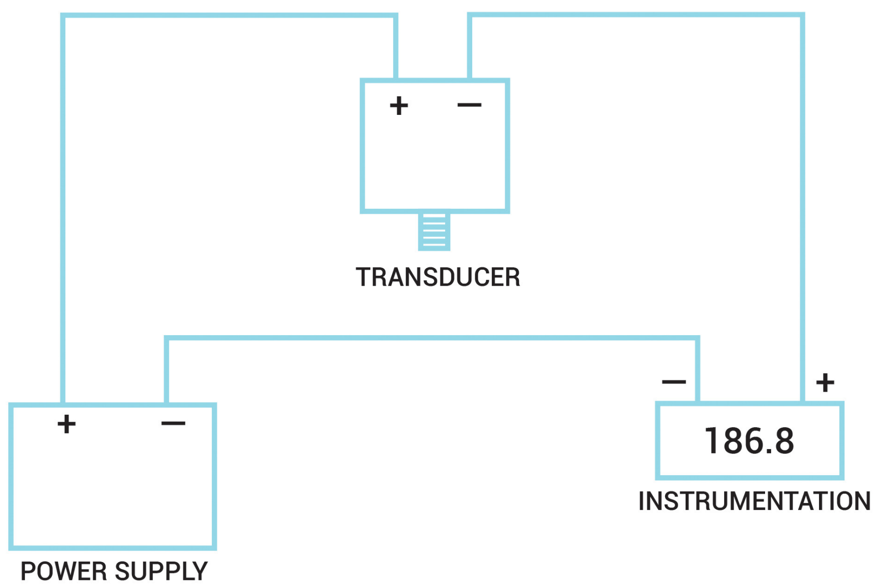
    - 3-wire configurations (0 to 20mA or 4 to 20mA) which includes an output signal with a separate positive supply and output connection



https://www.sensorsone.com/4-to-20-ma-current-loop-output-signal/
https://www.te.com/usa-en/products/sensors/pressure-sensors/pressure-transducers/pressure-sensor-vs-transducer-vs-transmitter.html

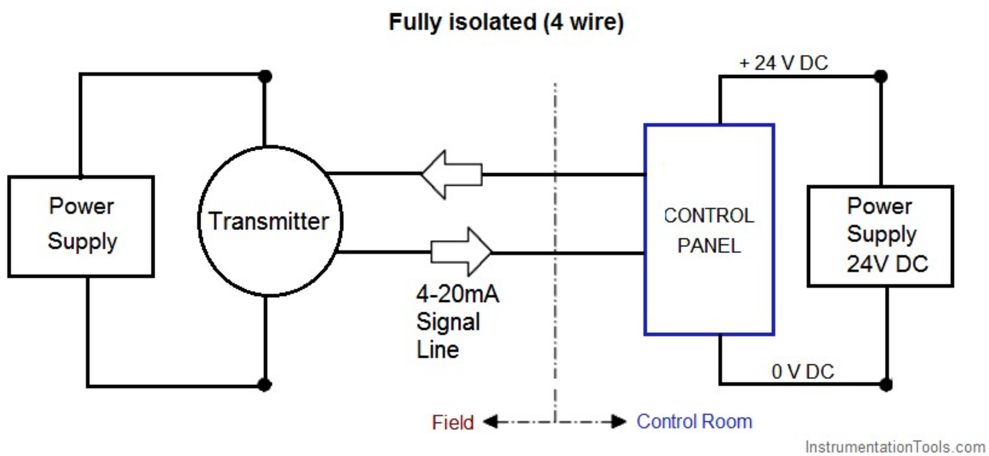
Sensor Output Signal

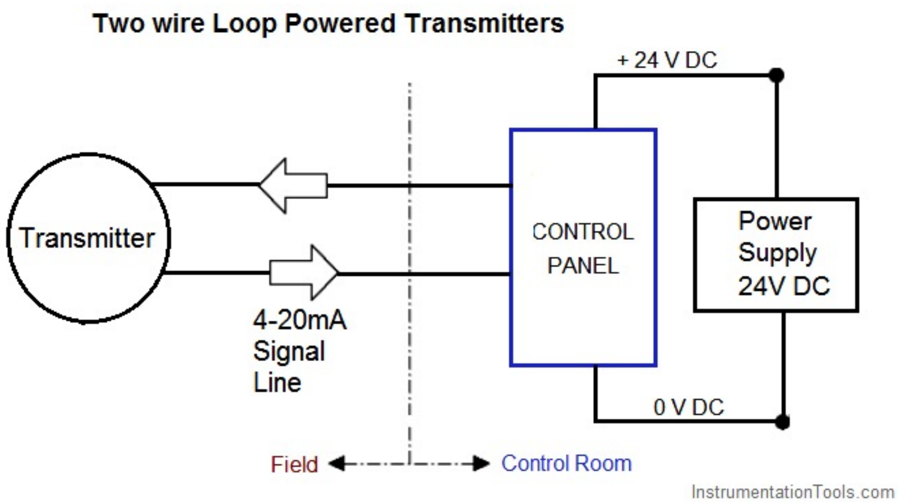
- 4 to 20 mA current output signal:
  - ❑ When connecting to a 4-20mA transmitter to a circuit with a measurement load resistor it is important to ensure that there is sufficient supply voltage available across the transmitter positive and negative supply contacts particularly at full scale output
  - ❑ It is used extensively because of the convenience of 2 wire connections



https://www.sensorsone.com/4-to-20-ma-current-loop-output-signal/

Sensor Output Signal

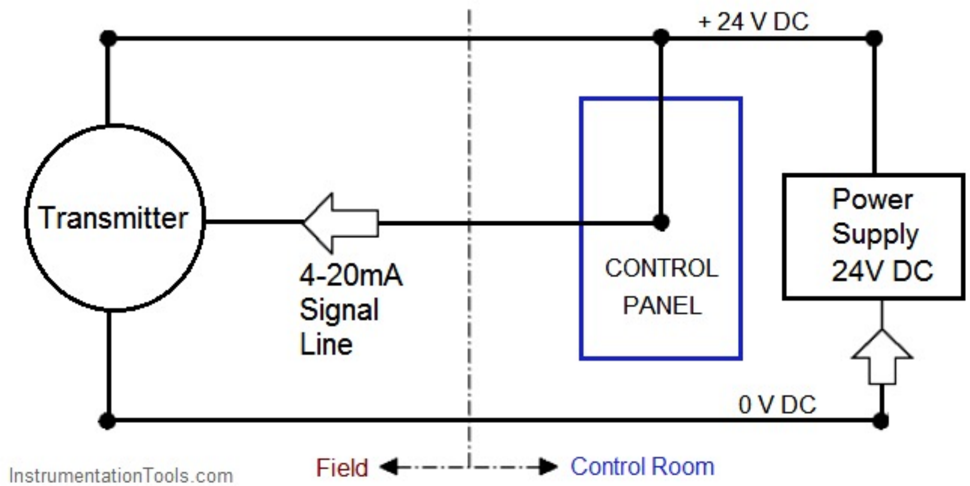




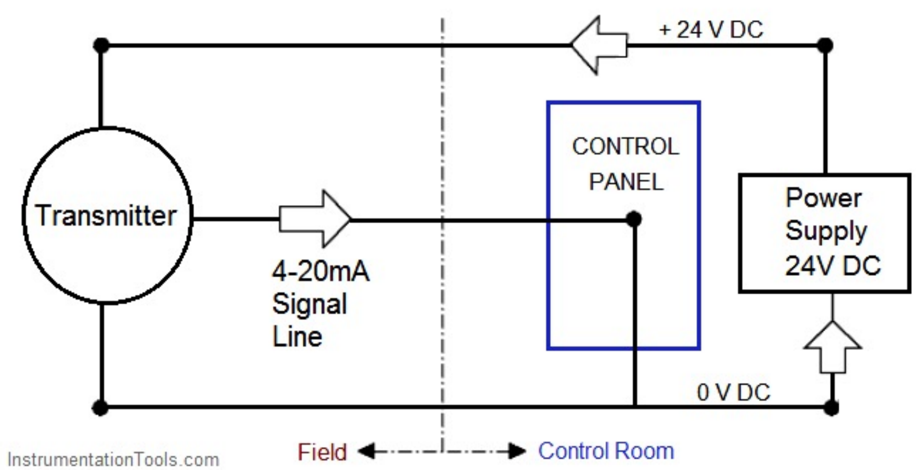
https://instrumentationtools.com/4-20-ma-transmitter-wiring/

Sensor Output Signal

Current Sink Transmitter, Non Isolated (3 wire)



Current Source Transmitter, Non Isolated (3 wire)



https://instrumentationtools.com/4-20-ma-transmitter-wiring/

Sensor Output Signal

- 4 to 20 mA current output signal:
  - ❑ Can be converted to voltage (1 to 5 V) with using a load resistor in series. For example:

$$(4\ to\ 20\ mA) = \frac{1\ to\ 5\ V}{250\ \Omega}$$

https://www.sensorsone.com/4-to-20-ma-current-loop-output-signal/

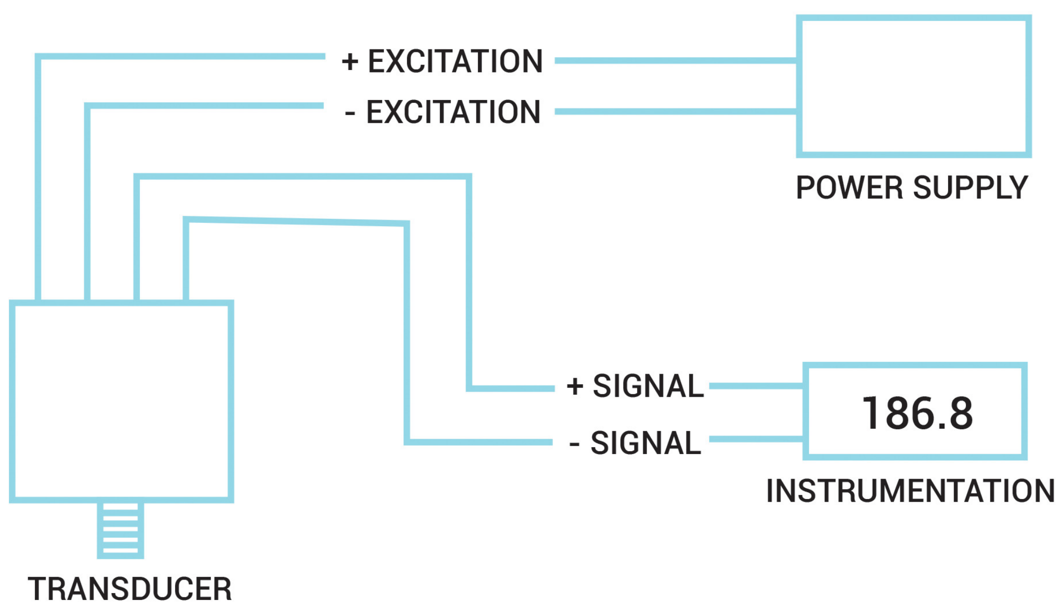
Sensor Output Signal

- Millivolt output:
  - ❑ Is one of the most economical output (e.g., 30mV)
  - ❑ Suitable for small applications
  - ❑ The actual output is directly proportional to the pressure transducer input power or excitation
  - ❑ With a fluctuation in the excitation, the output will change
  - ❑ Due to sensitivity to the excitation level, it is recommended to use regulated power supplies

https://www.omega.com/en-us/resources/pressure-transducers

Sensor Output Signal

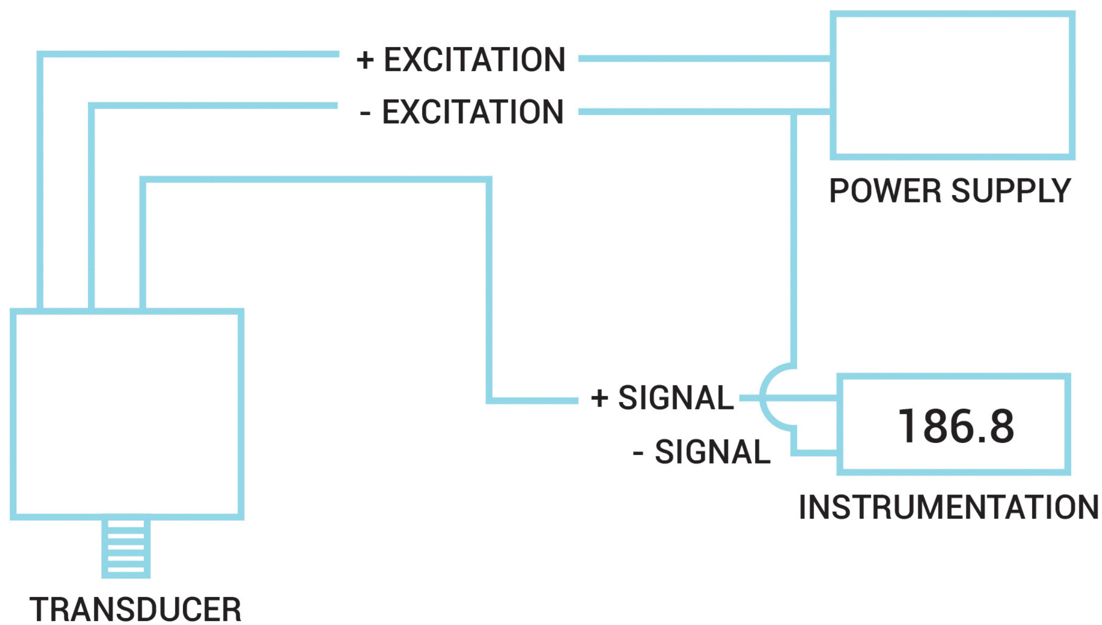
- Millivolt output:
  - ❑ Since the output signal is so low, the sensor is not suitable electrically noisy environments
  - ❑ The distances between the transducer and the readout instrument should also be kept relatively short



https://www.omega.com/en-us/resources/pressure-transducers https://www.omega.com/en-us/resources/pressure-transducers-troubleshooting

Sensor Output Signal

- 0 to 5 VDC (or 0 to 10 VDC):
  - Usually includes a signal conditioning to provide a much higher output than a millivolt
  - The output of the transducer is not normally a direct function of excitation; thus, unregulated power can be used
  - Due to a higher output signal, can be used in noisy environments



https://www.omega.com/en-us/resources/pressure-transducers

https://www.omega.com/en-us/resources/pressure-transducers-troubleshooting

Class Activity

- Let's look at this specs

CAREL

ENG

2. CAREL CODING

1 and 2 Series	3 Type	4 Measurement	5 Humid. sensor	6 Temp. sensor	7 Type of output	8 and 9 Custom	10 Packaging

1 and 2 Series:	DP (Digital sensors)
3- Type:	W = Wall P = Industrial environment D = Duct
4- Measurement:	T = Temperature H = Humidity C = Temperature and Humidity.
5- Type of humidity sensor:	0 = Not present; 1 = 10 to 90% rH; 2 = 0 to 100% rH.
6- Type of temperature sensor:	0 = Not present; 1 = NTC.
7- Type of output:	0 = 0 to 1 Vdc or 4 to 20 mA output; 1 = 0 to 1 V or 4 to 20 mA and NTC resistive output; 2 = 0 to 10 Vdc output; 3 = Modbus/Carel RS485 serial output, not optically-isolated; 4 = Modbus/Carel optically-isolated RS485 serial output; 5 = 0 to 10 V and NTC resistive output.
8 and 9 Custom features:	
10- Packaging:	0 = Single; 1 = Multiple; N = Neutral; * = Customised.

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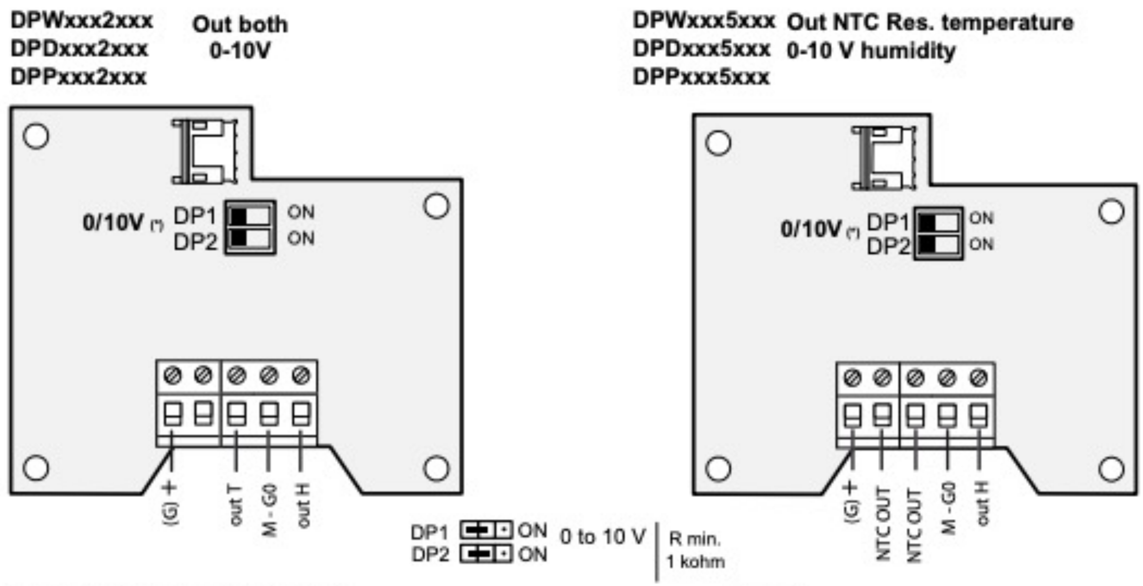
Class Activity

- Let's look at this specs



(*) 0-10 V version= default configuration

Fig. 4.a

Key:

out T	=	temperature output -0.5 to 1 Vdc or 0 to 1 Vdc or 4 to 20 mA for models (DPxxxx0 or 1);
out T	=	temperature output 0 to 10 Vdc for models (DPxxxx2 or 5);
out H	=	humidity output - 0.5 to 1 Vdc or 0 to 1 Vdc or 4 to 20 mA for models (DPxxxx0 or 1);
out H	=	humidity output 0 to 10 Vdc for models (DPxxxx2 or 5);
out NTC	=	output with NTC resistive sensor 10K at 25°C (Carel standard);
M(G0)	=	reference for both power supply and outputs;
+ (G)	=	power supply (12 to 24 Vac or 8 to 32 Vdc).

Note:

- with output configured for 0 to 1 Vdc or 0-10Vdc the load must be >1K Ω;
- with output configured for 4 to 20 mA the load must be < 100 Ω;
- with NTC resistive output the two signals are isolated from the reference M(G0).

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CLASS ACTIVITY