CAE 438/538 Control of Building Environmental Systems

Fall 2021

September 07, 2021

Instrumentation (2)

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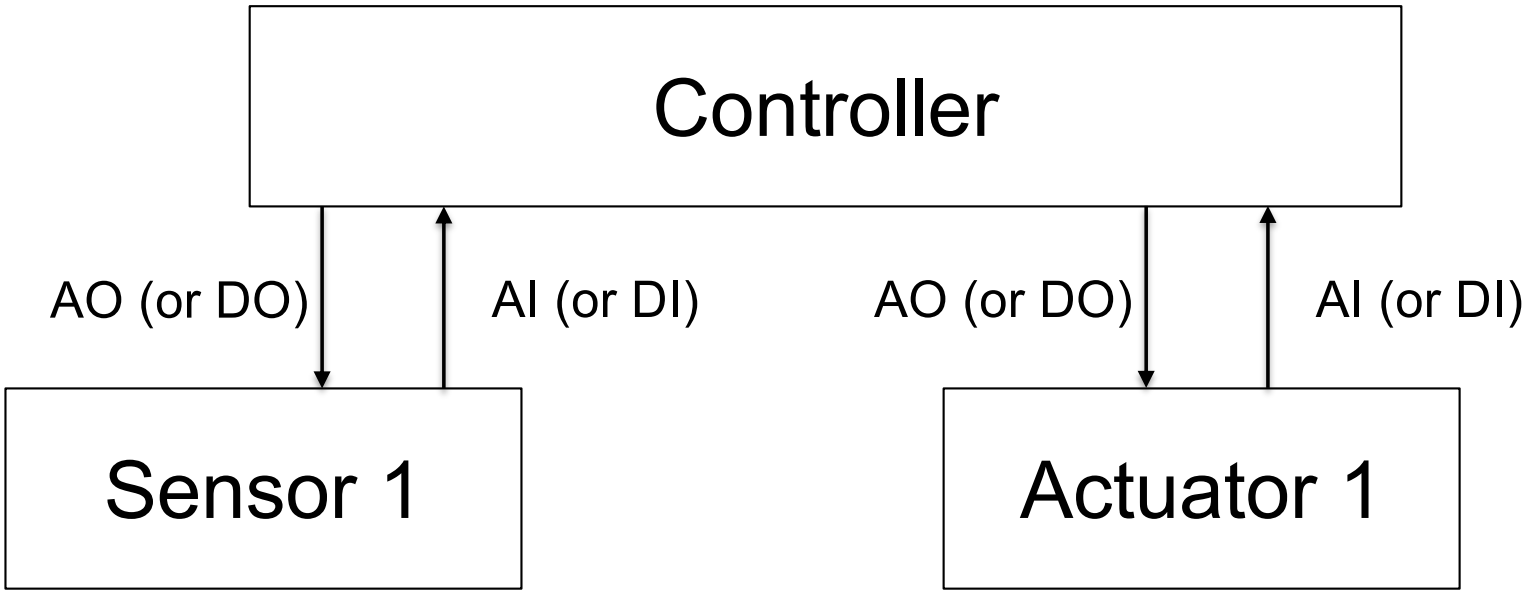
Dr. Mohammad Heidarinejad, Ph.D., P.E.
Civil, Architectural and Environmental Engineering
Illinois Institute of Technology
muh182@iit.edu

Recap

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

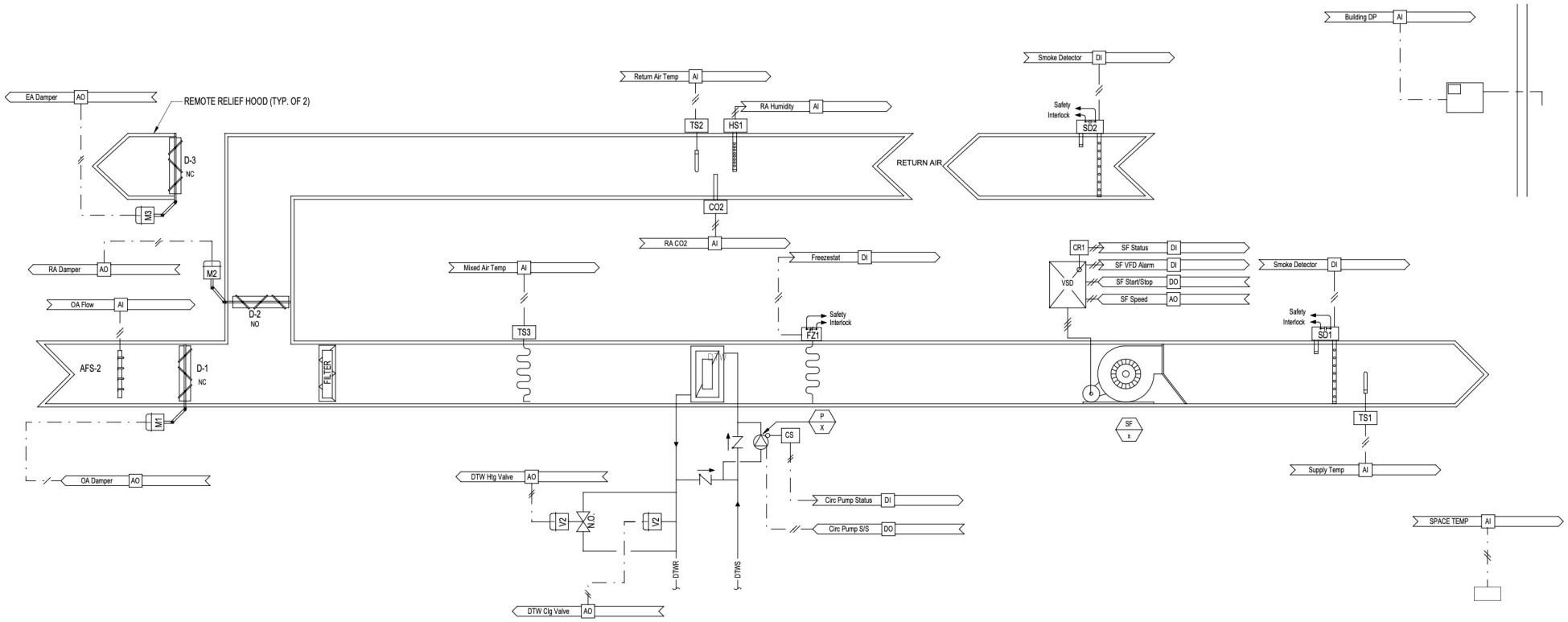
Recap

- We look at the context of building automation system to define inputs and outputs to a controller:



Recap

- It is always good to look at drawings from different design firms:



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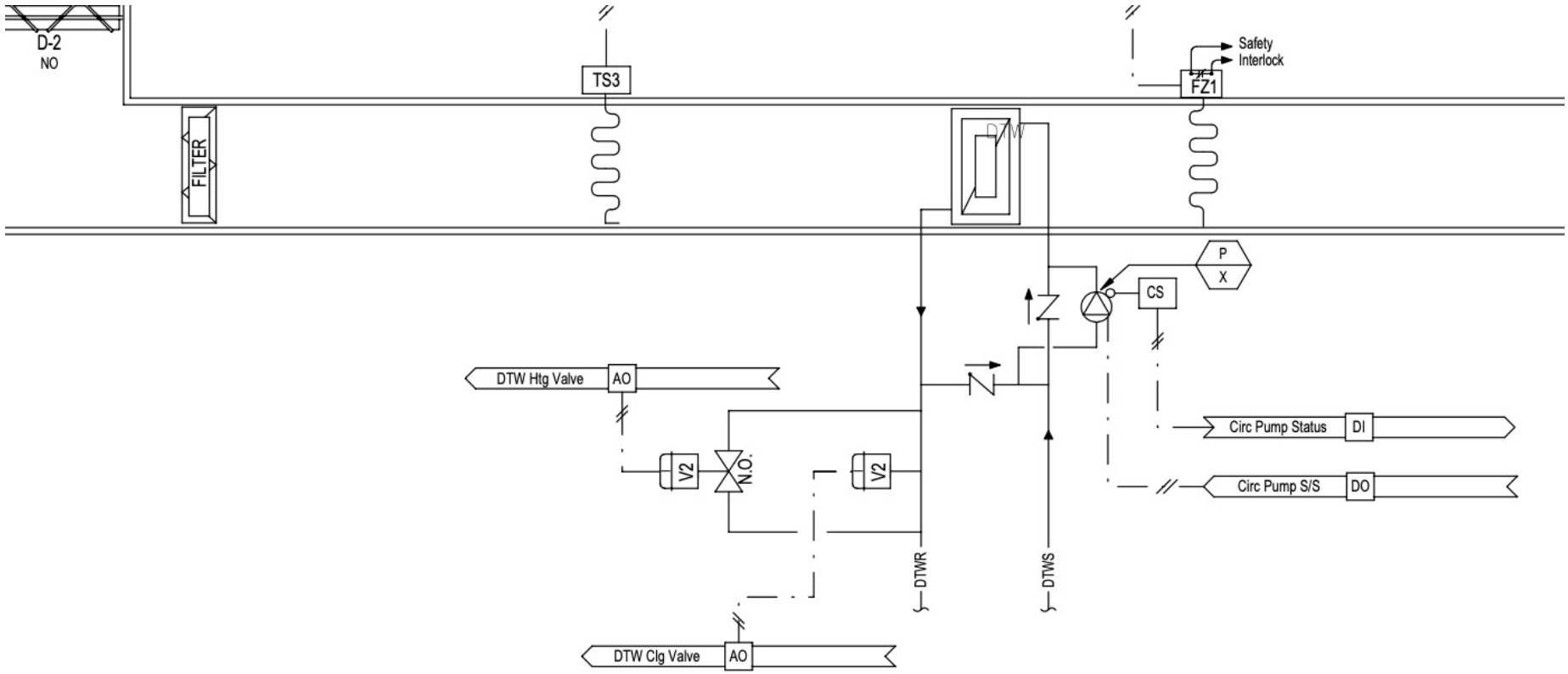
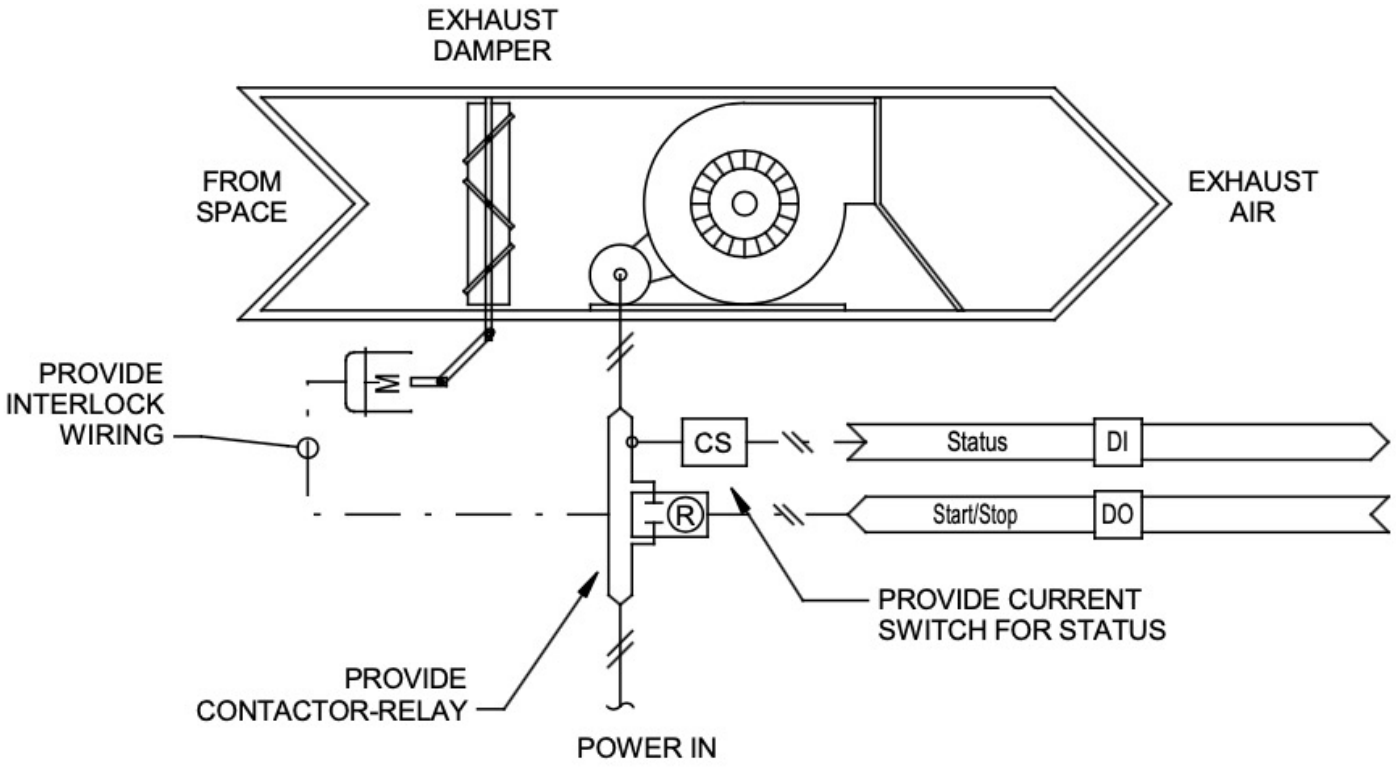


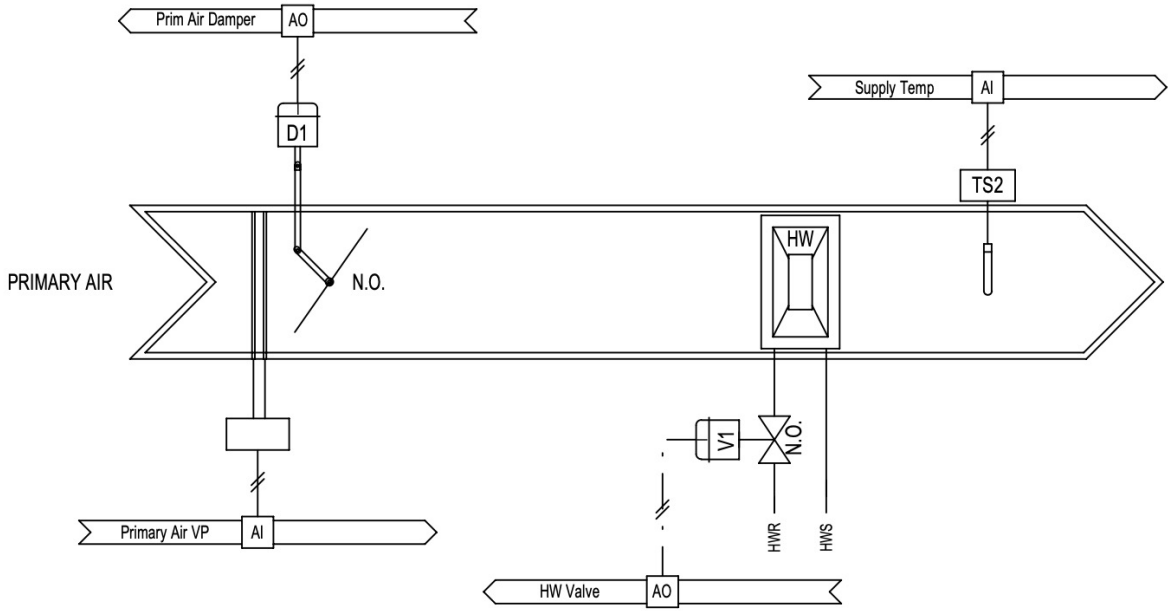
Recap

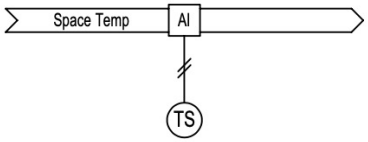
- System vs. component



TYPICAL - TOILET EXHAUST FAN - EF-1, 3, 4, 5, 6, 15, 23

Recap





POINTS LIST							
ADDRESS	POINT DESCRIPTOR	POINT TYPE					REMARKS
		DI	AI	DO	AO	VP	
	Space Temp		◦				Typ. for all VAV Boxes
	Prim Air Damper				◦		Typ. for all VAV Boxes
	Primary Air Flow		◦				Typ. for all VAV Boxes
	Supply Air Temp		◦				Typ. for all VAV Boxes
	HW Heating Valve				◦		Typ. for all VAV Boxes
	Dx Cooling Enable			◦			Typ. for 3 rooms
TOTALS		--	4	--	3		

Recap

- 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)

Recap

- 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

Recap

- 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)

Recap

There are two types of measurements:

- Primary measurements
- Derived measurements

Recap

- Sensor
- Transducer
- Transmitter

Recap

- Two main types of data transmission:
  - Hard-wired
  - Wireless

Recap

- Data acquisition is an 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

CLASS ACTIVITY

Class Activity

- Form 3 or 4 groups

- Look at “cae438_538_f21 lecture03 Instrumentation M703_T …” file on Blackboard

- Each pick one system and fill in the spreadsheet: https://docs.google.com/spreadsheets/d/1duxKfuy1kpYNJxXT6e9bHjVBBqUXnwBSBuR8Dkz4f7c/edit#gid=1342152195

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?

Temperature Sensors

- Temperature-sensing elements generally detect changes in either
  - ❑ Relative dimension (caused by differences in thermal expansion)
  - ❑ The state of a vapor or liquid
  - ❑ Some electrical property
- Within each category, there are a variety of sensing elements to measure room, duct, water, and surface temperatures

Temperature Sensors

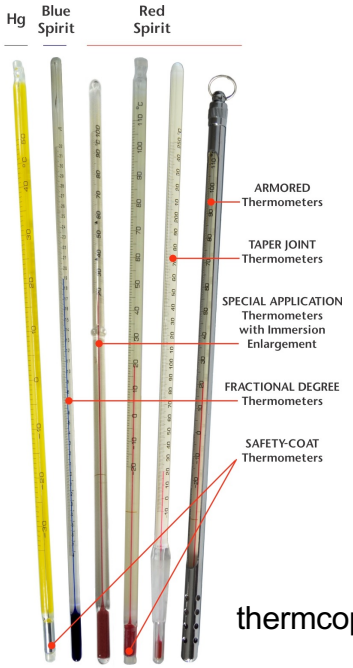
- For example, in the case of temperature, common sensor types are:
  - Thermistor (electric resistance decreases as temperature increases)
  - RTDs (resistance temperature devices): Electric resistance increases as temperature increases

Common Temperature Measurement Techniques

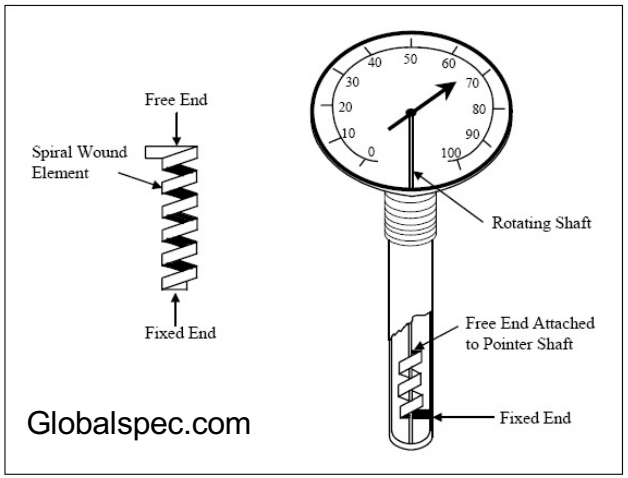
Liquid-in-Glass Mercy
(Discontinued as of March 2011)

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	
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

Measurement Means	Application	Approximate Range, °F	Uncertainty, °F	Limitations
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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

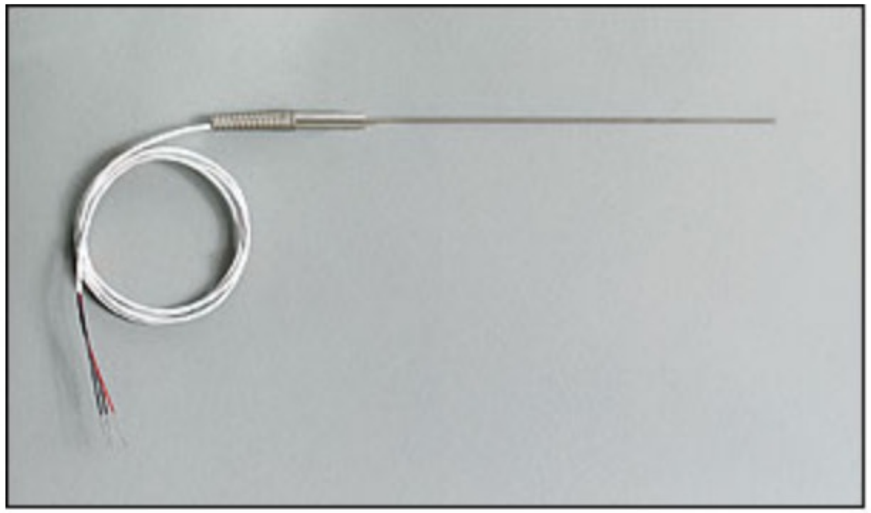
- Also by:
  - Simple circuit designs
  - High degree of linearity
  - Good sensitivity
  - Excellent stability

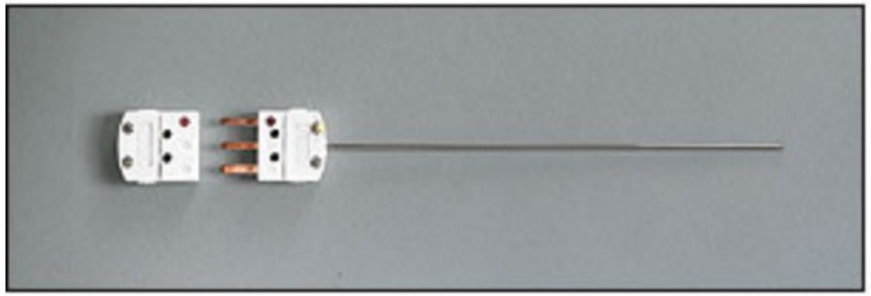
Resistance Temperature Devices

- 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 1000 Ω at 32 $^{\circ}\mathrm{F}$

- The most Platinum RTDs is ”Pt-1000-sensor”
  - 0 $^{\circ}C$ = 1000 Ω
  - Temperature increases or decreases by 3.85 Ω/K

Resistance Temperature Devices

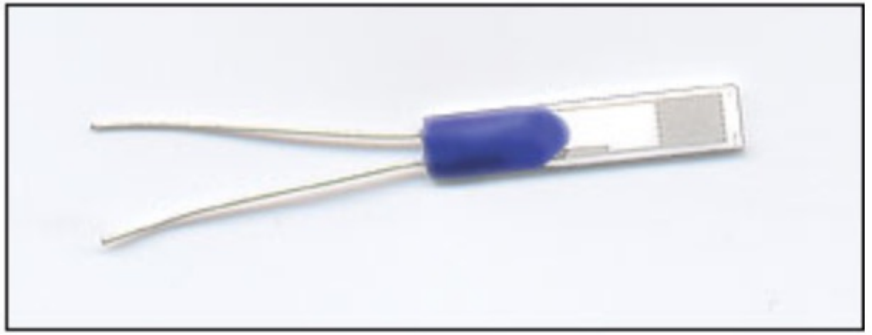




Typical RTD Probes

Thick Film Omega Film Element

Glass sealed Biflar Winding

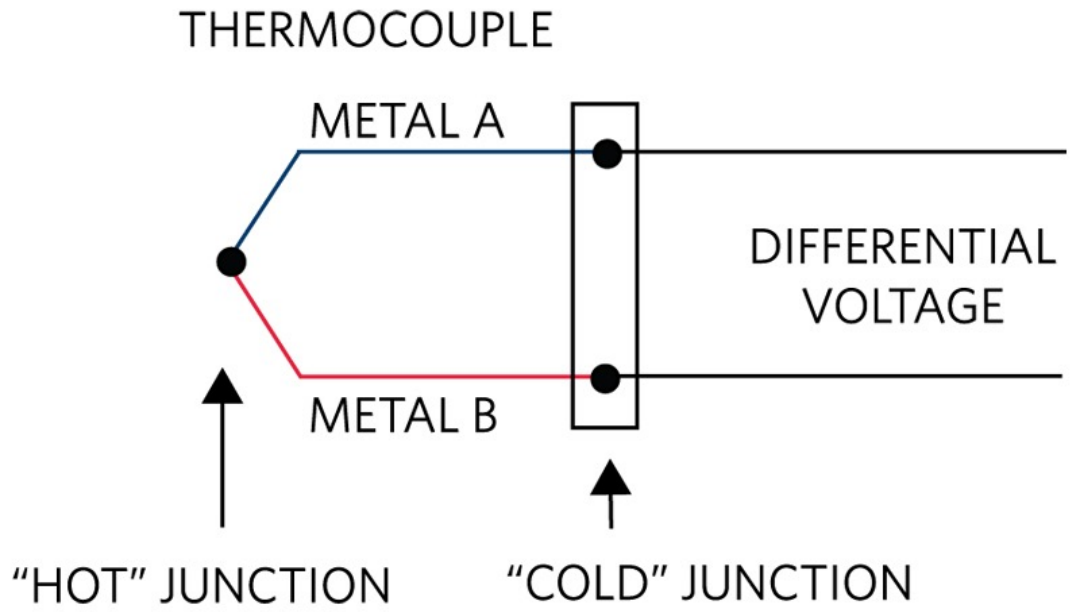


Thin Film Omega TFD Element

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 (create a voltage)



https://www.powersystemsdesign.com/articles/the-abcs-of-thermocouples/39/12198b

Thermocouples

- Thermocouples are:
  - ❑ 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)	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:

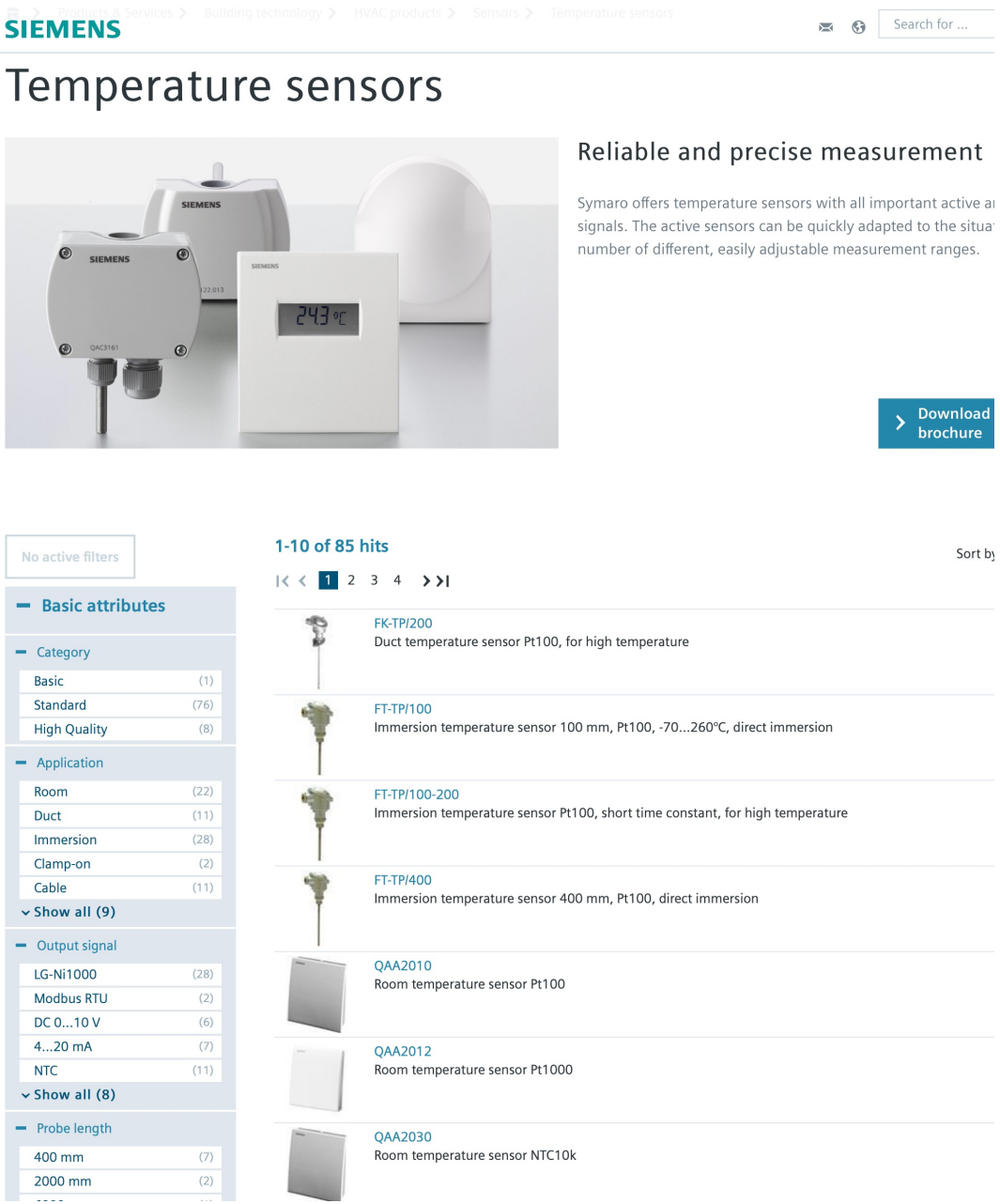
Type E −328 to 32°F; ±2°F or ±0.5% (whichever is greater)

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.

Temperature Sensors

- Some sources



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

Some Resources

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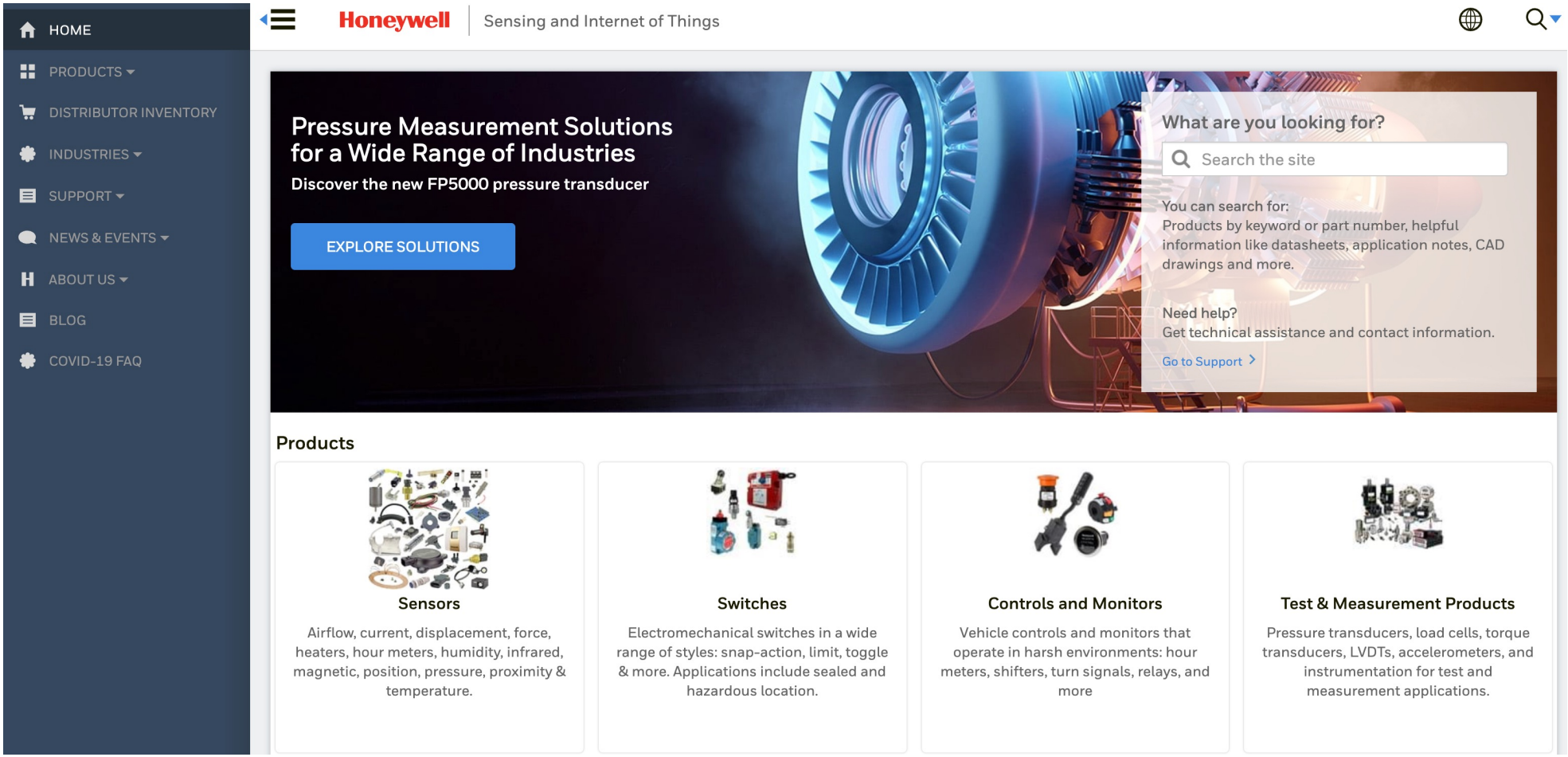

https://sensing.honeywell.com/2

Some Resources

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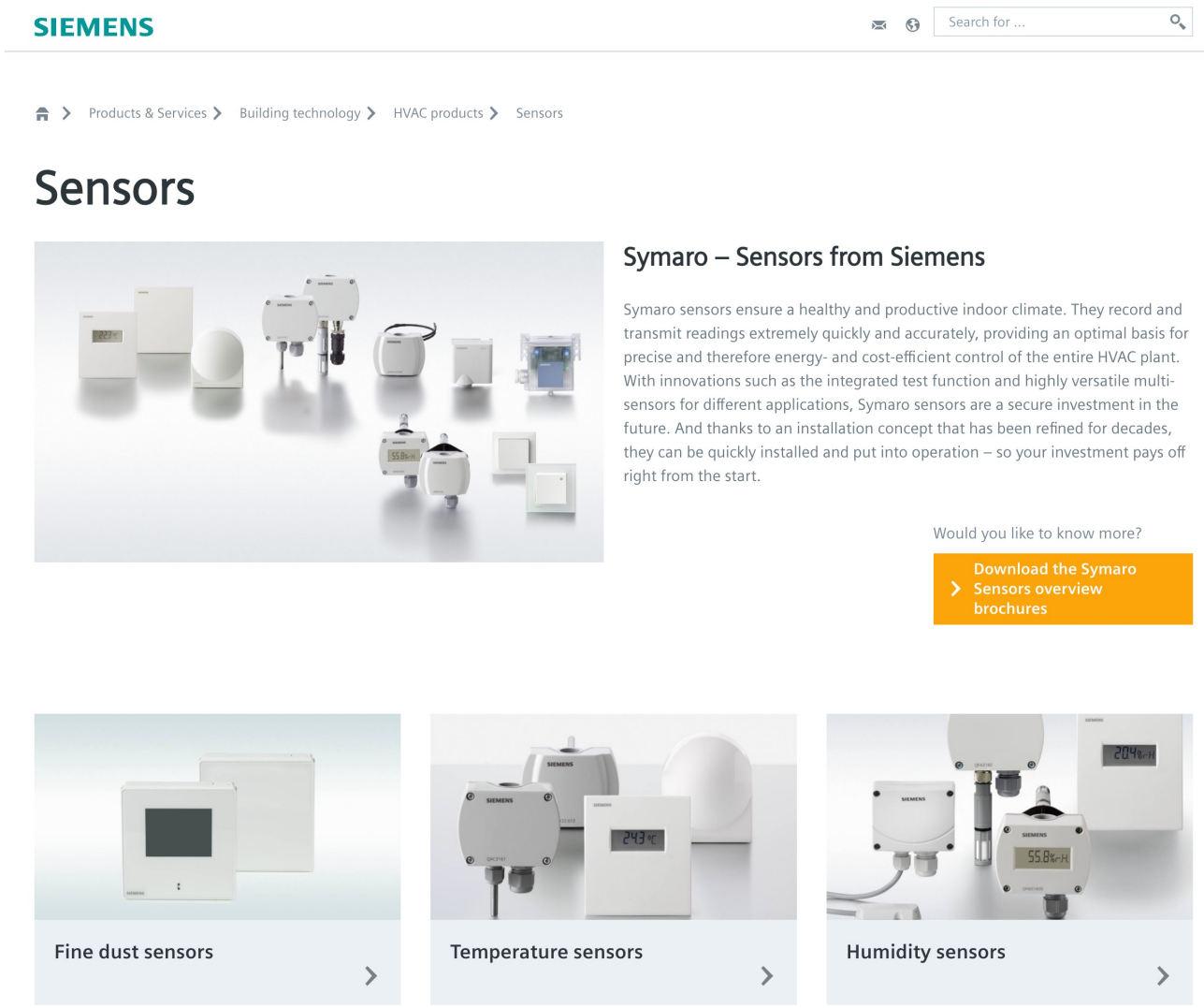

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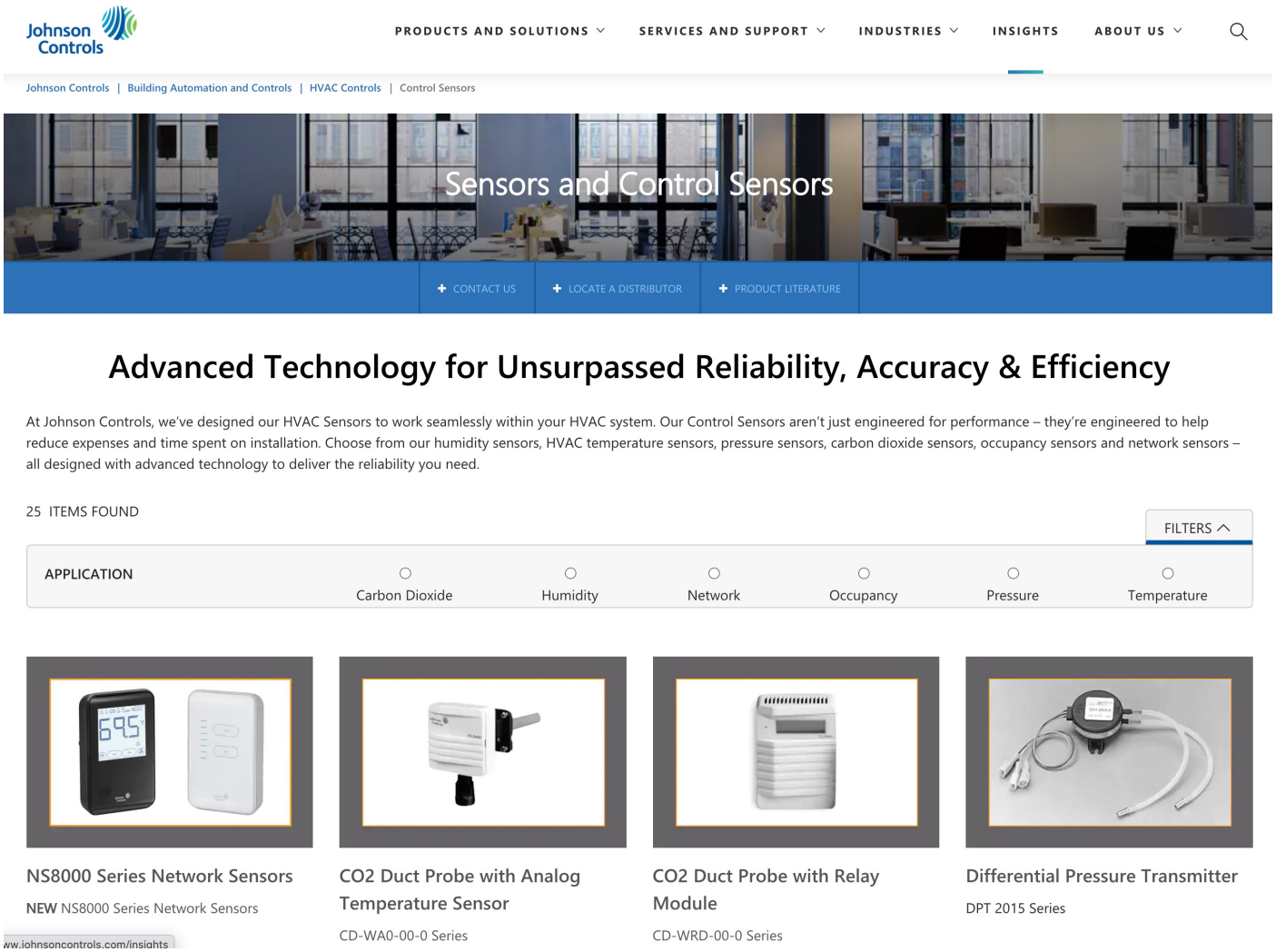

https://www.johnsoncontrols.com/building-automation-and-controls/hvac-controls/control-sensors

Some Resources

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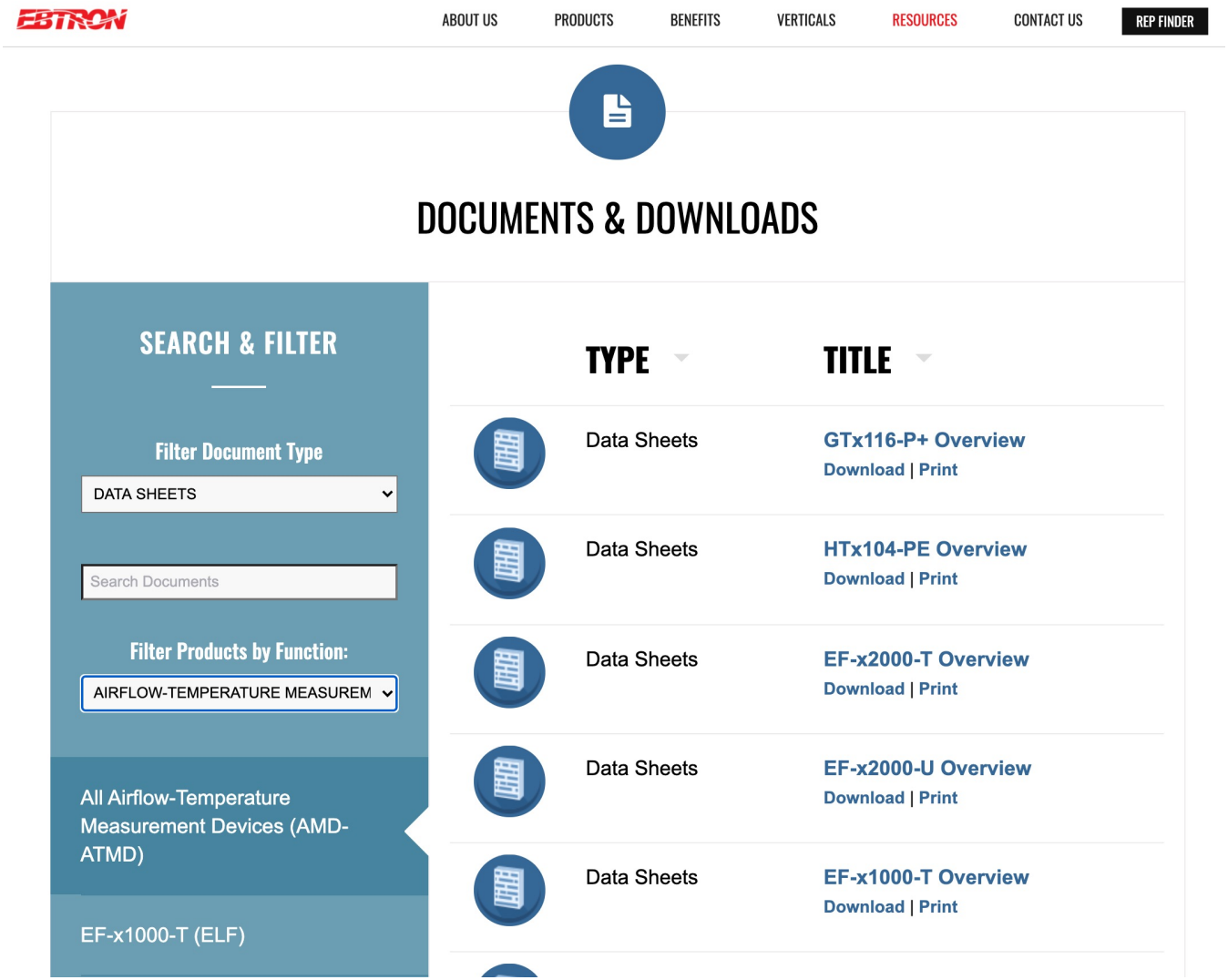

https://ebtron.com/document-library/

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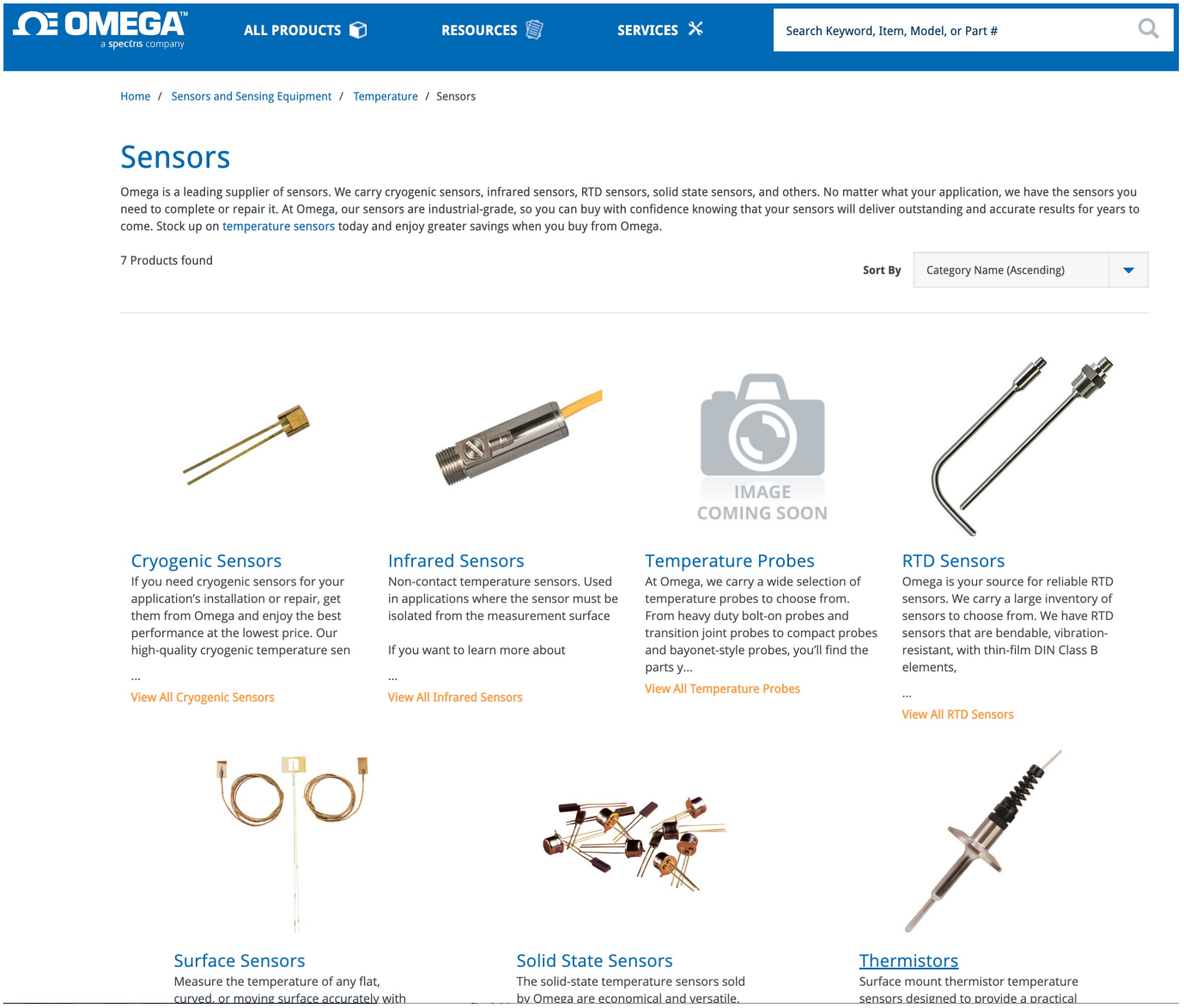

https://www.omega.com/en-us/sensors-and-sensing-equipment/temperature/c/sensors

Some Resources

- Some sources

Humidity and Temperature Transmitters HMD60

±1.5%RH transmitters for demanding HVAC, with a certificate

5 YEAR WARRANTY

The sturdy and reliable duct mounted Vaisala HUMICAP® Humidity Transmitter Series HMD60 is designed for monitoring relative humidity in demanding HVAC and light industrial applications. The combination of high accuracy, stability and reliable operation makes this product series an ideal choice for demanding applications. 5-year warranty is valid for instruments purchased in 2021 and beyond.

The HMD60 and HMD65 have been certified by the BACnet Testing Laboratories (BTL) with the BACnet Conformance Certificate.

https://www.vaisala.com/en/products/instruments-sensors-and-other-measurement-devices/instruments-industrial-measurements/hmd60

HUMIDITY MEASUREMENT

Humidity Sensors

- Humidity sensors, also known as hygrometers, measure humidity or psychrometric state of air

- A hygrometer can encompass:
  - ❑ Wet-bulb temperature
  - ❑ Relative humidity
  - ❑ Humidity (mixing) ratio
  - ❑ Dew point
  - ❑ Frost point

Humidity Sensors

Type of Sensor	Sensor Category	Method of Operation	Approximate Range	Some Uses	Approximate Accuracy
Psychrometer	Evaporative cooling	Temperature measurement of wet bulb	32 to 180°F	Measurement, standard	±3 to 7% rh
Adiabatic saturation psychrometer	Evaporative cooling	Temperature measurement of thermodynamic wet bulb	40 to 85°F	Measurement, standard	±0.2 to 2% rh
Chilled mirror	Dew point	Optical determination of moisture formation	−110 to 200°F dp	Measurement, control, meteorology	±0.4 to 4°F
Heated saturated salt solution	Water vapor pressure	Vapor pressure depression in salt solution	−20 to 160°F dp	Measurement, control, meteorology	±3°F
Hair	Mechanical	Dimensional change	5 to 100% rh	Measurement, control	±5% rh
Nylon	Mechanical	Dimensional change	5 to 100% rh	Measurement, control	±5% rh
Dacron thread	Mechanical	Dimensional change	5 to 100% rh	Measurement	±7% rh
Goldbeater's skin	Mechanical	Dimensional change	5 to 100% rh	Measurement	±7% rh
Cellulosic materials	Mechanical	Dimensional change	5 to 100% rh	Measurement, control	±5% rh
Carbon	Mechanical	Dimensional change	5 to 100% rh	Measurement	±5% rh
Dunmore type	Electrical	Impedance	7 to 98% rh at 40 to 140°F	Measurement, control	±1.5% rh
Polymer film electronic hygrometer	Electrical	Impedance or capacitance	10 to 100% rh		±2 to 3% rh
Ion exchange resin	Electrical	Impedance or capacitance	10 to 100% rh at −40 to 190°F	Measurement, control	±5% rh
Porous ceramic	Electrical	Impedance or capacitance	Up to 400°F	Measurement, control	±1 to 1.5% rh
Aluminum oxide	Electrical	Capacitance	5 to 100% rh	Measurement, control	±3% rh
	Electrical	Capacitance	−110 to 140°F dp	Trace moisture measurement, control	±2°F dp
Electrolytic hygrometer	Electrolytic cell	Electrolyzes due to adsorbed moisture	1 to 1000 ppm	Measurement	
Infrared laser diode	Electrical	Optical diodes	0.1 to 100 ppm	Trace moisture measurement	±0.1 ppm
Surface acoustic wave	Electrical	SAW attenuation	85 to 98% rh	Measurement, control	±1% rh
Piezoelectric	Mass sensitive	Mass changes due to adsorbed moisture	−100 to 0°F	Trace moisture measurement, control	±2 to 10°F dp
Radiation absorption	Moisture absorption	Moisture absorption of UV or IR radiation	0 to 180°F dp	Measurement, control, meteorology	±4°F dp, ±5% rh
Gravimetric	Direct measurement of mixing ratio	Comparison of sample gas with dry airstream	120 to 20,000 ppm mixing ratio	Primary standard, research and laboratory	±0.13% of reading
Color change	Physical	Color changes	10 to 80% rh	Warning device	±10% rh

Notes:
1. This table does not include all available technology for humidity measurement.
2. Approximate range for device types listed is based on surveys of device manufacturers.
3. Approximate accuracy is based on manufacturers' data.
4. Presently, NIST only certifies instruments with operating ranges within −103 to 212°F dew point.

Humidity Sensors

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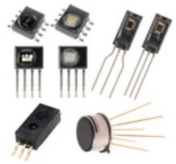
Humidity Sensors

Products › Sensors › Humidity, Thermal & Flexible Heater Products › Humidity Products › Humidity Sensors

Overview

A full line of humidity sensors from the premier Honeywell HumidIcon™ combined Digital Humidity/Temperature sensors to relative humidity absorption-based humidity sensor products, each sensor is designed to provide enhanced stability, reliability and sensitivity.



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Browse Humidity Sensors by Type

Make a selection to narrow in on the product that's right for you.

Honeywell HumidIcon™ HIH6000 Series
Digital output, relative humidity & temperature sensor combined in same package ● Humidity accuracy: ±4.5 %RH typ. ● Temp. accuracy: ±0.5 °C typ.

Honeywell HumidIcon™ HIH6100 Series
Digital output, relative humidity & temperature sensor combined in same package ● Humidity accuracy: ±4.0 %RH typ. ● Temp. accuracy: ±0.5 °C typ.

Honeywell HumidIcon™ HIH7000 Series
Digital output, relative humidity & temperature sensor combined in same package ● Humidity accuracy: ±3.0 %RH typ. ● Temp. accuracy: ±0.5 °C typ.

Honeywell HumidIcon™ HIH8000 Series
Digital output, relative humidity & temperature sensor combined in same package ● Humidity accuracy: ±2.0 %RH typ. ● Temp. accuracy: ±0.5 °C typ.

HIH-5030/5031 Series
Analog output, relative humidity sensor ● Humidity accuracy: ±3 %RH ● 2.7 Vdc to 5.5 Vdc supply ● SMD ● Covered, with/without hydrophobic filter

HIH-4000 Series
Analog output, relative humidity sensor ● Humidity accuracy: ±3.5 %RH ● 4 Vdc to 5.8 Vdc supply ● Uncovered

HIH-4010/4020/4021 Series
Analog output, relative humidity sensor ● Humidity accuracy: ±3.5 %RH ● 4 Vdc to 5.8 Vdc supply ● Covered or uncovered ● Filtered or unfiltered

HIH-4602-A/C Series
Analog output, relative humidity & temp. sensor combined in same package ● Humidity accuracy: ±3.5 %RH ● Factory calibration data with each listing

https://sensing.honeywell.com/sensors/humidity-sensors

AIRFLOW & PRESSURE

Airflow Rates

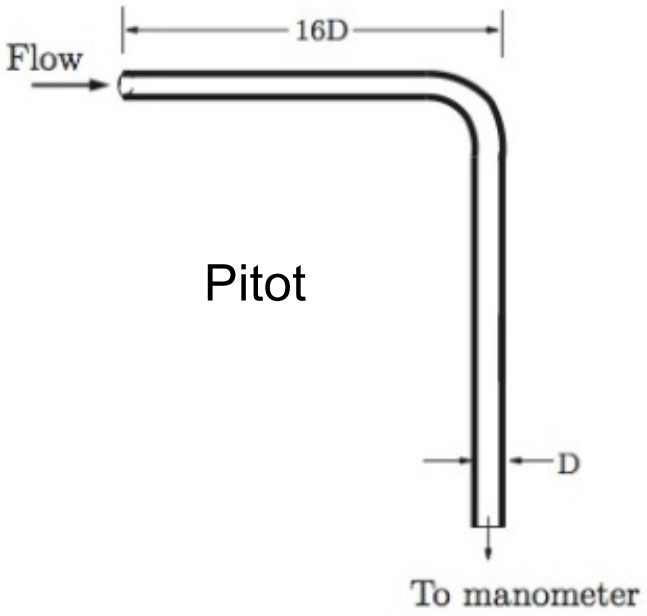
- How do we measure airflow rates?
  - ❑ Fan power (need fan curve)
    - ➢ Clip-on amp meter
  - ❑ Differential pressure
    - ➢ Manometer (various kinds)
  - ❑ Velocity
    - ➢ Pitot static tube
    - ➢ Anemometer (various kinds: deflecting vane, revolving vane, propeller, hot-wire, thermal mass)
  - ❑ Airflow
    - ➢ Cross-sectional velocity
    - ➢ Flow hoods (i.e., velocity through known area)
    - ➢ Various kinds

Airflow Rates

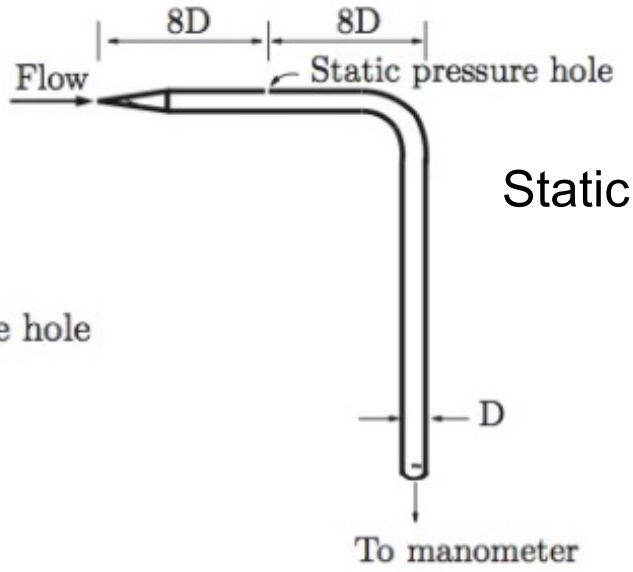
- Pressure measurements using manometer
  - Advantage:
    - Easy to fabricate
    - Accurate for steady-state measurements
  - Disadvantages:
    - Not suitable for very high or very low measurements
    - Very poor frequency response
    - A little bit of dirt in the tube or bubble in a line or presence of condensate can result in anomalous readings

Airflow Rates

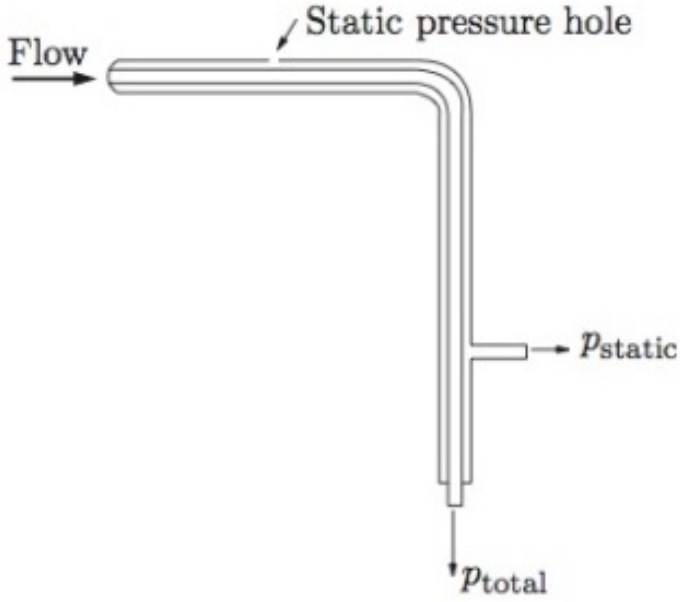
- Calculate velocity based on total and static pressure using the Bernoulli equation



Pitot



Static



Pitot-Static

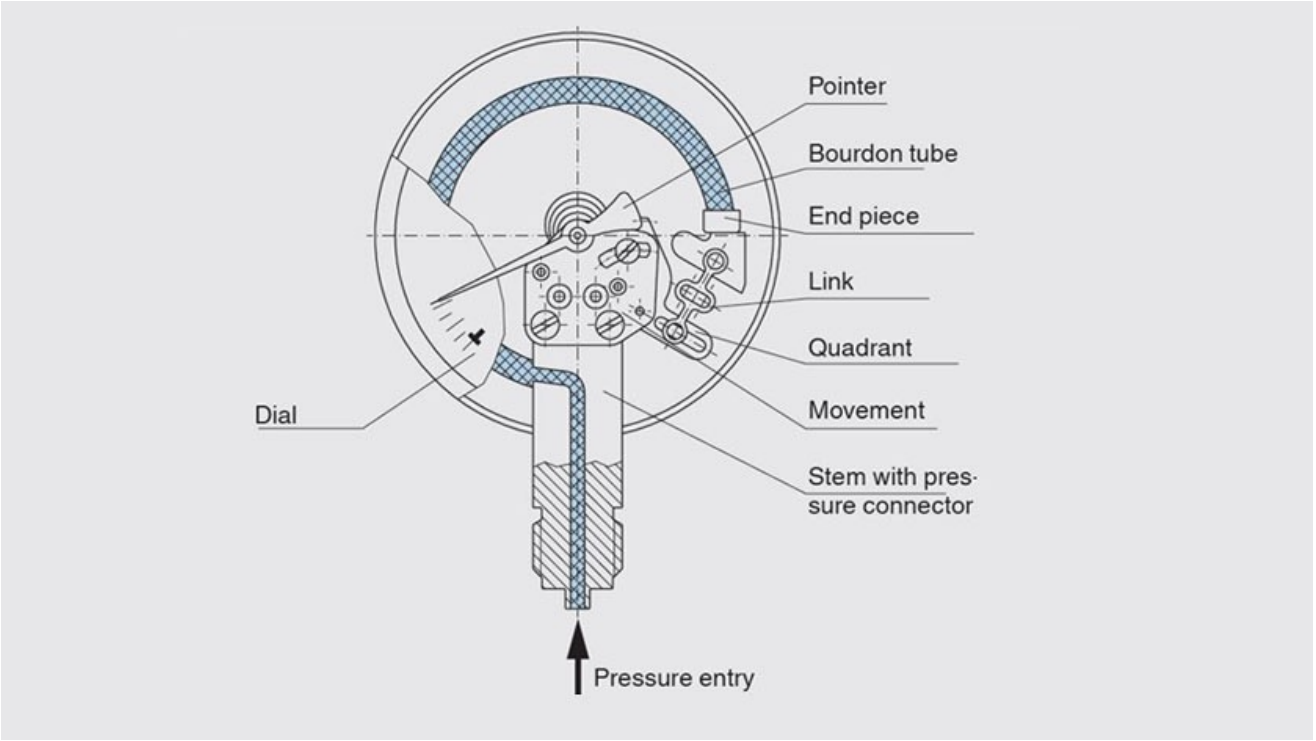
Airflow Rates

- Look at some options:

https://www.grainger.com/category/test-instruments/pressure-and-vacuum-measuring/pressure-and-vacuum-gauges/pressure-and-vacuum-gauge-accessories/differential-pressure-gauge-accessories

Airflow Rates

- Mechanical pressure gauges couple a pressure sensor to a mechanical readout, typically a pointer and dial
- Common type uses a Bourdon tube sensor, which is essentially a coiled metal tube of circular or elliptical cross section

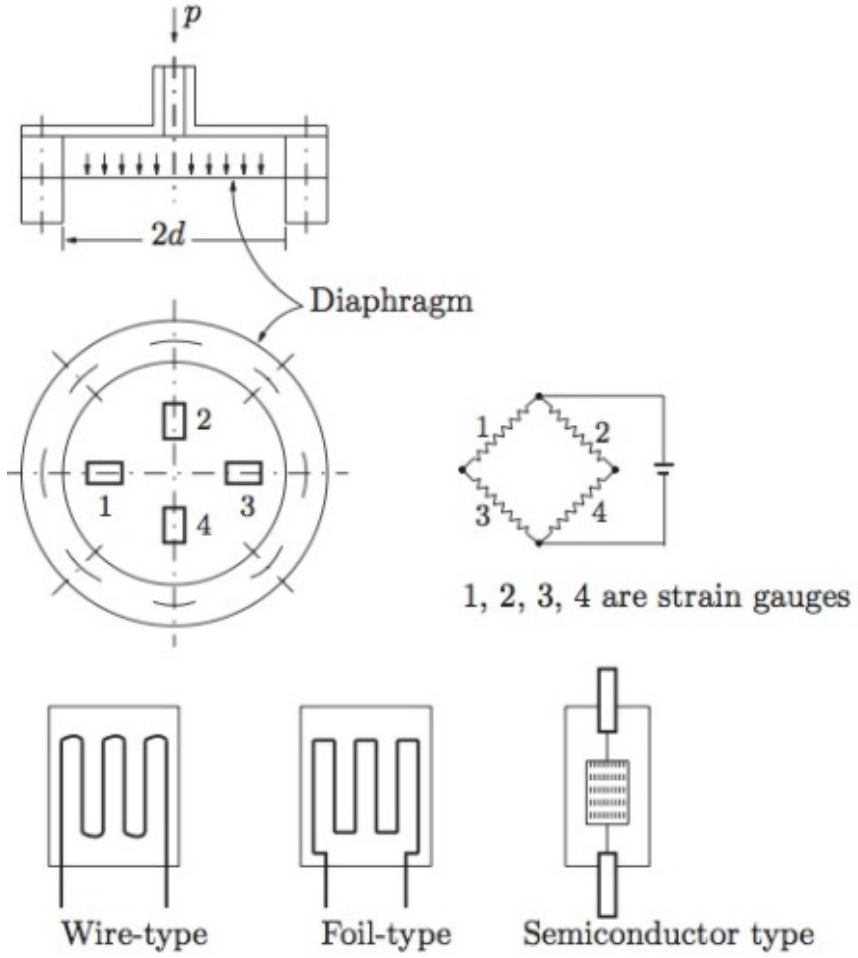


Airflow Rates

- Electromechanical transducers work based on producing a total strain produced on the diaphragm is proportional to the pressure applied
- For circular diaphragm:

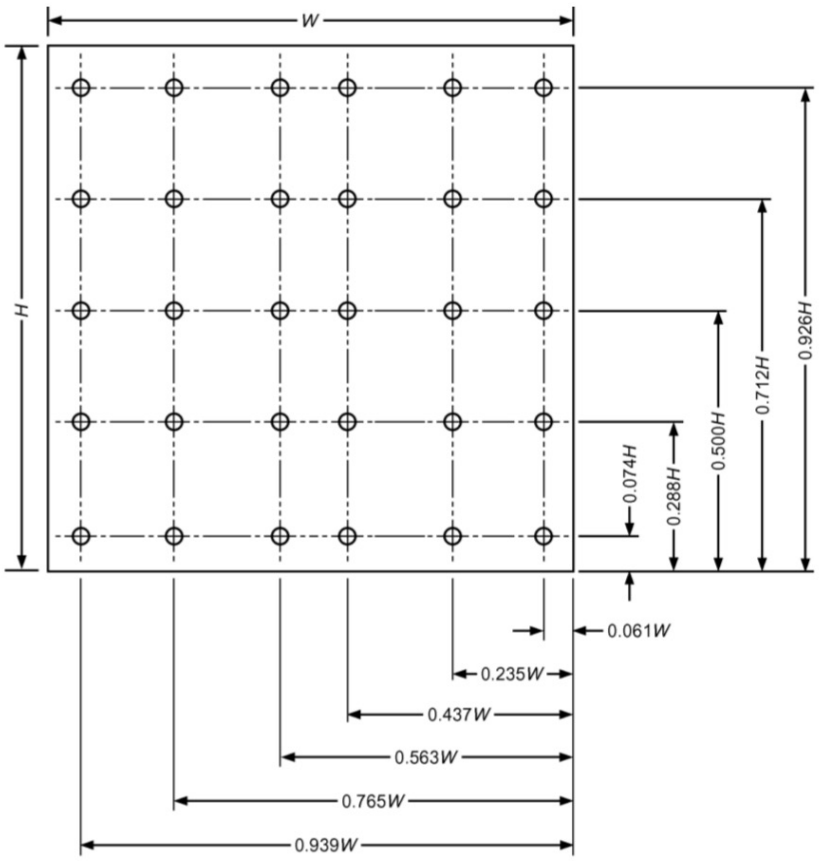
$$\delta = \frac{3pa^4}{16Et^2}(1-\mu_r^2)$$

  - δ : *deflection*
  - p : *pressure*
  - a : *radius of the diaphragm*
  - E : *Young's module*
  - t : *thinness of the diaphragm*
  - μ_r : Poisson's ratio



Measuring Flow in Ducts by Velocity

- Velocity in a duct is not uniform across:
  - ❑ Any section
  - ❑ Pitot tube reading
  - ❑ Thermal anemometer
- Avoid measuring at only one location
- Understand:
  - ❑ Lowest velocity occurs near the edges or corners
  - ❑ Greatest at or near the center



Duct Dimensions	No. of Points for Traverse Lines	Position Relative to Inner Wall
18 in. < *H*, *W* < 30 in.	5	0.074, 0.288, 0.500, 0.712, 0.926
30 in. ≤ *H*, *W* ≤ 36 in.	6	0.061, 0.235, 0.437, 0.563, 0.765, 0.939
H, *W* > 36 in.	7	0.053, 0.203, 0.366, 0.500, 0.634, 0.797, 0.947

Log-Tchebycheff Rule for Rectangular Ducts

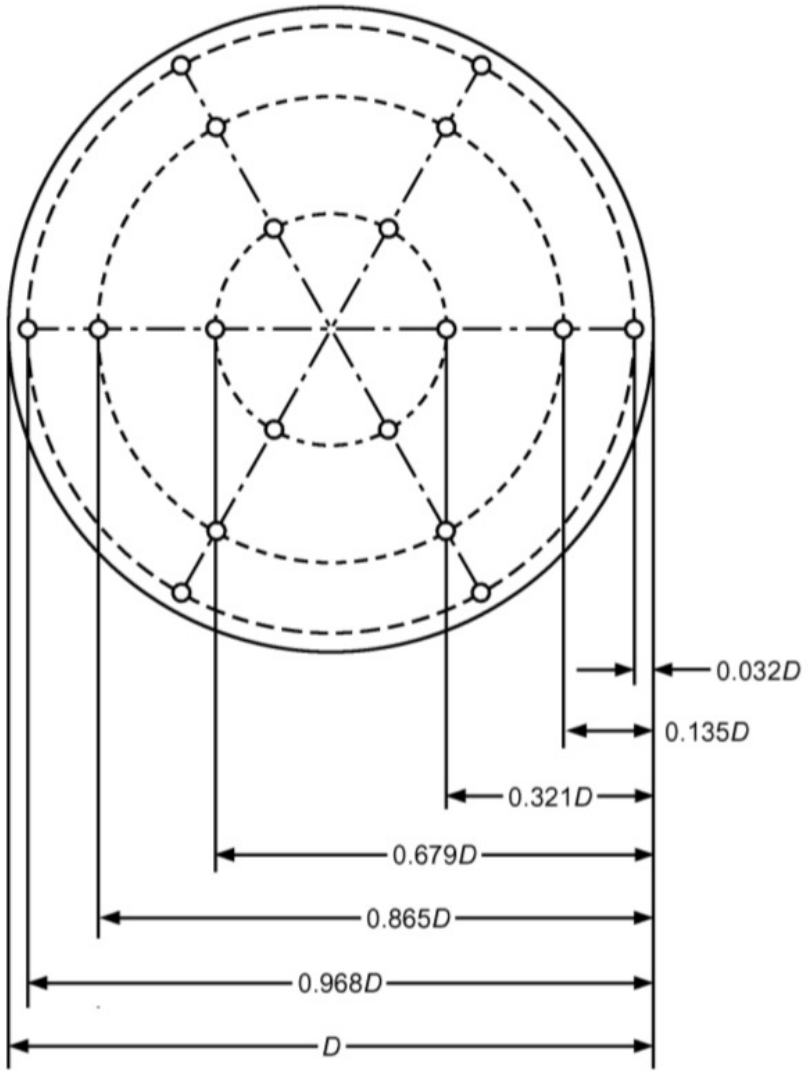
Note: Example duct has 5 × 6 (*H* × *W*) measurement pattern, as for rectangular duct of 24 × 30 in.

Measuring Flow in Ducts by Velocity

- log-Tchebycheff (log-T) rule or, if care is taken, by the equal-area method

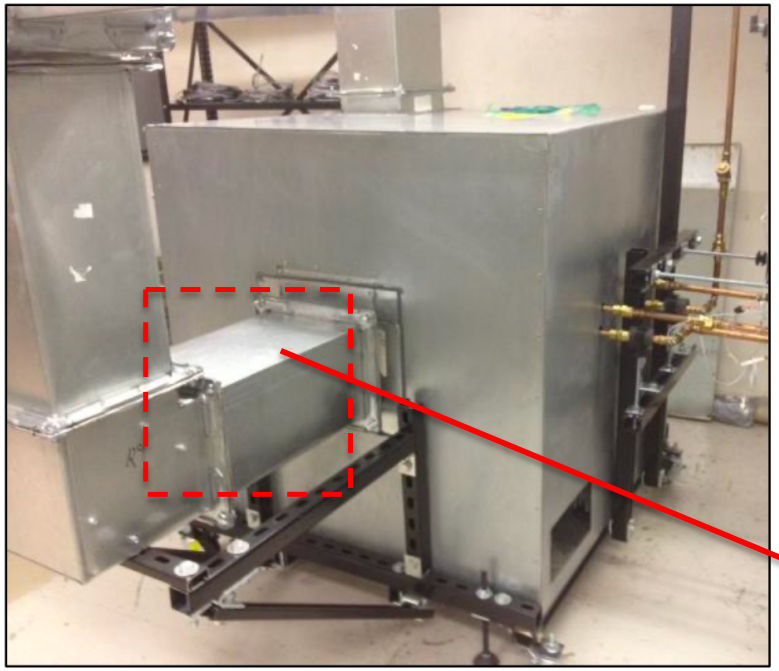
No. of Measuring Points per Diameter	Position Relative to Inner Wall
6	0.032, 0.135, 0.321, 0.679, 0.865, 0.968
8	0.021, 0.117, 0.184, 0.345, 0.655, 0.816, 0.883, 0.979
10	0.019, 0.077, 0.153, 0.217, 0.361, 0.639, 0.783, 0.847, 0.923, 0.981

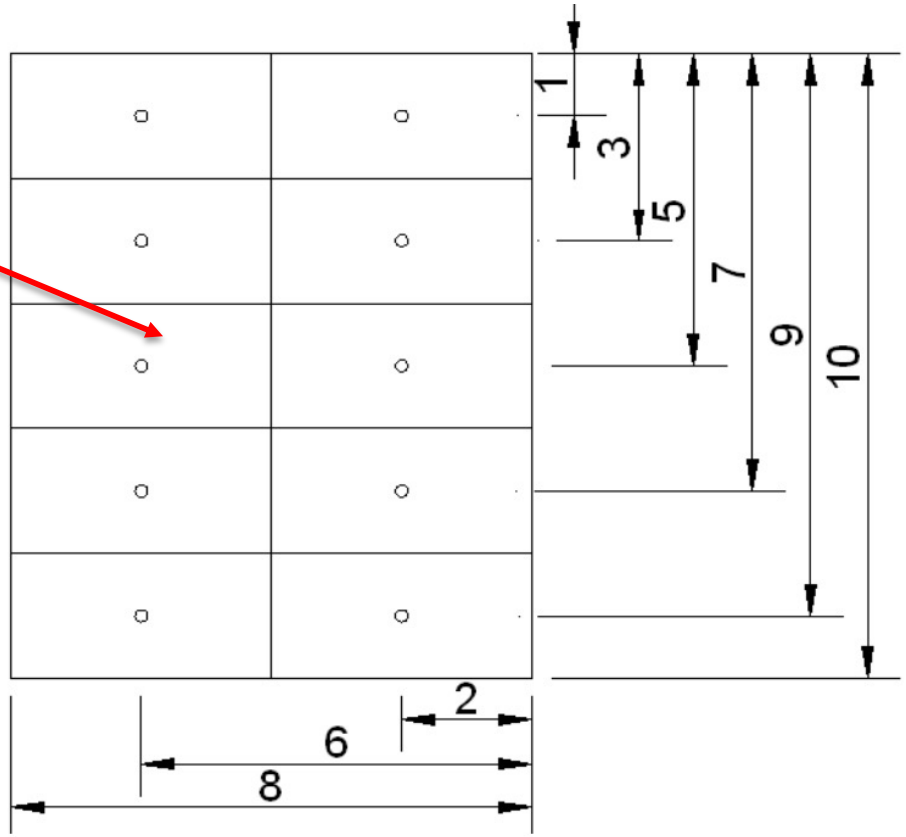
Log-Linear Rule for Circular Ducts



MEASURING FLOW IN DUCTS BY VELOCITY

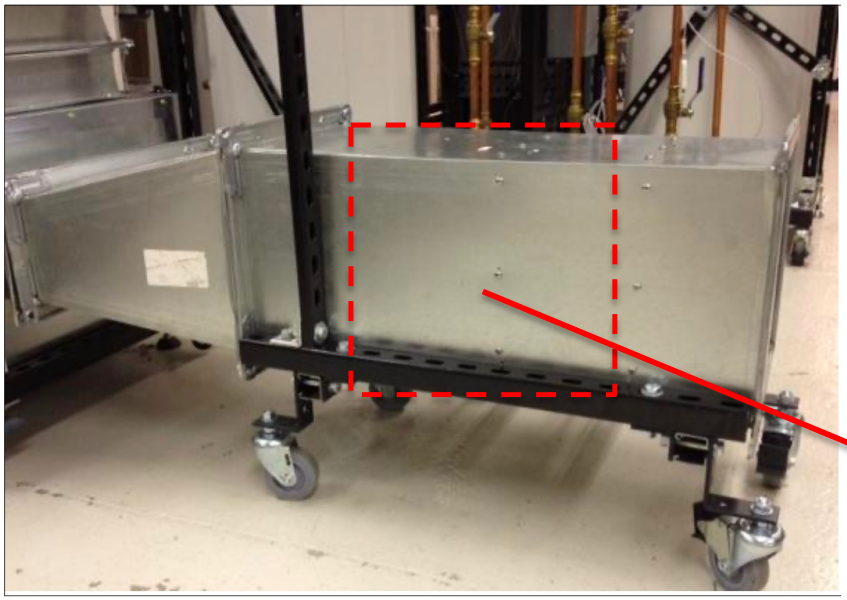
Measuring Flow in Ducts by Velocity

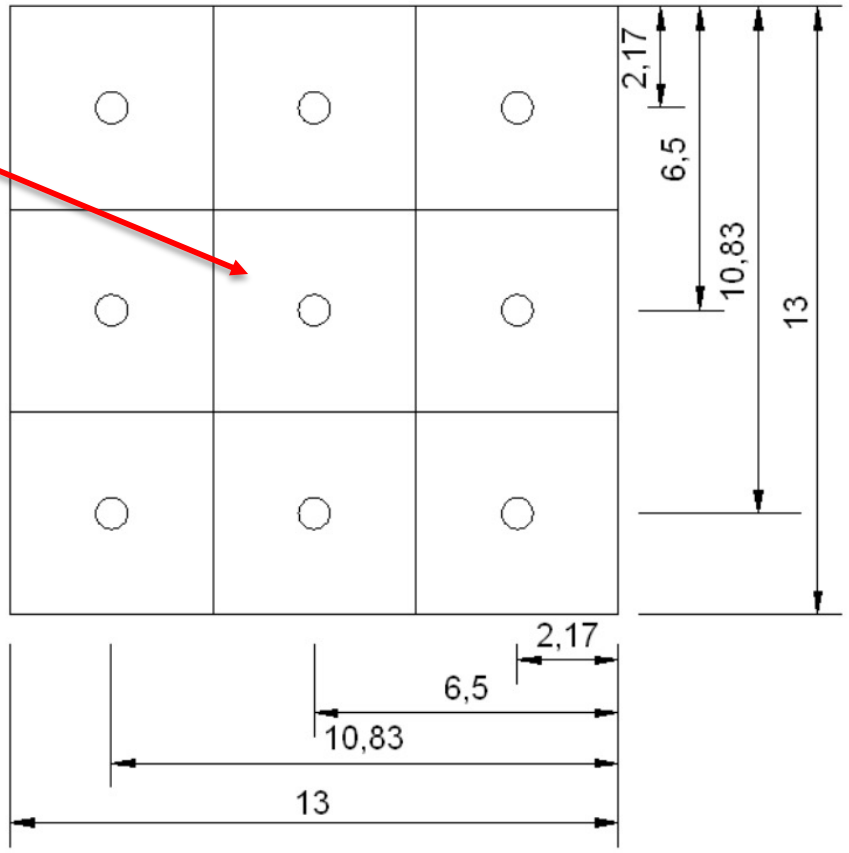




Li thesis, PSU 2014

Measuring Flow in Ducts by Velocity





Li thesis, PSU 2014

Measuring Flow in Ducts by Velocity

- Ebtron GP1 Flow Station (insertion probes): https://ebtron.com/wp-content/uploads/documents/IG_P_INT.pdf
- Ebtron GTx116 analog output transmitter: https://ebtron.com/wp-content/uploads/documents/GTx116-P+_Overview.pdf

Martin dissertation, PSU 2014 and Li thesis, PSU 2014

CLASS ACTIVITY

Class Activity

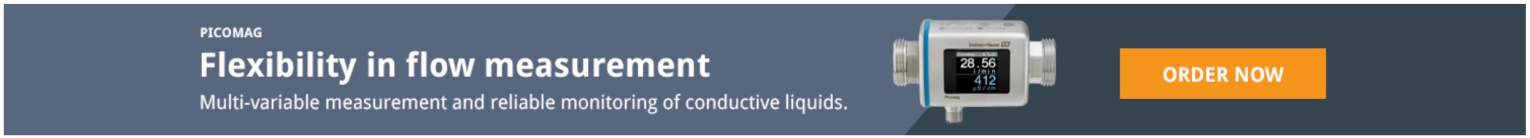
- Form 3-4 groups
- Fill in the spreadsheet (at least 3 air flow rates sensors):

https://docs.google.com/spreadsheets/d/1duxKfuy1kpYNJxXT6e9bHjVBBqUXnwBSBuR8Dkz4f7c/edit#gid=1229752403

WATER FLOW STATION

Water Flow Station

Home / Sensors and Sensing Equipment / Flow / Variable Area Flow Meters / Flow Meter with Analog Outputs



Flow Meter with Analog Outputs

$2,095.00 Item# FLR9310D-BSPP

Volume discounts available

Qty

1 ADD TO CART

0 In stock

Lead Time (If not in Stock): 6 weeks

Add to Project List

2.0 (1) Write a review

- 2% FS Accuracy
- No Straight Pipe Run Required
- Mounts in Any Position
- 4 to 20 mA, 0 to 5 Vdc and 0 to 10 Vdc Outputs Standard
- Digital Flow Rate and Total Flow Indicator
- In-Field Compensation for:
  - Specific Gravity of All Fluids
  - Viscosity of Petroleum-Based Fluids
  - Specific Gravity, Pressure, and Temperature of Pneumatic Applications

Data Sheet (PDF)

Edit Options

View all models

Not all combinations are valid. Options compatible with previous selections will be in bold.

Category
Meter

Media Type
Water

Gas Flow Range
Not Applicable

Liquid Flow Range
10 to 100 GPM

Accuracy
±2%

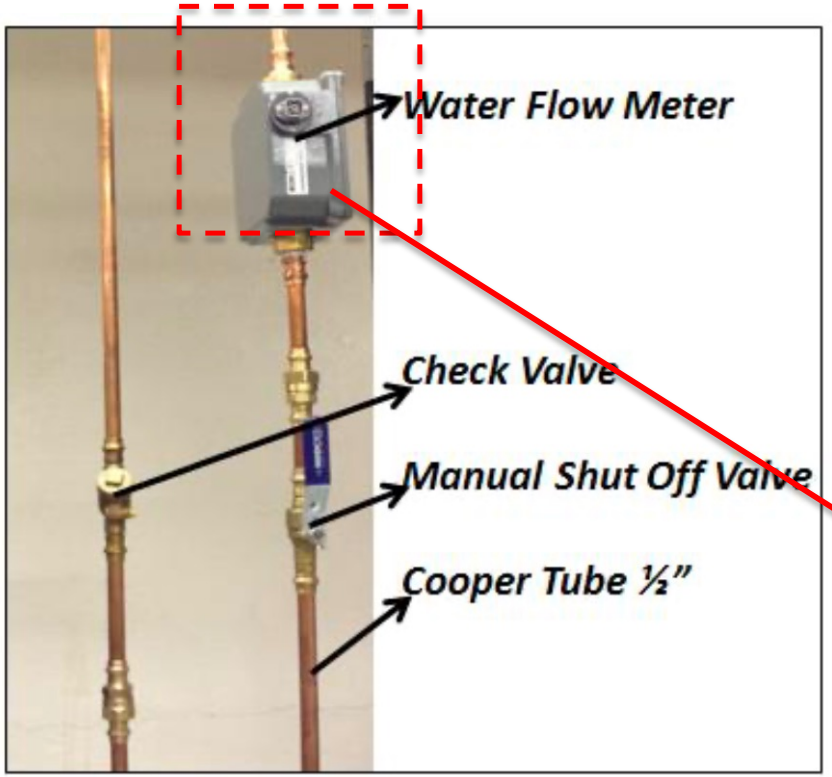
Process Connection Type
BSPP

Process Connection Size
1 1/4"

Wetted Materials
Aluminum, T302 SS, Carbon Steel,...

https://www.omega.com/en-us/sensors-and-sensing-equipment/flow/variable-area-flow-meters/p/FLR-D

Water Flow Station



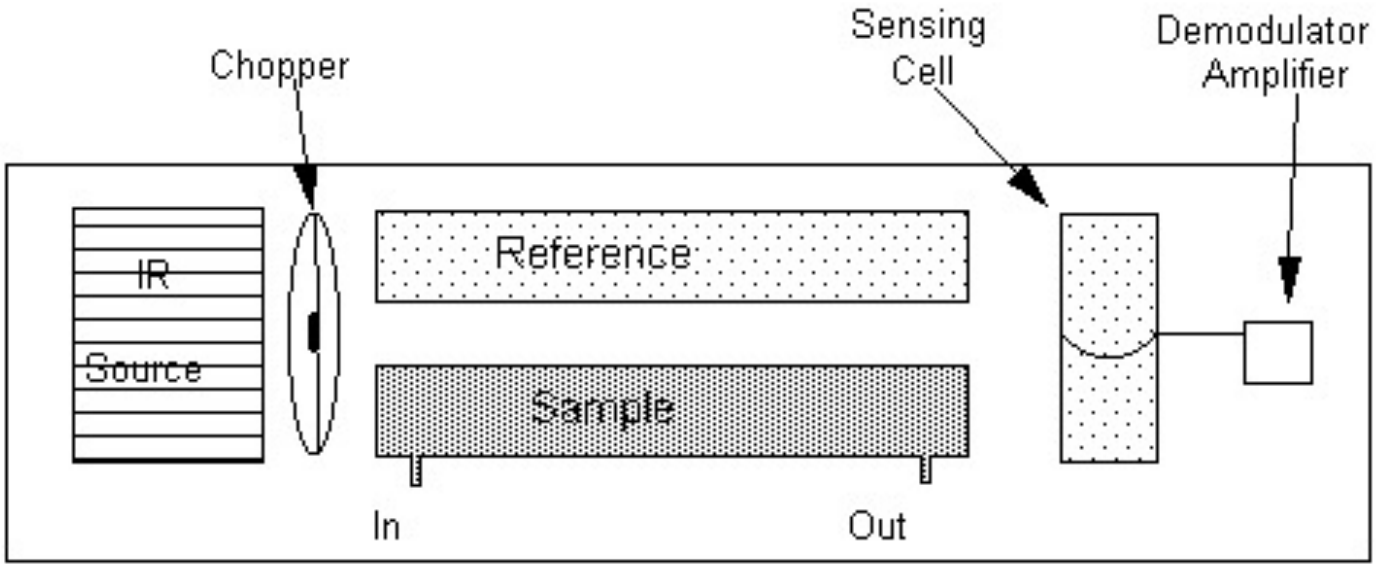
CO_2 CONCENTRATIONS

CO_2 Concentrations

- Common CO_2 measurement techniques are:
  - Non-dispersive infrared (NDIR) → most common
  - Electrochemical (reduce CO_2 → generate current)
  - Photoacoustic (CO_2 absorbs light energy → measure pressure change)
  - Photoacoustic effect relates pressure change to CO_2 concentration
  - Potentiometric (CO_2 into solution – changes pH)
  - Gas chromatography w/ MS or TCD
    - High sensitivity
    - High cost

CO_2 Concentrations

- Non-dispersive infrared (NDIR) sensor measures the infrared light absorbed by CO_2 as it passes through a flow-through IR absorption cell
  - CO_2 peak absorbance @ 4.3 μm (higher CO_2, higher absorption)
    - Possible interference from other species (H_2O, CO)
    - Interferences from other IR-absorbing gases are minimized by use of a highly wavelength-specific detector



CO_2 Concentrations

- Examples of CO_2 sensors are:

Manufacturer/Supplier	Accuracy Range	Response Time	Price	Model
Extech	±3% of reading or ±50ppm	600 sec (90%)	$800	Indoor Air Quality Meter/Datalogger Model EA80
TSI	±3% of reading or ±50 ppm	20 sec (63%)	$2,000	Q-TRAK™ Indoor Air Quality Monitor Model 7575
TSI	±3% of reading or ±50 ppm	20 sec (63%)	$650	TSI™ IAQ-Calc™ CO_2 meter
Vaisala	±1.5% of range +2% of reading	30 sec (63%)	$2,100	Vaisala GM70 Hand-Held Carbon Dioxide Meter
Extech	± 5% of reading or ±50ppm	120 sec (63%)	$400	Model CO250
Bacharach®	±2% over range	N/A	$2,600	IEQ Chek Indoor Air Quality Monitor for Incubators, with CO_2 sensor, sampling pump, remote probe
GE (Telaire)	±5% of reading or ±50 ppm	60 sec (90%)	$550	Dual-Position CO2/Temperature Meter
Davis	±3% of reading or ±50ppm	40 sec (63%)	$610	Indoor Air Quality Meter WO-81973-25
	±3% of reading or ±75ppm	60 sec (90%)	$660	TPI 1008 Indoor Air Quality IAQ Meter
	±3% of reading or ±50ppm, whichever is greater	45 sec (90%)	$1,880	Kanomax 2211 Indoor Air Quality Monitor
	±2% of reading ±1% range	20 sec (90%)	$2,700	Viasensor G150-02N IAQ Indoor Air Quality Meter CO2 with RH/T probe
Testo	±50 ppm CO_2 ±2% of mv)	120 sec (90%)	$800	Testo 535 Ambient CO_2 Analyzer
Telaire	±100 ppm ±3% of reading	120 sec (63%)	$161	Ventostat 8001
Telaire	±50 ppm value at 20°C (68°F)	60 sec (90%)	$550	7001
Digital Control System, Inc.	±5% of reading or ±75 ppm	60 sec (63%)	$195	Airsense M307
Greystone Energy Systems, Inc.	±75 ppm or 3% of reading (15°C to 32°C (59°F to 90°F))	120 sec (90%)	$402-$500	CDDIA2000
Johnson Controls, Inc.	±100 ppm at 75C (wall mount)	60 sec (63%)	$280	5001
Intec Controls	±5% of reading or ±75 ppm, whichever is greater	60 sec (63%)	$231	I-310e

Jareemit, PSU Dissertation

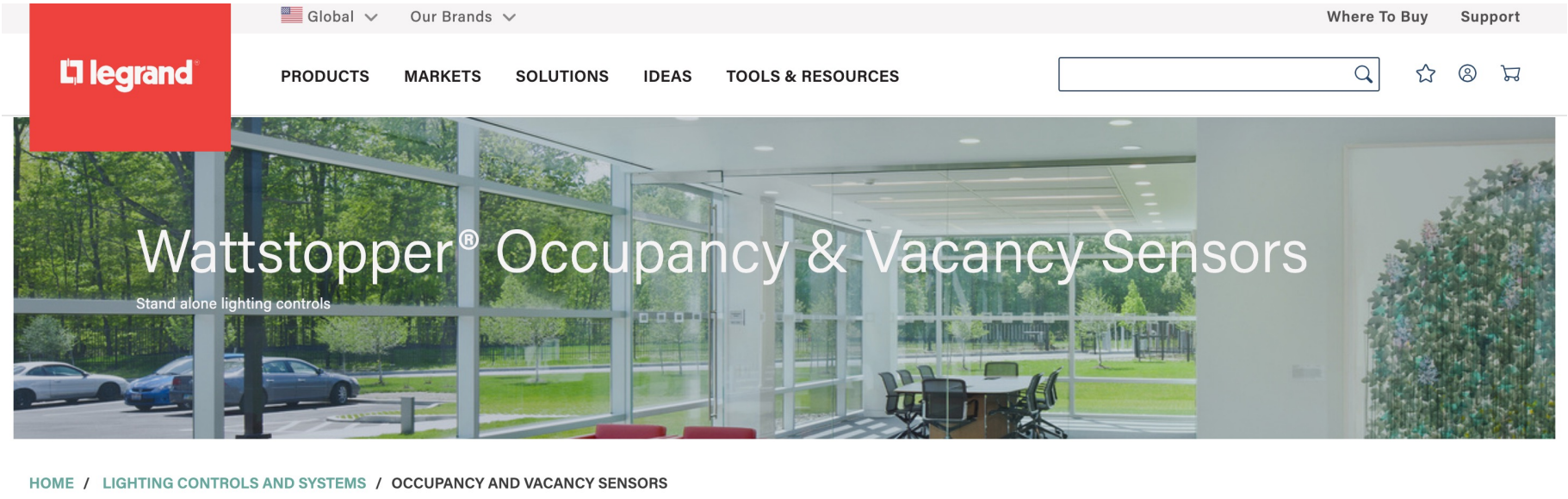
LIGHTING SENSORS

Lighting Sensors

- A few vendors in the US are:
  - Lutron
  - Wattstopper
  - Nlight
  - Leviton
  - Amatis

Lighting Sensors

- Wattstopper examples are:

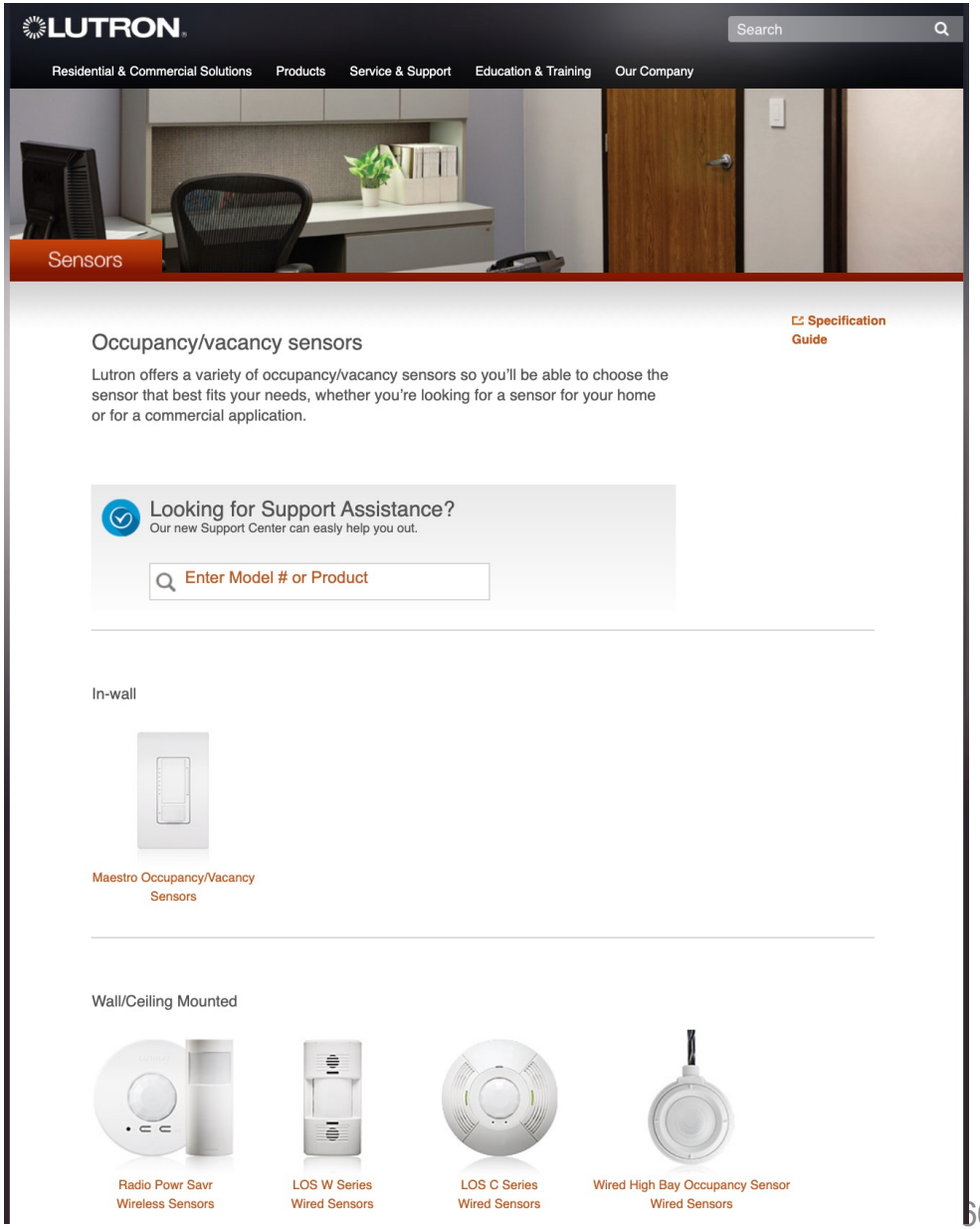


https://www.legrand.us/lighting-controls-building-systems/sensors.aspx

Lighting Sensors

- Lutron examples are:

https://www.lutron.com/en-US/Products/Pages/Sensors/Occupancy-Vacancy/Occupancy.aspx

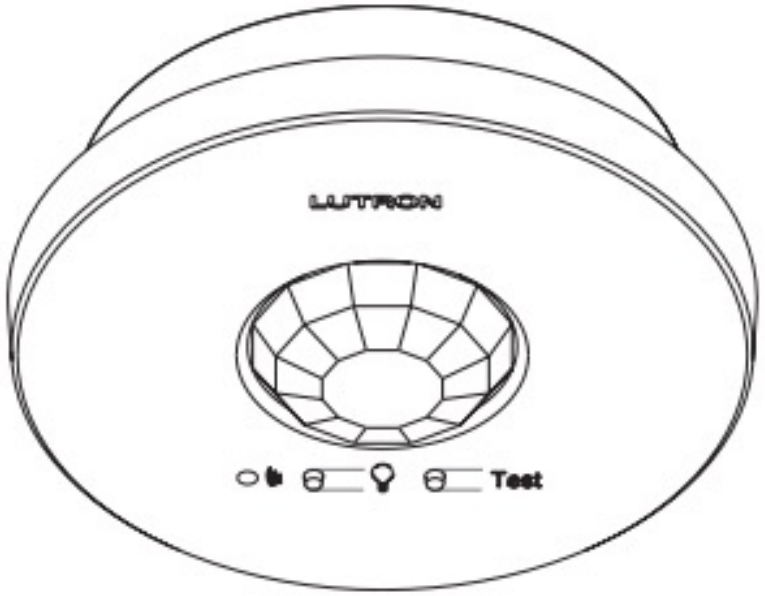


Lighting Sensors

- Lutron examples are:

Radio Powr Savr Wireless Occupancy/Vacancy Ceiling Sensor

Lutron Radio Powr Savr occupancy/vacancy sensors are wireless, battery-powered, passive infrared (PIR) sensors that automatically control lights via RF communication to compatible dimming and switching devices. These sensors detect the heat (IR radiation of 9.5 µm) from people moving within an area to determine when the space is occupied. The sensors then wirelessly transmit the appropriate commands to the associated dimming and switching devices to turn the lights on or off automatically. They combine both convenience and exceptional energy savings potential along with ease of installation.



https://www.lutron.com/TechnicalDocumentLibrary/369480_ENG.pdf

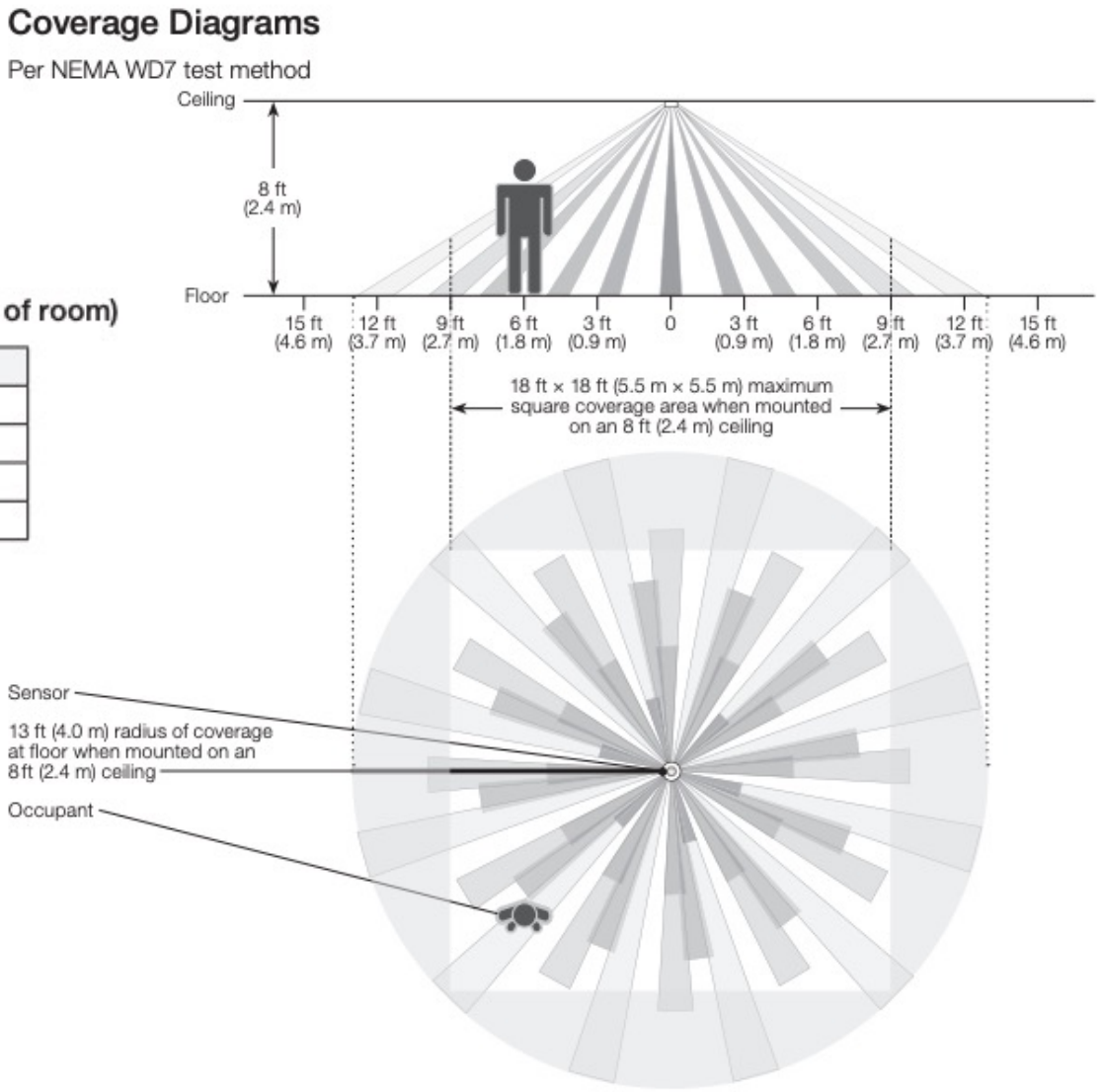
Lighting Sensors

- Lutron examples are:

Sensor Coverage Chart (for sensor mounted in center of room)

Ceiling Height	Maximum Square Coverage Area*	
8 ft (2.4 m)	18 ft × 18 ft (5.5 m × 5.5 m)	324 ft² (30.2 m²)
9 ft (2.7 m)	20 ft × 20 ft (6.1 m × 6.1 m)	400 ft² (37.2 m²)
10 ft (3.0 m)	22 ft × 22 ft (6.7 m × 6.7 m)	484 ft² (44.9 m²)
12 ft (3.7 m)	26 ft × 26 ft (7.9 m × 7.9 m)	676 ft² (62.4 m²)

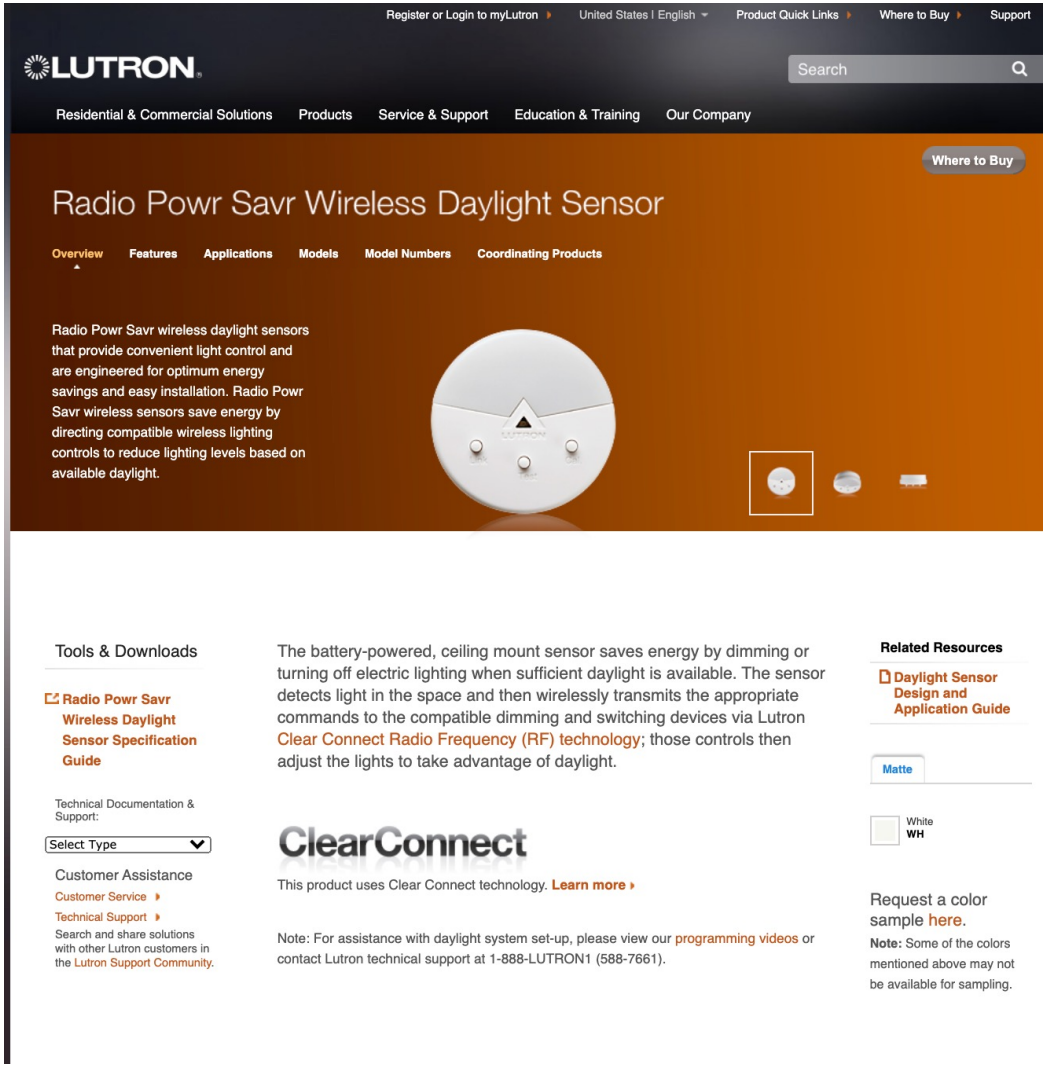
* 12 ft (3.7 m) is the recommended maximum mounting height



https://www.lutron.com/TechnicalDocumentLibrary/369480_ENG.pdf

Lighting Sensors

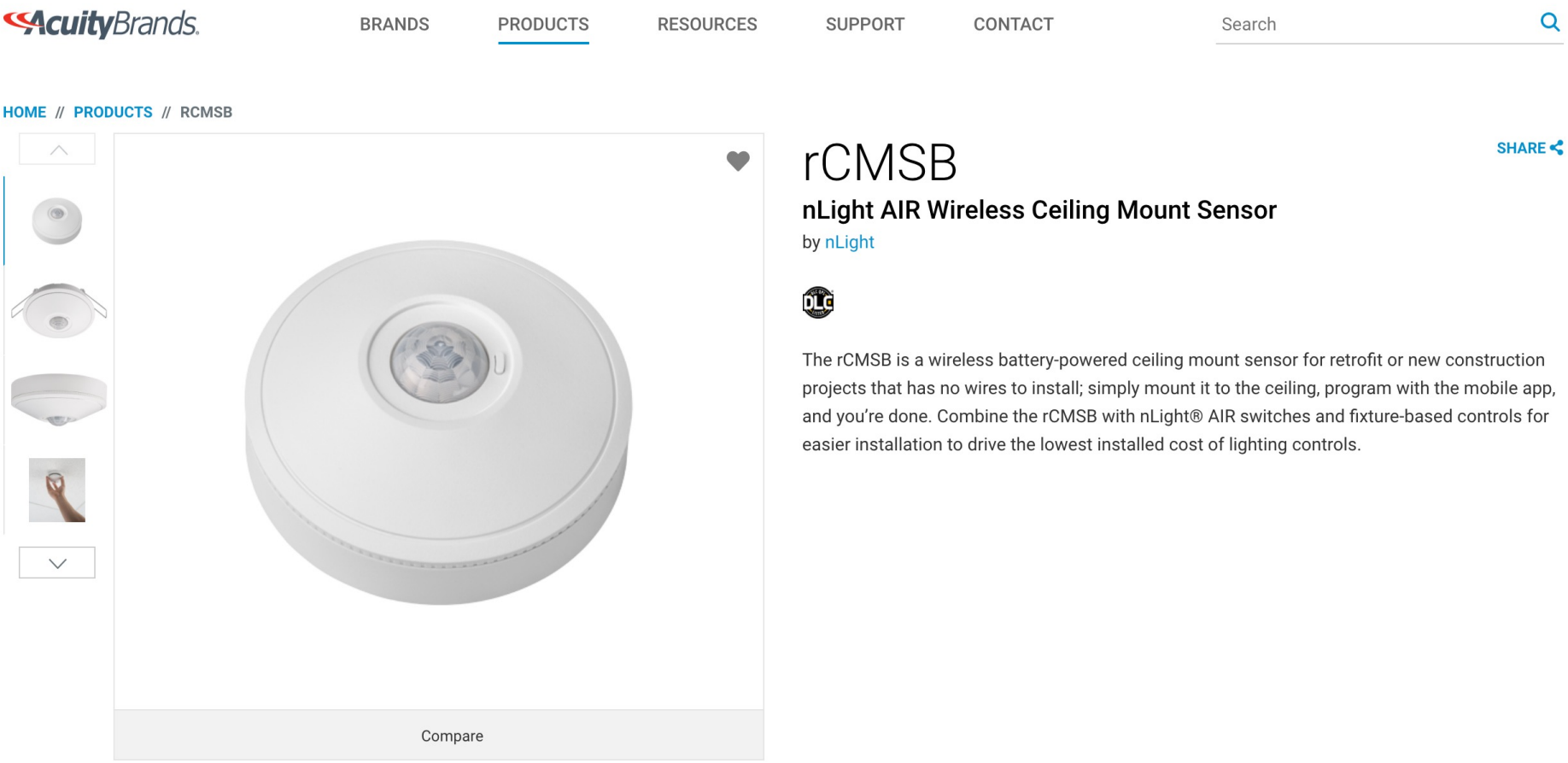
- Lutron examples are:



https://www.lutron.com/en-US/Products/Pages/Sensors/RadioPowrSavrDaylightSensor/Overview.aspx

Lighting Sensors

- nLight examples are:



https://www.acuitybrands.com/products/detail/1085254/nlight/rcmsb/nlight-air-wireless-ceiling-mount-sensor

Lighting Sensors

- Amatis examples:

amatis™

Product specifications

Detect MLTH with:

SENSOR 1

Mesh network enabled motion, light, temperature and humidity sensor

PRODUCT OVERVIEW

The Amatis Controls Sensor1 MLTH communicates wirelessly with other connected Amatis devices using our proprietary 6LoWireless protocol to enable controls for vacancy, occupancy, daylight harvesting, temperature and humidity.

The Sensor1 MLTH is a stand alone device that does not require a driver or controller to communicate with the 6LoWireless mesh network. Amatis provides one of the smallest and most powerful combination motion and light sensors on the market.

https://static.amatiscontrols.com/1942_Sensor1-2%20Spec%20Sheets.pdf

Lighting Sensors

- Lighting sensors and lighting fixtures

FLR	WALL	CLG	
	$P		LIGHT SWITCH - WITH PILOT LIGHT
	$TO		SWITCH - WITH THERMAL OVERLOAD
	D		DIMMER
	OS	OS	OCCUPANCY SENSOR
	PC		PHOTOCELL
		PP	OCCUPANCY SENSOR POWER PACK
	OR		OVERRIDE SWITCH

CLASS ACTIVITY

Class Activity

- Form 3-4 groups
- Fill in the spreadsheet

https://docs.google.com/spreadsheets/d/1duxKfuy1kpYNJxXT6e9bHjVBBqUXnwBSBuR8Dkz4f7c/edit#gid=1229752403

SHADING DEVICES

Shading Devices

- Some examples

Power Supply DRM 24V DC 1.5A

animeo IB+ Touchbuco Sensor Hub Power Supply DRM 24V DC 1.5A

Soliris RTS Sun and Wind Sensor 24V DC Kit (includes sensor and transfomer)

See product sheet

Sunis Indoor WireFree™ RTS

Sunshine and shade at your service

Sunis Outdoor WireFree™ RTS Sun Sensor

Solar Protection – An Automatic Choice

https://www.somfysystems.com/en-us/products/smart-home-controls/controls/sensors

CLASS ACTIVITY

Class Activity

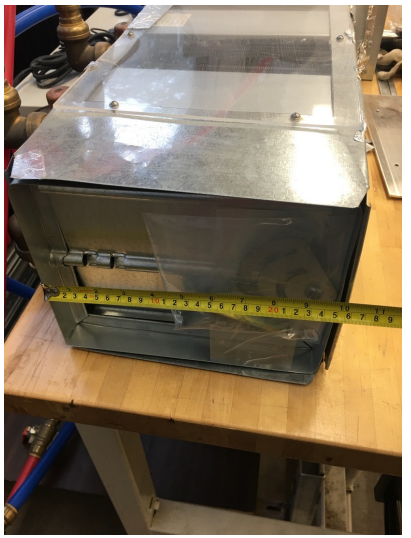
- Form 3-4 groups
- Identify a few other vendors and fill in the spreadsheet

https://docs.google.com/spreadsheets/d/1duxKfuy1kpYNJxXT6e9bHjVBBqUXnwBSBuR8Dkz4f7c/edit#gid=1229752403

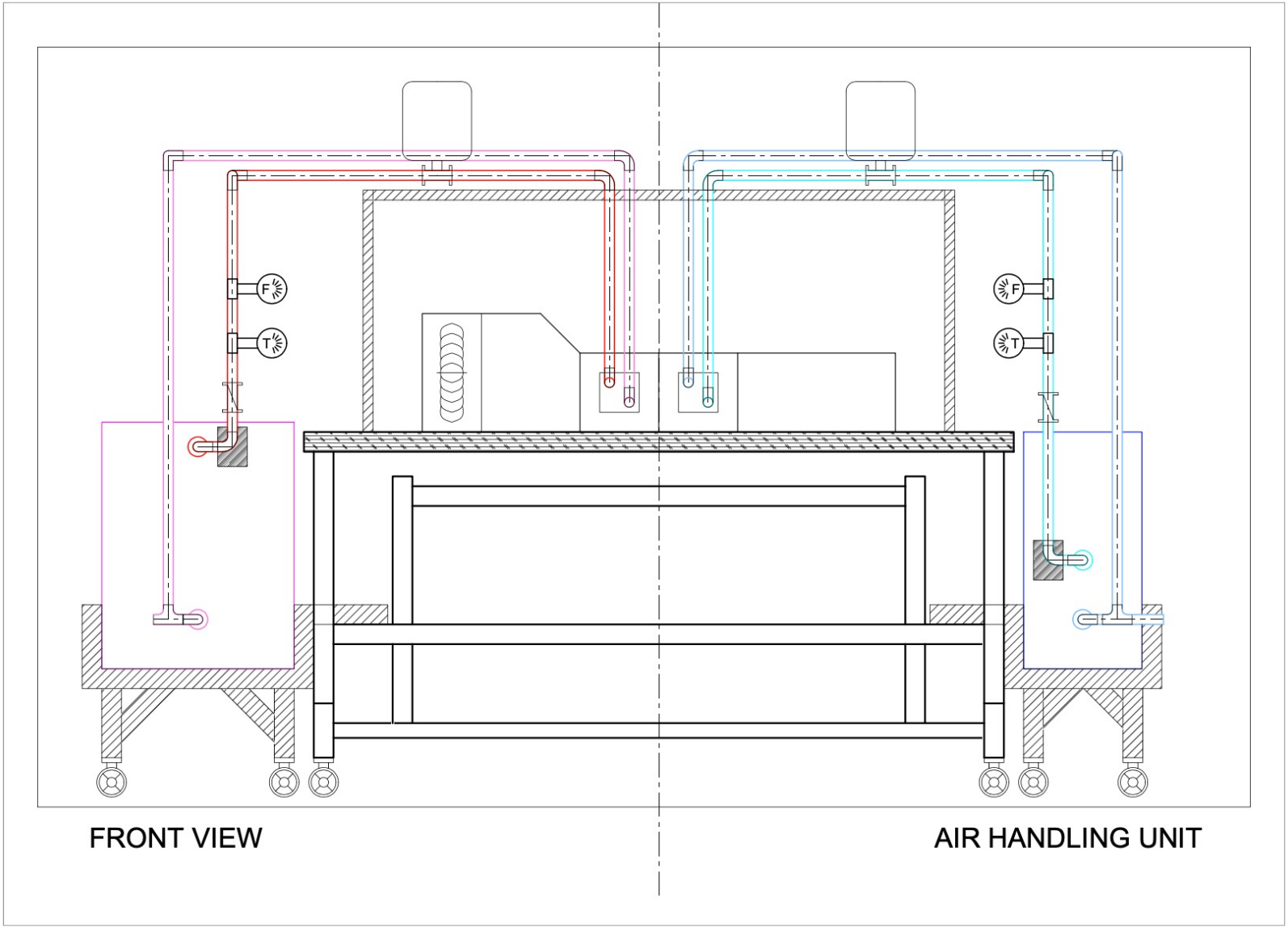
CLASS ACTIVITY

Class Activity

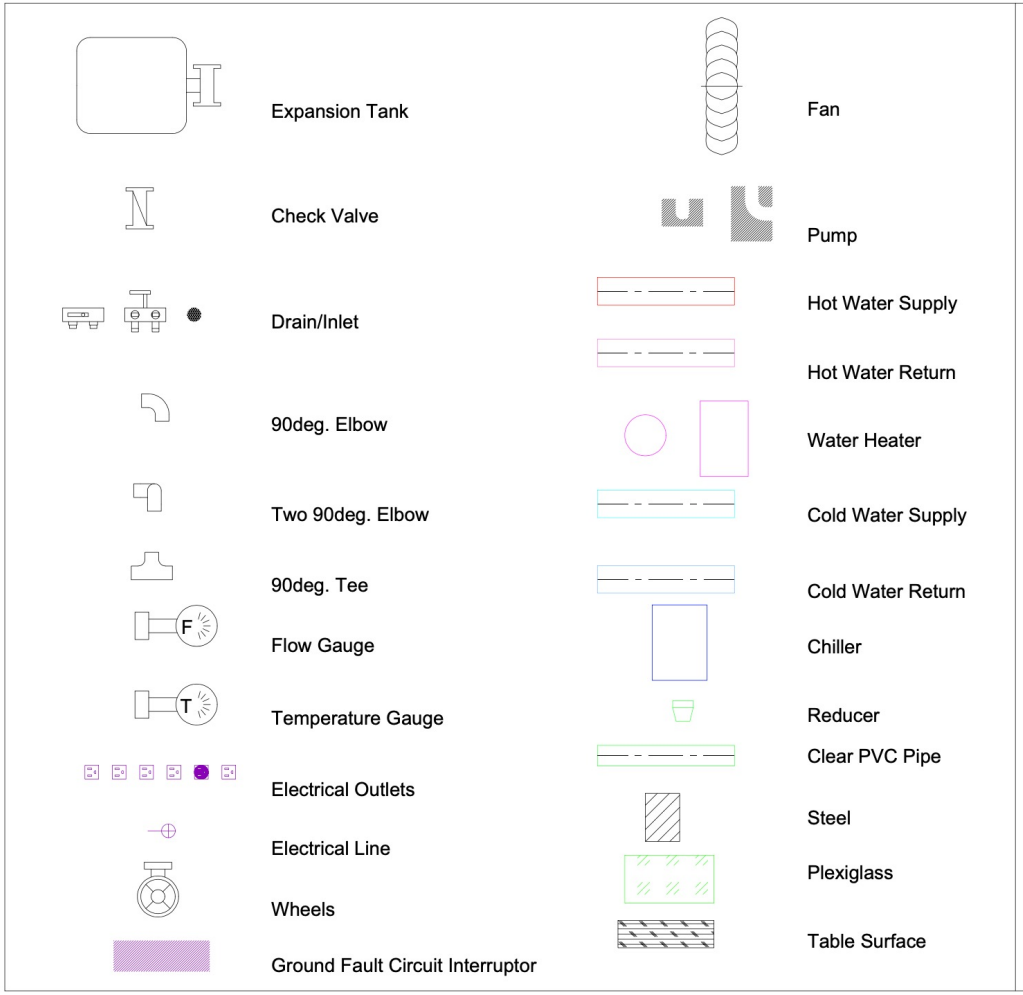
- Consider designing and selecting sensors to measure temperature, humidity, air flow, and water flow for the ASHRAE AHU facility



Class Activity



Class Activity



ADDITIONAL NOTES:

1. USE ENGINEERING JUDGEMENT WHEN MEASURING.
2. THE DIMENSIONS SHOWN ARE BASED ON ESTIMATES.
3. TOLERANCE: WITHIN 1" TO 1.5".
4. SUPPORT SYSTEMS BELOW CHILLER AND HEATER ARE INTENDED TO BE STEEL PLATFORMS WITH WELDED CONNECTIONS.
5. SUPPORT SYSTEMS BELOW CHILLER AND HEATER SHALL BE ATTACHABLE AND DETACHABLE FROM THE MAIN TABLE.
6. SUPPORT FRAME ABOVE TABLE SHALL BE STEEL WITH PLEXIGLAS SURFACES COVERING THE RIGHT AND THE LEFT TOP OPENINGS, THE AREAS NOTED AS 11.50" BY 22.50". USE ADHESIVE TO ATTACH PLEXIGLASS TO STEEL FRAME.

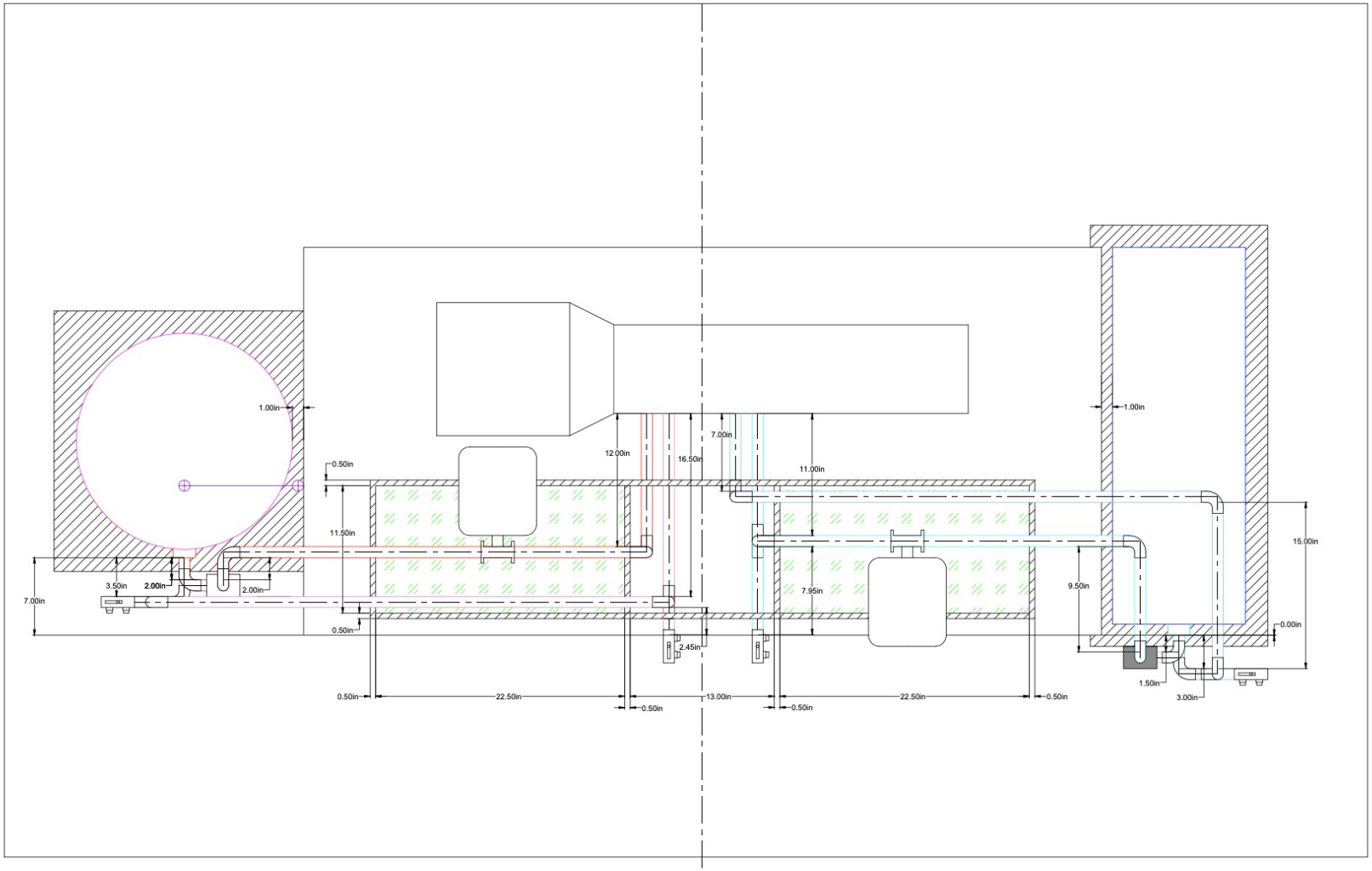
LEGEND & ADDITIONAL NOTES

SCALE: 0'3" = 1'0"
NOTE: USE ENGINEERING JUDGEMENT WHEN MEASURING.
THE DIMENSIONS SHOWN ARE BASED ON ESTIMATES.

AIR HANDLING UNIT

AUTHOR: KARI MILLER
LAST EDITED: 04/16/2020

Class Activity



TOP VIEW

SCALE: 0'3" = 1'0"
NOTE: USE ENGINEERING JUDGEMENT WHEN MEASURING.
THE DIMENSIONS SHOWN ARE BASED ON ESTIMATES.

AIR HANDLING UNIT

AUTHOR: KARI MILLER
LAST EDITED: 04/16/2020