

CAE 438/538 Control of Building Environmental Systems

Fall 2021

September 07, 2021
Instrumentation (2)

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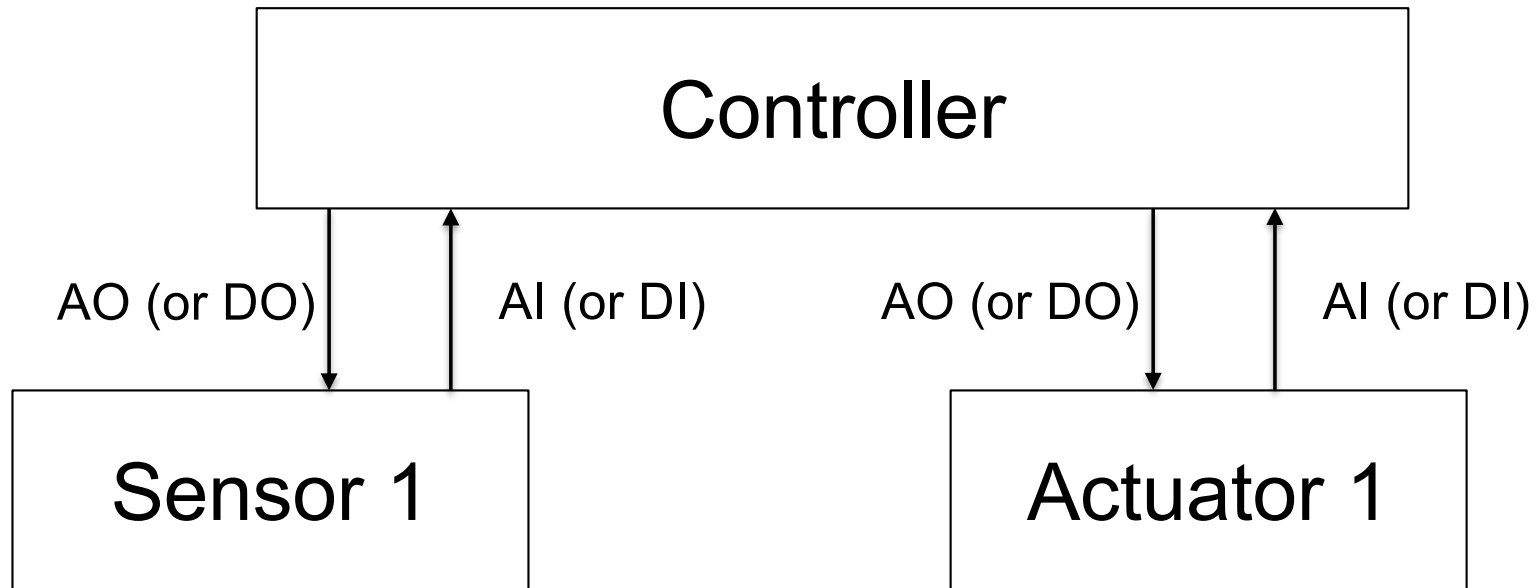
muh182@iit.edu

Recap

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

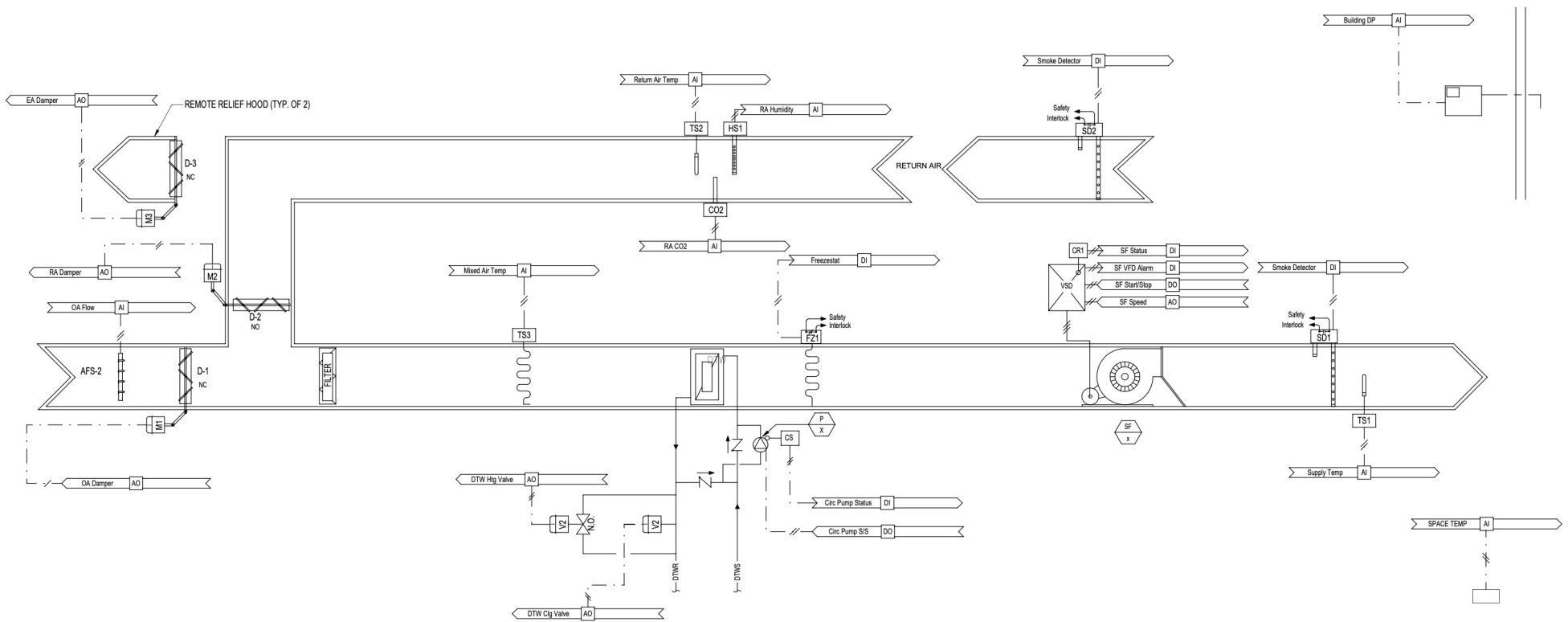
Recap

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



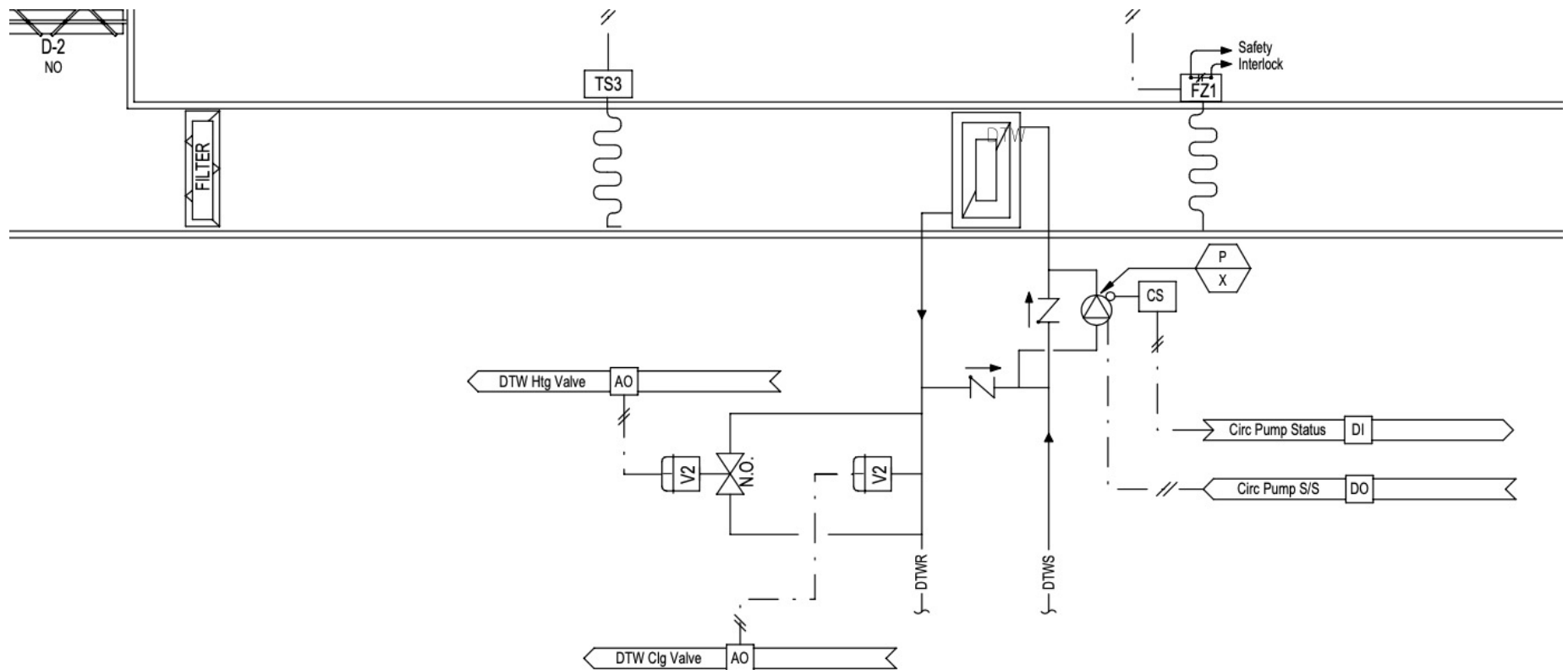
Recap

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



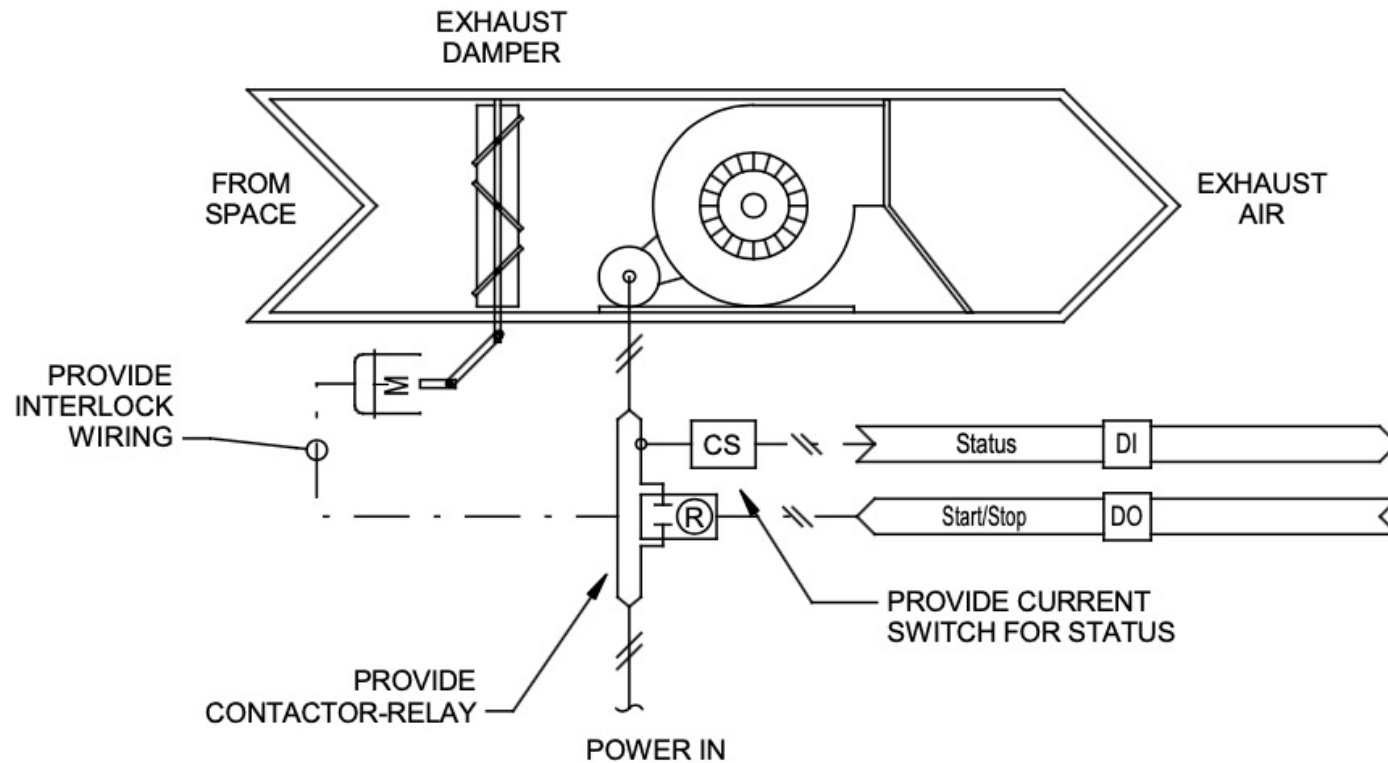
Recap

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



Recap

- System vs. component



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

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

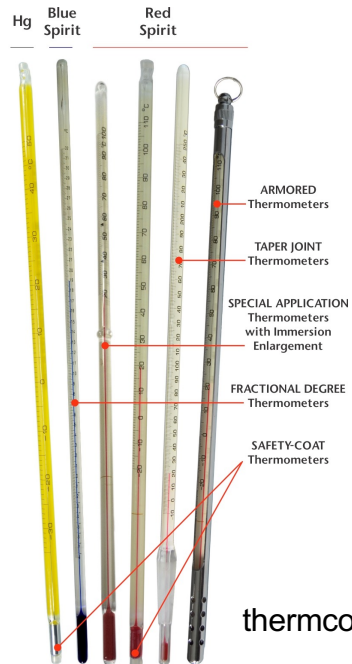
Temperature Sensors

- 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 Mercury
(Discontinued as of March 2011)



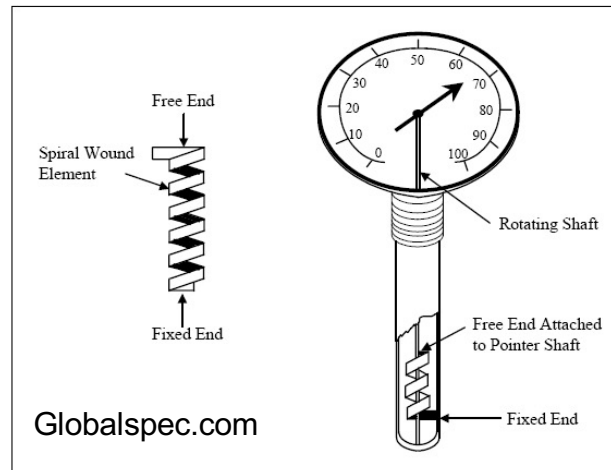
Liquid-in-Glass



Resistance thermometers



Thermocouple



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 |
| Seeger 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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| 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

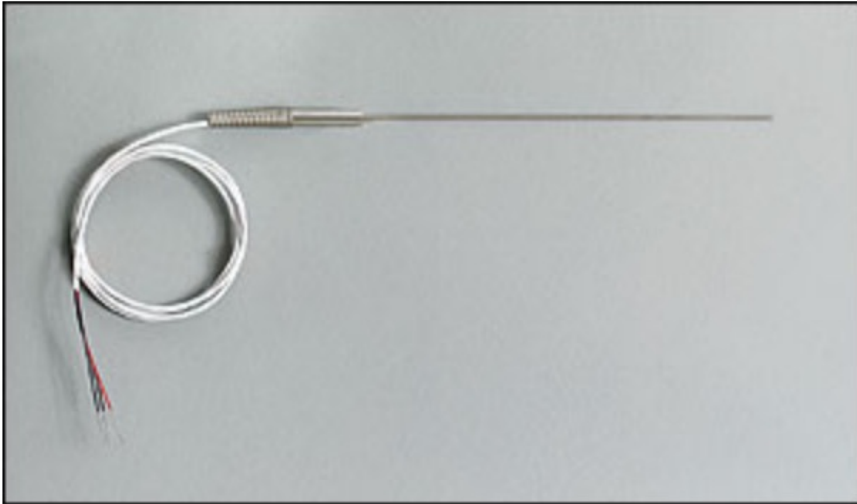
- Also by:

- 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 °F
- The most Platinum RTDs is "Pt-1000-sensor"
 - 0 °C = 1000 Ω
 - Temperature increases or decreases by 3.85 Ω /K

Resistance Temperature Devices



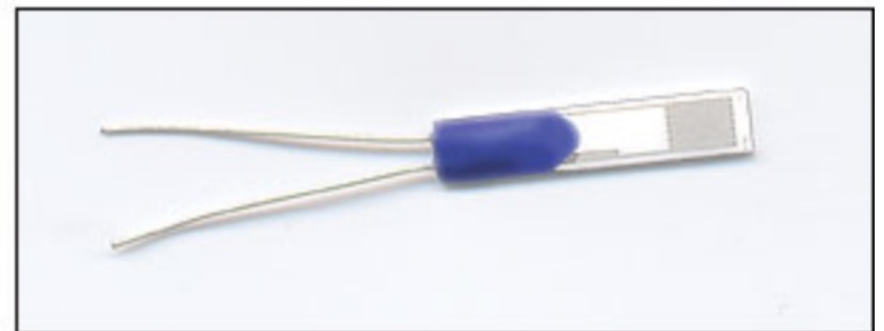
Thick Film Omega Film Element



Glass sealed Bifilar Winding



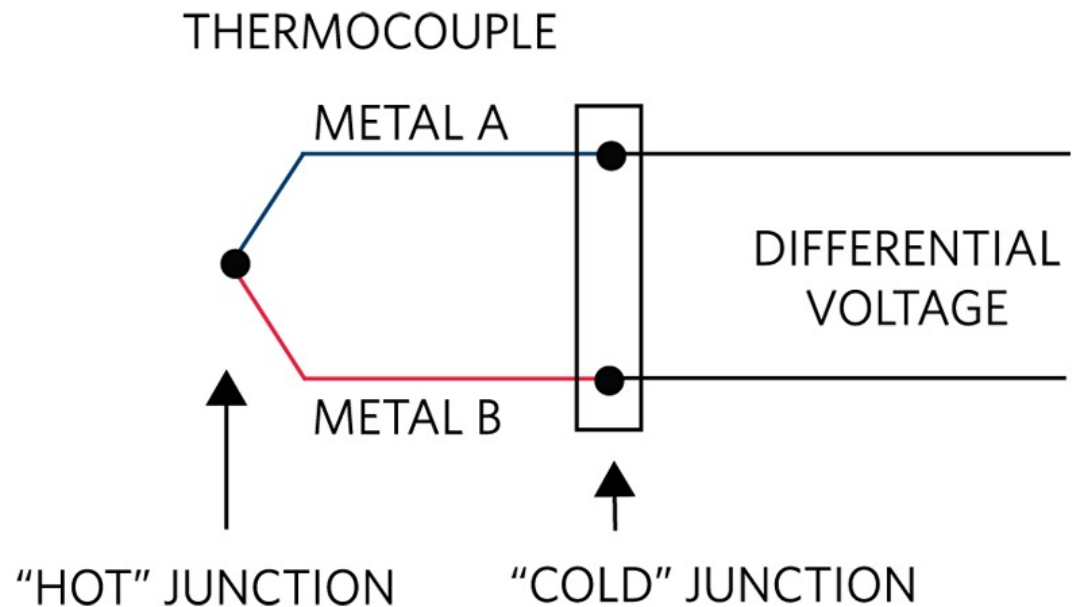
Typical RTD Probes



Thin Film Omega TFD Element

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)



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.

^aTolerances 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.

^bThermocouples 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.

^cLittle 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

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Room temperature sensor NTC10k

Basic attributes

Category

| | |
|--------------|------|
| Basic | (1) |
| Standard | (76) |
| High Quality | (8) |

Application

| | |
|-----------|------|
| Room | (22) |
| Duct | (11) |
| Immersion | (28) |
| Clamp-on | (2) |
| Cable | (11) |

Output signal

| | |
|-------------|------|
| LG-Ni1000 | (28) |
| Modbus RTU | (2) |
| DC 0...10 V | (6) |
| 4...20 mA | (7) |
| NTC | (11) |

Probe length

| | |
|---------|-----|
| 400 mm | (7) |
| 2000 mm | (2) |

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Sensors



Symaro – Sensors from Siemens

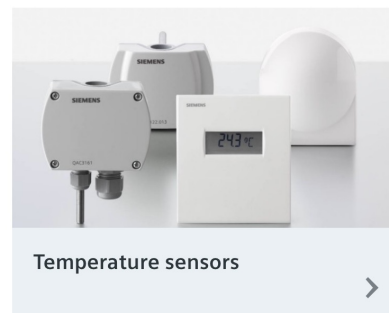
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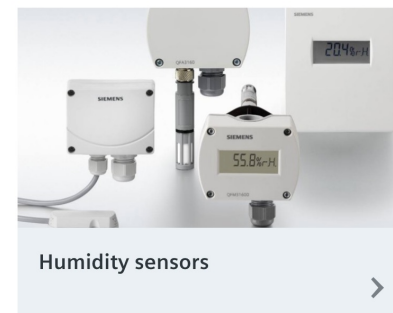
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Fine dust sensors



Temperature sensors



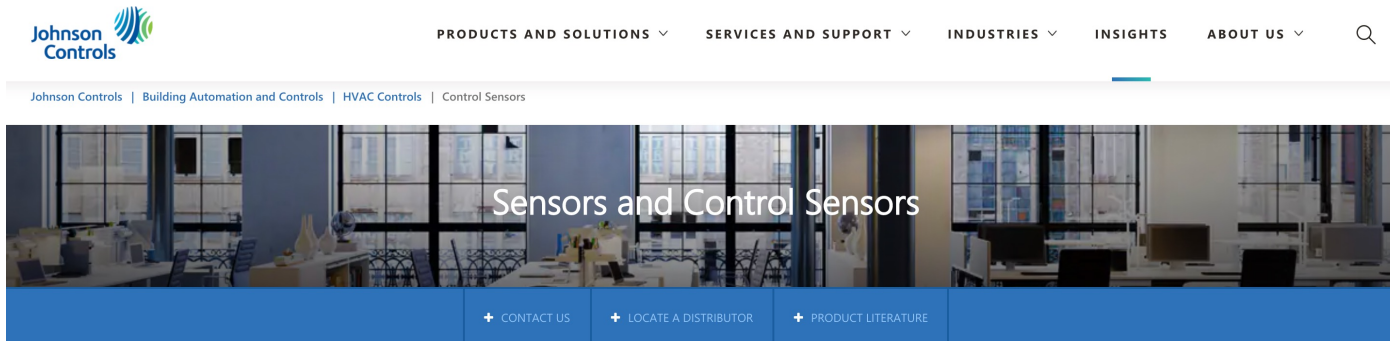
Humidity sensors



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

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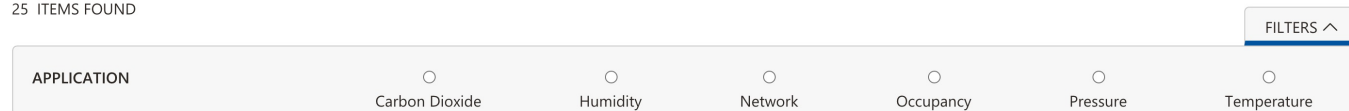
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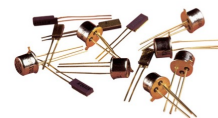
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HUMIDITY MEASUREMENT

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

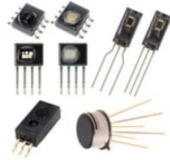
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Overview

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| | | | |
|---|---|---|---|
| <p>Honeywell HumidCon™ HIH6000 Series</p> <p>Digital output, relative humidity & temperature sensor combined in same package • Humidity accuracy: ±4.5 %RH typ. • Temp. accuracy: ±0.5 °C typ.</p> | <p>Honeywell HumidCon™ HIH6100 Series</p> <p>Digital output, relative humidity & temperature sensor combined in same package • Humidity accuracy: ±4.0 %RH typ. • Temp. accuracy: ±0.5 °C typ.</p> | <p>Honeywell HumidCon™ HIH7000 Series</p> <p>Digital output, relative humidity & temperature sensor combined in same package • Humidity accuracy: ±3.0 %RH typ. • Temp. accuracy: ±0.5 °C typ.</p> | <p>Honeywell HumidCon™ HIH8000 Series</p> <p>Digital output, relative humidity & temperature sensor combined in same package • Humidity accuracy: ±2.0 %RH typ. • Temp. accuracy: ±0.5 °C typ.</p> |
| <p>HIH-5030/5031 Series</p> <p>Analog output, relative humidity sensor • Humidity accuracy: ±3 %RH • 2.7 Vdc to 5.5 Vdc supply • SMD • Covered, with/without hydrophobic filter</p> | <p>HIH-4000 Series</p> <p>Analog output, relative humidity sensor • Humidity accuracy: ±3.5 %RH • 4 Vdc to 5.8 Vdc supply • Uncovered</p> | <p>HIH-4010/4020/4021 Series</p> <p>Analog output, relative humidity sensor • Humidity accuracy: ±3.5 %RH • 4 Vdc to 5.8 Vdc supply • Covered or uncovered • Filtered or unfiltered</p> | <p>HIH-4602-A/C Series</p> <p>Analog output, relative humidity & temp. sensor combined in same package • Humidity accuracy: ±3.5 %RH • Factory calibration data with each listing</p> |

<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

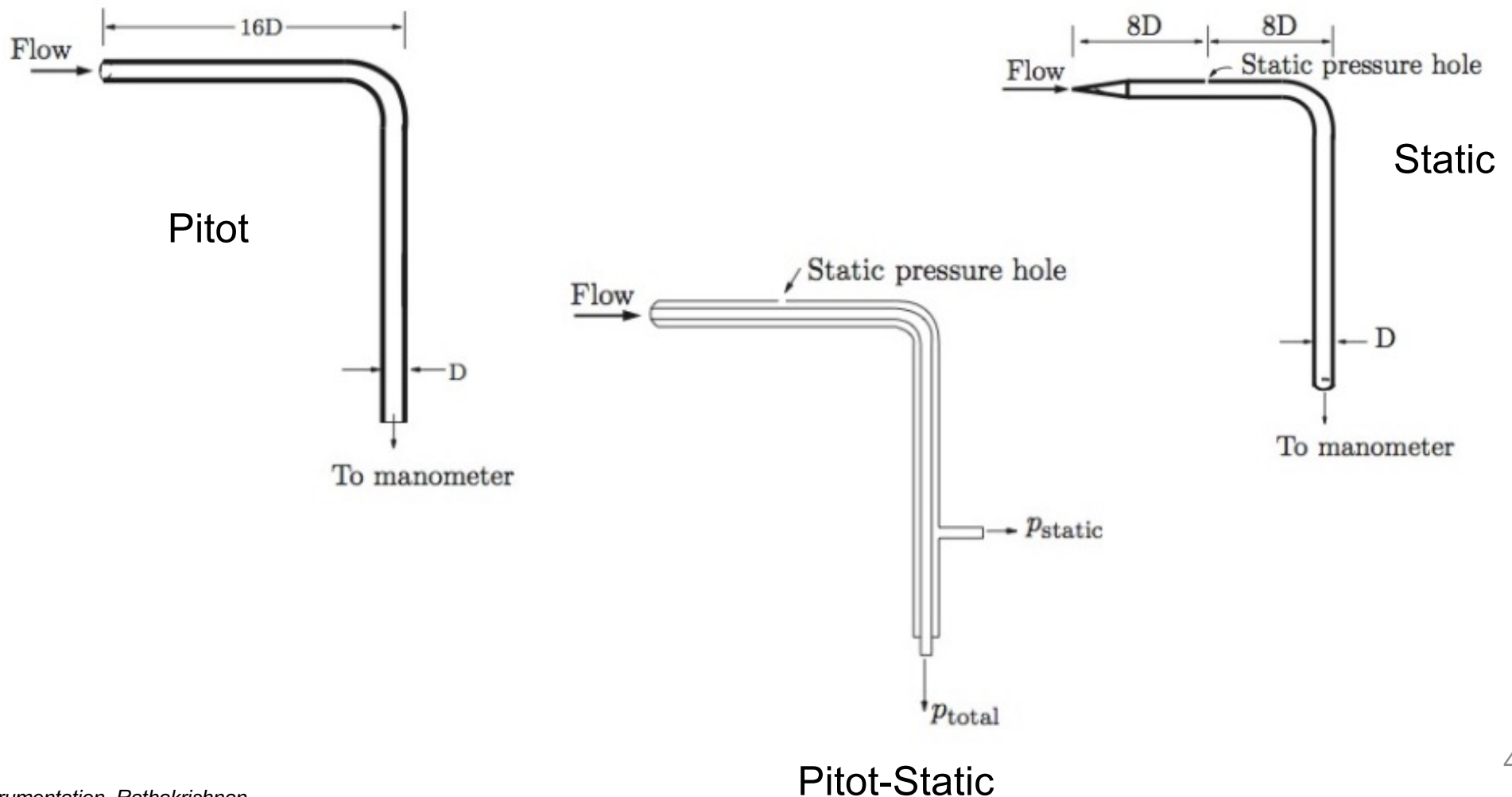
- Pressure measurements using manometer
 - ❑ Advantage:
 - ❖ Easy to fabricate
 - ❖ Accurate for steady-state measurements

 - ❑ 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



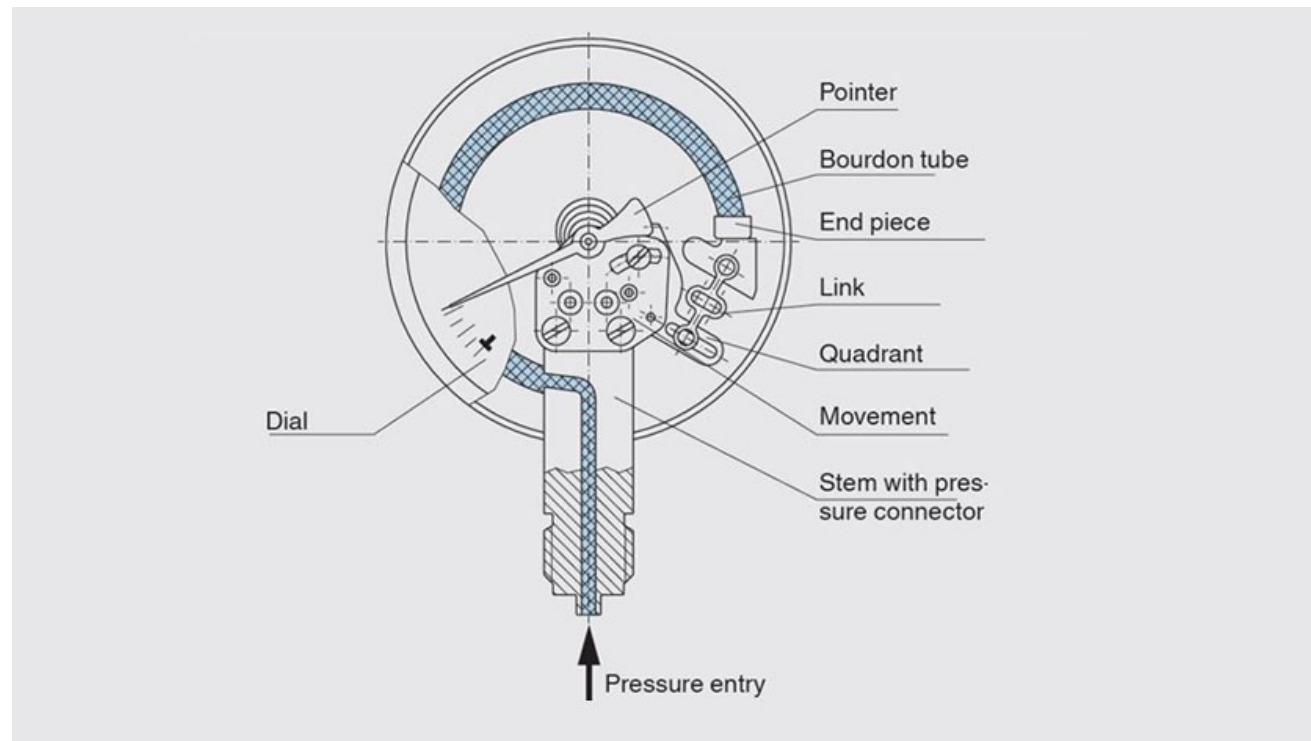
Airflow Rates

- Look at some options:



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

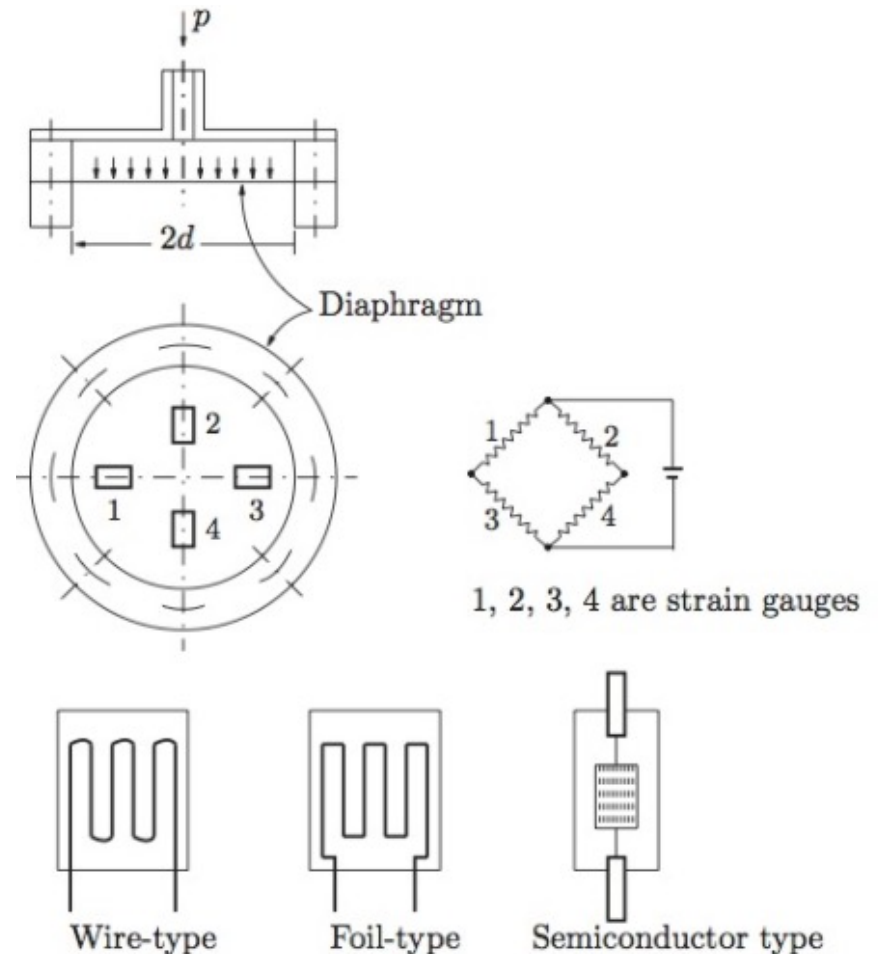


Airflow Rates

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

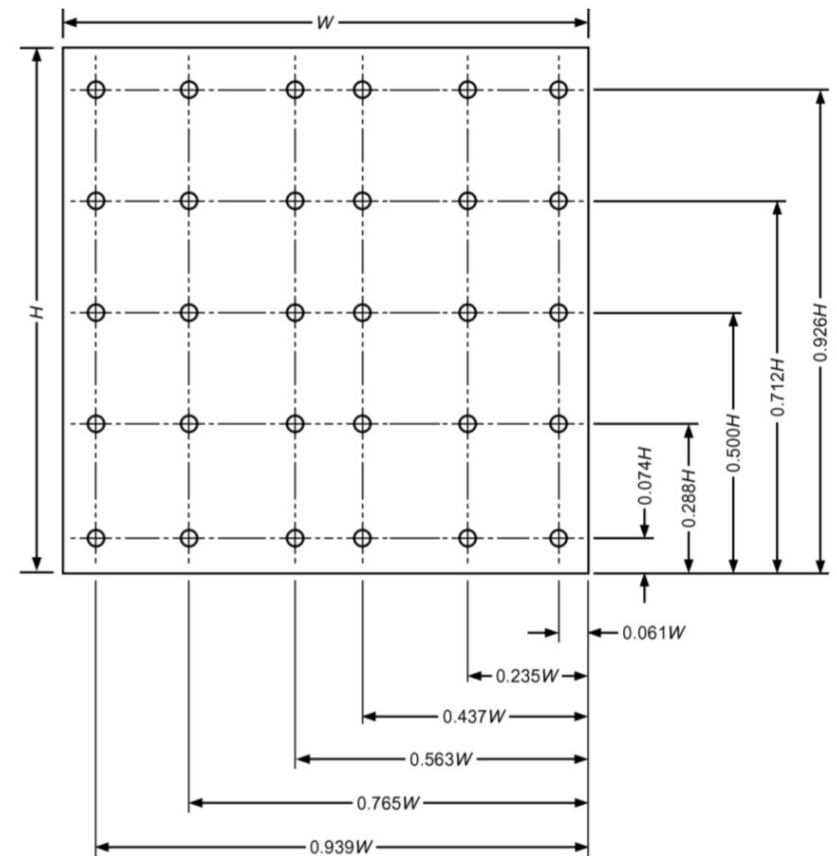
$$\delta = \frac{3pa^4}{16Et^2} (1 - \mu_r^2)$$

- 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. $\leq H, W \leq 36$ 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

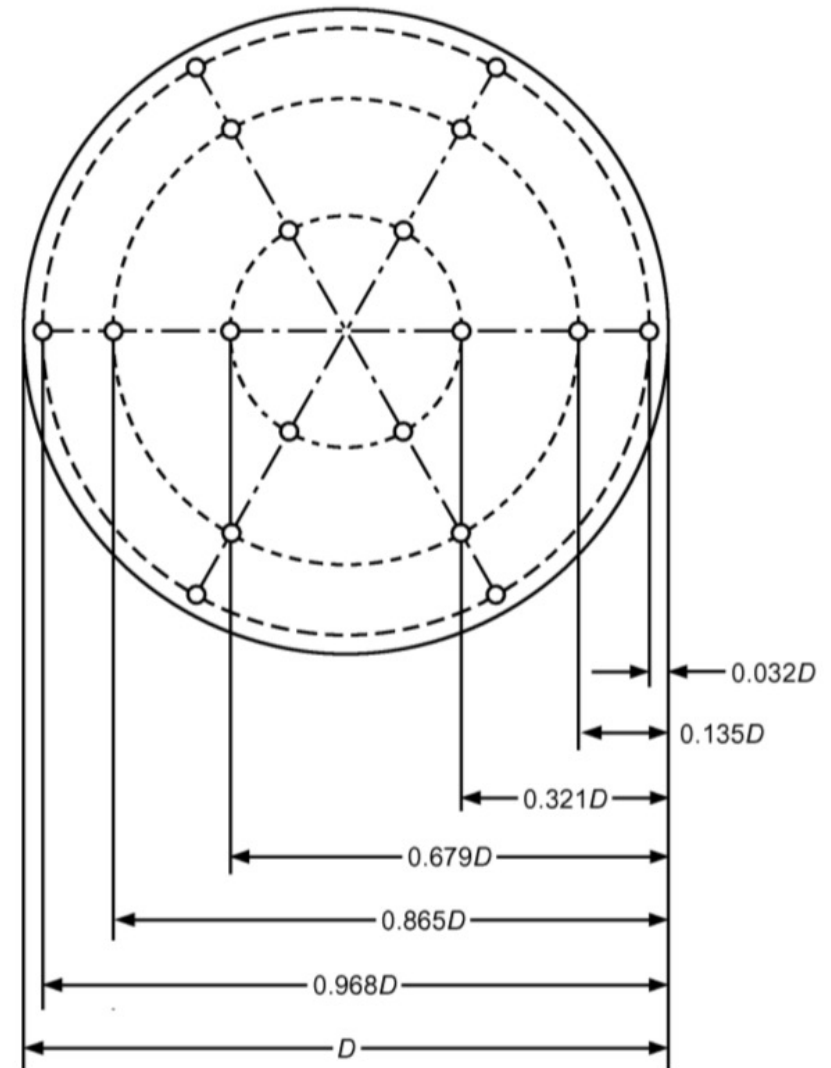
Note: Example duct has 5×6 ($H \times W$) measurement pattern, as for rectangular duct of 24×30 in.

Measuring Flow in Ducts by Velocity

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

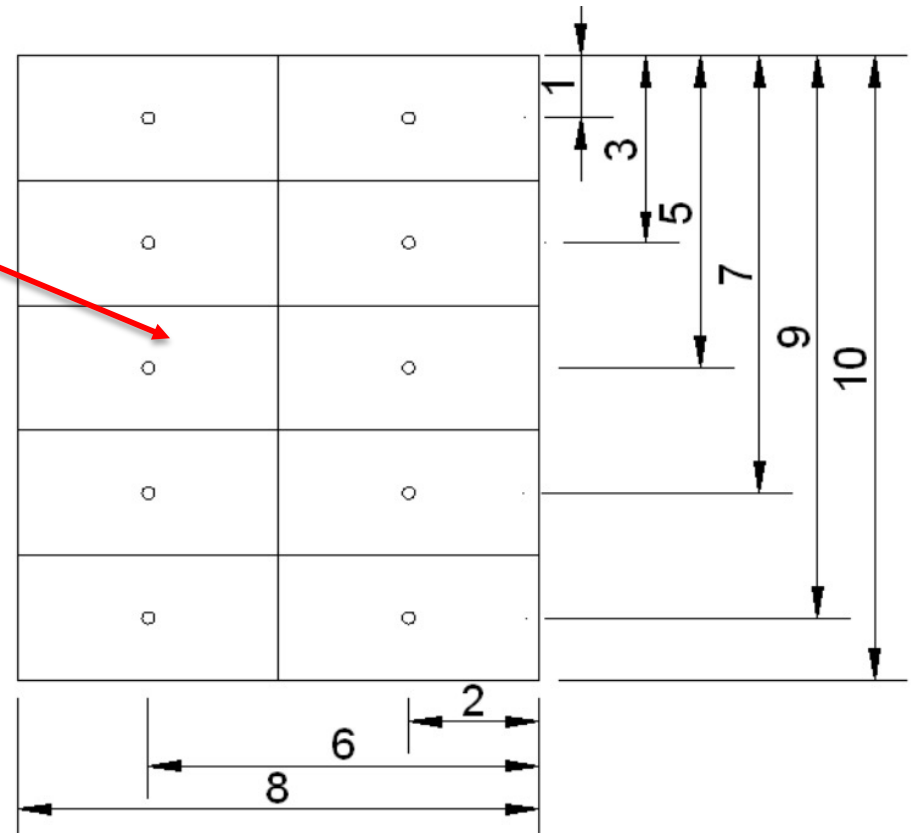
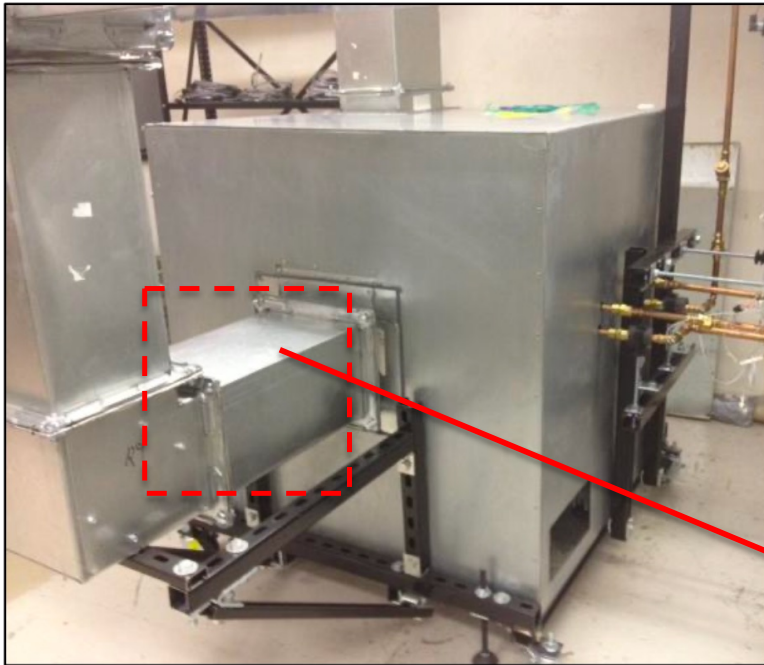
| No. of Measuring Points per Diameter | Position Relative to Inner Wall |
|--------------------------------------|--|
| 6 | 0.032, 0.135, 0.321, 0.679, 0.865, 0.968 |
| 8 | 0.021, 0.117, 0.184, 0.345, 0.655, 0.816, 0.883, 0.979 |
| 10 | 0.019, 0.077, 0.153, 0.217, 0.361, 0.639, 0.783, 0.847, 0.923,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

Log-Linear Rule for Circular Ducts

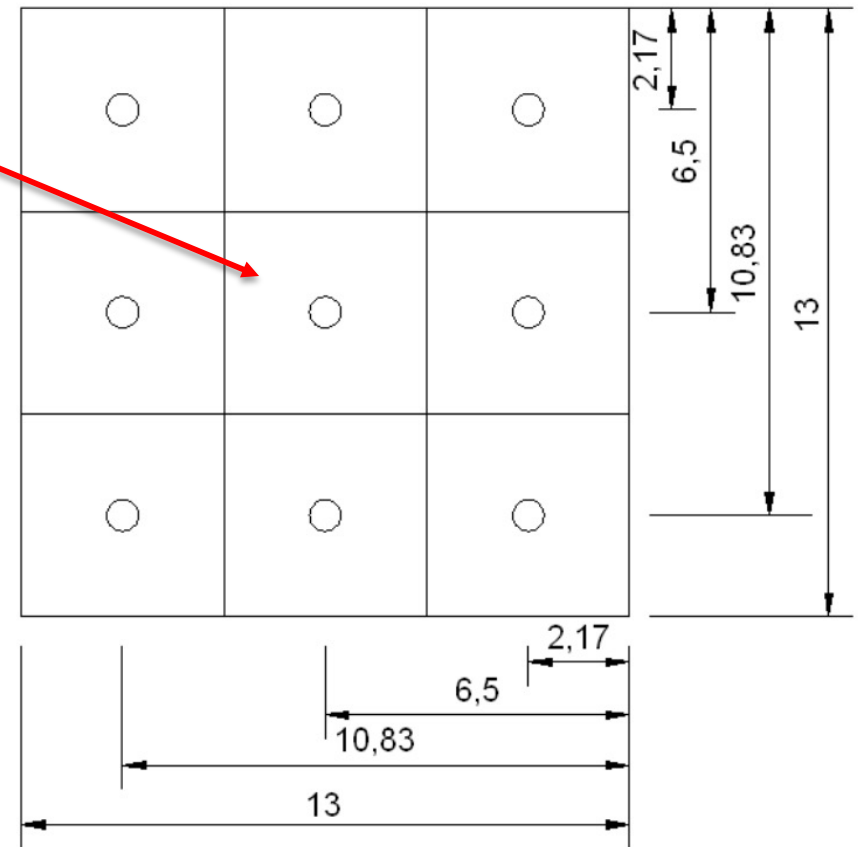
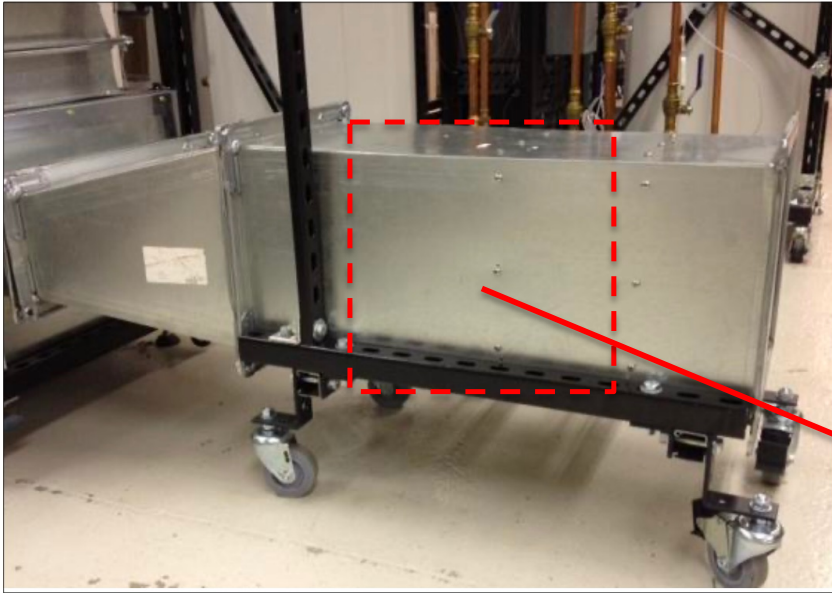


MEASURING FLOW IN DUCTS BY VELOCITY

Measuring Flow in Ducts by Velocity



Measuring Flow in Ducts by Velocity



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>



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](#)

PICOMAG
Flexibility in flow measurement
Multi-variable measurement and reliable monitoring of conductive liquids.



ORDER NOW

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

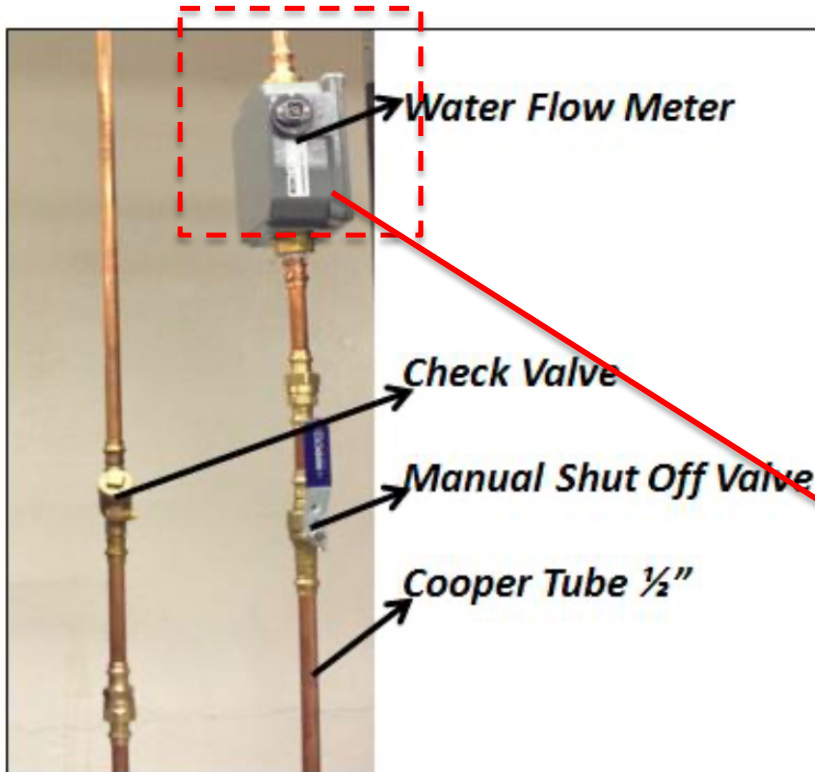
1 1/4"

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



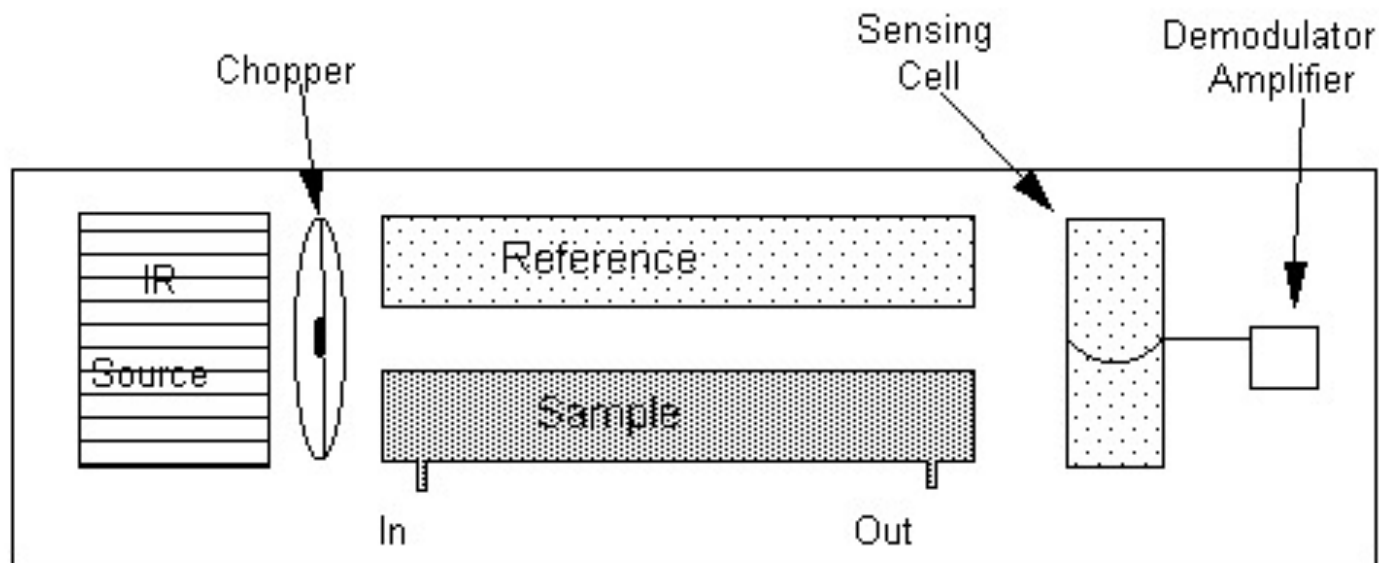
CO₂ CONCENTRATIONS

CO₂ Concentrations

- Common CO₂ measurement techniques are:
 - ❑ Non-dispersive infrared (NDIR) → most common
 - ❑ Electrochemical (reduce CO₂ → generate current)
 - ❑ Photoacoustic (CO₂ absorbs light energy → measure pressure change)
 - ❑ Photoacoustic effect relates pressure change to CO₂ concentration
 - ❑ Potentiometric (CO₂ into solution – changes pH)
 - ❑ Gas chromatography w/ MS or TCD
 - ❖ High sensitivity
 - ❖ High cost

CO₂ Concentrations

- Non-dispersive infrared (NDIR) sensor measures the infrared light absorbed by CO₂ as it passes through a flow-through IR absorption cell
 - CO₂ peak absorbance @ 4.3 μm (higher CO₂, higher absorption)
 - Possible interference from other species (H₂O, CO)
 - Interferences from other IR-absorbing gases are minimized by use of a highly wavelength-specific detector



CO₂ Concentrations

- Examples of CO₂ 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 CO ₂ /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 CO ₂ 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 |

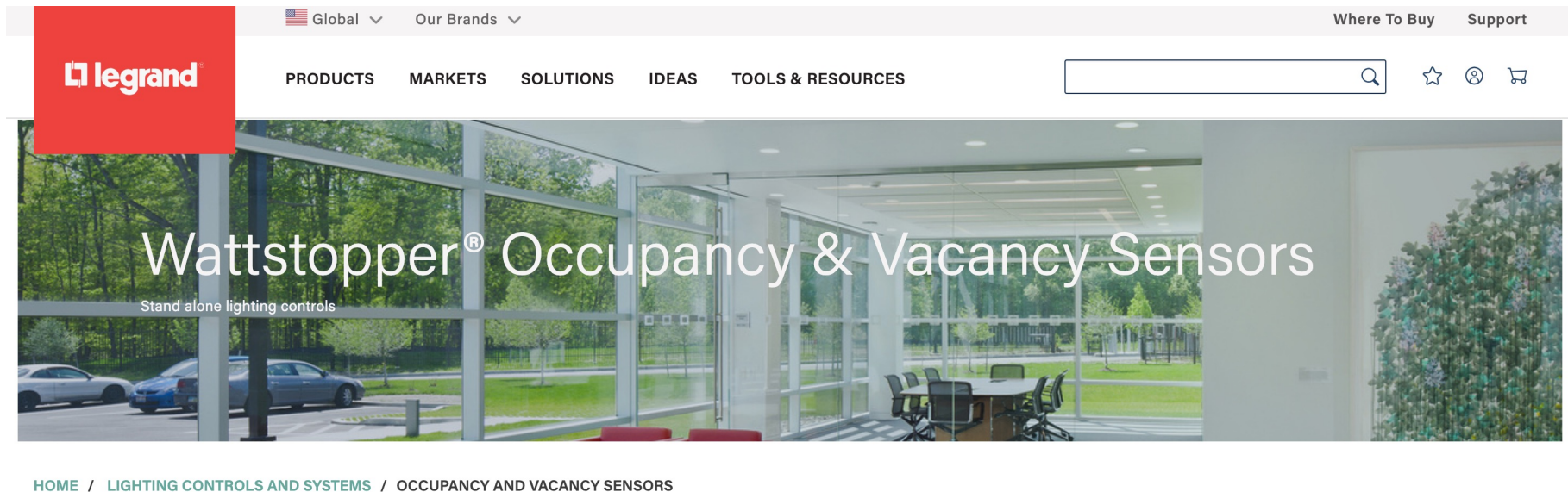
LIGHTING SENSORS

Lighting Sensors

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

Lighting Sensors

- Wattstopper examples are:



Occupancy and Vacancy Sensors

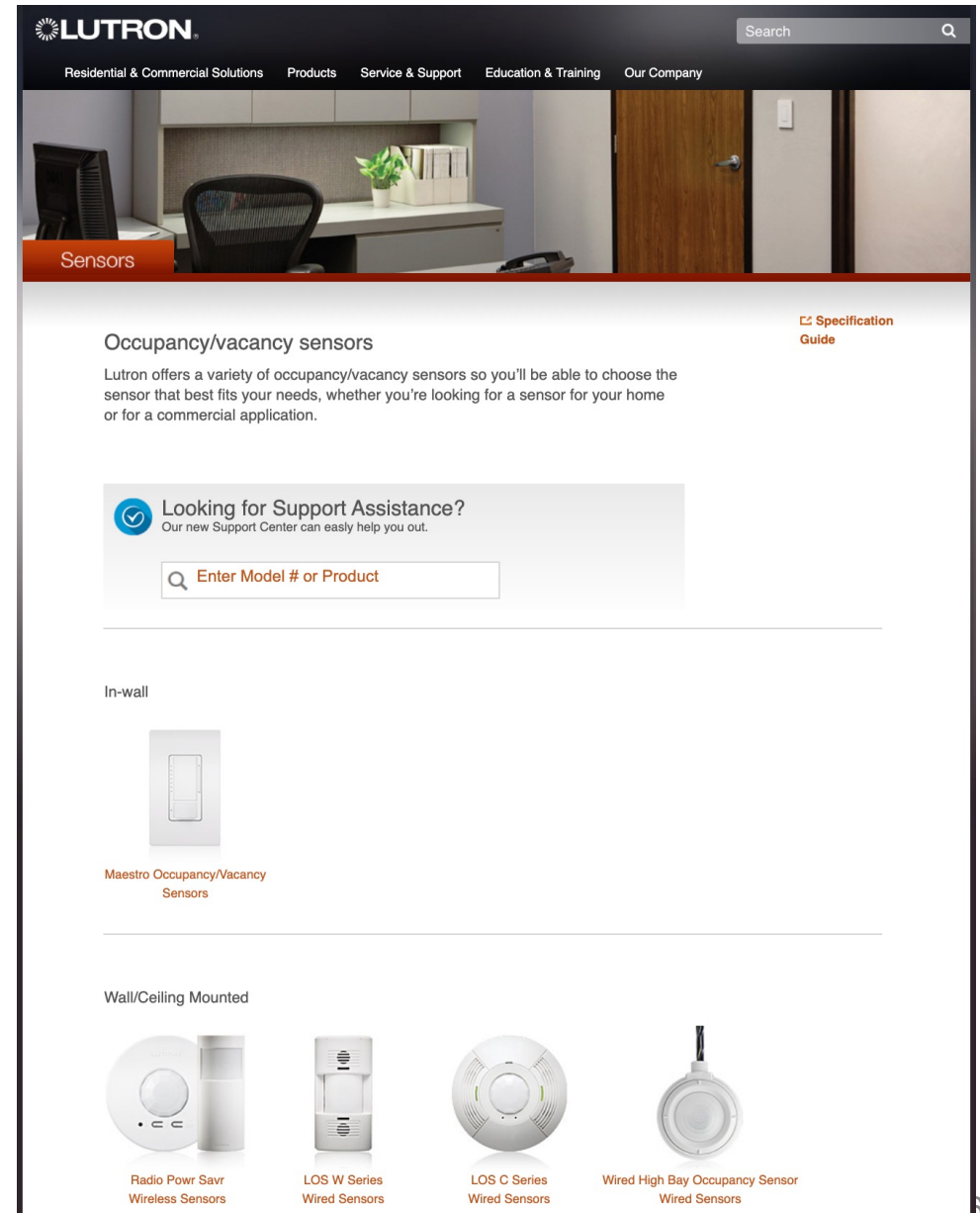
Occupancy and Vacancy Sensors maximize energy savings, ensuring that lights are turned on when occupied and turned off or to a lower level when spaces are unoccupied or adequate daylight exists.

<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>



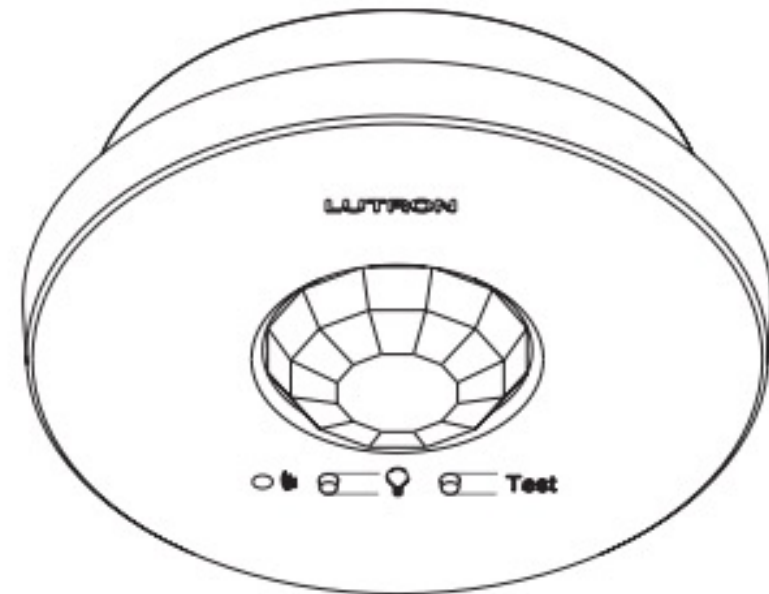
The screenshot shows the Lutron website's Sensors page. At the top, there is a navigation bar with the Lutron logo and a search bar. Below the navigation bar, there is a header image of an office desk with a chair and a plant. A red banner with the word "Sensors" is overlaid on the image. The main content area features a section titled "Occupancy/vacancy sensors" with a "Specification Guide" link. Below this, there is a "Looking for Support Assistance?" section with a search bar for "Enter Model # or Product". The page is divided into two sections: "In-wall" and "Wall/Ceiling Mounted". The "In-wall" section shows a "Maestro Occupancy/Vacancy Sensors" product. The "Wall/Ceiling Mounted" section shows four products: "Radio Powr Savr Wireless Sensors", "LOS W Series Wired Sensors", "LOS C Series Wired Sensors", and "Wired High Bay Occupancy Sensor Wired Sensors".

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 $9.5\ \mu\text{m}$) 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.

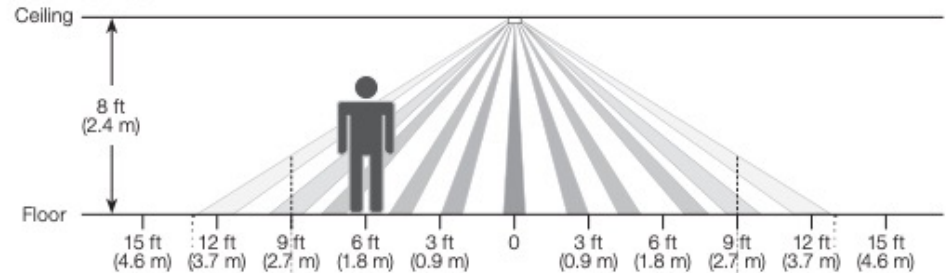


Lighting Sensors

- Lutron examples are:

Coverage Diagrams

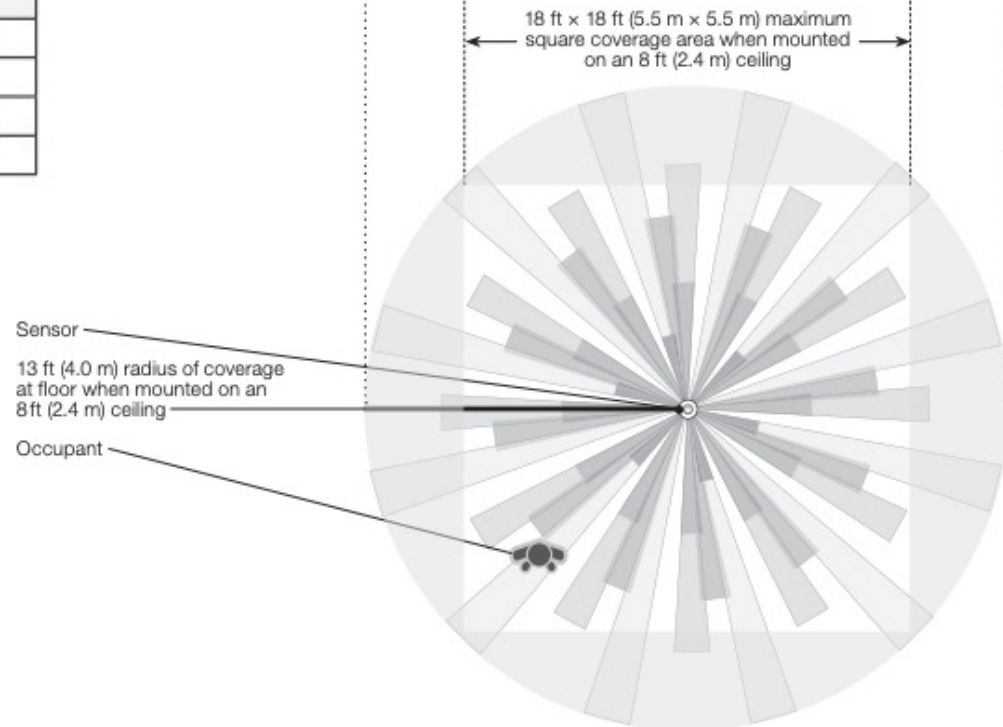
Per NEMA WD7 test method



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

| Ceiling Height | Maximum Square Coverage Area* | |
|----------------|-------------------------------|--|
| 8 ft (2.4 m) | 18 ft x 18 ft (5.5 m x 5.5 m) | 324 ft ² (30.2 m ²) |
| 9 ft (2.7 m) | 20 ft x 20 ft (6.1 m x 6.1 m) | 400 ft ² (37.2 m ²) |
| 10 ft (3.0 m) | 22 ft x 22 ft (6.7 m x 6.7 m) | 484 ft ² (44.9 m ²) |
| 12 ft (3.7 m) | 26 ft x 26 ft (7.9 m x 7.9 m) | 676 ft ² (62.4 m ²) |

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



Lighting Sensors

- Lutron examples are:

The screenshot shows the Lutron website interface for the Radio Powr Savr Wireless Daylight Sensor. The page features a dark blue header with the Lutron logo and navigation links. The main content area has a dark blue background with white text. The product title is "Radio Powr Savr Wireless Daylight Sensor". Below the title are navigation tabs for Overview, Features, Applications, Models, Model Numbers, and Coordinating Products. The Overview tab is selected. The main text describes the sensor's benefits: "Radio Powr Savr wireless daylight sensors that provide convenient light control and are engineered for optimum energy savings and easy installation. Radio Powr Savr wireless sensors save energy by directing compatible wireless lighting controls to reduce lighting levels based on available daylight." A large image of the sensor is shown, along with smaller images of the sensor's components. Below the main text are sections for "Tools & Downloads" (including a link to the "Radio Powr Savr Wireless Daylight Sensor Specification Guide"), "Customer Assistance" (with links to "Customer Service" and "Technical Support"), and "Related Resources" (including a link to the "Daylight Sensor Design and Application Guide"). A "ClearConnect" section highlights that the product uses Clear Connect technology. A "Request a color sample" section is also present, with a note that some colors may not be available for sampling.

Register or Login to myLutron | United States | English | Product Quick Links | Where to Buy | Support

LUTRON Search

Residential & Commercial Solutions | Products | Service & Support | Education & Training | Our Company

Where to Buy

Radio Powr Savr Wireless Daylight Sensor

Overview | Features | Applications | Models | Model Numbers | Coordinating Products

Radio Powr Savr wireless daylight sensors that provide convenient light control and are engineered for optimum energy savings and easy installation. Radio Powr Savr wireless sensors save energy by directing compatible wireless lighting controls to reduce lighting levels based on available daylight.

Tools & Downloads

Radio Powr Savr Wireless Daylight Sensor Specification Guide

Technical Documentation & Support:
Select Type

Customer Assistance
Customer Service | Technical Support

Search and share solutions with other Lutron customers in the Lutron Support Community.

Related Resources
Daylight Sensor Design and Application Guide

Matte

White WH

ClearConnect
This product uses Clear Connect technology. [Learn more](#)

Note: For assistance with daylight system set-up, please view our [programming videos](#) or contact Lutron technical support at 1-888-LUTRON1 (588-7661).

Request a color sample [here](#).
Note: Some of the colors mentioned above may not be available for sampling.

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

Lighting Sensors

- nLight examples are:

The screenshot shows the Acuity Brands website product page for the rCMSB nLight AIR Wireless Ceiling Mount Sensor. The page features a navigation bar with the Acuity Brands logo and links for BRANDS, PRODUCTS, RESOURCES, SUPPORT, and CONTACT. A search bar is located on the right. The breadcrumb trail reads HOME // PRODUCTS // RCMSB. The main content area displays a large image of the rCMSB sensor, a smaller thumbnail gallery on the left, and a 'Compare' button at the bottom. To the right of the main image, the product name 'rCMSB' is displayed in a large font, followed by 'nLight AIR Wireless Ceiling Mount Sensor' and 'by nLight'. A 'SHARE' button is visible in the top right corner. Below the product name is the DLC logo and a descriptive paragraph: 'The rCMSB is a wireless battery-powered ceiling mount sensor for retrofit or new construction projects that has no wires to install; simply mount it to the ceiling, program with the mobile app, and you're done. Combine the rCMSB with nLight® AIR switches and fixture-based controls for easier installation to drive the lowest installed cost of lighting controls.'

<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.

CONFIGURATIONS

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 transformer)

[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>

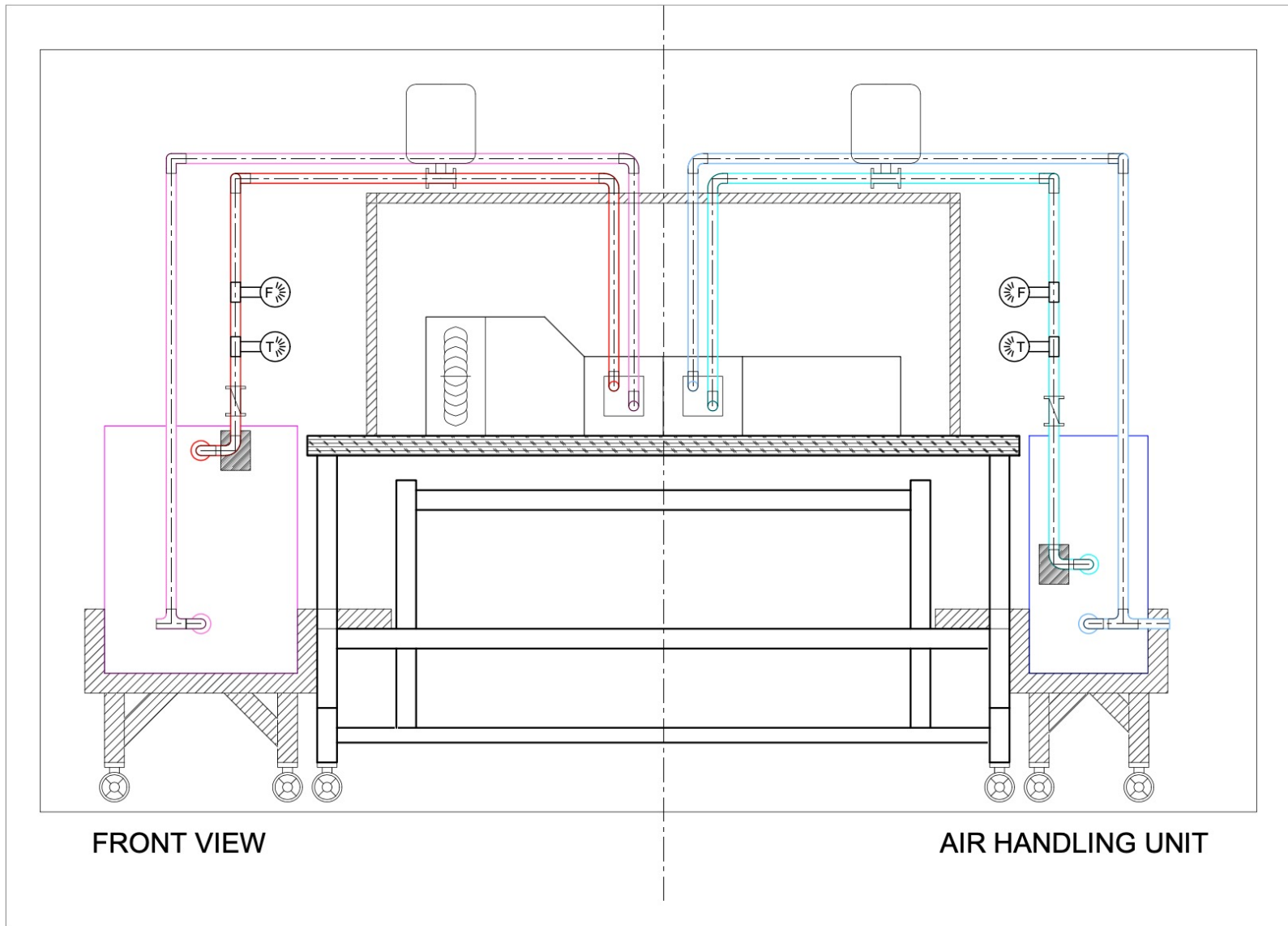
CLASS ACTIVITY

Class Activity

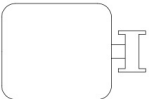
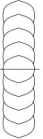


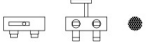




















- Consider designing and selecting sensors to measure temperature, humidity, air flow, and water flow for the ASHRAE AHU facility



Class Activity



Class Activity

| | | | | |
|---|----------------------------------|---|-------------------|---|
|  | Expansion Tank |  | Fan | <p>ADDITIONAL NOTES:</p> <ol style="list-style-type: none"> 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 PLEXIGLAS TO STEEL FRAME. |
|  | Check Valve |  | Pump | |
|  | Drain/Inlet |  | Hot Water Supply | |
|  | 90deg. Elbow |  | Hot Water Return | |
|  | Two 90deg. Elbow |  | Water Heater | |
|  | 90deg. Tee |  | Cold Water Supply | |
|  | Flow Gauge |  | Cold Water Return | |
|  | Temperature Gauge |  | Chiller | |
|  | Electrical Outlets |  | Reducer | |
|  | Electrical Line |  | Clear PVC Pipe | |
|  | Wheels |  | Steel | |
|  | Ground Fault Circuit Interruptor |  | Plexiglass | |
| | |  | Table Surface | |

LEGEND & ADDITIONAL NOTES

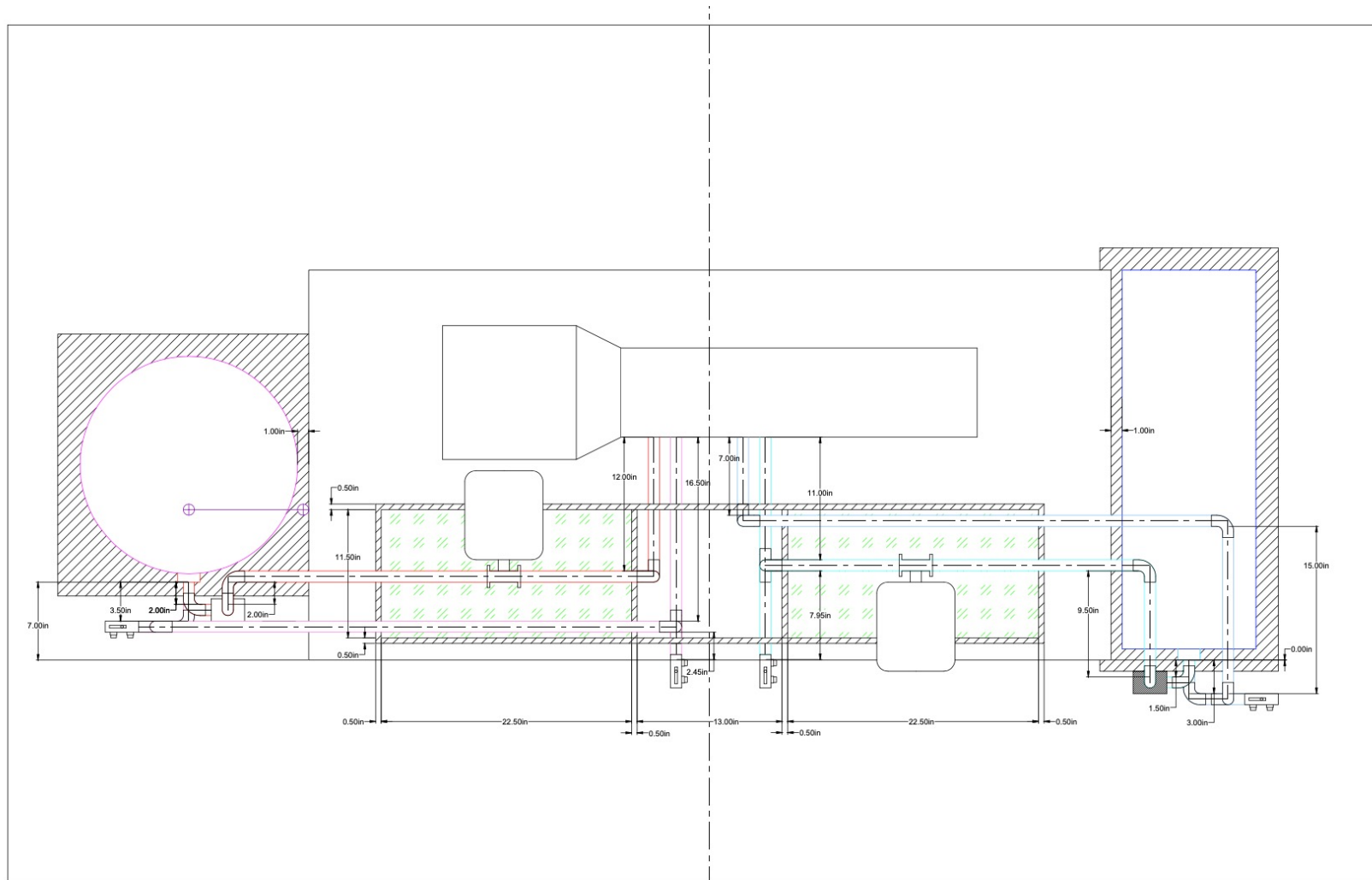
SCALE: 0'3" = 1'0"

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

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