CAE 553 Measurements and Instrumentation in Architectural Engineering

Fall 2018

October 9, 2018

HVAC/Energy: Heat flux and energy meters

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How do we consume energy in buildings?

What are the fuel sources?

ENERGY DEFINITIONS

Definition

- Steam typically measured based on volume or heat/energy content:
  - 100 cubic feet (CCF)
  - British Thermal Unit (BTU)
  - Therms (100,000 BTU)
  - Pound of steam (klb)
  - Example of conversion factors:
    - 1klb = 1194 kBtu
    - 3.412 kBtu = 1 kWh

- Questions:
  - Find the conversion factors from klb to kWh?
  - Why do we consider different units?

Definition

- Chilled water is typically in heat/energy content:
  - Ton-Hr, BTU
  - $\dot{Q} = \dot{m} C_p \Delta T = \rho \dot{V} C_p \Delta T$
    - ρ = 999.78 kg/m^3
    - C_p =4.19 kJ/kg-K

  – $\dot{Q} = \dot{m} C_p \Delta T = \rho \dot{V} C_p \Delta T$
    - ρ = 61.14 lb/ft^3
    - C_p =1.00076 Btu/lb-F

$$\frac{(GPM)\Delta T}{24} = Ton$$

Definition

- Electricity
  - Power = kW
  - Energy consumed = kWh
  - Relationship = kW × Time = kWh

Common Conversion Table

Meter Type	Input Unit Options	U.S. Property Assumptions[1]		Canadian Property Assumptions[2]	
		Multiplier to get kBtu	Heat Content	Multiplier to get kBtu	Heat Content
District Steam	kBtu	1	1,194 Btu/Lb	1	1,194 Btu/Lb
	MBtu	1,000		1,000	
	Lbs	1.194		1.194	
	kLbs	1,194		1,194	
	MLbs	1,194,000		1,194,000	
	therms	100.0		100.000	
	GJ	947.817		947.817	
	kg	2.632		2.632	
District Chilled Water (All Types)	kBtu	1	Not Needed - No Volume Entry Units	1	Not Needed - No Volume Entry Units
	MBtu	1,000		1,000	
	Ton Hours	12.0		12.0	
	GJ	947.817		947.817	
Electricity (Grid Purchase and Onsite Renewable)	kBtu	1	Not Applicable	1	Not Applicable
	MBtu	1,000		1,000	
	kWh	3.412		3.412	
	MWh	3,412		3,412	
	GJ	947.817		947.817	

Common Conversion Table

Meter Type	Input Unit Options	U.S. Property Assumptions[1]		Canadian Property Assumptions[2]	
		Multiplier to get kBtu	Heat Content	Multiplier to get kBtu	Heat Content
Fuel Oil (No. 2)	kBtu	1	0.138 MBtu/gallon	1	0.139210 MBtu/gallon
	MBtu	1,000		1,000	
	Gallons (US)	138		139.210	
	Gallons (UK)	165.726		167.184	
	liters	36.456		36.775	
	GJ	947.817		947.817	
Fuel Oil (No. 4)	kBtu	1	0.146 MBtu/gallon	1	0.139210 MBtu/gallon
	MBtu	1,000		1,000	
	Gallons (US)	146		139.210	
	Gallons (UK)	175.333		167.184	
	liters	38.569		36.775	
	GJ	947.817		947.817	
Fuel Oil (No. 5 & No. 6)[3]	kBtu	1	0.150 MBtu/gallon	1	0.152485 MBtu/gallon
	MBtu	1,000		1,000	
	Gallons (US)	150		152.485	
	Gallons (UK)	180.137		183.127	
	liters	39.626		40.282	
	GJ	947.817		947.817	
Diesel	kBtu	1	0.138 MBtu/gallon	1	0.137416 MBtu/gallon
	MBtu	1,000		1,000	
	Gallons (US)	138		137.416	
	Gallons (UK)	165.726		165.029	
	liters	36.456		36.301	
	GJ	947.817		947.817	
Kerosene	kBtu	1	0.135 MBtu/gallon	1	0.135191 MBtu/gallon
	MBtu	1,000		1,000	
	Gallons (US)	135		135.191	
	Gallons (UK)	162.123		162.358	
	liters	35.663		35.714	
	GJ	947.817		947.817	

Common Conversion Table

Meter Type	Input Unit Options	U.S. Property Assumptions[1]		Canadian Property Assumptions[2]	
		Multiplier to get kBtu	Heat Content	Multiplier to get kBtu	Heat Content
Propane[4]	kBtu	1	0.092 MBtu/gallon	1	0.09089 MBtu/gallon
	MBtu	1,000		1,000	
	cf	2.516		2.516	
	ccf	251.6		251.6	
	kcf	2,516		2,516	
	Gallons (US)	92		90.809	
	Gallons (UK)	110.484		109.057	
	liters	24.304		23.989	
	GJ	947.817		947.817	
District Steam	kBtu	1	1,194 Btu/Lb	1	1,194 Btu/Lb
	MBtu	1,000		1,000	
	Lbs	1.194		1.194	
	kLbs	1,194		1,194	
	MLbs	1,194,000		1,194,000	
	therms	100.0		100.000	
	GJ	947.817		947.817	
	kg	2.632		2.632	
District Hot Water	kBtu	1	Not Needed - No Volume Entry Units	1	Not Needed - No Volume Entry Units
	MBtu	1,000		1,000	
	Therms	100		100	
	GJ	947.817		947.817	
District Chilled Water (All Types)	kBtu	1	Not Needed - No Volume Entry Units	1	Not Needed - No Volume Entry Units
	MBtu	1,000		1,000	
	Ton Hours	12.0		12.0	
	GJ	947.817		947.817	
Coal (anthracite)	kBtu	1	25.09 MBtu/ton	1	23.818 MBtu/ton
	MBtu	1,000		1,000	
	Tons	25,090		23,818	
	Lbs	12.545		11.909	
	kLbs	12,545		11,909	
	MLbs	12,545,000		11,909,055	
	Tonnes (metric)	27,658.355		26,255	
	GJ	947.817		947.817	

Common Conversion Table

Meter Type	Input Unit Options	U.S. Property Assumptions[1]		Canadian Property Assumptions[2]	
		Multiplier to get kBtu	Heat Content	Multiplier to get kBtu	Heat Content
Coal (bituminous)	kBtu	1	24.93 MBtu/ton	1	21.496 MBtu/ton
	MBtu	1,000		1,000	
	Tons	24,930		21,496	
	Lbs	12.465		10.748	
	kLbs	12,465		10,748	
	MLbs	12,465,000		10,748,245	
	Tonnes (metric)	27,482		23,695	
	GJ	947.817		947.817	
Coke	kBtu	1	24.80 MBtu/ton	1	21.50 MBtu/ton
	MBtu	1,000		1,000	
	Tons	24,800		24,790	
	Lbs	12.4		12.395	
	kLbs	12,400		12,395	
	MLbs	12,400,000		12,394,876	
	Tonnes (metric)	27,339		27,326	
	GJ	947.817		947.817	
Wood	kBtu	1	15.38 MBtu/Ton	1	15.48 MBtu/Ton
	MBtu	1,000		1,000	
	Tons	17,480		15,477	
	Tonnes (metric)	15,857		17,061	
	GJ	947.817		947.817	
Other	kBtu	1.0	Not Needed - No Volume Entry Units	1.0	Not Needed - No Volume Entry Units
	GJ	947.817		947.817	

Source vs. Site Energy

- Site energy is the energy consumed, secondary energy, at the building site (e.g. electricity, steam, CHW)

- Source energy represents the raw amount of fuel, primary energy, that is required to operate the building (e.g. natural gas, fuel oil)

- Benefits of using of source energy:
  - Reduce likelihood of unintentionally penalized of one energy fuel type
  - Correlate more with the energy cost and impact on the climate

- Site energy also provides insights for the building energy use

Source vs. Site Energy

- There are conversion factors (source-to-site ratios) to convert the secondary energy to primary energy based on the location and fuel type

- The commonly accepted global conversion factors are presented by EPA:

Fuel Type	Source-to-Site Ratio
Electricity (grid purchase)	3.34
Electricity (on-site solar or wind energy)	1.0
Natural Gas	1.047
Steam	1.21
Chilled Water	1.05

http://www.energystar.gov/ia/business/evaluate_performance/site_source.pdf

Source vs. Site Energy

Figure 1 – Source-Site Ratios for all Portfolio Manager Energy Meter Types

Energy Type	U.S. Ratio	Canadian Ratio
Electricity (Grid Purchase)	3.14	1.96
Electricity (on-Site Solar or Wind Installation)	1.00	1.00
Natural Gas	1.05	1.01
Fuel Oil (1,2,4,5,6,Diesel, Kerosene)	1.01	1.01
Propane & Liquid Propane	1.01	1.04
Steam	1.20	1.33
Hot Water	1.20	1.33
Chilled Water	1.00	0.57
Wood	1.00	1.00
Coal/Coke	1.00	1.00
Other	1.00	1.00

Source vs. Site Energy

Figure 2 – Comparison of Alternate Heating Scenarios

	Building A	Building B	Building C	Building D	Building E	Building F
Heating Fuel	**Natural Gas**	**Natural Gas**	**District Steam**	**Electric**	**Electric**	**Electric**
Heating System	Gas-fired Boiler 90% combustion efficiency 80% system efficiency	District Steam 70% combustion efficiency 55% system efficiency	District Steam 95% system efficiency	Geothermal COP=4.0	Air Source Heat Pump COP = 2.5	Electric Resistance Heat
Heat to Space (MBtu)	1000	1000	1000	1000	1000	1000
Site Energy (MBtu)	1250	1818	1053	250	400	1000
Source Energy (MBtu)	**1313**	**1909**	**1264**	**785**	**1256**	**3140**

Note that the U.S. source-site ratios were applied:

- *Electricity: 1 unit site = 3.14 units source*
- *Natural Gas: 1 unit site = 1.05 units source*
- *Steam: 1 unit site = 1.20 units source*

Electricity Bill

ComEd
An Exelon Company

SERVICE FROM 1/11/16 THROUGH 2/11/16 (31DAYS)
Residential - Single

Customer Name
Service Address
City, State, Zip
000.000.0000

Issued 2/11/16 Account # 0000000000

Total Amount Due by 3/4/16 $71.29

Thank you for your payments totaling $77.44.

TOTAL USAGE (kWh)

Current month's reading is **actual.**

AVERAGE DAILY USE (monthly usage/days in period)

Current Month	25° avg. temp
15.8 kWh	⬆ 24% from last year

Last Month 36° avg. temp	Last Year 25° avg. temp
17.1 kWh	12.7 kWh

Ten 100W light bulbs for 1 hour = 1 kWh

CURRENT CHARGES SUMMARY
See reverse side for details

SUPPLY
$31.98

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ComEd.com
1.800.334.7661

DELIVERY
$30.96

ComEd delivers electricity to your home.
ComEd.com
1.800.334.7661

TAXES & FEES $8.35

For Electric Supply Choices visit pluginillinois.org

Return only this portion with your check made payable to ComEd. Please write your account number on your check.

1126-52-0114786-0001-0010346

ComEd
An Exelon Company

0114786 01 AV 0.388 **AUTO T4 0 1126 60502-694260 -C04-B1-P14800-I1 4 6 89A C

CUSTOMER NAME
ADDRESS 1
ADDRESS 2
CITY, STATE, ZIP

Pay your bill online, by phone or by mail.
See reverse side for more info
Account # 0000000000

Total Amount Due by 3/4/16	$71.29
Payment Amount:	

COMED
PO BOX 6111
CAROL STREAM, IL 60197-6111

Electricity Bill

For Questions, Support, and Outages visit ComEd.com

English	1.800.EDISON1 (1.800.334.7661)
Español	1.800.95.LUCES (1.800.955.8237)
Hearing/Speech Impaired	1.800.572.5789 (TTY)
Federal Video Relay Services (VRS)	Fedvrs.us/session/new

***Please seek assistance from **ComEd** prior to contacting the ICC Consumer Services Division

- Inside Illinois	1.800.524.0795
- Outside Illinois	1.217.782.2024
- TTY	1.800.858.9277

Issued **2/11/16** Account # **0000000000**

Total Amount Due by 3/4/16 **$71.29**

METER INFORMATION

Read Dates	Meter Number	Load Type	Reading Type	Previous		Present		Difference	Multiplier	Usage
1/11-2/11	000000000	General Service	Total kWh	94278	**Actual**	94769	**Actual**	491	x 1	491

CHARGE DETAILS

Residential - Single 2/8/17 - 3/9/17 (29 Days)

SUPPLY		**$31.98**
Electricity Supply Charge	491 kWh X 0.05865	$28.80
Transmission Services Charge	491 kWh X 0.01122	$5.51
Purchased Electricity Adjustment		-$2.33
DELIVERY - ComEd		**$30.96**
Customer Charge		$10.53
Standard Metering Charge		$4.36
Distribution Facilities Charge	491 kWh X 0.03156	$15.50
IL Electricity Distribution Charge	491 kWh X 0.00116	$0.57
TAXES & FEES		**$8.35**
Environmental Cost Recovery Adj	491 kWh X 0.00038	$0.19
Renewable Portfolio Standard	491 kWh X 0.00189	$0.92
Zero Emission Standard	491 kWh X 0.00195	$0.95
Energy Efficiency Programs	491 kWh X 0.00345	$1.69
Franchise Cost	$30.39 X 2.36300%	$0.72
State Tax		$1.62
Municipal Tax		$2.26
Service Period Total		**$71.29**

UPDATES

ComEd

- WAYS TO PAY: ComEd offers a variety of ways to Pay. Learn more at ComEd.com/pay
- WE ARE HERE FOR YOU: As of Feb. 1st, we'll be open 1 hour later. Call us from 7 am to 7pm Monday through Friday. 1-800-EDISON-1 ComEd.com/ContactUs
- APPLIANCE REBATES: Get Appliance Rebates from the ComEd Energy Efficiency Program to upgrade your appliances. ComEd.com/Rebates
- SCAM ALERT: ComEd will never call you to request cash or ask you to buy a prepaid credit card to pay a bill. ComEd.com/ScamAlert
- PART 280: View a copy of the ICC Commission 83 Ill. Adm. Code 280 rules at ComEd.com/Part280
- YOUR COMED BILL: Need help understanding your bill line item definitions? Please visit us at ComEd.com/UnderstandBill or call us at 1-800-334-7661
- ENVIRONMENTAL DISCLOSURE STATEMENT: ComEd's Environmental Disclosure Statement can now be found online at ComEd.com/EnvironmentalDisclosure
- Past due balances are subject to late charges.

1126-52-0114786-0001-0010347

SAMPLE

OTHER WAYS TO PAY YOUR BILL

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Online

Set up an automatic payment, enroll in paperless billing, or make a convenience payment at ComEd.com/Pay.

Mobile App

Download the ComEd mobile app on your Apple® or Android™ device to view and pay your bill, or manage your account.

Phone

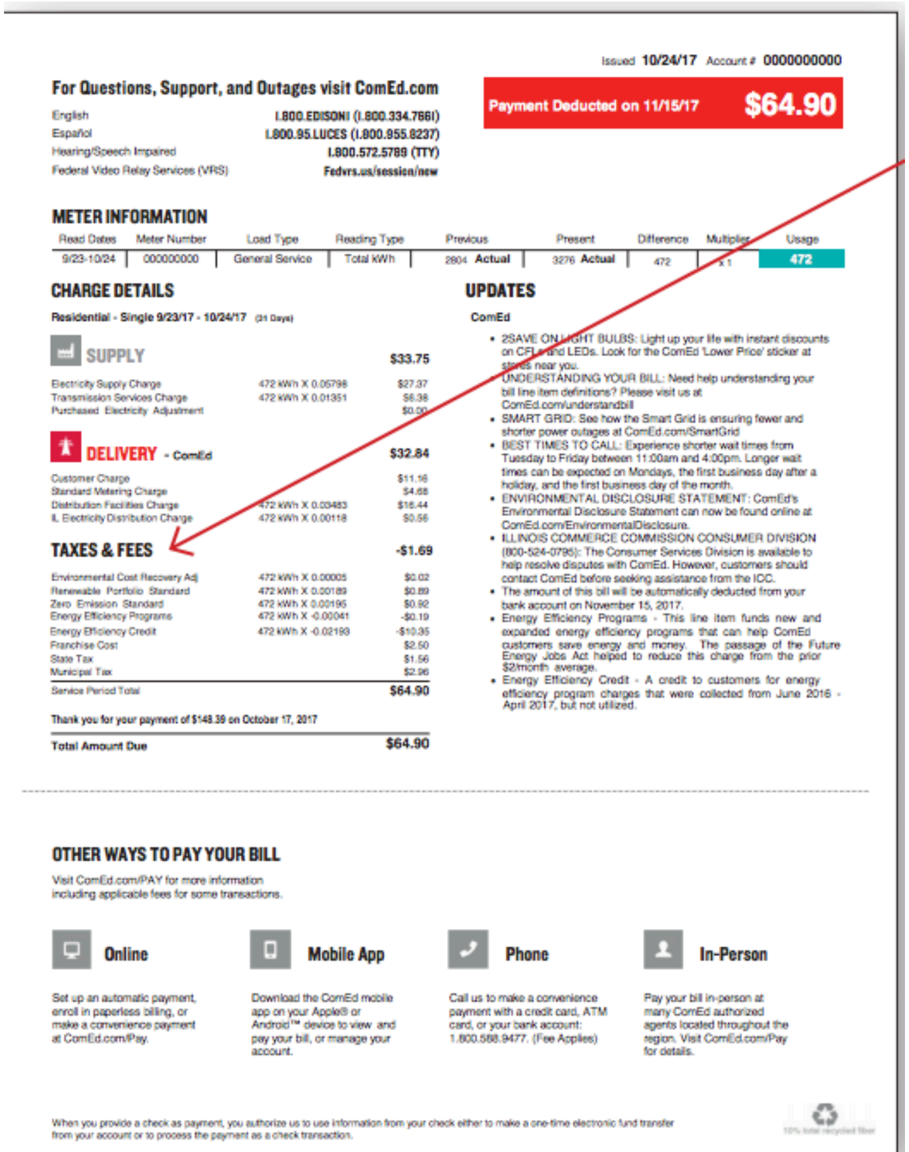
Call us to make a convenience payment with a credit card, ATM card, or your bank account: 1.800.588.9477. (Fee Applies)

In-Person

Pay your bill in-person at many ComEd authorized agents located throughout the region. Visit ComEd.com/Pay for details.

When you provide a check as payment, you authorize us to use information from your check either to make a one-time electronic fund transfer from your account or to process the payment as a check transaction.

Electricity Bill



Issued 10/24/17 Account # 0000000000

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English	1.800.EDISON1 (1.800.334.7661)
Español	1.800.95.LUCES (1.800.955.8237)
Hearing/Speech Impaired	1.800.572.5789 (TTY)
Federal Video Relay Services (VRS)	Fedvrs.us/session/new

Payment Deducted on 11/15/17 $64.90

METER INFORMATION

Read Dates	Meter Number	Load Type	Reading Type	Previous	Present	Difference	Multiplier	Usage
9/23-10/24	000000000	General Service	Total kWh	2804 Actual	3276 Actual	472	x 1	472

CHARGE DETAILS

Residential - Single 9/23/17 - 10/24/17 (31 Days)

SUPPLY		**$33.75**
Electricity Supply Charge	472 kWh X 0.05798	$27.37
Transmission Services Charge	472 kWh X 0.01351	$6.38
Purchased Electricity Adjustment		$0.00
DELIVERY - ComEd		**$32.84**
Customer Charge		$11.16
Standard Metering Charge		$4.68
Distribution Facilities Charge	472 kWh X 0.03483	$16.44
IL Electricity Distribution Charge	472 kWh X 0.00118	$0.56
TAXES & FEES		**-$1.69**
Environmental Cost Recovery Adj	472 kWh X 0.00005	$0.02
Renewable Portfolio Standard	472 kWh X 0.00189	$0.89
Zero Emission Standard	472 kWh X 0.00195	$0.92
Energy Efficiency Programs	472 kWh X -0.00041	-$0.19
Energy Efficiency Credit	472 kWh X -0.02193	-$10.35
Franchise Cost		$2.50
State Tax		$1.56
Municipal Tax		$2.96
Service Period Total		**$64.90**

Thank you for your payment of $148.39 on October 17, 2017

Total Amount Due	**$64.90**

UPDATES

ComEd

- 2SAVE ON LIGHT BULBS: Light up your life with instant discounts on CFLs and LEDs. Look for the ComEd 'Lower Price' sticker at stores near you.
- UNDERSTANDING YOUR BILL: Need help understanding your bill line item definitions? Please visit us at ComEd.com/understandbill
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- BEST TIMES TO CALL: Experience shorter wait times from Tuesday to Friday between 11:00am and 4:00pm. Longer wait times can be expected on Mondays, the first business day after a holiday, and the first business day of the month.
- ENVIRONMENTAL DISCLOSURE STATEMENT: ComEd's Environmental Disclosure Statement can now be found online at ComEd.com/EnvironmentalDisclosure.
- ILLINOIS COMMERCE COMMISSION CONSUMER DIVISION (800-524-0795): The Consumer Services Division is available to help resolve disputes with ComEd. However, customers should contact ComEd before seeking assistance from the ICC.
- The amount of this bill will be automatically deducted from your bank account on November 15, 2017.
- Energy Efficiency Programs - This line item funds new and expanded energy efficiency programs that can help ComEd customers save energy and money. The passage of the Future Energy Jobs Act helped to reduce this charge from the prior $2/month average.
- Energy Efficiency Credit - A credit to customers for energy efficiency program charges that were collected from June 2016 - April 2017, but not utilized.

OTHER WAYS TO PAY YOUR BILL

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Mobile App

Download the ComEd mobile app on your Apple® or Android™ device to view and pay your bill, or manage your account.

Phone

Call us to make a convenience payment with a credit card, ATM card, or your bank account: 1.800.588.9477. (Fee Applies)

In-Person

Pay your bill in-person at many ComEd authorized agents located throughout the region. Visit ComEd.com/Pay for details.

When you provide a check as payment, you authorize us to use information from your check either to make a one-time electronic fund transfer from your account or to process the payment as a check transaction.

10% total recycled fiber

ComEd

Taxes & Fees				**-$1.69**
Environmental Cost Recovery Adj	472 kWh	X	0.00005	$0.02
Renewable Portfolio Standard	472 kWh	X	0.00189	$0.89
Zero Emission Standard	472 kWh	X	0.00195	$0.92
Energy Efficiency Programs	**472 kWh**	**X**	**-0.00041**	**-$0.19**
Energy Efficiency Credit	**472 kWh**	**X**	**-0.02193**	**-$10.35**
Franchise Cost				$2.50
State Tax				$1.56
Municipal Tax				$2.96

CAMPUS EXAMPLE

Campus Buildings

- Campuses Typically:
  - Have sustainability programs that monitor energy consumption of buildings. Record energy commodities with different level of granularity such as 15 minutes, hourly, monthly
  - Open to share monitored energy consumption of buildings with the research community
  - Operate with different energy commodities such as electricity, natural gas, steam, and chilled water, enabling better disaggregation of end-uses without sub-metering end-uses
  - Spend close to $2 billon each year on energy
  - Endeavor to construct new buildings or renovate existing buildings to meet the requirements for energy efficient buildings

Campus Buildings

- Steam/Natural gas power plant(s), Combined Heat and Power (CHP), or Purchased steam

http://www.opp.psu.edu/about-opp/divisions/ee/util/steam-services

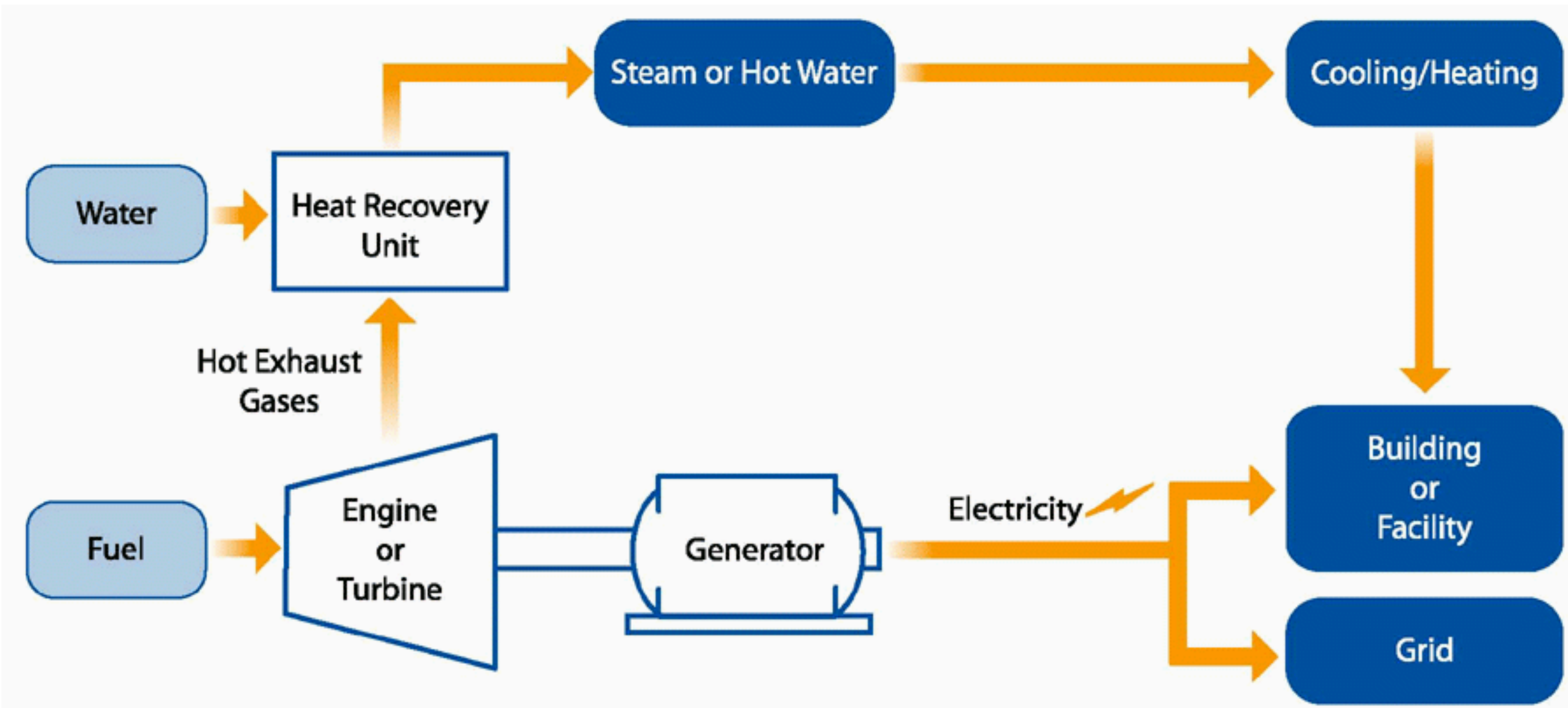
- Chilled Water (CHW) plant(s) or Purchased CHW

http://www.opp.psu.edu/services/energy/chilled-water-pipes/view

- Purchased electricity from the grid or generated electricity

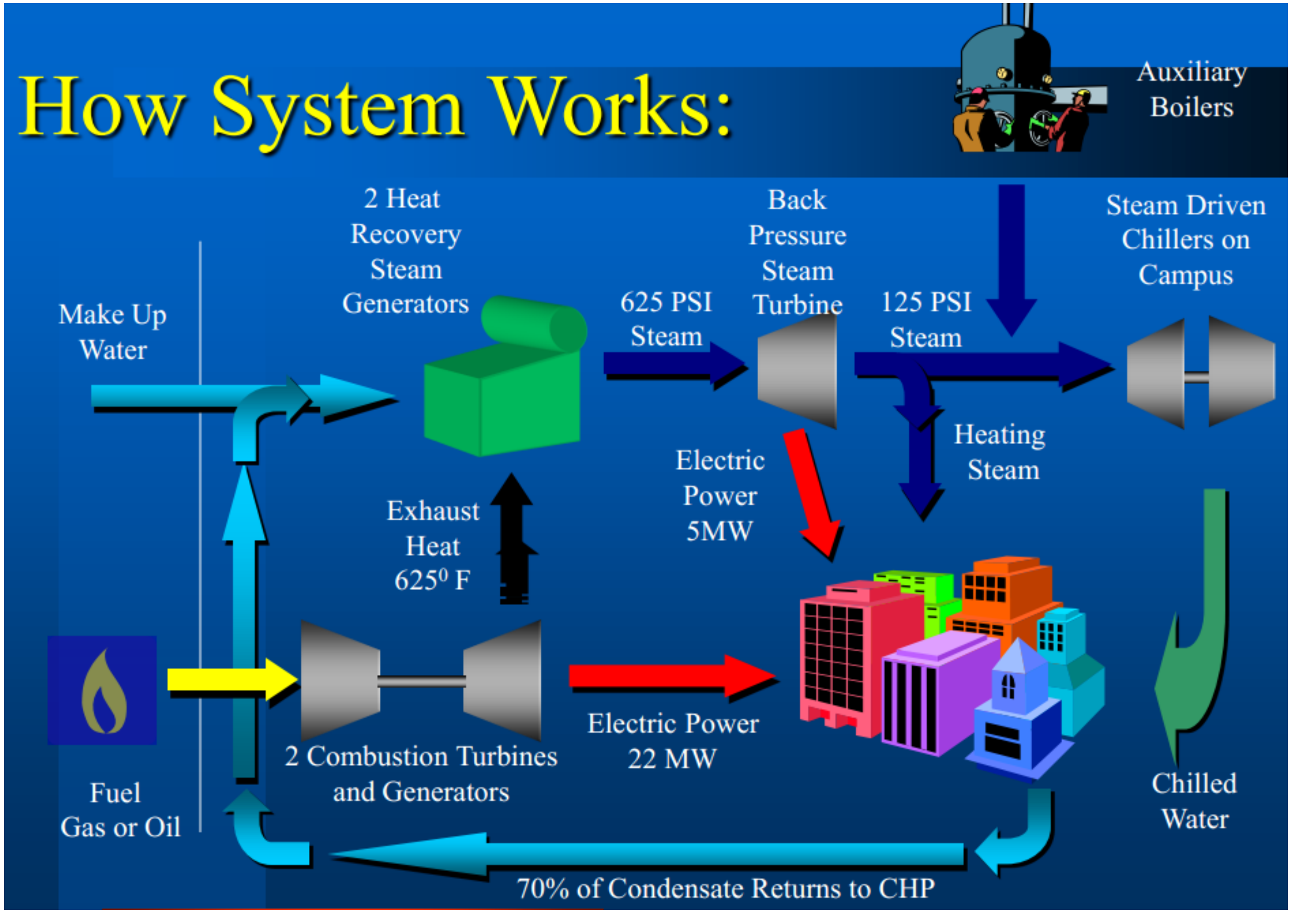
Campus Buildings

- Power plants can benefit from the CHP system to increase efficiency of the system



Campus Buildings

- Example from University of Maryland campus:
  - 27.5MW natural gas, CHP plant
  - Doubled efficiency from 35% to 70%



http://www.sustainability.umd.edu/documents/UMD_Energy_Overview_100109.pdf

IIT Examples

Tracking Energy at Illinois Tech

- Only a few ComEd electric meters for entire campus, not individual buildings
- Some buildings have a Peoples Gas meter, however most buildings use steam from steam plant for heating

- Illinois Tech has submeters for almost every building on campus:
  - 83 electric meters
  - 30 steam meters (Heating)
  - 18 chilled water meters (Cooling)

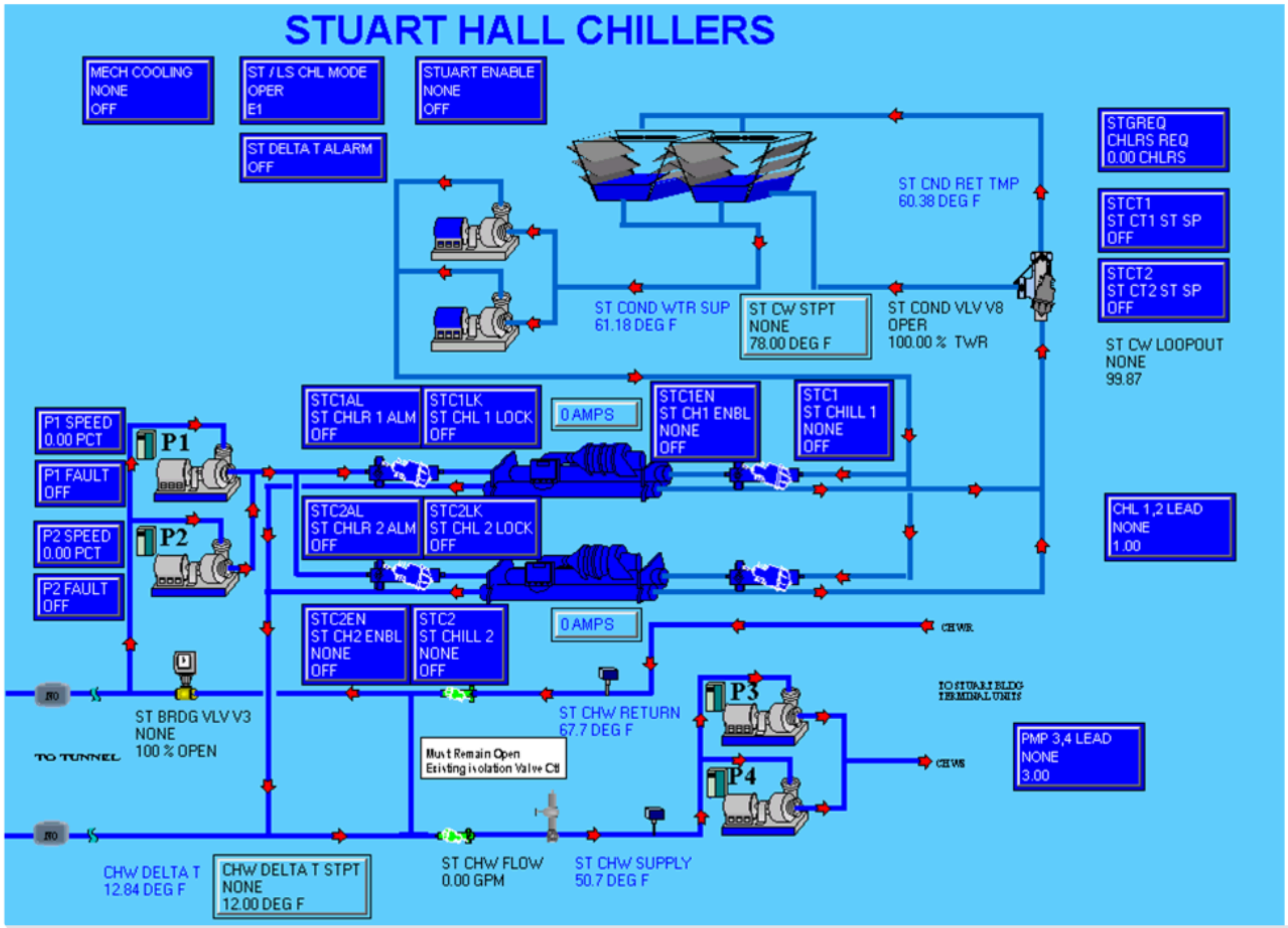
- An energy management system collects data from all meters and stores it in server.

IIT Examples

- Cooling plant

IIT Examples

- Stuart Hall example



IIT Examples

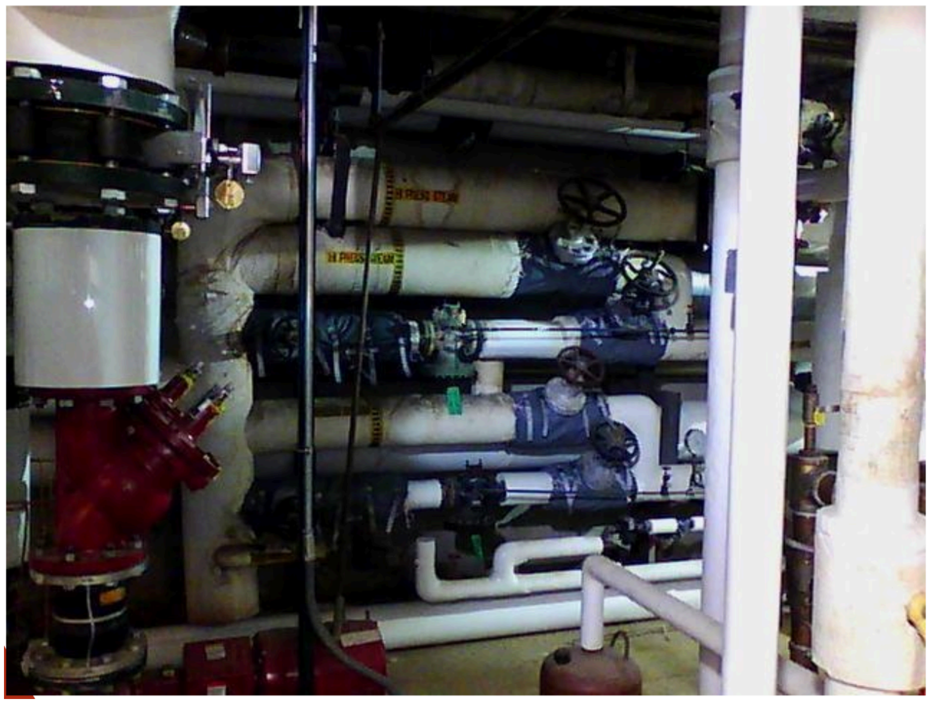
- Heating plant

IIT Examples

- Energy efficiency measure for steam reduction
  - Steam and condensate pipe insulation
    - Uninsulated steam pipe can have surface temperatures up to 350 degrees F.
    - Insulated over 7,800 linear feet of pipe in 28 buildings on campus
  - Steam traps
    - Steam traps are used to remove condensate from steam system. Many steam traps fail open, wasting steam.
    - Replaced 185 failed steam traps on campus
  - Annual energy savings of:
    - 20 million KBTU

IIT Examples

- Examples of insulating the system



IIT Examples

- Examples of smart thermostats and associate savings

  - Targeting buildings with standalone rooftop units

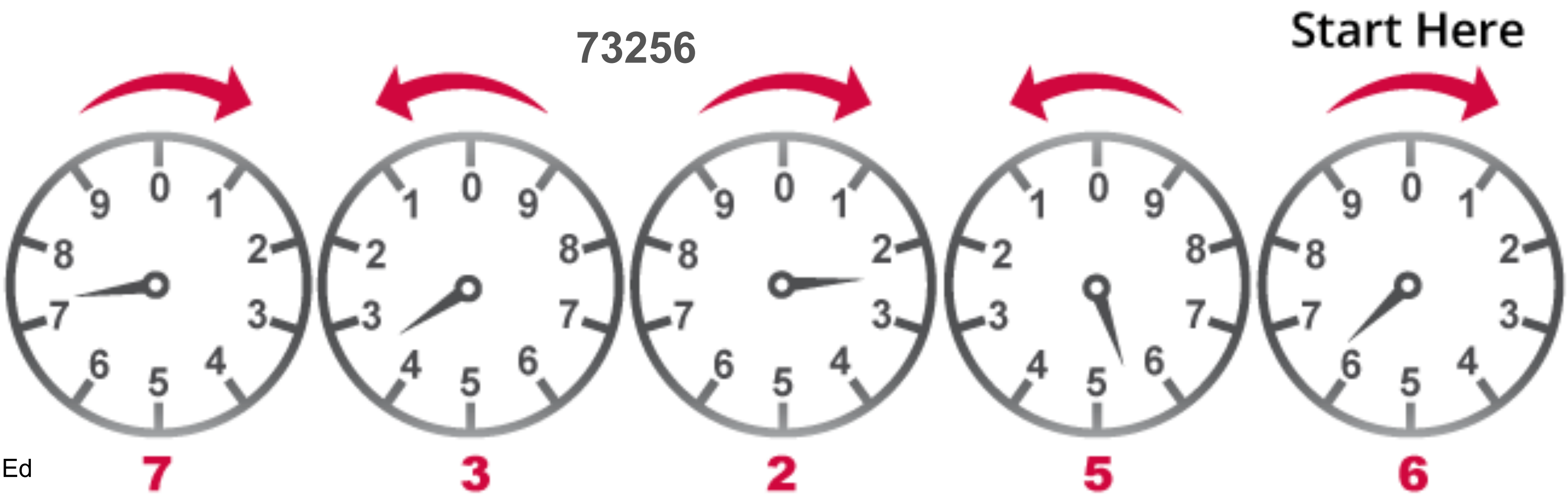
Building	Qty of Rooftop Units
Perlstein	19
Siegel	7
Alumni	3
Machinery	1

  - Smart thermostats provide many improvements:
    - Programmable schedules
    - Setback temperatures at night / weekends
    - Remote access for maintenance staff
    - Smart recovery
  - Annual energy savings of:
    - 500,000 KBTU

ELECTRICITY METERS

Electricity Meters

- ComEd is upgrading analog meters across northern Illinois
- Plan to install approximately 4 million smart meters by 2018
- How to read:
  - Always begin with the dial on the far right
  - Record the lowest number the pointer has passed
  - Each dial as you move from right to left is in the opposite direction of the one before it. If the first dial rotates clockwise, the next will rotate counterclockwise, the third clockwise.



Electricity Meters

- Three type of electricity meters:
  - Digital meters

  - Dial meters

  - Electronic meters

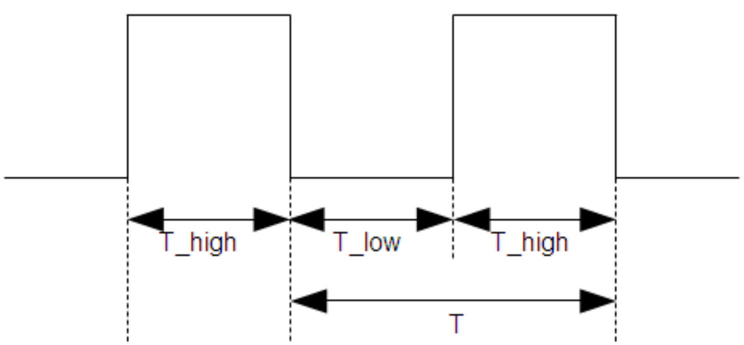
Electricity Meters

- Pulse meters:
  - Cheapest and easiest way to collect energy data
  - Tap into existing meters

- Example:
  - One pulse = 0.5 kWh
  - Four pulse per minute is: ??

Electricity Meters

- Single phase electricity meters usually have pulse meters
- Each pulse usually is one Wh (1000 pulses per kWh)
- Power calculation:
  - 3600 s per hour = 3600 per pulse (1 Wh = 3600 J)
  - P = 3600/T



ENERGY METERS

Basis of Steam Meters

Velocity (ft/s)

↓ Internal area (ft^2)

Volumetric Flow Rate (ft^3/m)

↓ Density (lb/ft^3)

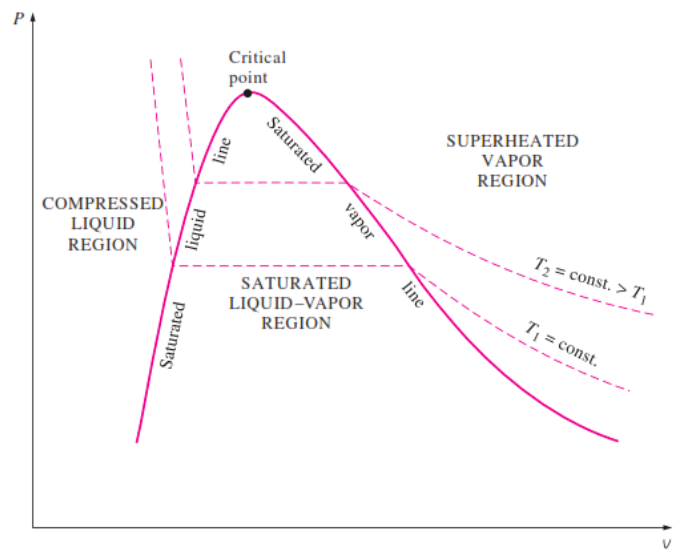
Mass Flow Rate (lb/hr)

↓ Enthalpy (Btu/lb)

Energy Rate (Btu/hr)

Steam Flow Measurement

- Density:
  - Steam is a compressible fluid
  - is a function of both temperature and pressure
  - For saturated steam, temperature and pressure are dependent variables
  - Can be calculated by measuring one variable
  - For superheated steam, temperature and pressure are independent variables.



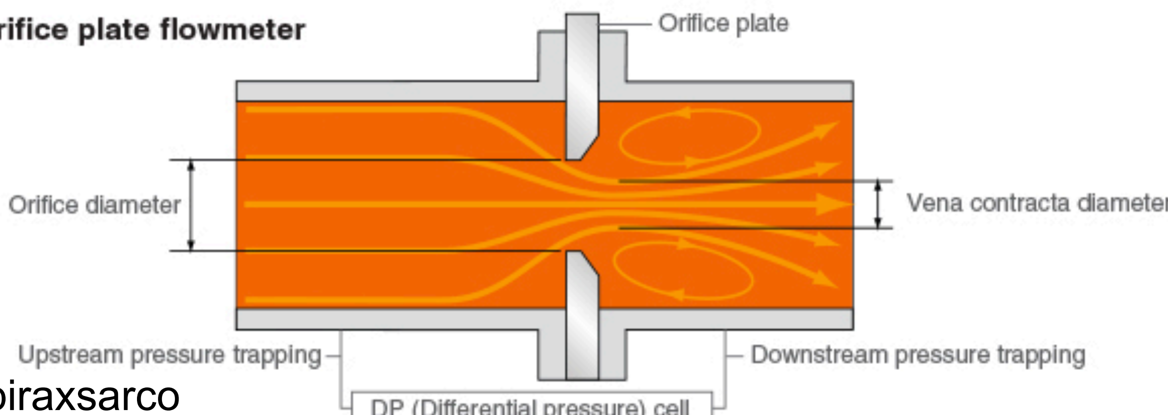
Steam Flow Measurement

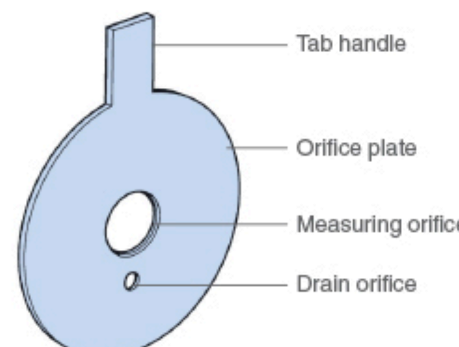
- Measure flow based on the pressure difference

- Simple, low cost, no moving parts, and no calibration

- Avoid condensation issue with a drain hole

Fig. 4.3.2 Orifice plate flowmeter





EPA & spiraxsarco

Steam Flow Measurement

- Installation:

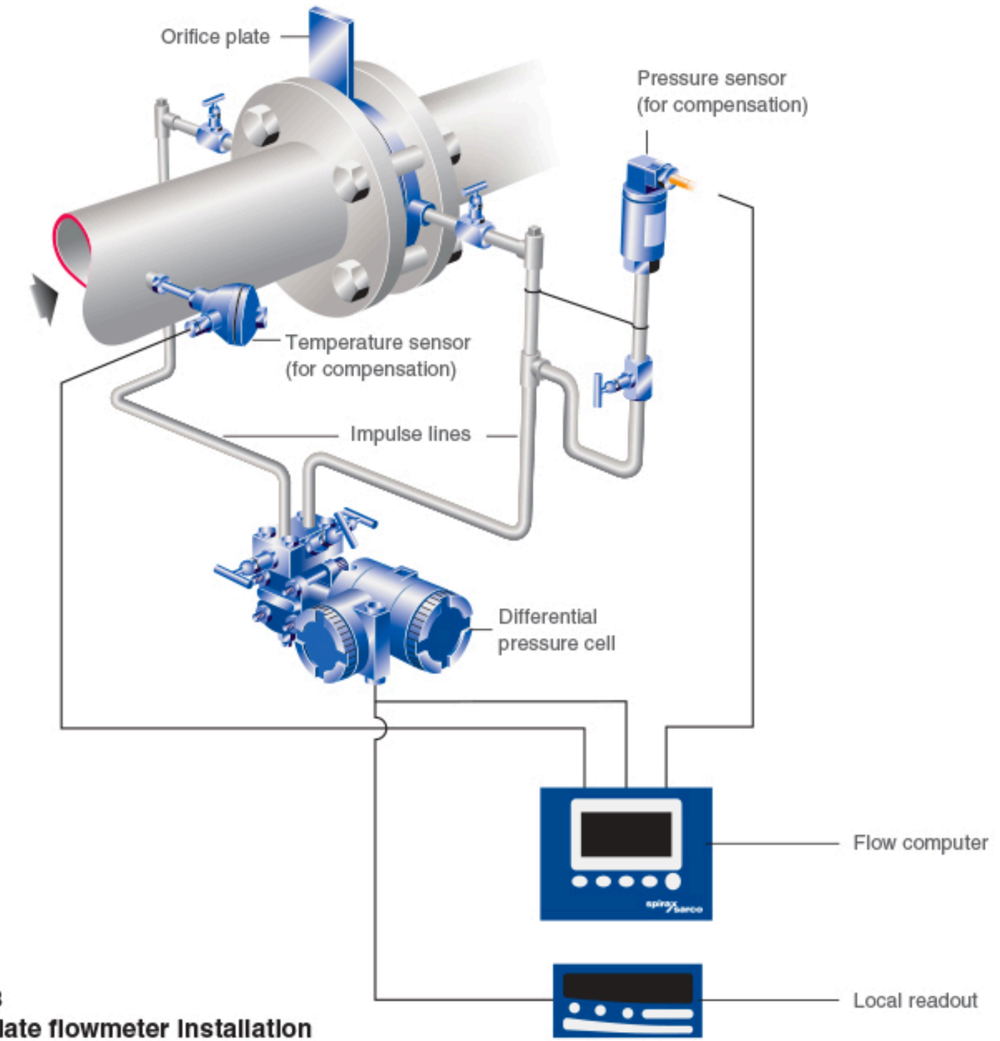


Fig. 4.3.3
Orifice plate flowmeter installation

spiraxsarco

Steam Flow Measurement

- Installation:
  - From the flanges (or carrier) containing the orifice
  - One pipe diameter on the upstream side and 5x pipe diameter on the downstream side
  - Corner tappings

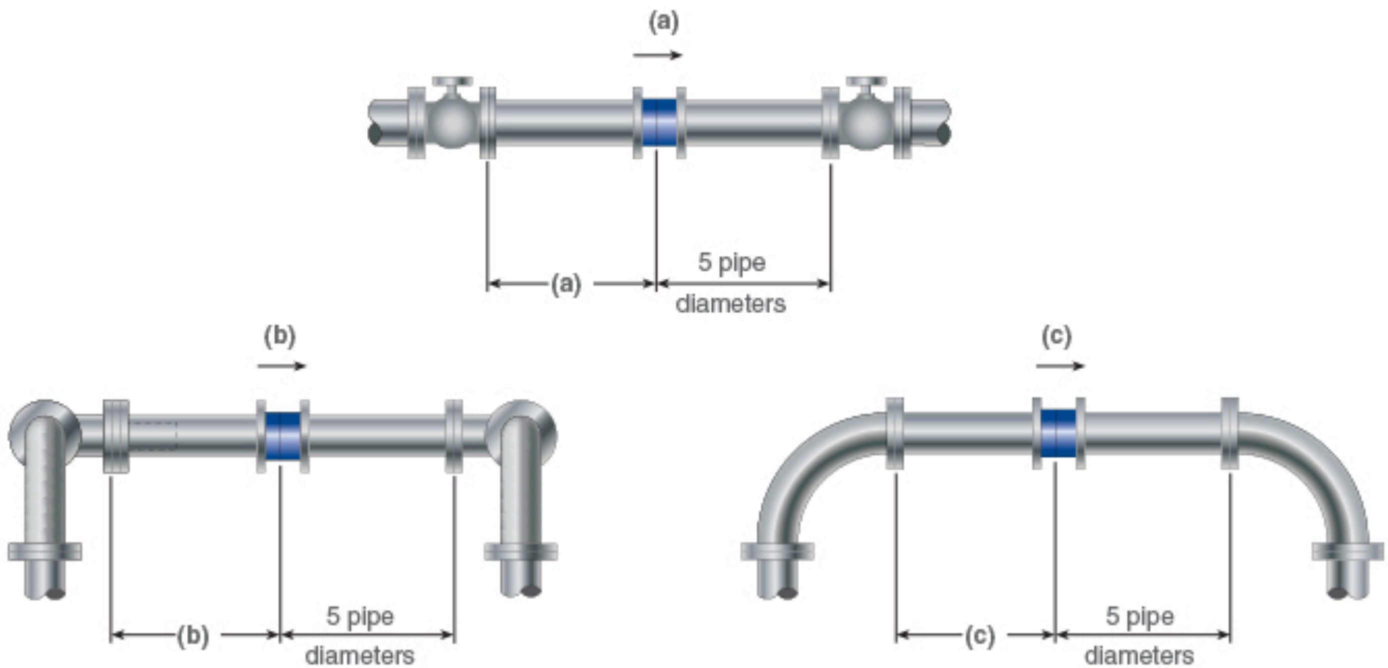


Fig. 4.3.4 Orifice plate installations

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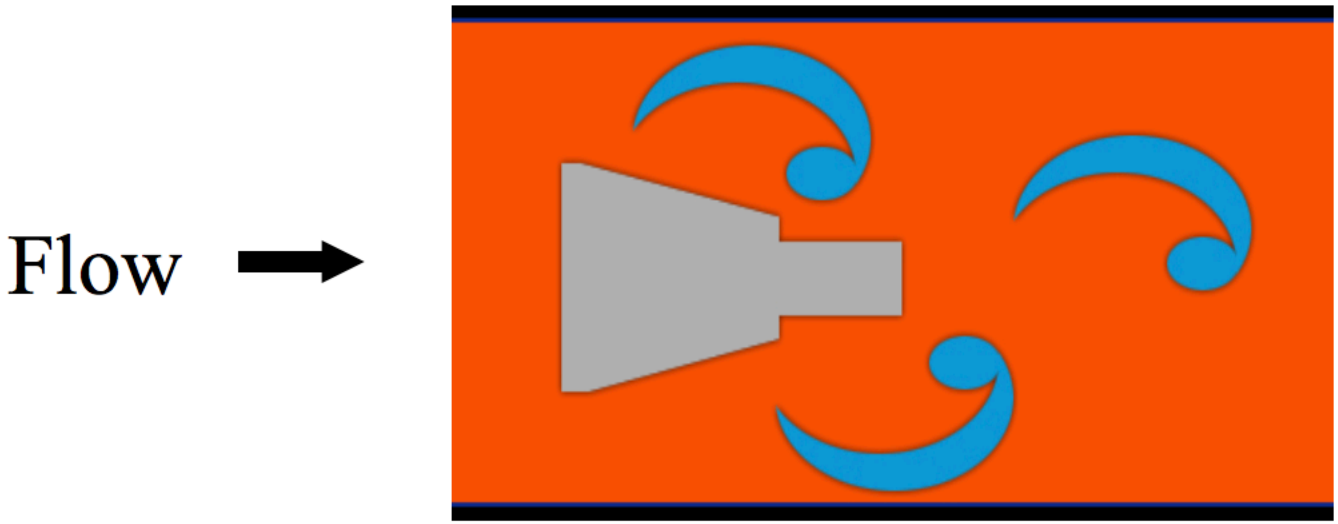
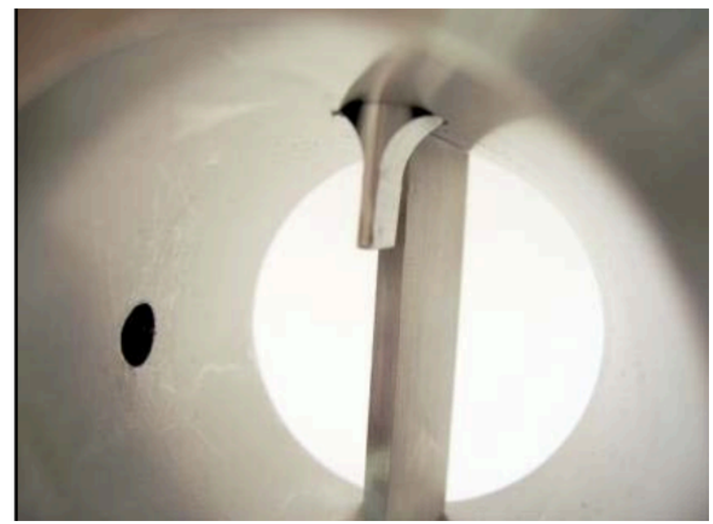
Steam Flow Measurement

- Vortex flow meters:
  - When any liquid, gas or vapor in motion hits a solid body in its path, it flows around it shedding vortices alternately on either side of the body
  - The frequency of the vortices is directly proportional to the velocity of the fluid



Steam Flow Measurement

- Vortex flow meters:



Steam Flow Measurement

- Vortex flow meters:

Equation 4.3.3	$f \propto \frac{Sr\ u}{d}$

Where:
f = Shedding frequency (Hz)
Sr = Strouhal number (dimensionless)
u = Mean pipe flow velocity (m/s)
d = Bluff body diameter (m)

$$f = k \times u$$

Where:

k = A constant for all fluids on a given design of flowmeter.

Hence:

$$u = \frac{f}{k}$$

Equation 4.3.4	$q_v = A \frac{f}{k}$

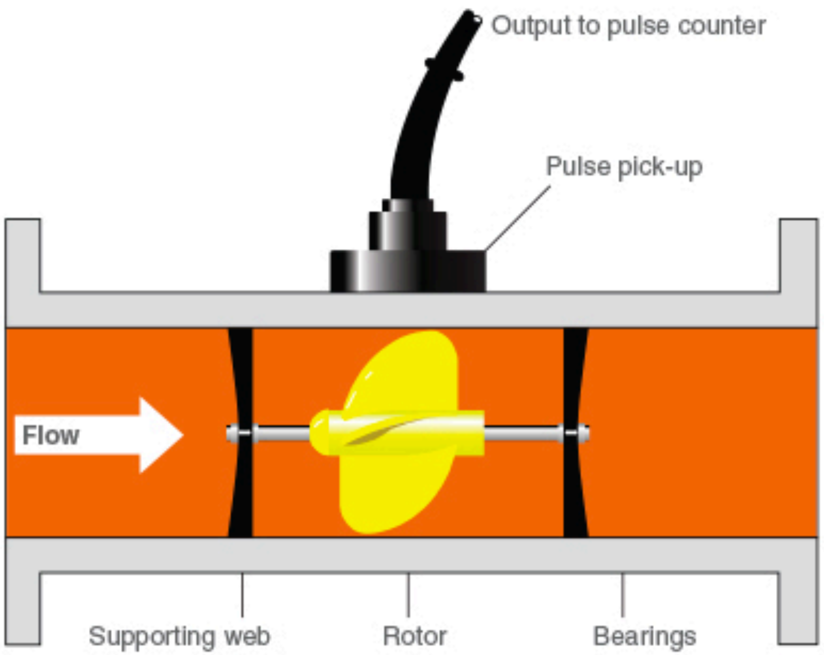
Where:
A = Area of the flowmeter bore (m^2)

Steam Flow Measurement

- Vortex shedding flow meters:
  - Advantages:
    - Reasonable turn down (providing high velocities and high pressure drop acceptable)
    - No moving parts
    - Little resistance to flow
  - Disadvantages:
    - Pulses are not generated at low flow rates
    - Vibration can cause error
    - Correct installation is critical
    - Long and clear lengths are required

Steam Flow Measurement

- Turbine flow meters:
  – Consists of a multi bladed rotor: mounted at right angle
  – Rotational speed proportional to the velocity
  – Calculate volume flowmeteric from known fluid



Steam Flow Measurement

- Turbine flow meters can be installed in operation with no system shut down need

- Require profile correction to measure average flow

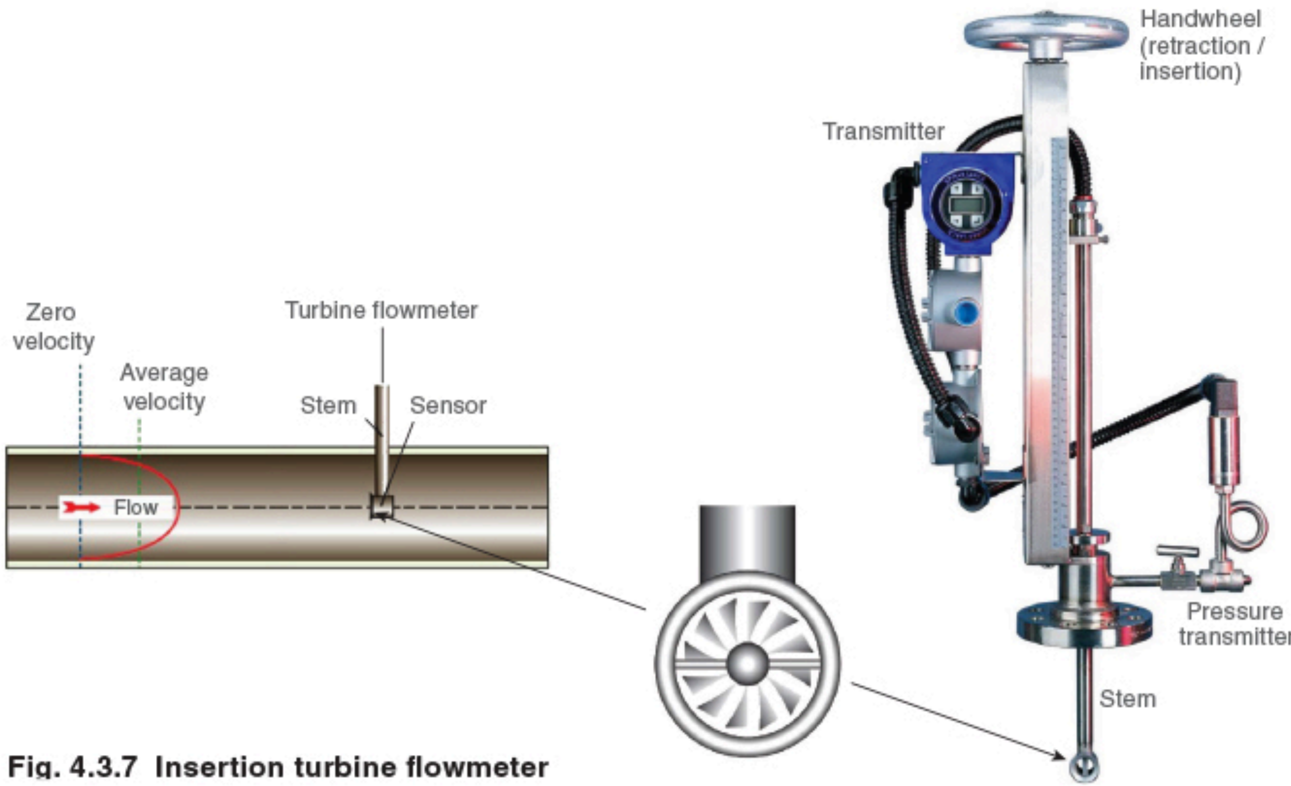


Fig. 4.3.7 Insertion turbine flowmeter

Steam Flow Measurement

- Turbine flow meters:
  - Advantages:
    - Installation under full operation
    - Relatively inexpensive for large pipelines
    - Can be installed for all media
    - Low influence on the measurements
    - Moderate to high accuracy
  - Disadvantages:
    - Relatively expensive for small pipes
    - Regular maintenance due to the moving parts
    - Wet steam can damage the turbine or accuracy

Steam Flow Measurement

- Ultrasonic flowmeters
  - Based on transit-time
  - Take ultrasound pulses to pass between two transducers attached to the pipe

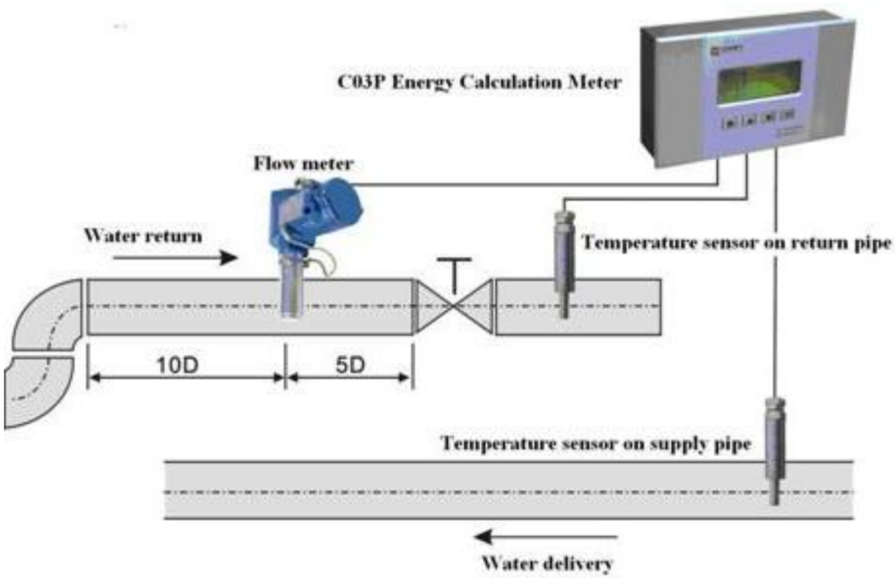
Fig. 4.3.18

Steam Flow Measurement

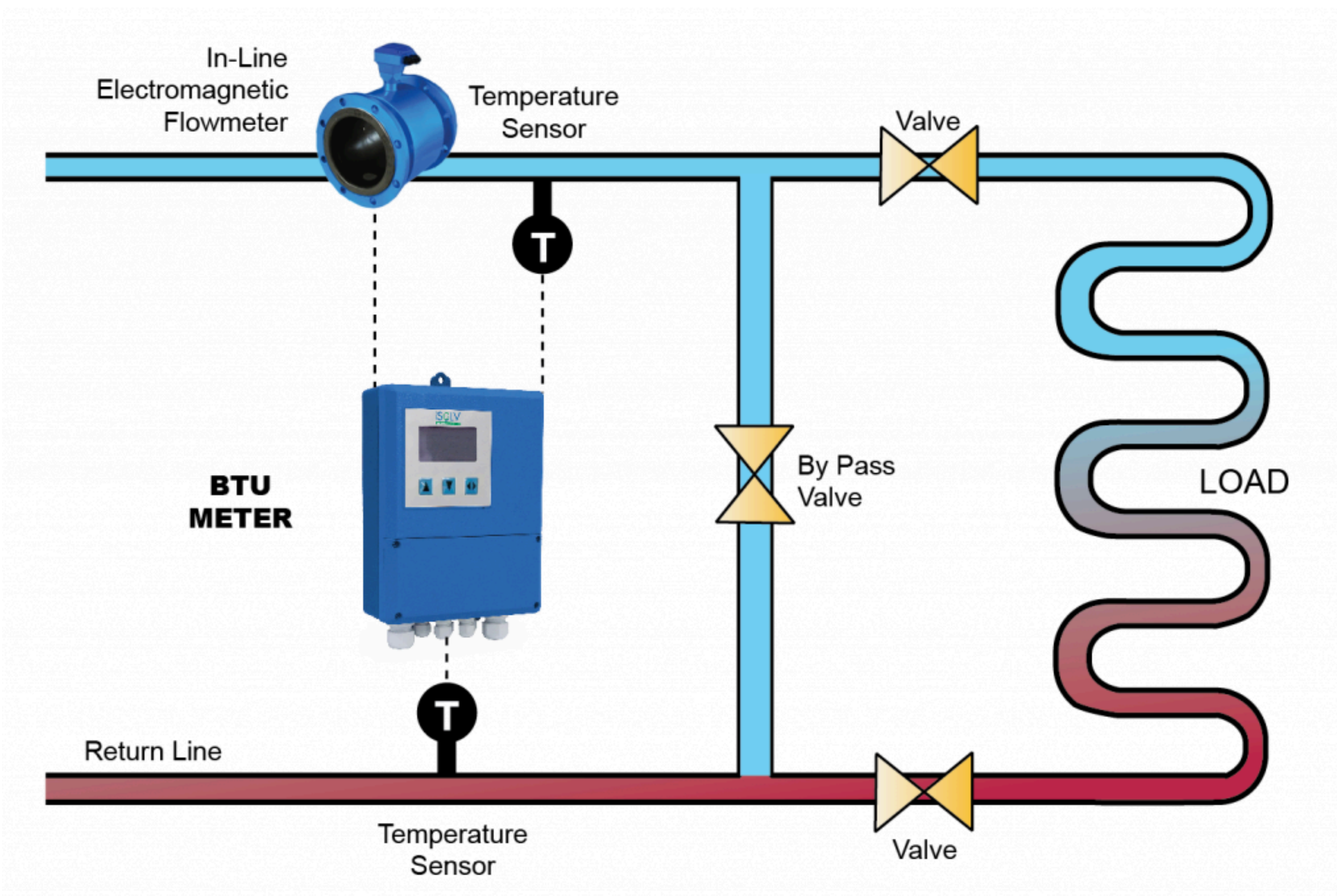
- Ultrasonic flow meters:
  - Advantages:
    - Quick and simple
    - Bidirectional measurements
    - Highly accurate
    - Corrosive fluid not an issue
    - Turndown 30:1
    - Cost is independent of the pipe size
  - Disadvantages:
    - For single phase liquid only
    - Straight line
    - Not accurate as in-line flowmeters
    - Unreliable if there is more than 5% gas or vapor in the pipeline

Btu Meter

- BTU meters measure the energy content of liquid flow in BTU based on:
  - Flow rate
  - Temperature difference



Btu Meter



In-Line
Electromagnetic
Flowmeter
Temperature
Sensor
Valve
BTU
METER
By Pass
Valve
LOAD
Return Line
Temperature
Sensor
Valve

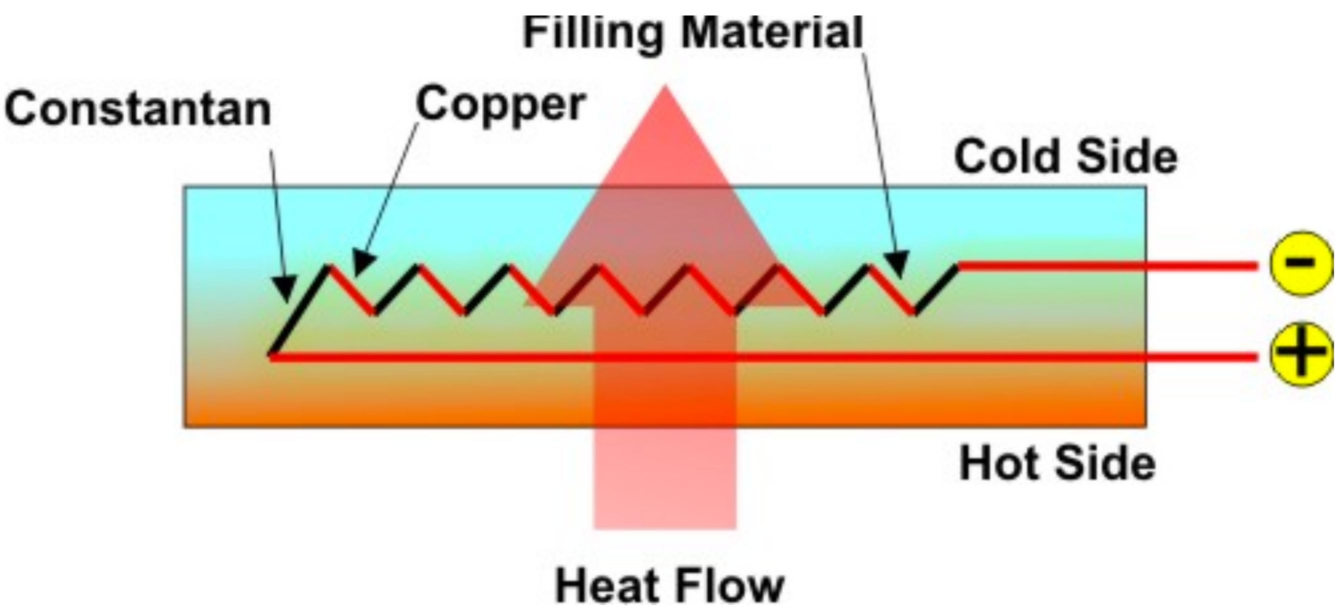
HEAT FLUX

Heat Flux Applications

- Determine thermal properties of materials
- Monitor structural heat transfer
- Control production processes
- Measure effective convection, conduction and radiation heat transfer
- Determine heat loss and insulation efficiency in housing

Heat Flux Meters

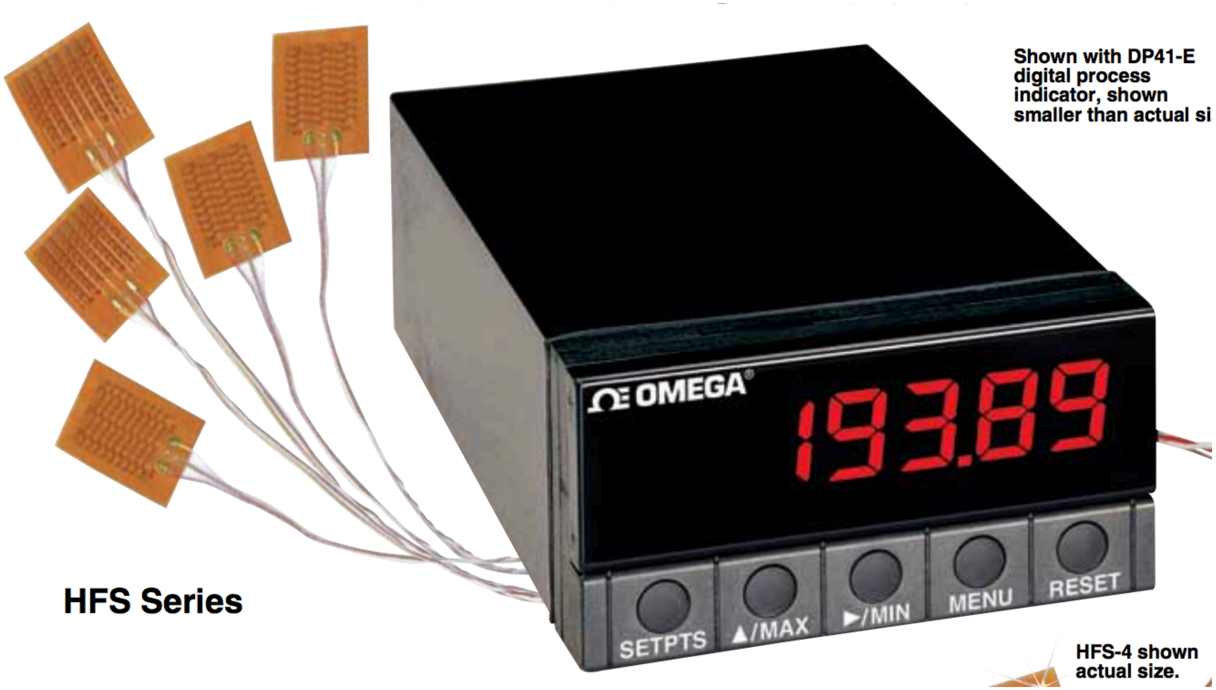
- Convert heat energy to electrical signal
- Measure signal proportional to the rate of heat flow
- Install thermocouples to the cold and hot sides
- Sandwich a thin film between two thermocouples
- Movement create voltage



azosensors

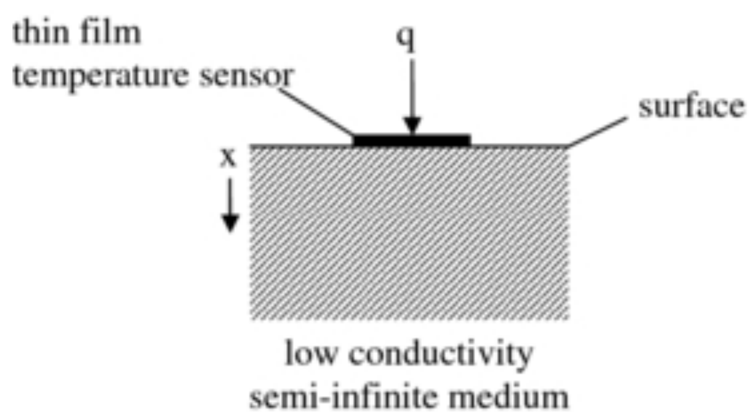
Thin Film Heat Flux Arrays

- Knowns as film heat flux arrays (HFA)
- Most of them requires no reference junction or wiring
- Send directly data to a data acquisition system (e.g. microvoltmeter or recorder)



Thin Film Heat Flux Arrays

- HFA are based on:
  - Deposit a thin resistance layers used as resistance temperature devices (RTDs) on one side of a layer of plastic
  - Utilize a semi-infinite transient conduction model to convert surface temperature to heat flux
  - Capable of measuring extremely high frequency measurements



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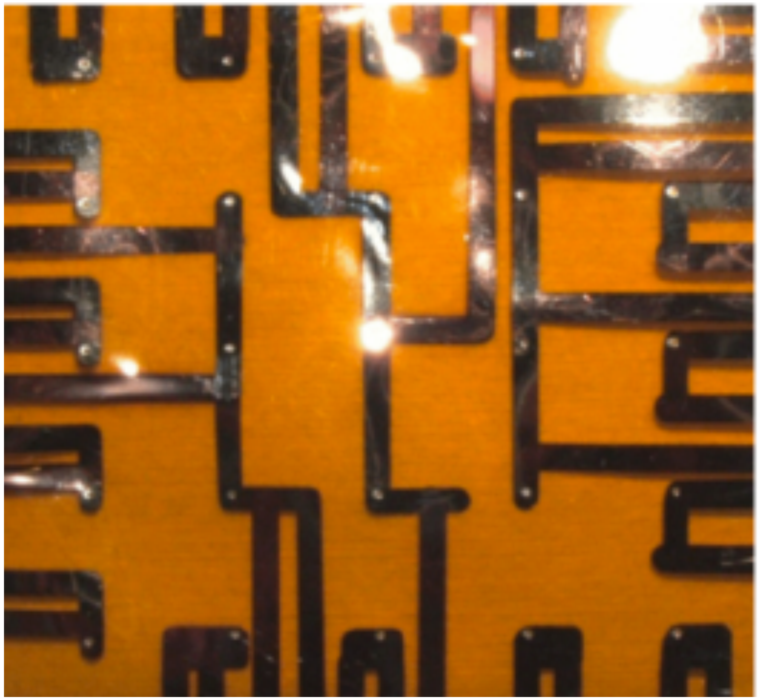
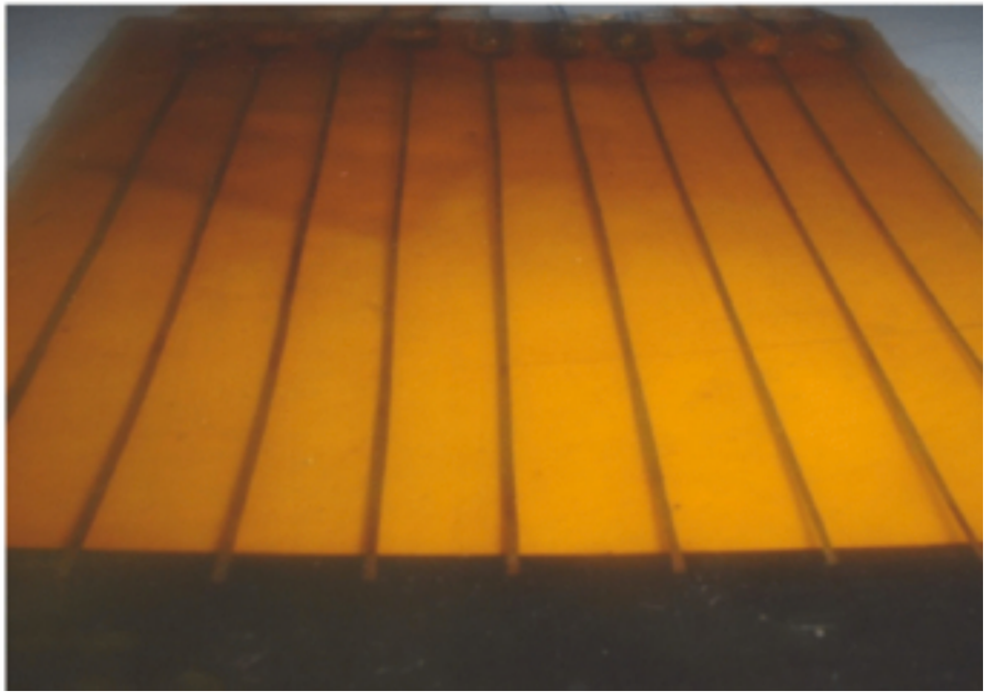
Thin Film Heat Flux Arrays

- Example of configurations



25 junctions

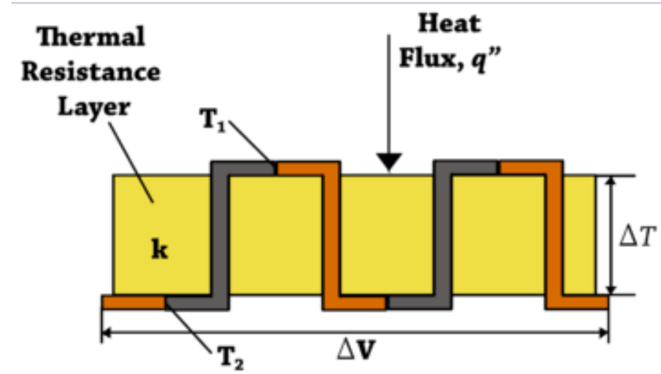


10 junctions

Ewing et al.

Thin Film Heat Flux (Thermopile)

- Two heat flux sensitivity levels
- Type K Thermocouple
- Conveniently interfaces with voltmeters or recorders and temperature indicators
- Easily attaches to curved and flat surfaces
- Temperature range from -200 to 150°C (-330 to 300°F)



omega

SOLAR RADIATION

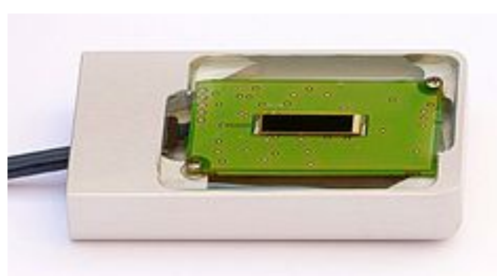
Pyranometers

- A type of actinometer used for measuring solar irradiance on a planar surface
  - Actinometers measure the heating power of radiation
  - Measures number of photos in a beam per unit time
  - Can be wavelength specific

- Pyranometers focus on solar radiation
  - Typically wavelengths from 0.3 to 3 μm

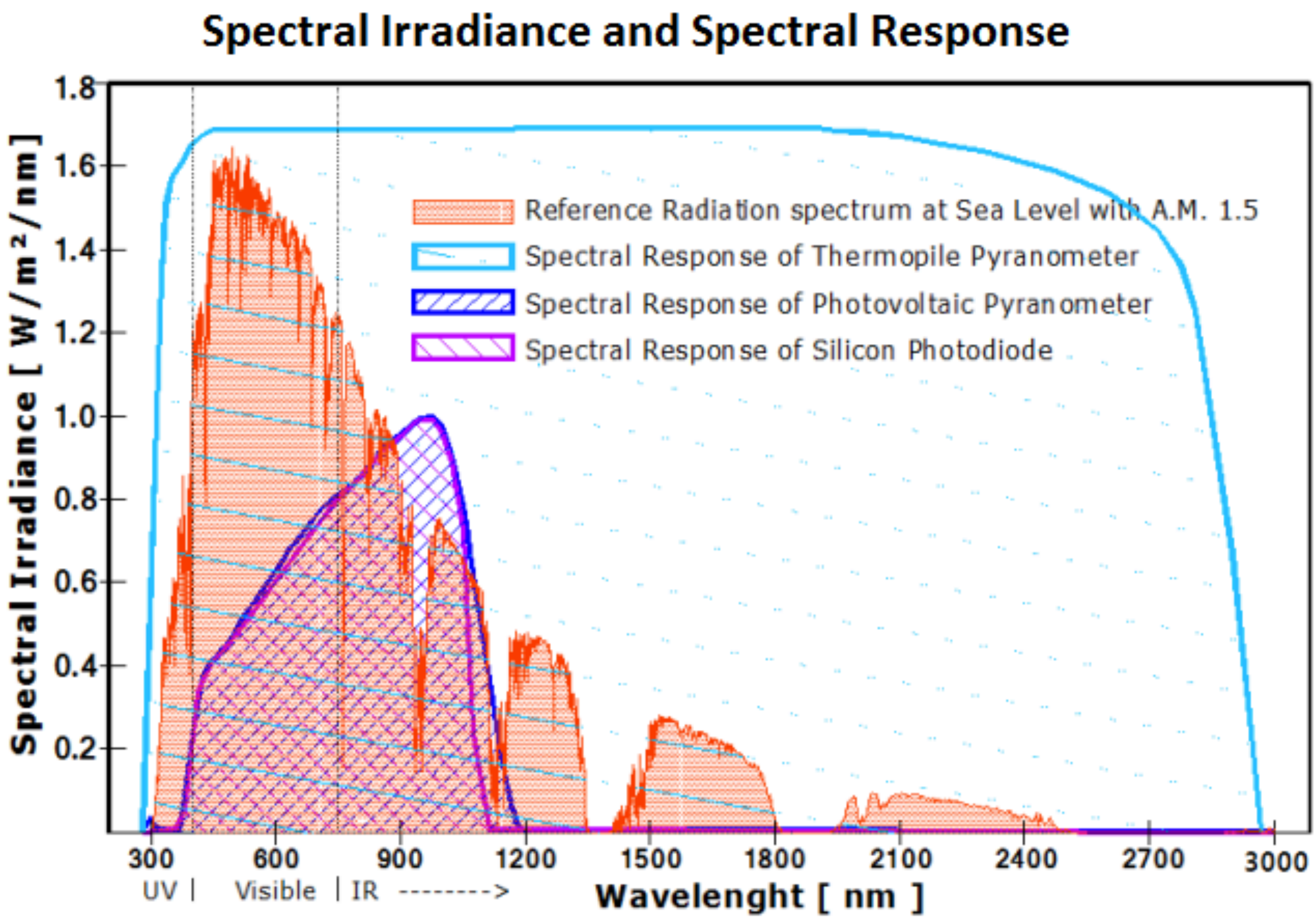
- Types:
  - Thermopile
  - Photodiode
  - Photovoltaic


Thermopile


Photovoltaic


Photodiode

Pyranometers



CLASS ACTIVITY

Class Activity

- Finish electricity data logging exercise from last week