CAE 553 Measurements and Instrumentation in Architectural Engineering

Fall 2018

October 2, 2018

HVAC/Energy: Electric Power

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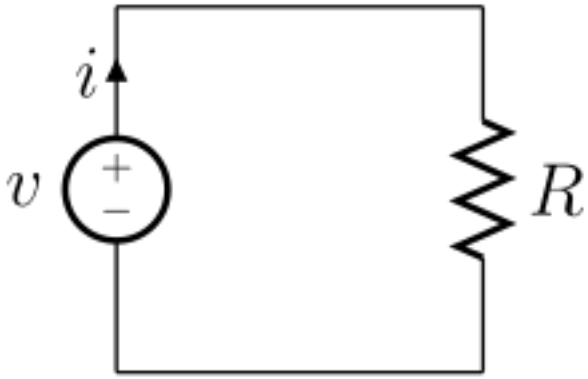
ELECTRIC DEFINITIONS

Definitions

- Electric Current:
  - Flow of electrons
  - Unit is ampere



- Electric Resistance:
  - Measure of difficulty to pass electric current
  - Unit is ohm

$$I = \frac{V}{R}$$

- Voltage:
  - Electric potential
  - Unit is voltage (V)

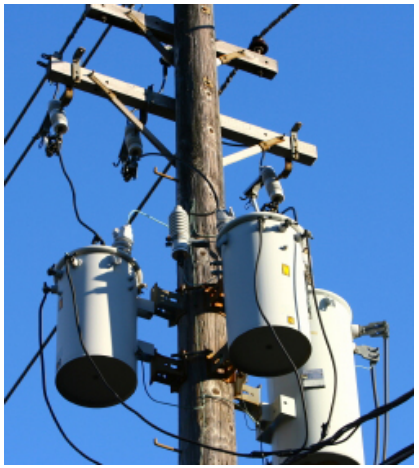
Have you seen similar terminology in heat transfer?

Definitions

- Power:
  - The rate of electrical energy transformed
  - Unit is J/S = Watt
  - P = V x I (Apparent vs real power)

- Electric consumption:
  - Is the form of energy consumption that uses electric energy

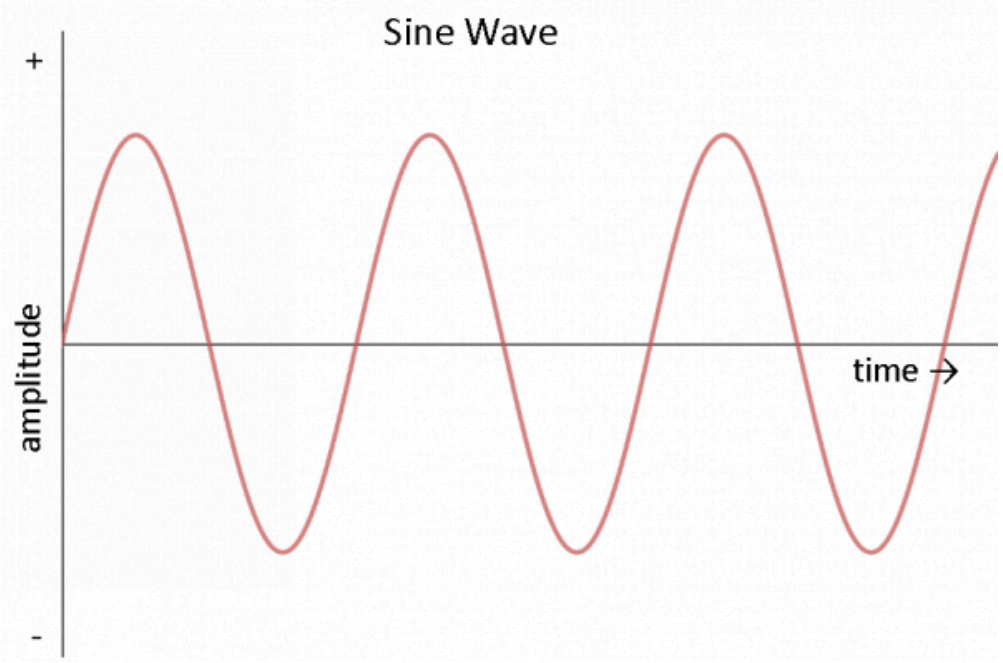
- Transformers
  - Reduce voltage from the power lines (from more than 110 kV to 110 V)



upsbatterycenter.com

Definitions

- Alternating Current:
  - Change of current direction periodically, change the voltage level
  - https://youtu.be/i-j-1j2gD28
  - https://cdn.sparkfun.com/assets/a/0/7/b/a/522783e0757b7fc2168b4567.gif



$$V(t) = V_P \sin(2\pi f t + \phi)$$

Definitions

- Alternating Current:
  - What's the voltage and current in this form?

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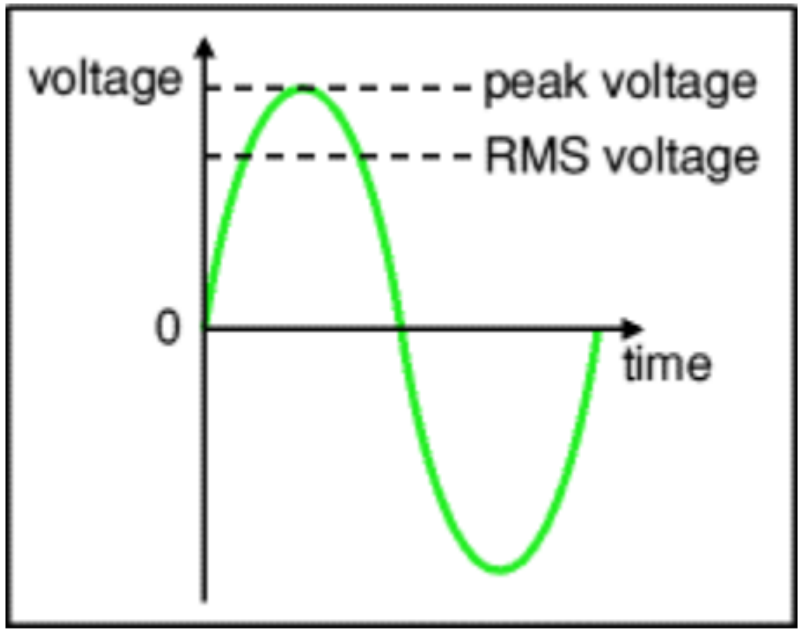
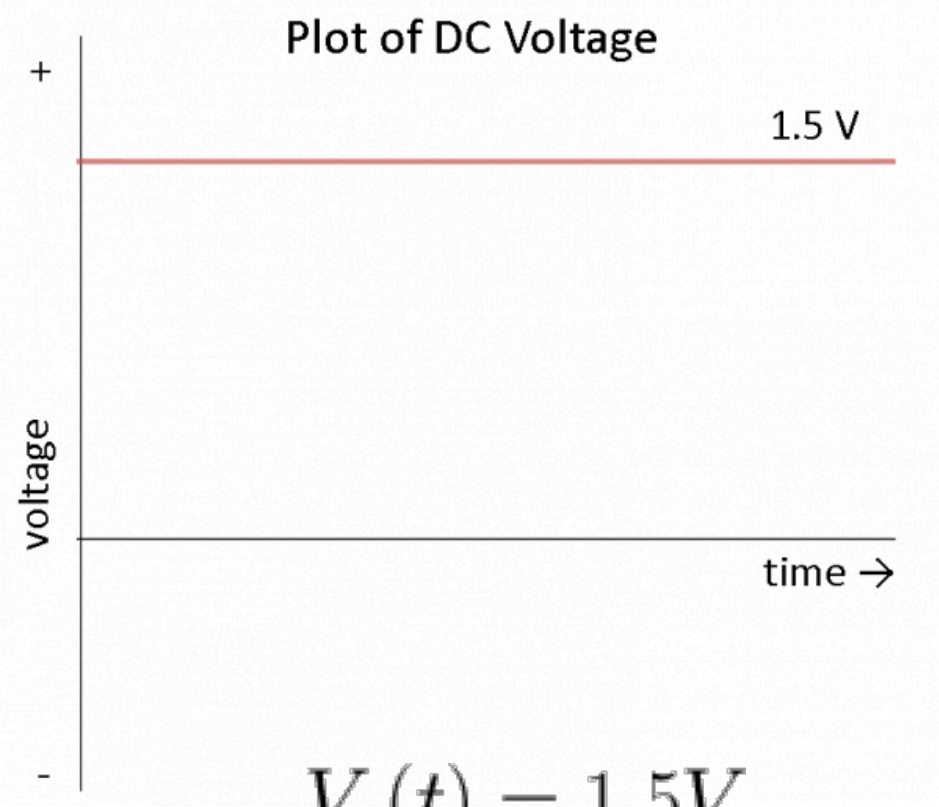


$$\text{RMS value} = \sqrt{\frac{1}{b-a}\int_a^b y^2 dt}$$

$$V_{RMS} = 0.7 \times V_{peak} \text{ or } V_{peak} = 1.4 \times V_{RMS}$$

Definitions

- Direct Current:
  - Provides a constant voltage and current



Definitions

- AC vs. DC

- AC is
  - Used for building electrical outlets
  - Easier to transport and generate across long distances
  - Transported at high voltage (110 kV)
    - Low amperage
    - Less heat generated
    - Use transformers to lower voltage on the distribution site

Definitions

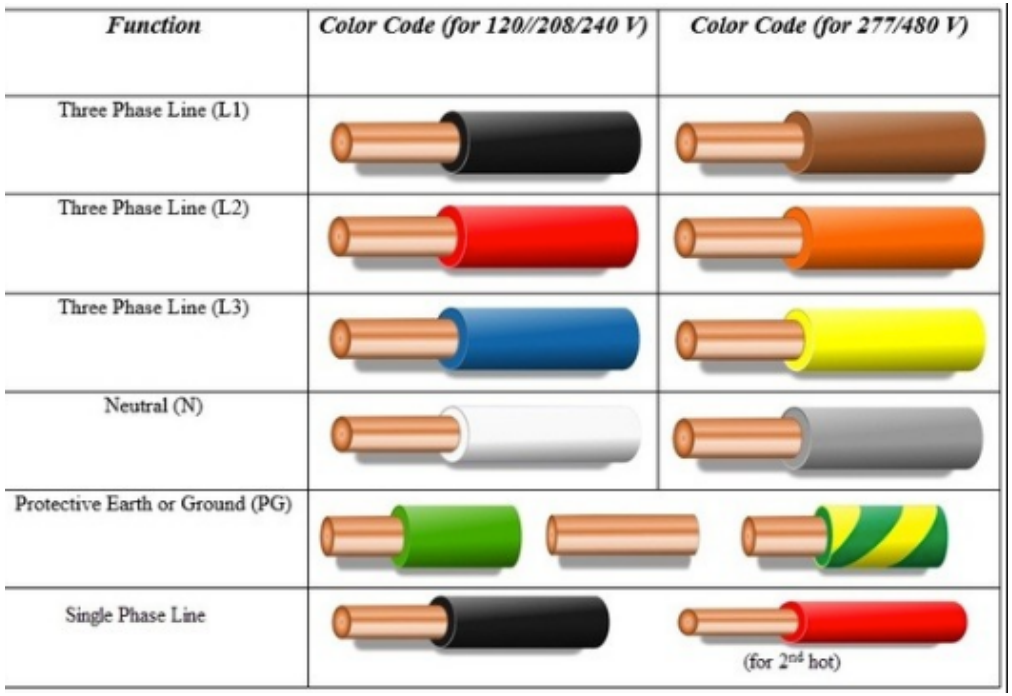
- AC vs. DC

- DC:
  - Most appliances convert from AC back to DC
  - Examples:
    - Cell phones
    - Flatscreen TVs
    - Laptops

Definitions

Electric wiring

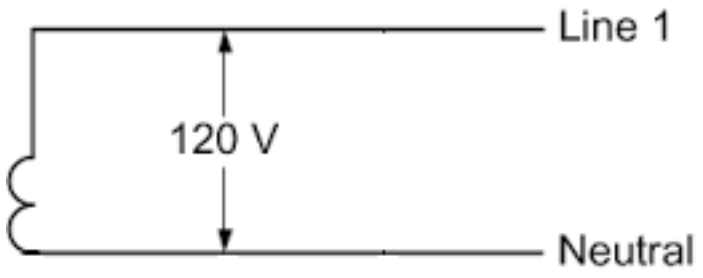
- Line:
  - Usually black color wire known as hot comes from the electric panel
- Load:
  - Usually black or red color wire
  - Continuation of the line and goes to the device
- Neutral:
  - Usually white color wire
  - Completes the circuit
  - Carries excess current to ground
- Ground:
  - Usually green
  - Carries any inadvertent current from the circuit



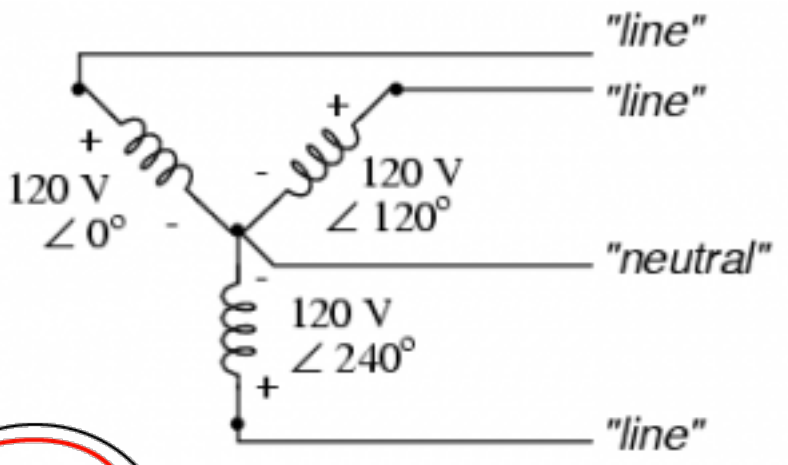
gogowire.co

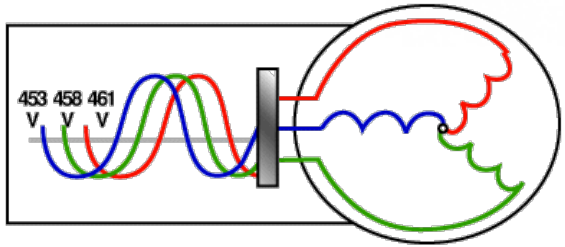
Electric Power

- Single Phase:
  - Entail two wires of Alternating Current (AC) power
  - Use mostly in residential buildings
  - What is the voltage in the US?
    - Other countries?



- Three phase:
  - Entail three wires of AC power
  - Use mostly in commercial buildings
  - Provide 1.732 times more power than single phase (sqrt(3))





Oempanels.com

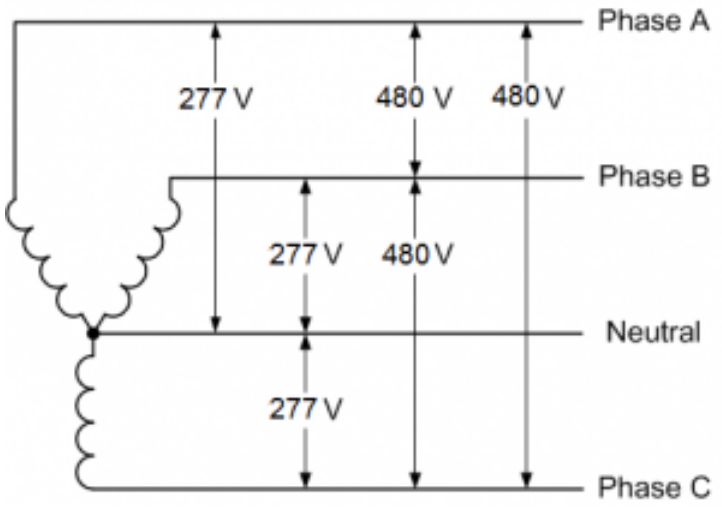
Electric Power

- Most US industrial facilities use two high voltage configurations:
  - 480V Three phase Wye (“Y”)
  - 480V Three phase Delta

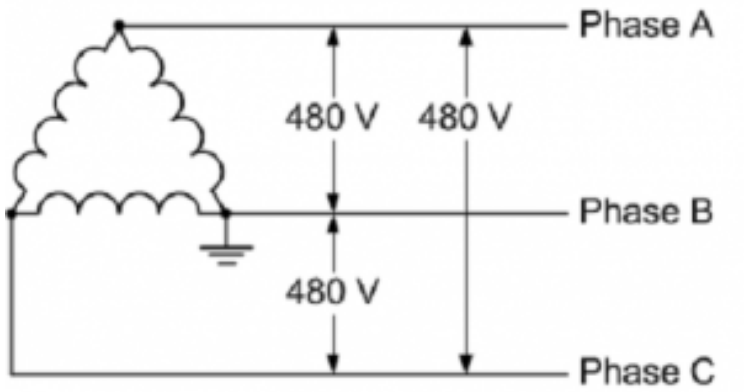
- Benefits are:
  - Reduce construction cost for electrical service, wiring, and electrical devices
  - Reduce energy loses

Electric Power

- 480V Three phase Wye:
  - Use 277V or below 300V
  - Can be used for single phase lighting load



- 480V Three phase Delta:



Electric Power

- What is the typical electric power draw for the following items:
  - Your personal laptop?
  - Your phone?
  - LED lights?
  - Fluorescent lights?
  - Your office desktop?

- Calculate the monthly electric consumption of the devices the above devices

Examples of Devices

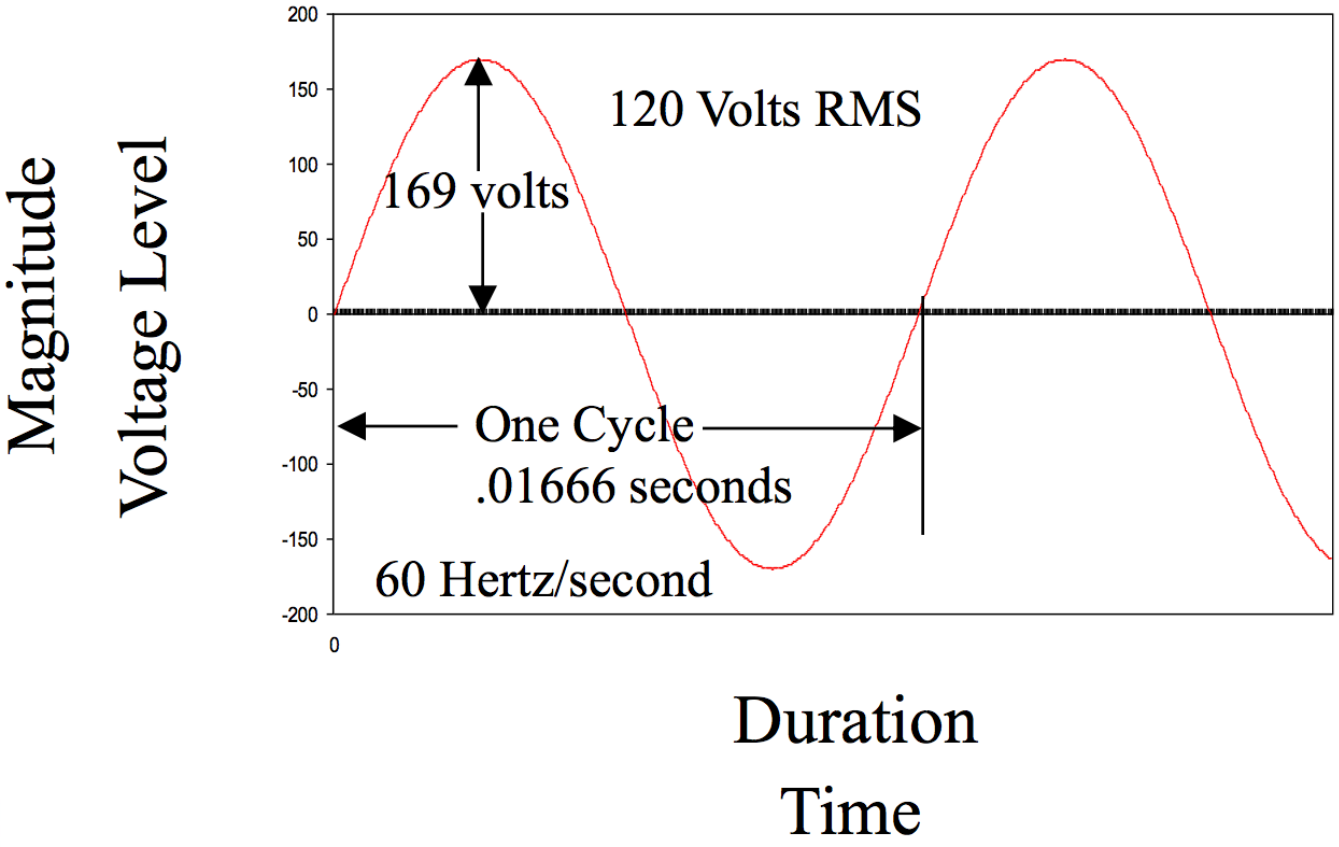
Appliance	Power rating(in Watts) Standard	Current consumption in 1 Hour (in Amps)
Compact Fluorescent Lamp CFL	8,11,18,35	0.03,0.040,0.078,0.15
Bulb Fluorescent Lamp	25,40,60,100 20,40	0.11,0.17,0.26,0.43 0.01,0.2
Fan	25-80	0.1-0.4
TV Fridge	80-400 200-300	0.4--2 1-1.4
Heater Vacuum cleaner	1000-3000 150-400	4.5-15 0.7-2
Mixi	300-600	1.4-2.8
Washing Machine Microwave Oven	800-1000 600-1500	4-4.5 2.6-6.5
Table Fan Computer	10-25 80-150	0.04-0.11 1-1.3
Laptop	20-50	0.09-0.22
Laser Printer Ink Jet Printer	1000-1500 25-50	4.3-6.5 0.11-0.22
Electric Iron DVD	450-1000 20-50	2-3 0.09-0.22
A/C 1HP	1000-1500	4.3-6.5
Water Pump ½ HP Hair Dryer	500-1000 1200-1500	2.17-4.3 5.2-6.5
Music system	20-40	0.09-0.17

Examples of Devices

1 hp = 745.7 Watt

Power Factor

- Power factor “true power”: is the cosine of the phase angle between current and voltage



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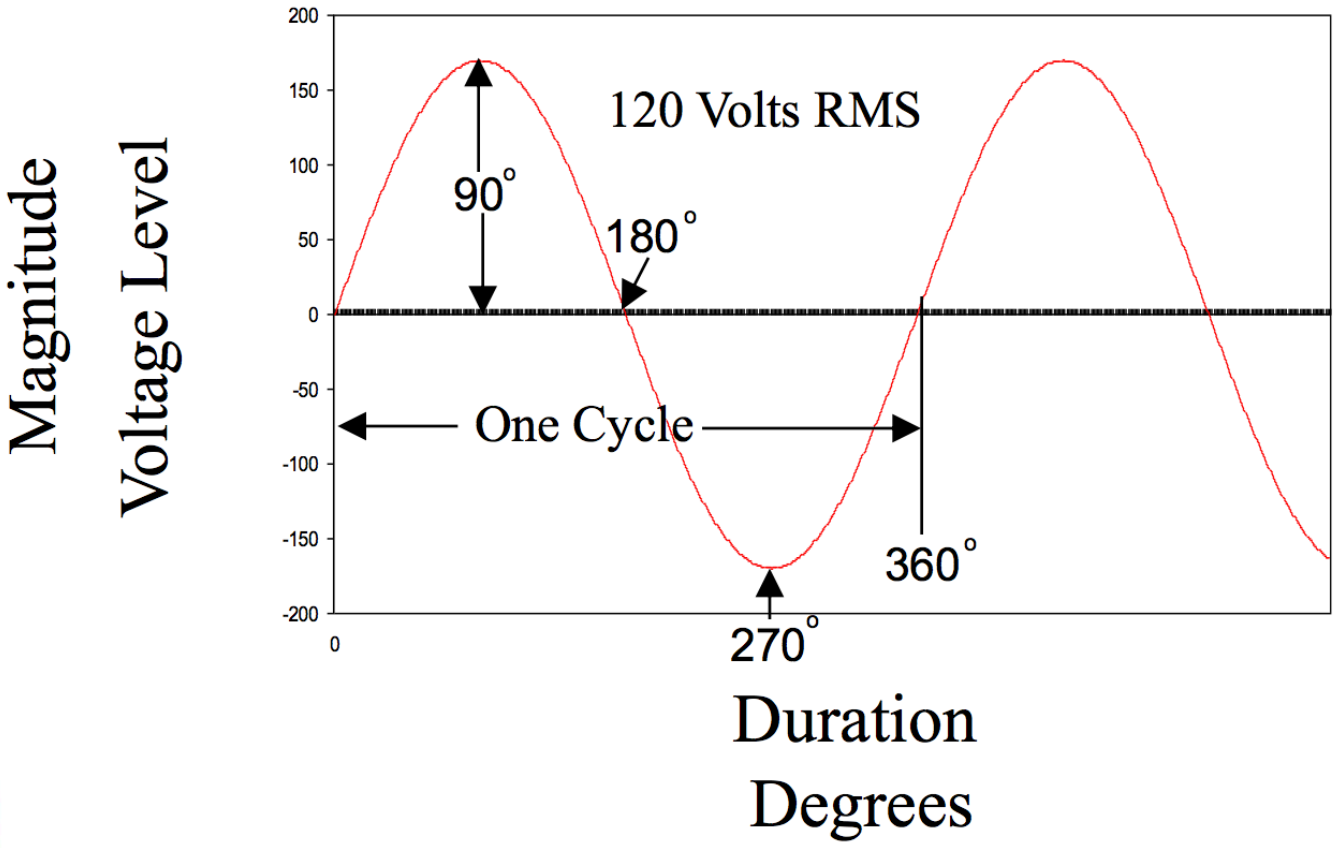
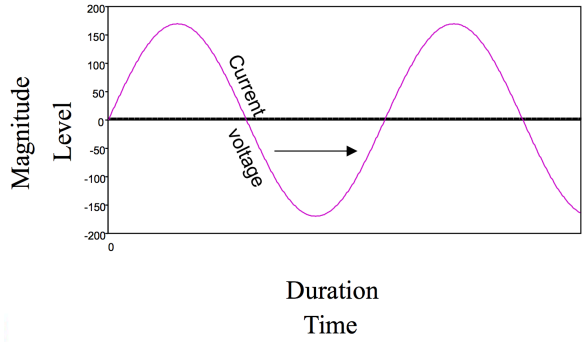


Load Types

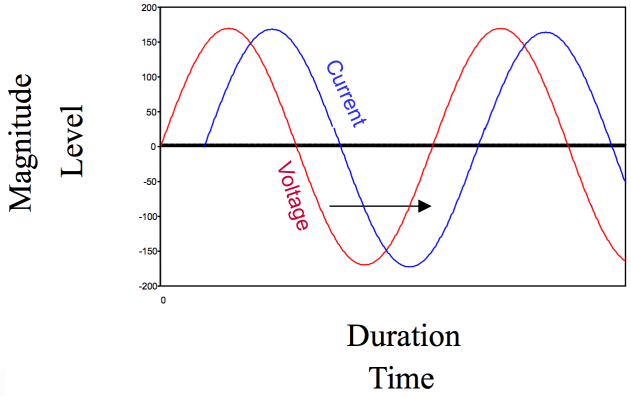
- Type of loads:
  - Resistive:
    - Incandescent lamp, resistance heat
  - Inductive
    - Motors, contractor coils, relays
  - Capacitive
    - Start capacitors
  - Combination of these loads

Load Types

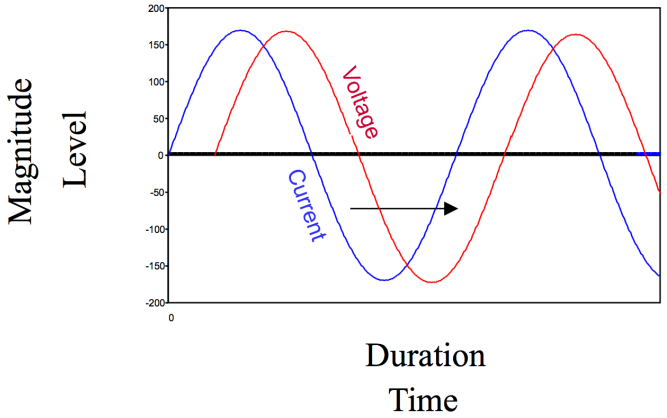
- Resistive load profile:



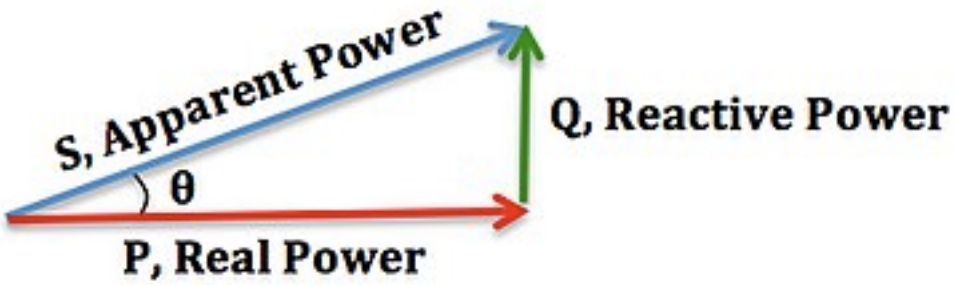
- Inductive load lagging:



- Capacitive load leading:



Power Factor



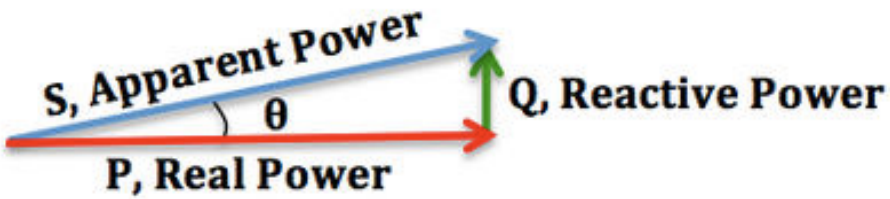
$$S = P + jQ$$

$$|S|^2 = P^2 + Q^2$$

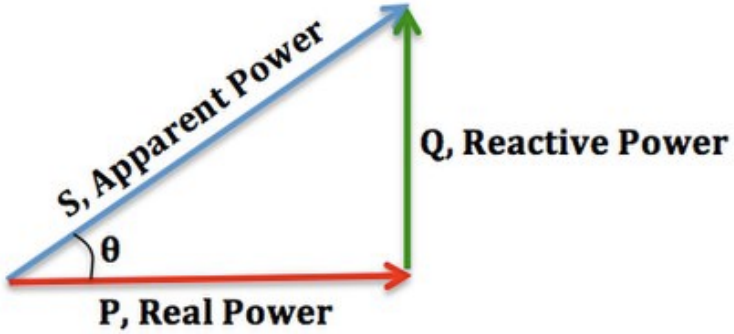
$$|S| = \sqrt{P^2 + Q^2}$$

$$\cos\theta, \text{ power factor} = \frac{P, \text{ real power}}{|S|, \text{ apparent power}}$$

Increasing power factor



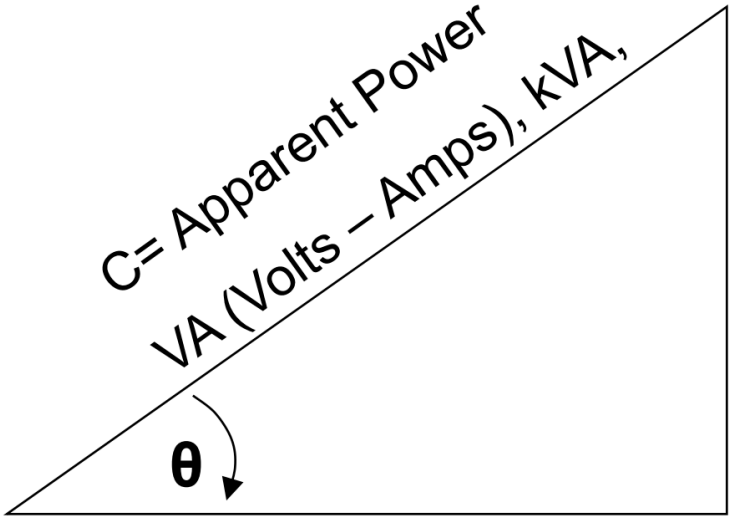
Decreasing power factor



Power factor is usually less than 1

Power Factor

- Power factor is equal to:



A= Reactive Power

VAR, kVAR Reactance

B= True Power

Watts, KW, Power

$$PF = \frac{kW}{KVA} = \frac{kW}{\sqrt{kW^2 + KVAr^2}} = COS(\Theta)$$

PF = Power Factor (PU)

kW = KW of the load (Real Power)

$KVAr$ = KVAr of the load (Imaginary Power)

KVA = KVA of the load (Apparent Power)

θ = Power Factor Angle (deg)

ELECTRIC POWER MEASUREMENTS

Ammeter

- Ammeters:
  - Are low-resistance instruments for measuring current
  - Should be connected in series with the circuit being measured
  - Have minimal influences on the measurement
  - Have several ranges

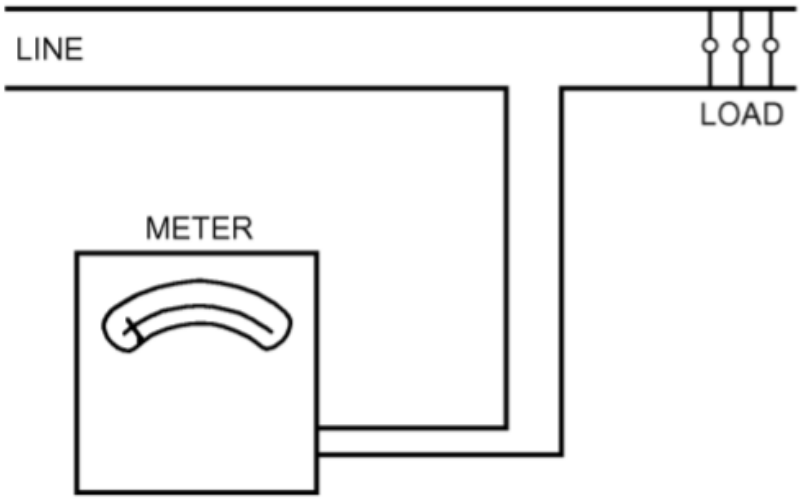
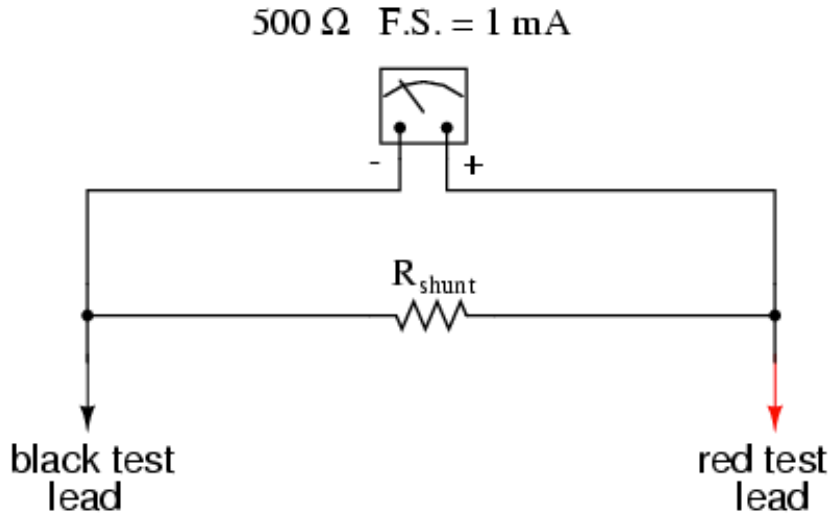


Fig. 16 Ammeter Connected in Power Circuit



Ammeter

- Have two windings:
  - Connect the primary in series with the circuit in which the current is measured
  - Connect the secondary winding a scaled-down version of the primary current, which is connected to an ammeter

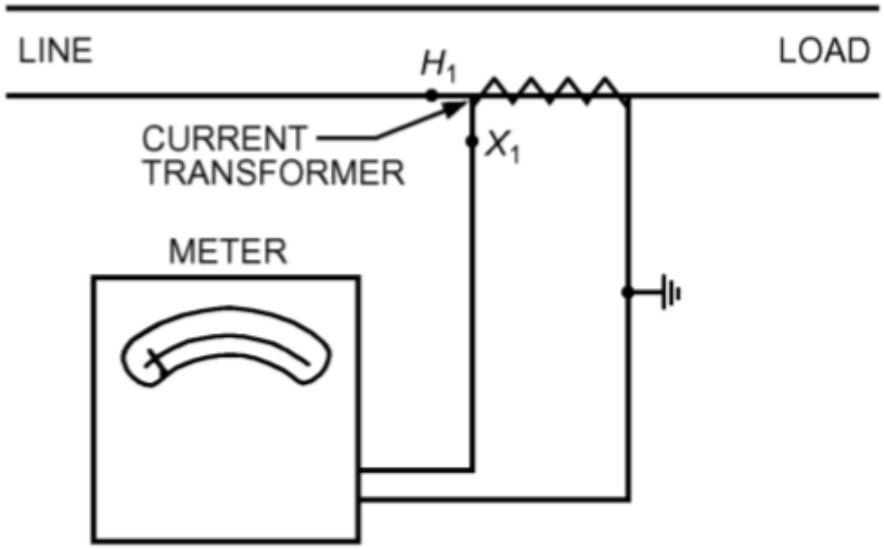
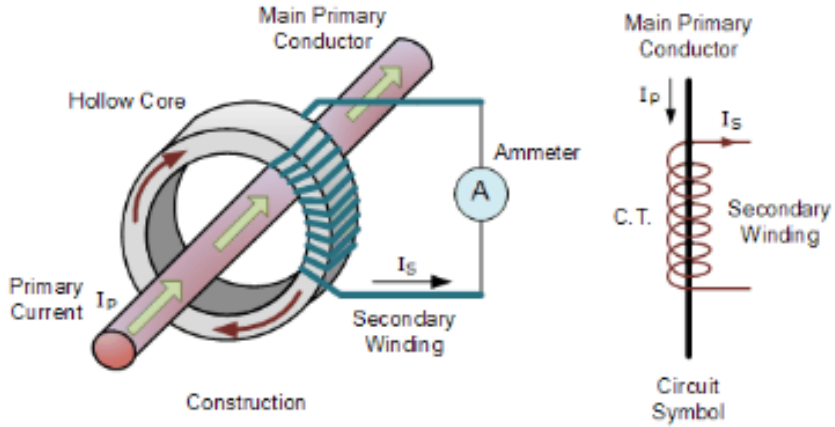
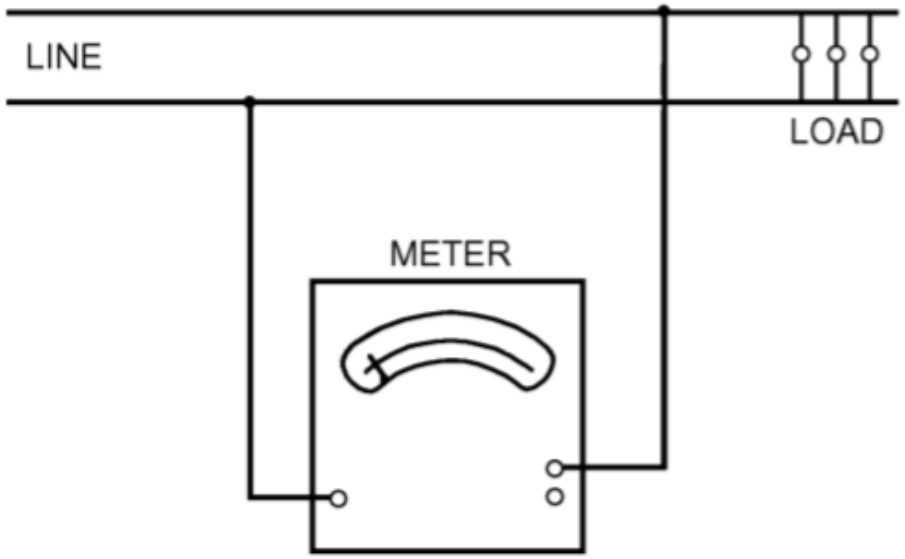


Fig. 17 Ammeter with Current Transformer



Voltmeter

- Benefit from high-resistance instruments
- Connect across the load in parallel
- Influence measurements (ideally has finite impedance)



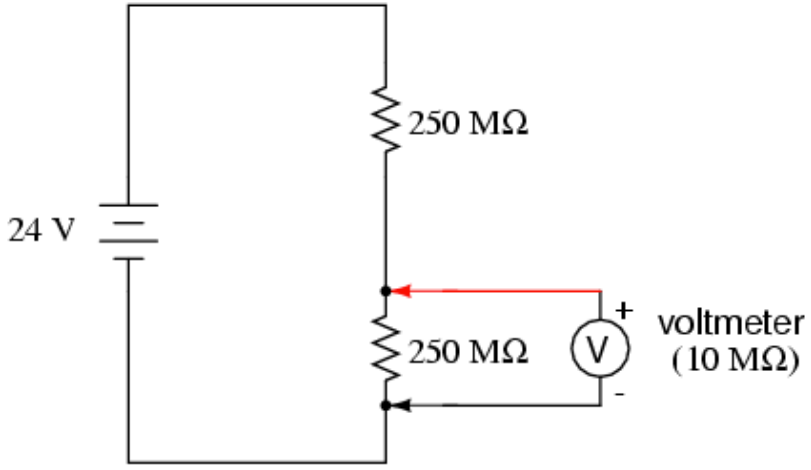


Fig. 18 Voltmeter Connected Across Load

Voltmeter

- Utilize voltage transformers to increase the operating range of a voltmeter
- Typically use isolation from high voltages and prevent operator injury

- Similar to Ammeters:
  - One winding is connected across the high voltage to be measured
  - One connected to the voltmeter

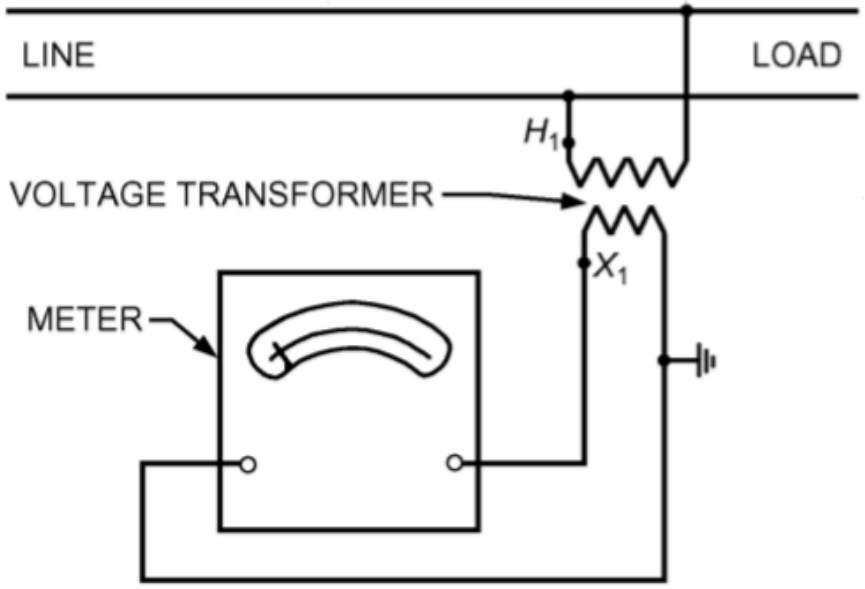


Fig. 19 Voltmeter with Potential Transformer

Watt Meters

- Measure the active power of an AC circuit
- Combines voltmeter and ammeter
- Entail two sets of terminals:
  - One connected to the load voltage
  - One connected in series to the load current

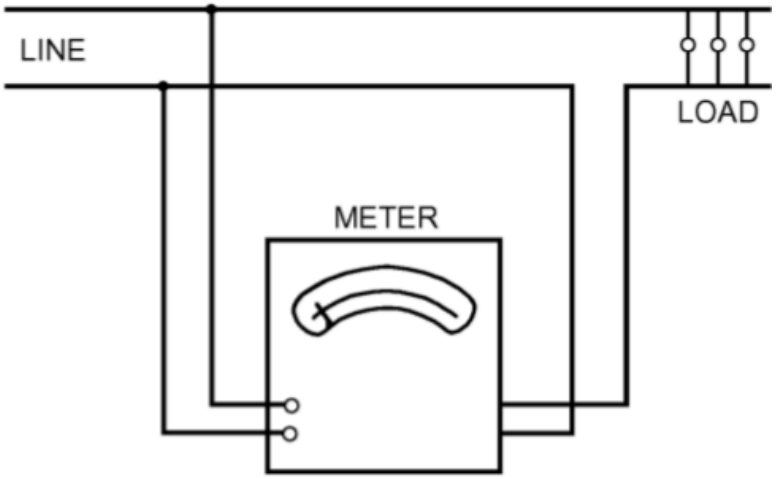


Fig. 20 Wattmeter in Single-Phase Circuit Measuring Power Load plus Loss in Current-Coil Circuit

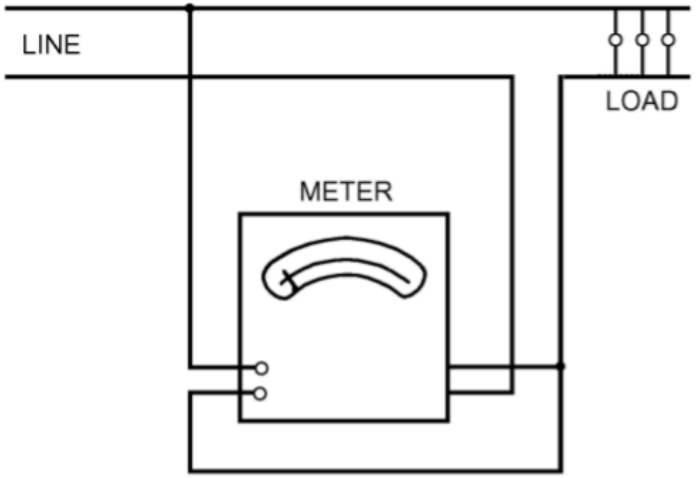


Fig. 21 Wattmeter in Single-Phase Circuit Measuring Power Load plus Loss in Potential-Coil Circuit

Watt Meters

- Extend the range with transformers or isolate it from high voltage

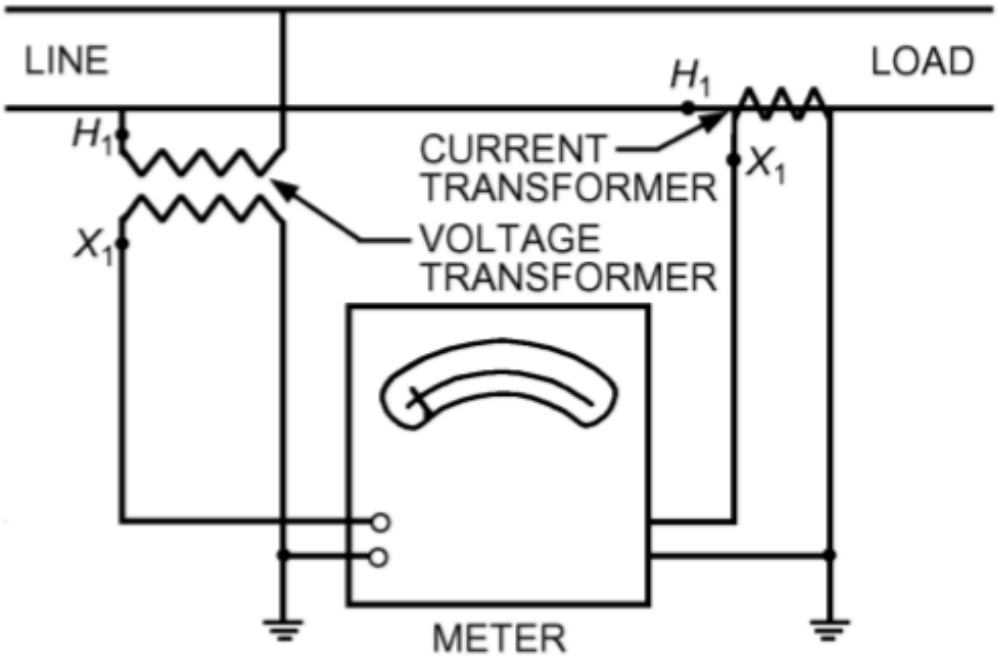


Fig. 22 Wattmeter with Current and Potential Transformer

Power-Factor Meters

- Meter measure the ratio of active to apparent power
- Have similar connections to wattmeters
- Extend the range using current and voltage transformer

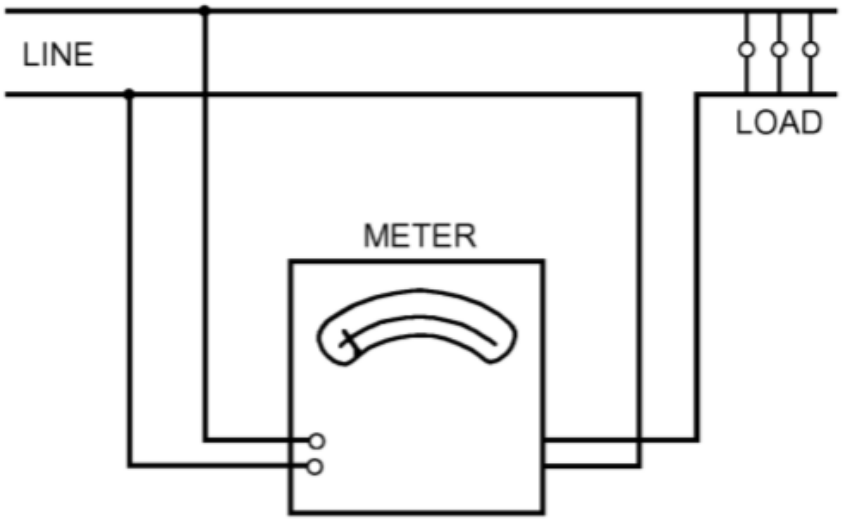


Fig. 25 Single-Phase Power-Factor Meter

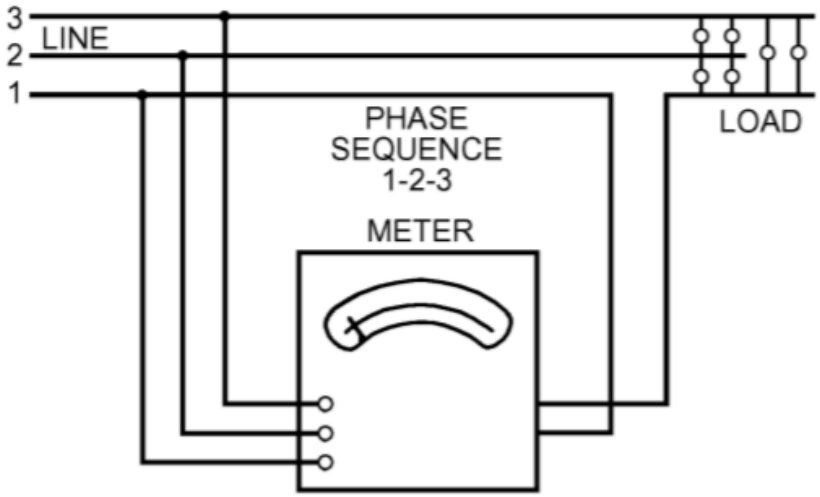


Fig. 26 Three-Wire, Three-Phase Power-Factor Meter

Clamp Meter

- Clamp Meter = Ampmeter + Voltmeter

- Created primarily as a single purpose test tool for electricians

- Evolved to:
  - Include additional measurement functions
  - Provide higher accuracy
  - Use for specific measurement features

Clamp Meter

- Can measure large AC currents based on simple transformer action:
  - Clamp around a conductor carrying AC current
  - Convert that current into a secondary winding that is connected across the shunt of the meter's input

- If the secondary has 1000 windings, then the secondary current is 1/1000 the current flowing in the primary:
  - 1 amp of current in the conductor being measured would produce 0.001 amps or 1 milliamp

Digital Multimeter (DMM)

Product Comparison	 Fluke 3000 FC Series Wireless Multimeter »	 Fluke 87V Industrial Multimeter »	 Fluke 279 FC TRMS Thermal Multimeter »
Price comparison	$299.99	$449.99	$999.99
Safety rating: CAT IV 600 V/ CAT III 1000 V	✓	✓	✓
Counts	6,000	20,000	6,000
Voltage AC/DC	1000 V	1000 V	1000 V
Current AC/DC	400 mA	10 A	2500 A AC w/iFlex current clamp DC Current via accessory clamp
Measurement temperature	with T3000 temp module	✓	
Frequency and capacitance measurements	✓	✓	✓
Resistance, continuity and diode measurements	✓	✓	✓
Logging/Graphing	with optional FC modules and phone app or PC software		via phone app

Fluke.com

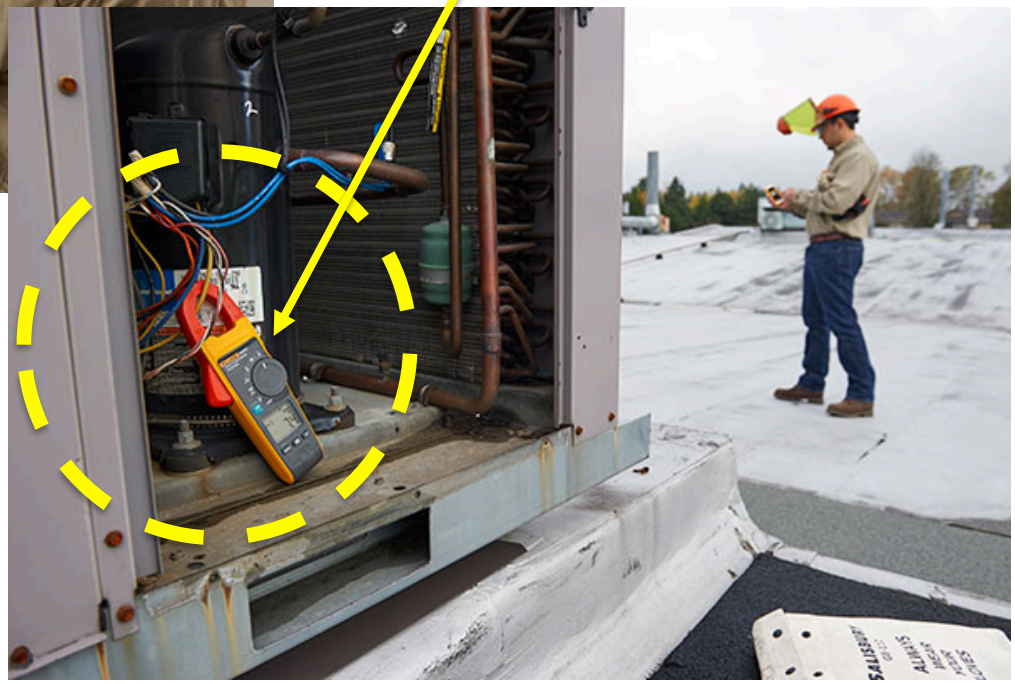
Clamp Meter vs Digital Multimeter

- Clamp meters vs. common digital multimeter (DMM):
  - Similar functionality with an internal current transformer

Transcat.com

Fluke.com

Clamp Meter



Fluke.com

Clamp Meter

- Specification of Fluke 902 Clamp Meter:
  - 600 A AC current measurement
  - 600 V AC and DC voltage measurement
  - Temperature measurement from -10 °C to 400 °C (14 °F to 752 °F)
  - 1000 µF capacitance measurement
  - DC Current measurement to 200 µA
  - Resistance measurement to 60 kΩ

Fluke.com

Home Electric Measurements & Utilities

- Advanced Power Strips

TRICKLESTAR 7-OUTLET APS

$12

After a $10 Instant Rebate

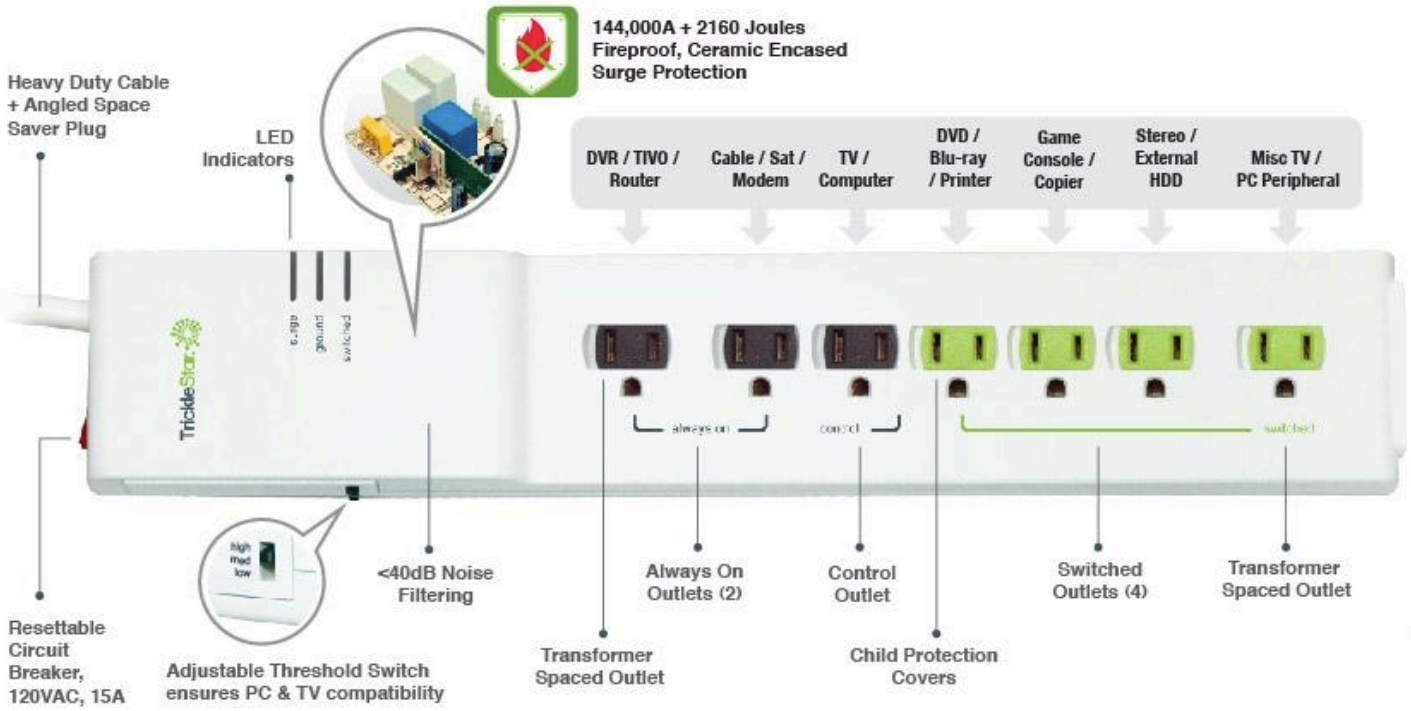
TRICKLESTAR 7-OUTLET MULTI SENSING APS

$48

ComedMarket.com

Home Electric Measurements & Utilities

- Advanced Power Strips works based on the idea of plug load managements. They include:
  - Couple of controlled outlets:
    - Different thresholds (e.g. 10 W, 22 W, and 42 W)
  - 1-2 always on outlet(s)
  - 1 master outlet



ELECTRICITY DATA LOGGERS

Logging electricity use

- Power is instantaneous
- Energy is integral

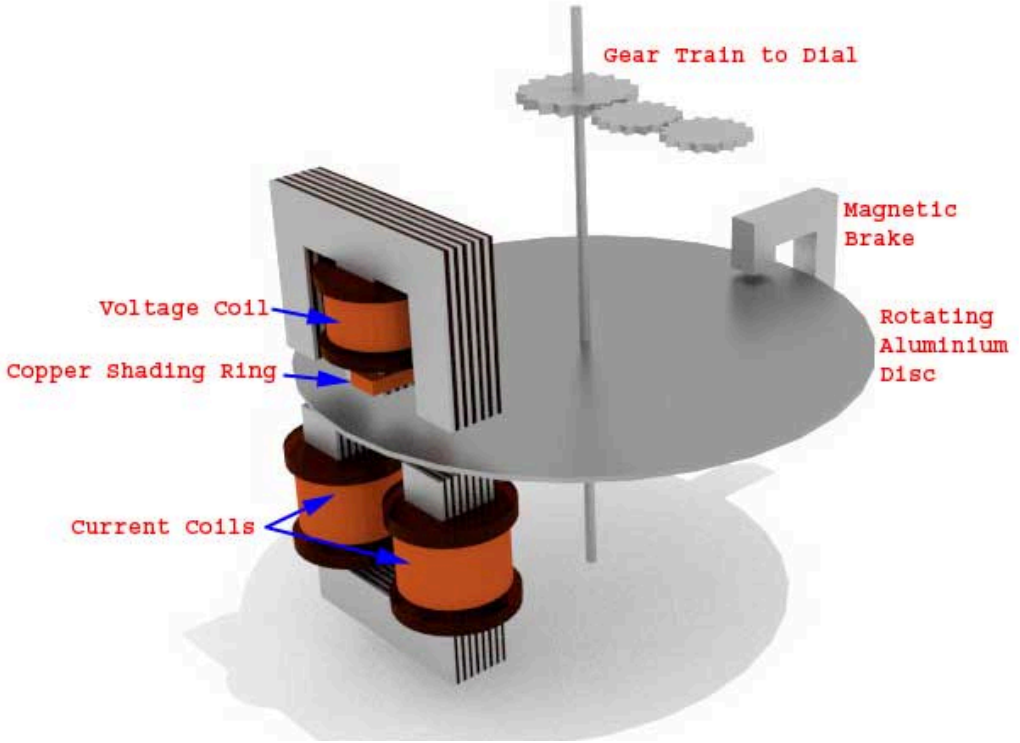
- Do electricity data loggers log power or energy?
  - i.e. power *draw* or power *consumption?*

Logging electricity use

https://the-gadgeteer.com

Electromechanical induction watt-hour meter

Counts the revolutions of a metal disc that rotates at a speed proportional to the power

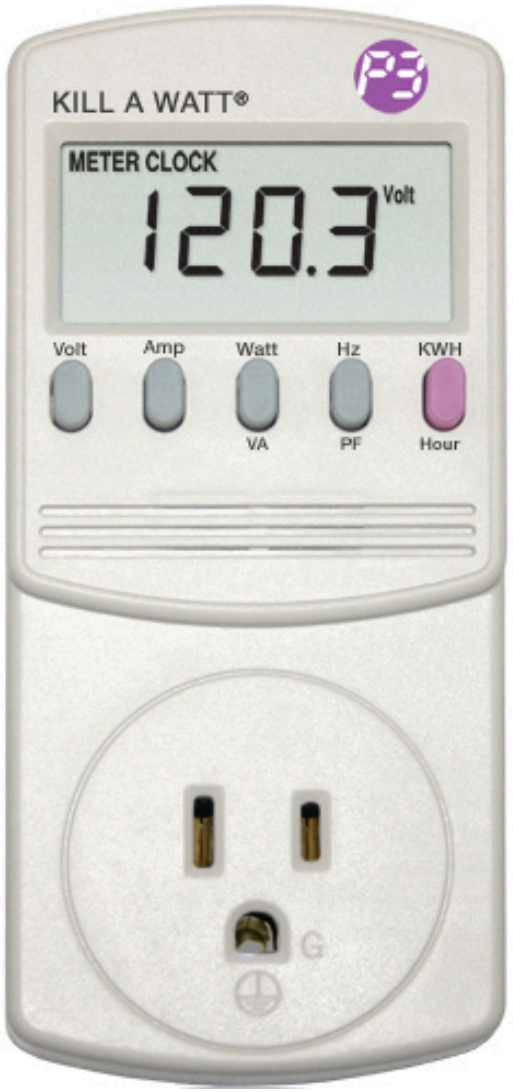


https://www.electrical4u.com

Plug-Load Monitors “Kill A Watt”

- Monitor appliance consumption
- Record for an interval

Model:	**P4400**
Operating Voltage:	**115 VAC**
Max Voltage:	**125 VAC**
Max Current:	**15 A<**
Max Power:	**1875 VA**
Weight:	**5 oz.**
Dimensions:	**5 1/8" H x 2 3/8" W x 1 5/8" D**

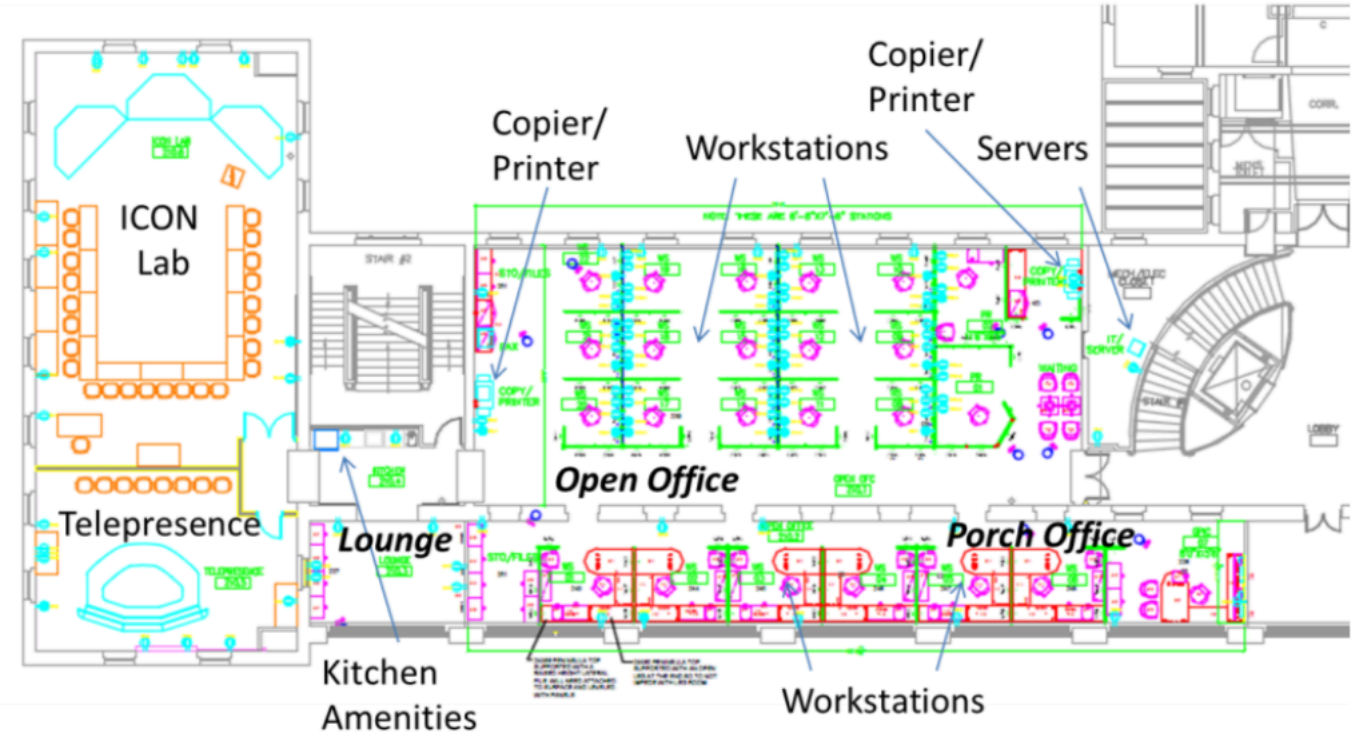


P3international.com

Building Measurement Example

- Actual building measurement

Space Type:	ICON Lab	Telepresence Room	Open Office	Porch Office	Lounge	Kitchen
Area (ft^2):	1647	676	2374	1218	270	157



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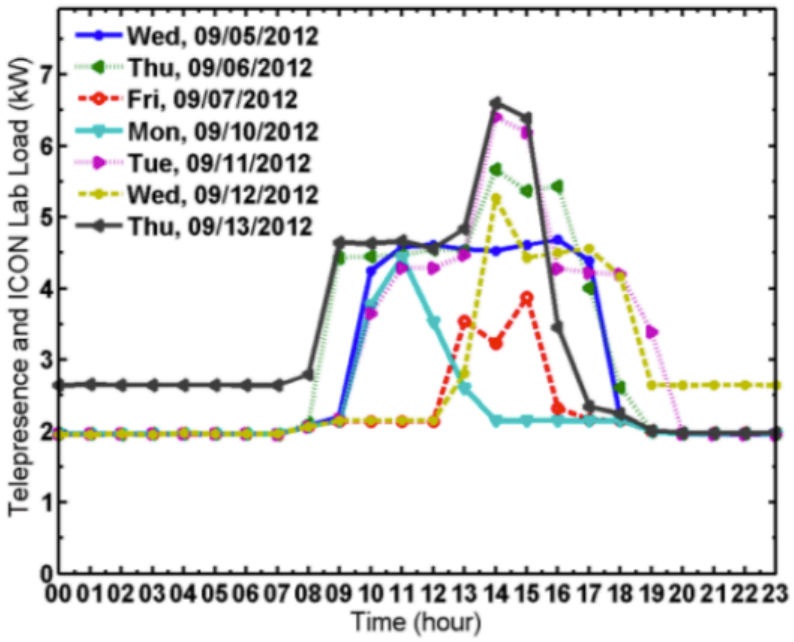
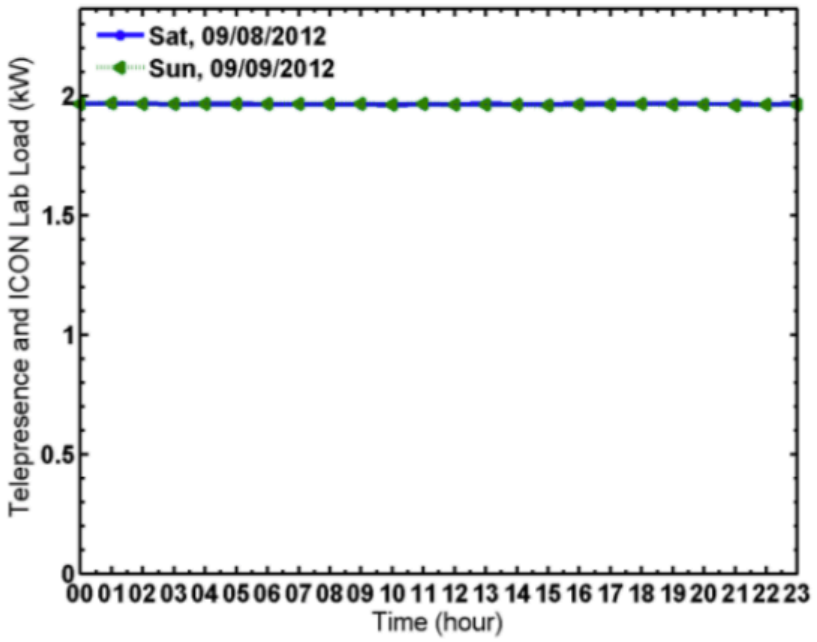
Building Measurement Example

- ICON Lab Measurements

Weekday



Weekend



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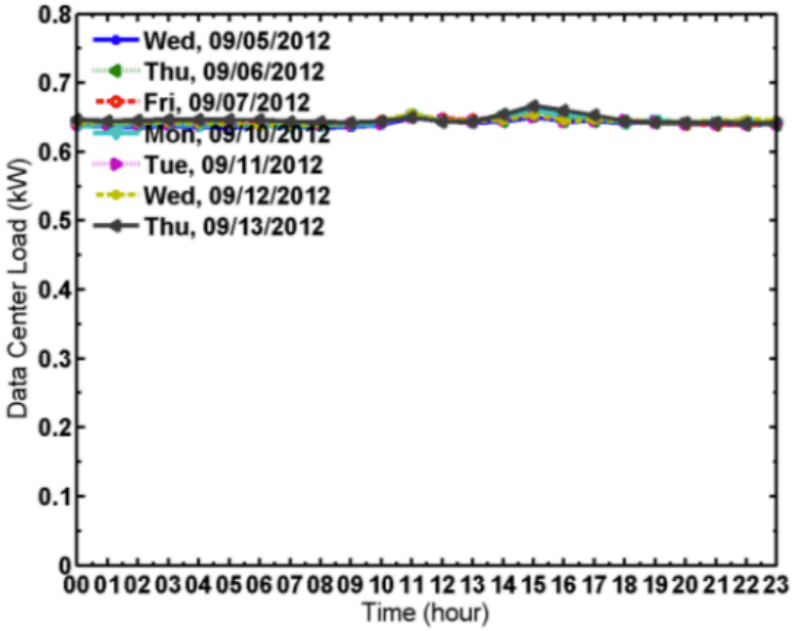
Building Measurement Example

- Servers

Weekday



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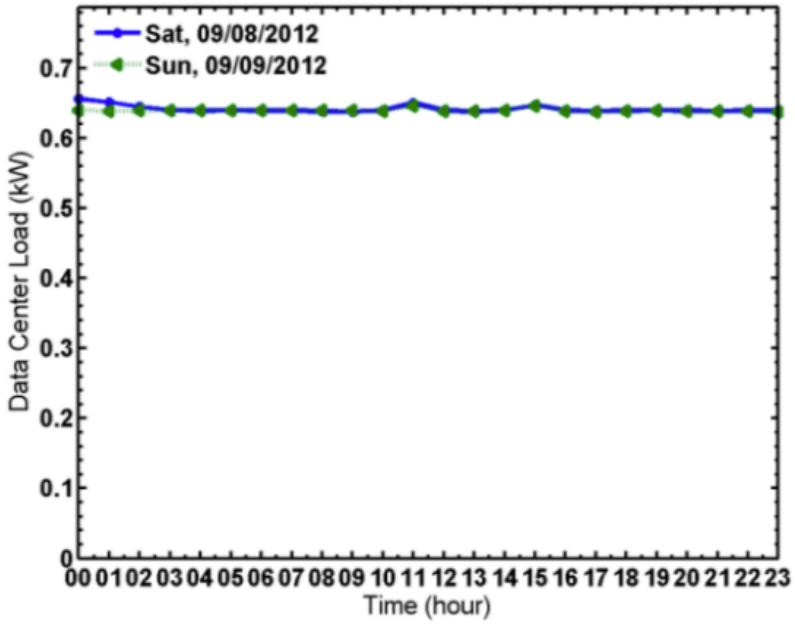

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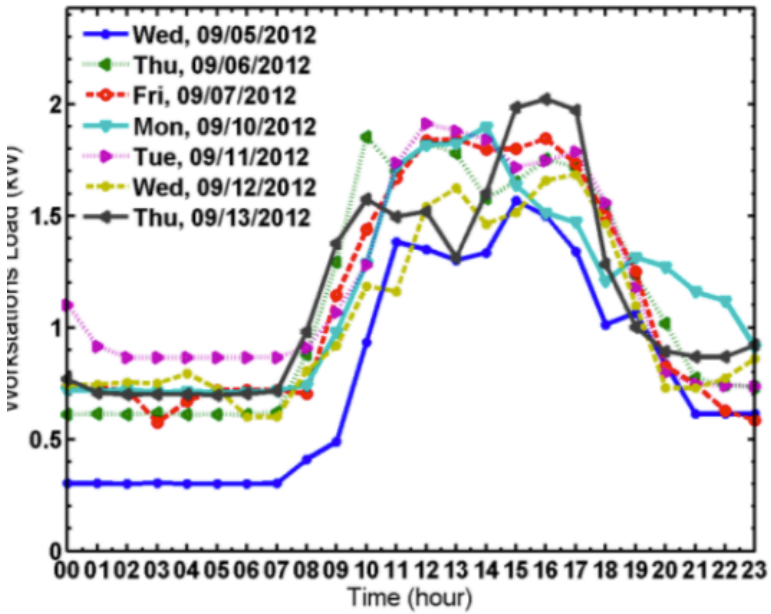
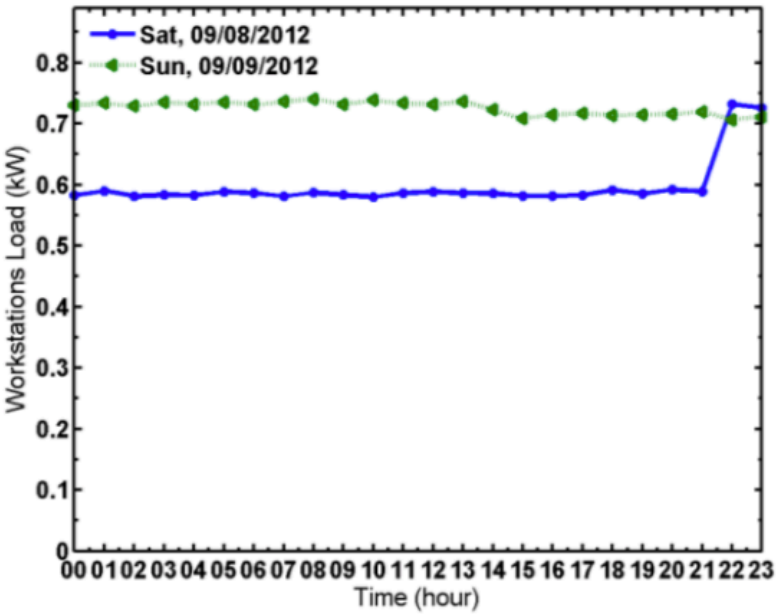
Building Measurement Example

- Workstations

Weekday



Weekend



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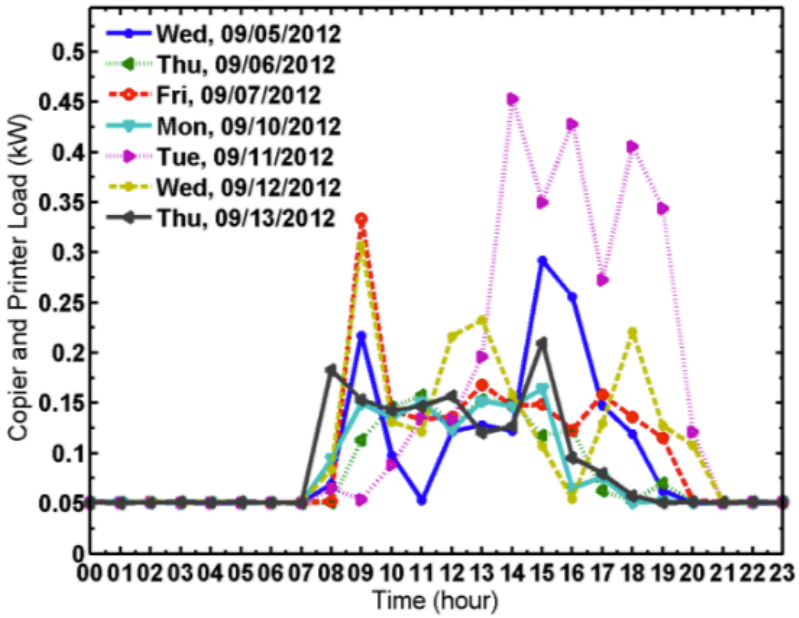
Building Measurement Example

- Copier / Printer

Weekday



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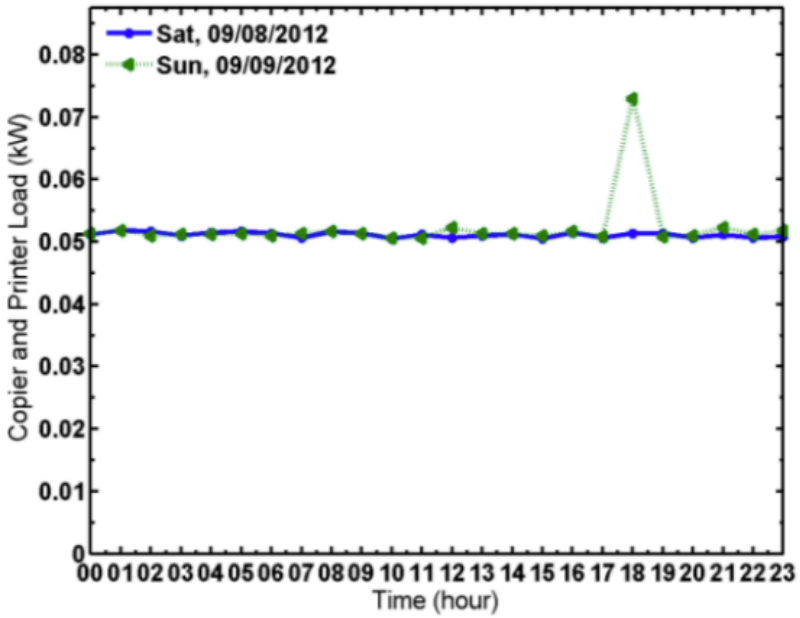

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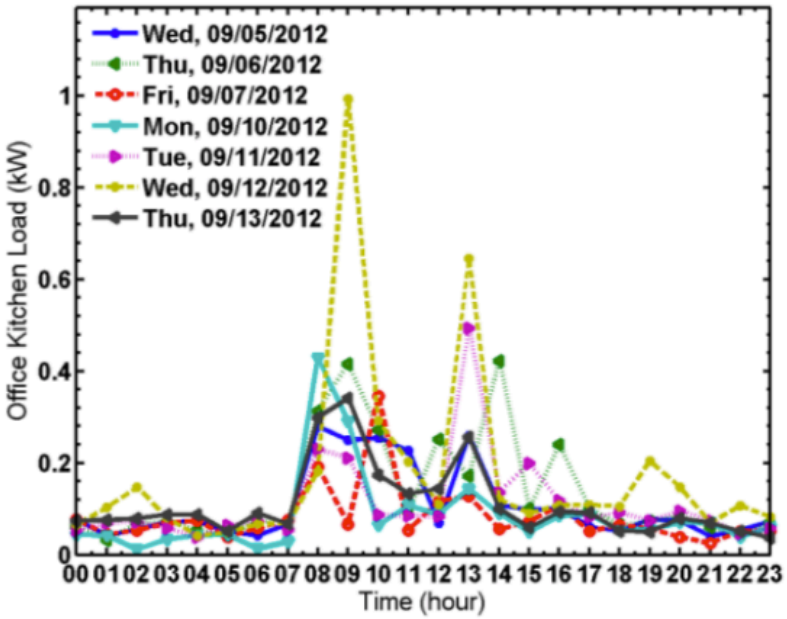
Building Measurement Example

- Kitchen

Weekday



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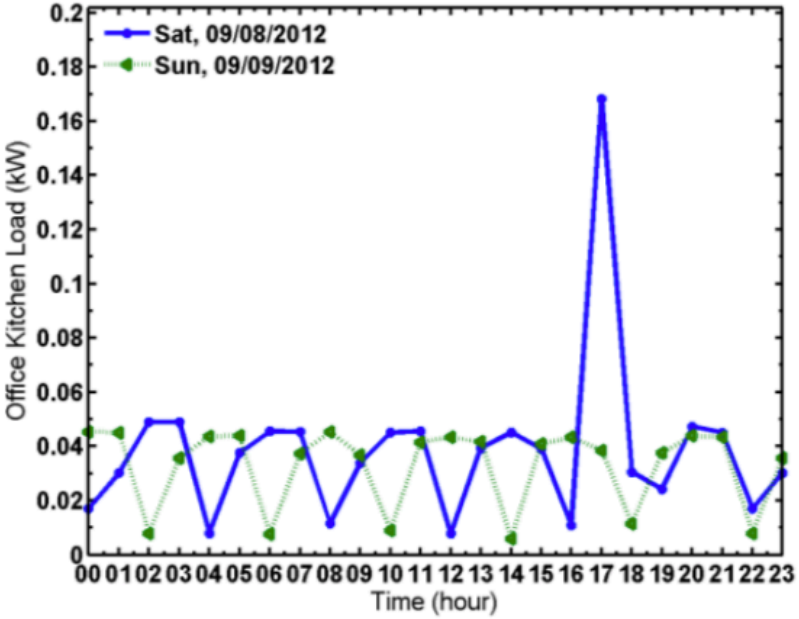

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CLASS ACTIVITY

Class Activity: Electrical Power Measurements

- Activity:
  - Measure power draw / electricity consumption of:
    1. A fan at three different fan speeds (low, medium, and high)
    2. A portable space heater
    3. Lamps with CFL and incandescent light bulbs

- Using the following tools:
  - Onset Energy Logger Pro with CT only (no voltage)
  - Onset HOBO Plug Load Logger
  - Fluke hand held clamp meter
  - Kill a Watt
  - Watts Up Pro

Class Activity

Onset Energy Logger Pro w/ CT

Fluke clamp meter

Class Activity

Onset plug load loggers

Kill A Watt meters