Graphic Excellence for the Commissioning Profession: Strategies for Representing Building Performance Data

Ryan Stroupe, PG&E Pacific Energy Center

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Questions related to specific materials, methods, and services will be addressed at the conclusion of this presentation.

Session Learning Objectives

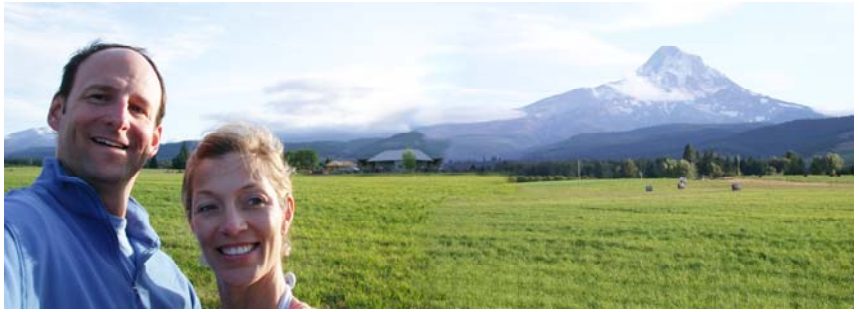
Commissioning in the Digital Age: Data, Software and Graphs

At the end of this session participants will be able to:

1. Decipher data graphs by looking for specific visual clues.
2. Discover a number of graph types and understand the appropriate application of each.
3. Understand the basic principles of whole building interval meter data modeling and anomaly detection.
4. Learn how any software-as-service can be improved with the human element.

Ryan Stroupe Bio

- 19 years at PG&E Pacific Energy Center (PEC) in San Francisco
- Coordinates the Center's Existing Building Curricula
  - Building commissioning
  - Energy audits
  - Measurement
  - Financial calculations
  - Water conservation
- Teaches many PEC classes covering 32 different EE topics
- Oversees the Center's Tool Lending Library Program
- Manages Universal Translator software development project
- Six-time Speaker at National Conference on Building Commissioning
- Instructor for several college and university extension programs



Mystery Graph Activity

Mystery Graph Instructions

1. NCBC participants with highest score on Mystery Graph quiz will win a HOBO datalogger and earn the admiration and respect of their NCBC peers.

2. For each mystery graph, fill-in the oval corresponding to the single best option on the provided answer sheet.

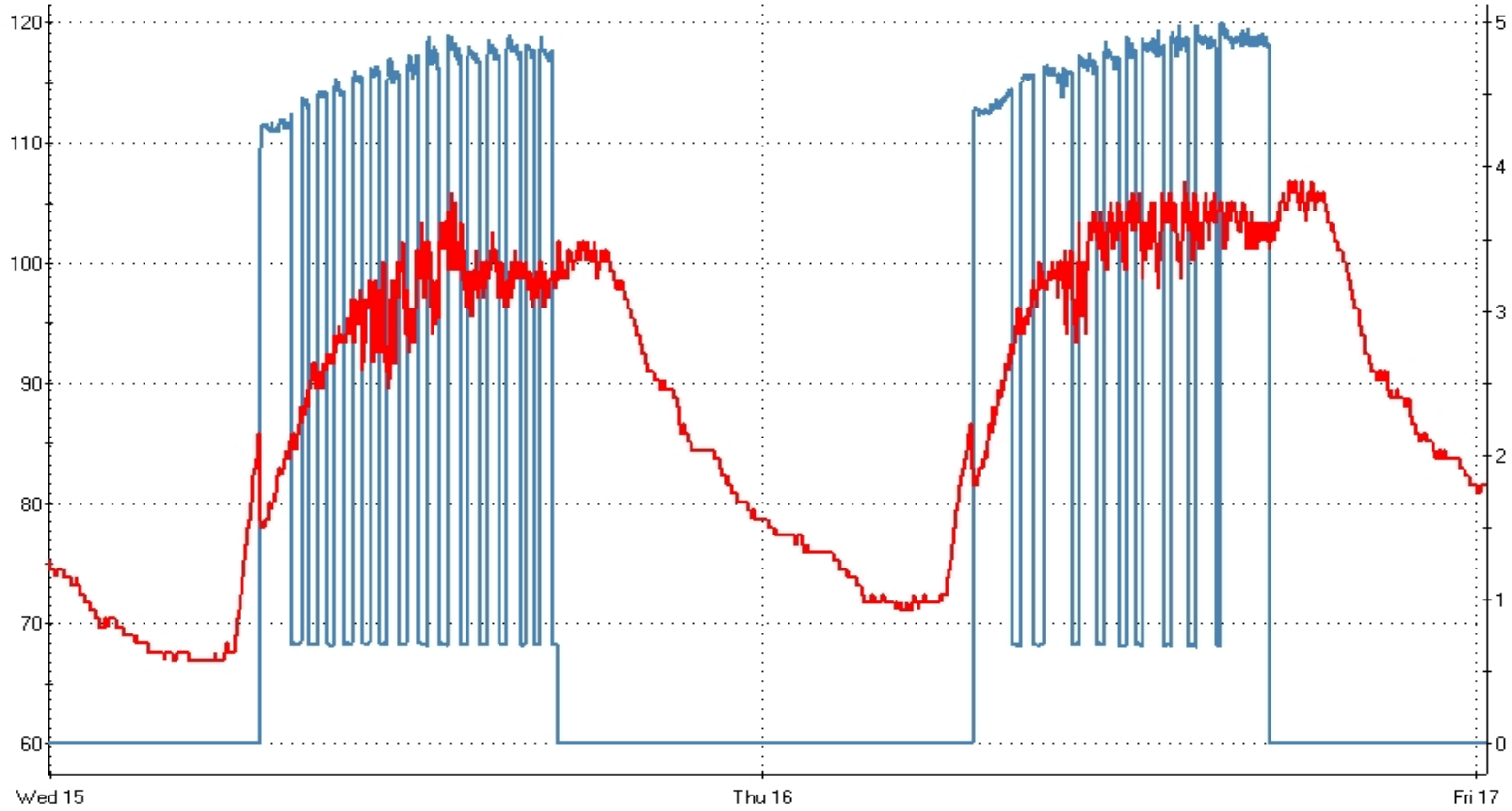
3. Complete the answer sheet and include your contact information at the bottom of the card.

4. The completed form must be turned in before answers are revealed to be eligible for the datalogger prizes.

5. This is an individual effort; please do not share answers.

Mystery Graph 1

This graph illustrates:



a. Leaving boiler temperature (L) and pump amps (R) for a boiler loop used for space heating

b. Exterior illuminance (L) and interior illuminance (R) in klux for a warehouse with skylights.

c. Outside air temperature (L) and power draw (R) for a packaged unit with a single-stage of cooling.

d. CO2 levels (L) and amps for the lighting systems (R) at a movie theater.

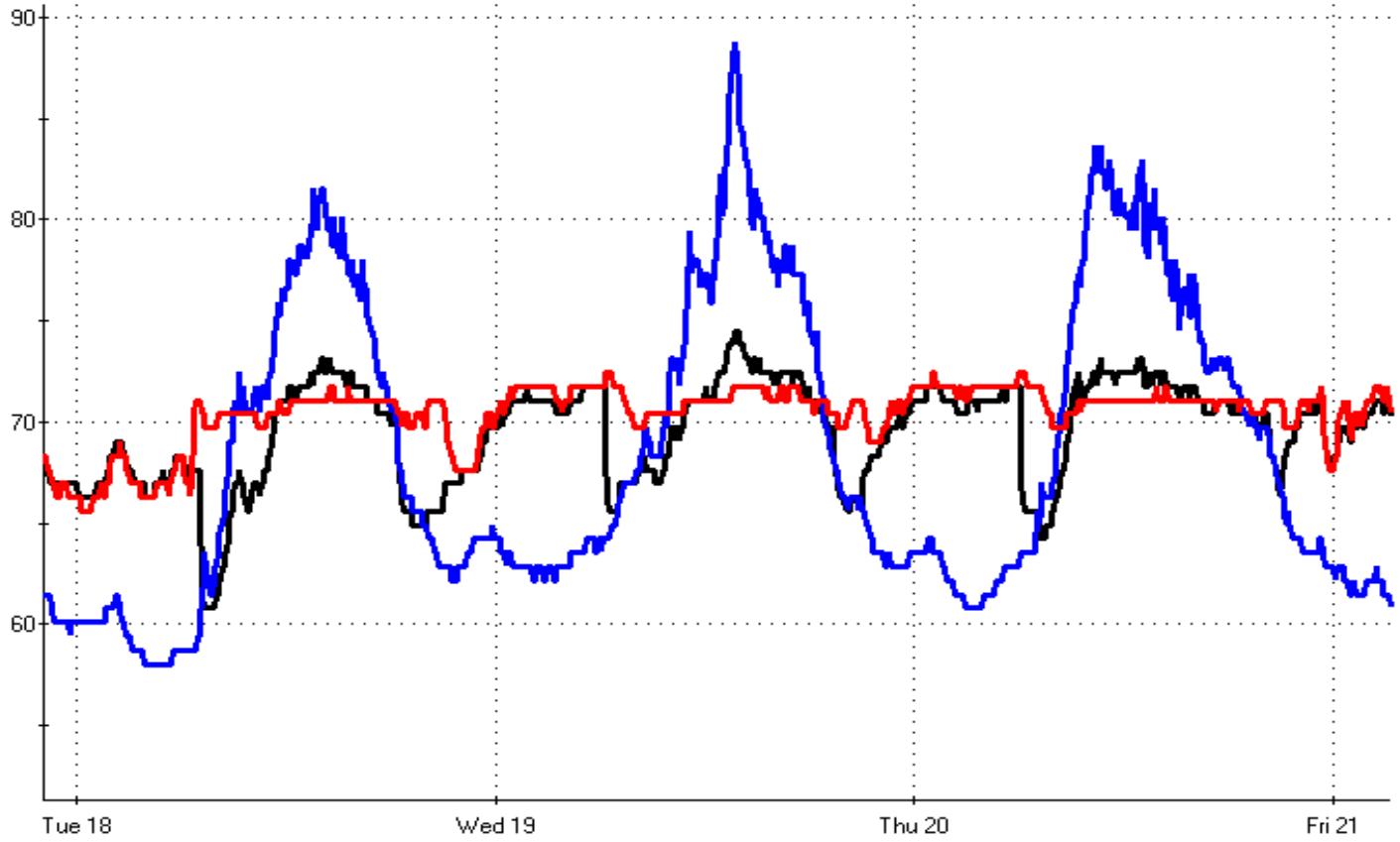
e. % load (L) and amps (R) for a motor used for ventilating a restroom in an airport terminal.

(L) = variable references left axis

(R) = variable references right axis

Mystery Graph 2

The three variables illustrated in the graph depicted here are?



a. daily electricity, natural gas and water use.

b. outside air, mixed air and return air temperatures at an air handler with a working economizer

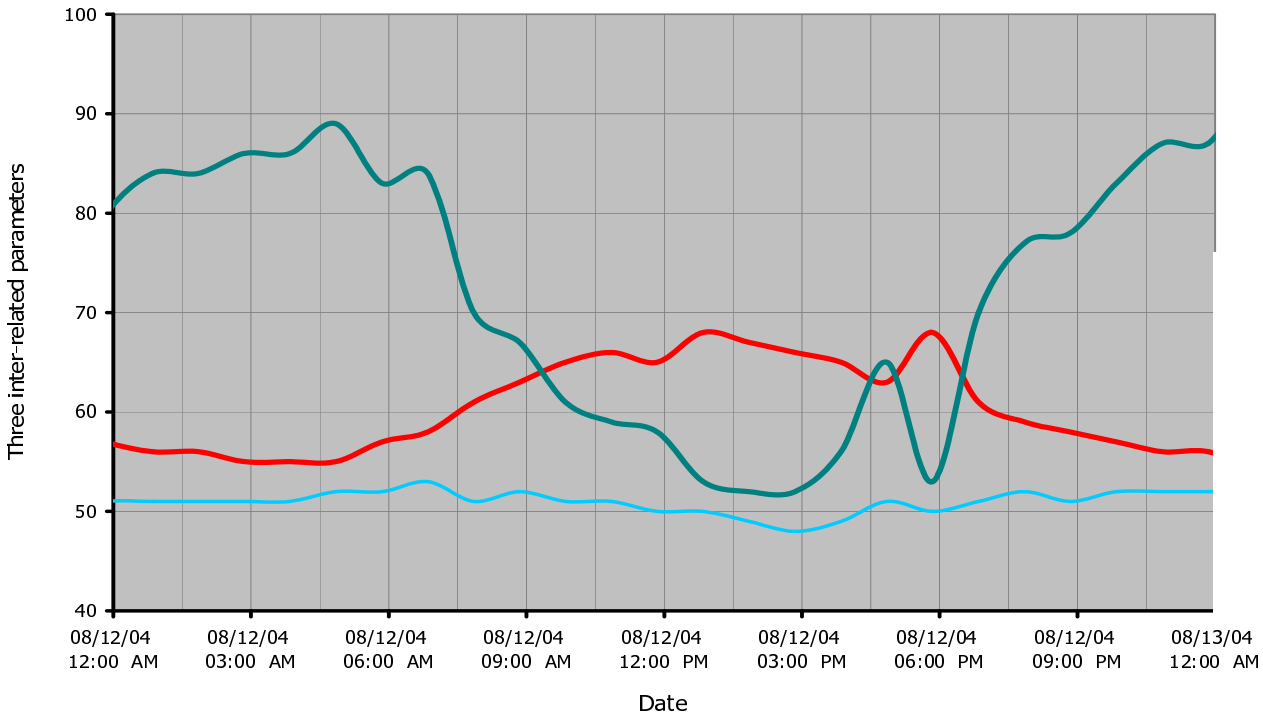
c. space temperature, air flow and damper position for a working VAV box.

d. temperature, relative humidity and dew point of an air volume.

e. chilled water flow, chilled water supply temperature and condenser water supply temperature for an optimized chiller.

Mystery Graph 3

This graph illustrates:



a. Voltage, amperage and power factor for a server room.

b. space temperature, air flow and damper position for a working VAV box.

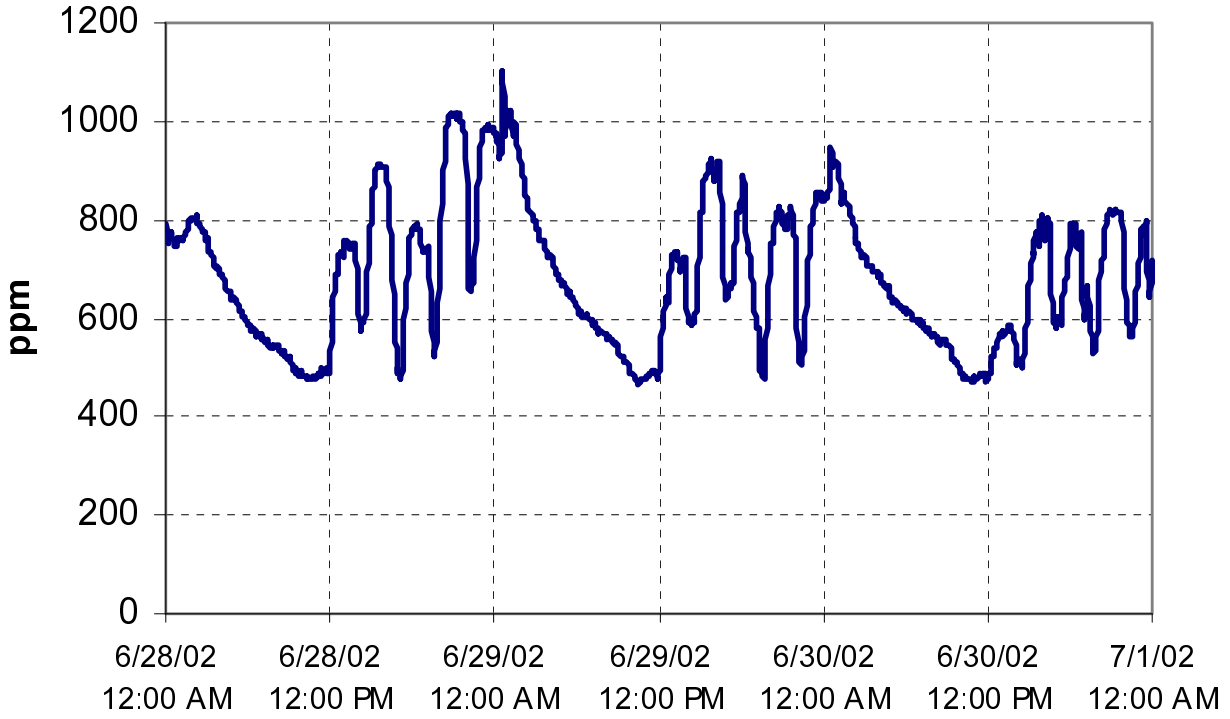
c. outside air, mixed air and return air temperatures at an air handler with an economizer

d. Temperature, relative humidity and dew point of an air volume

e. chilled water flow, chilled water supply temperature and condenser water supply temperature for an optimized chiller.

Mystery Graph 4

The data shown to the right is an indication of which condition?



a. Total dissolved solids in condenser water for a cooling tower.

b. Volatile organic compounds (VOC) levels during construction of an office building.

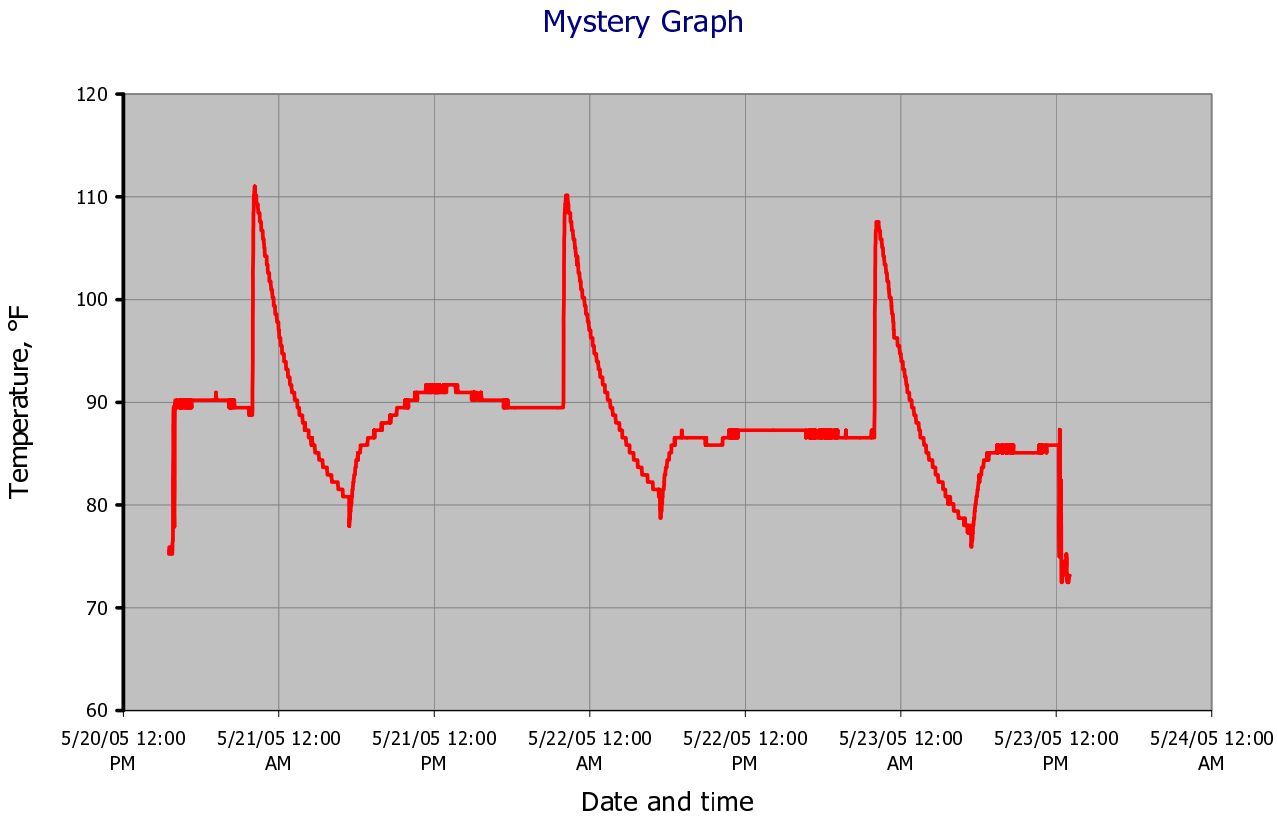
c. CO levels in a parking garage.

d. CO_2 levels in the open office area of a law office.

e. CO_2 levels in a movie theater.

Mystery Graph 5

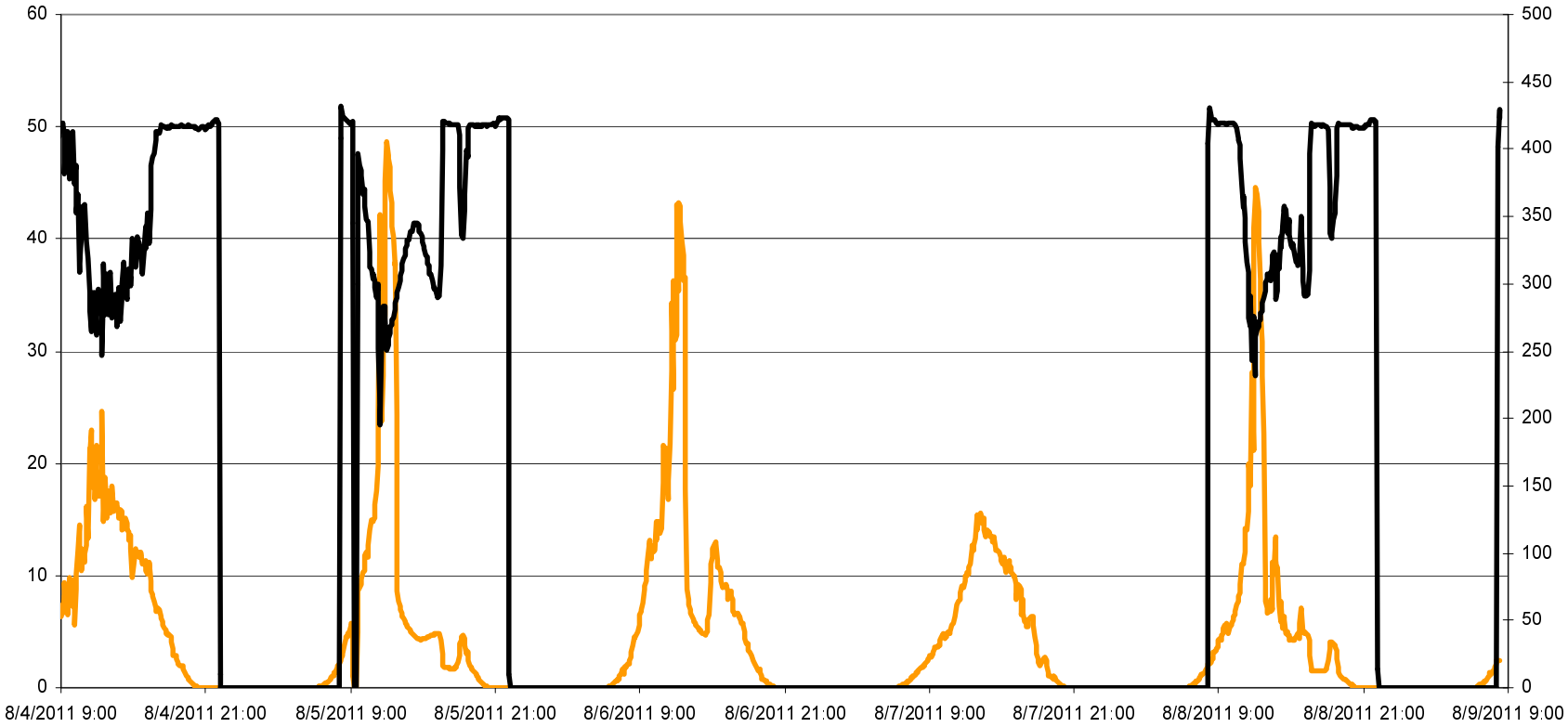
This graph illustrates:



a. light levels from daylight in a library.
b. run time data for a light fixture
c. Space temperature in an unconditioned warehouse.
d. the scheduled operation of a motor
e. flue temperature for a non-condensing heating hot water boiler.

Mystery Graph 6

This graph illustrates:



a. Temperature and humidity data for a lab.

b. Occupancy and light data for an office.

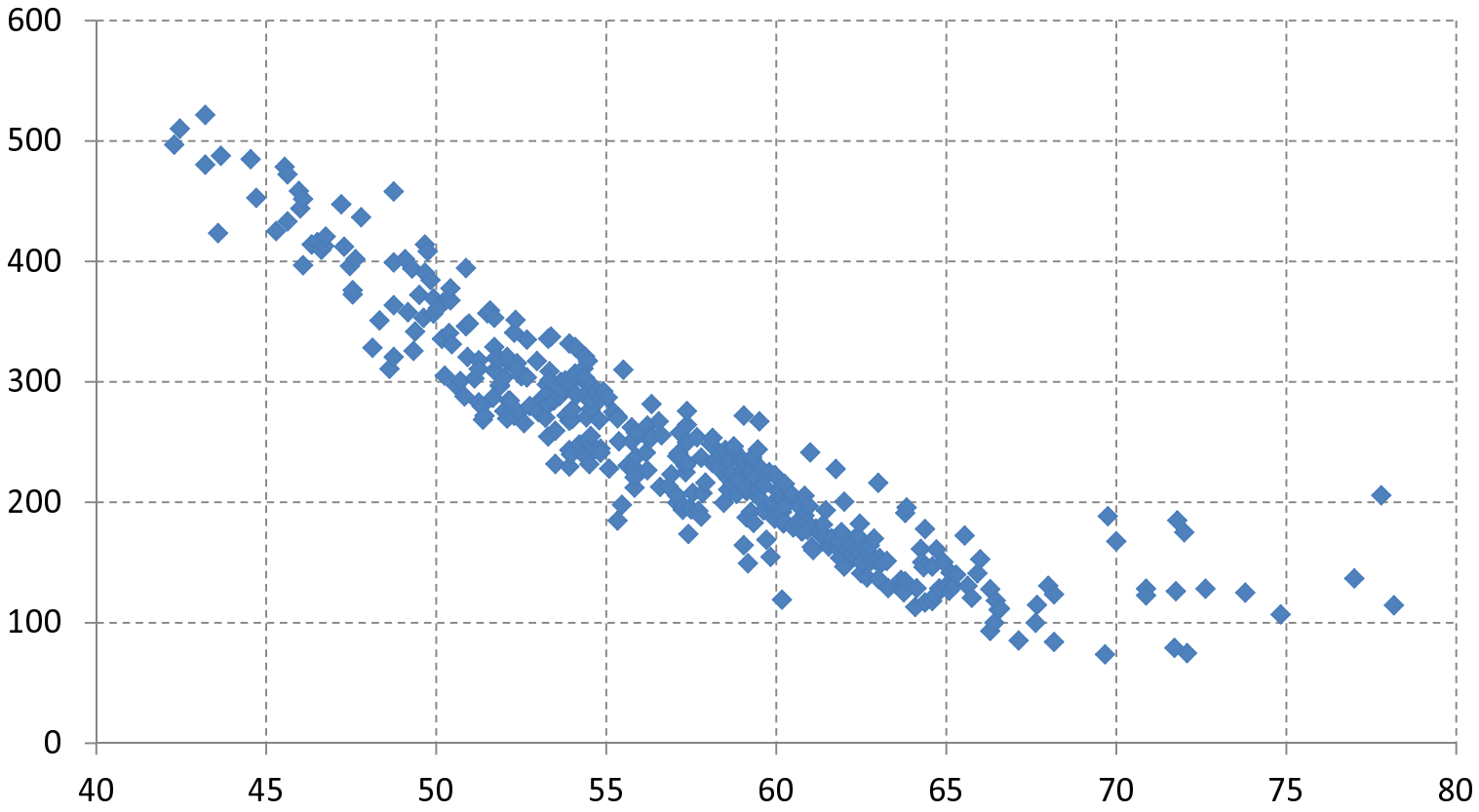
c. Temperature and therm use for a boiler on a schedule control at a warehouse.

d. Wattage and exterior daylight levels for corridor lights controlled by both a photo-sensor and schedule.

e. Zone temperature and air flow for a VAV box serving a classroom.

Mystery Graph 7

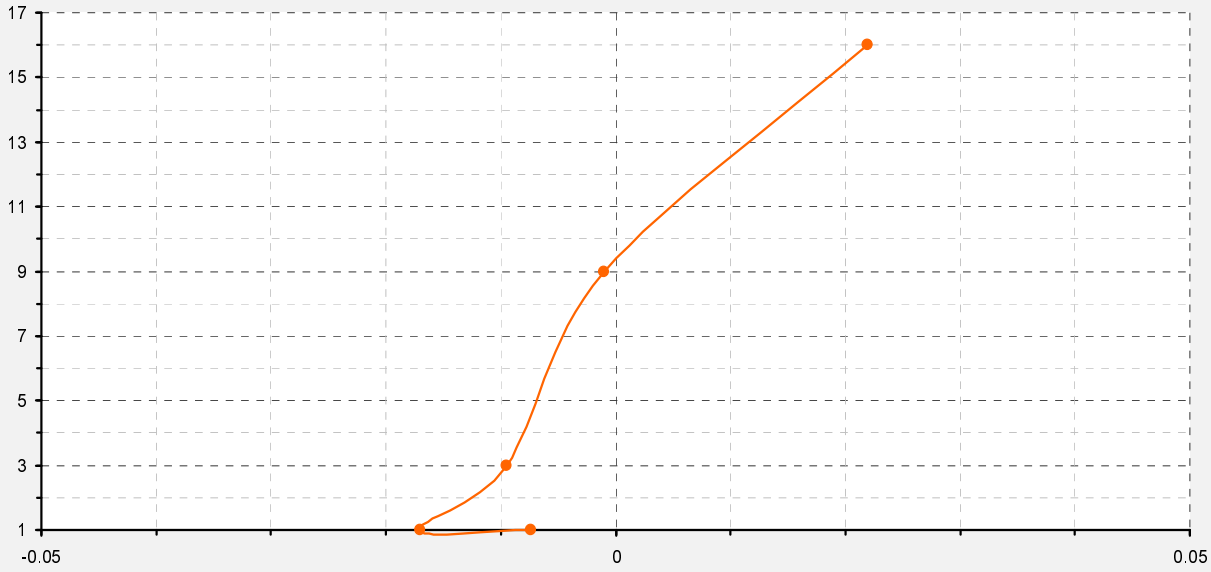
This graph illustrates the relationship between:



a. the percent load and power draw in watts for a motor.
b. the cooling load in kWh per day and the average zone temperature per day for a hospital.
c. the VFD speed in hertz and power in watts for a packaged unit supply air fan.
d. the humidity and enthalpy for air downstream from a direct evaporative cooling system.
e. the heating load for a building in therms per day and the average outside temperature per day.

Mystery Graph 8

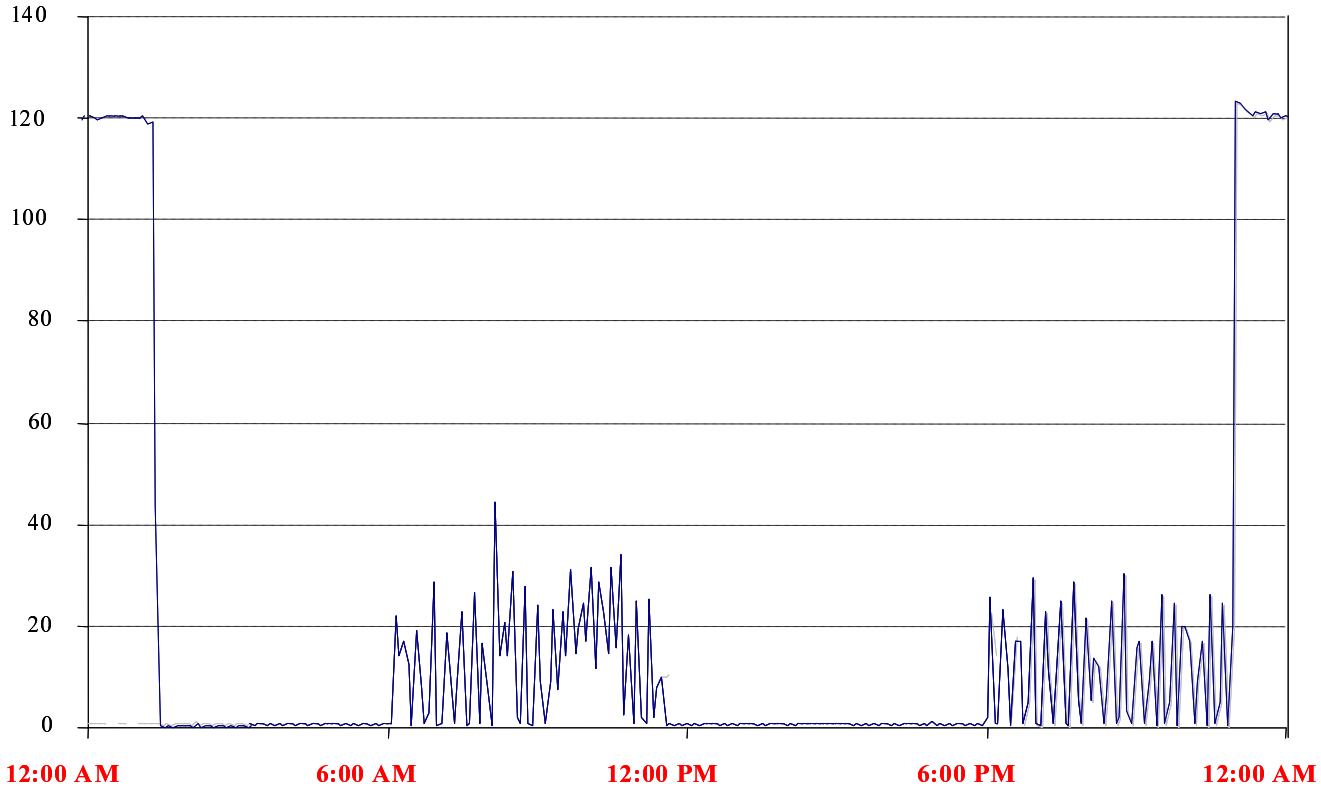
This graph illustrates:



a. Pressure differential across filters relative to months installed.
b. The building pressure (inWG) relative to outside for a 16 storey building under normal operating conditions on a 60F day.
c. The relationship between wind speed (MPH) and altitude (100 ft) in an open field.
d. Wind pressure on the down-wind face of a building with a steady 10 mph wind blowing.
e. Supply static pressure relative to height for a 2 story building.

Mystery Graph 9

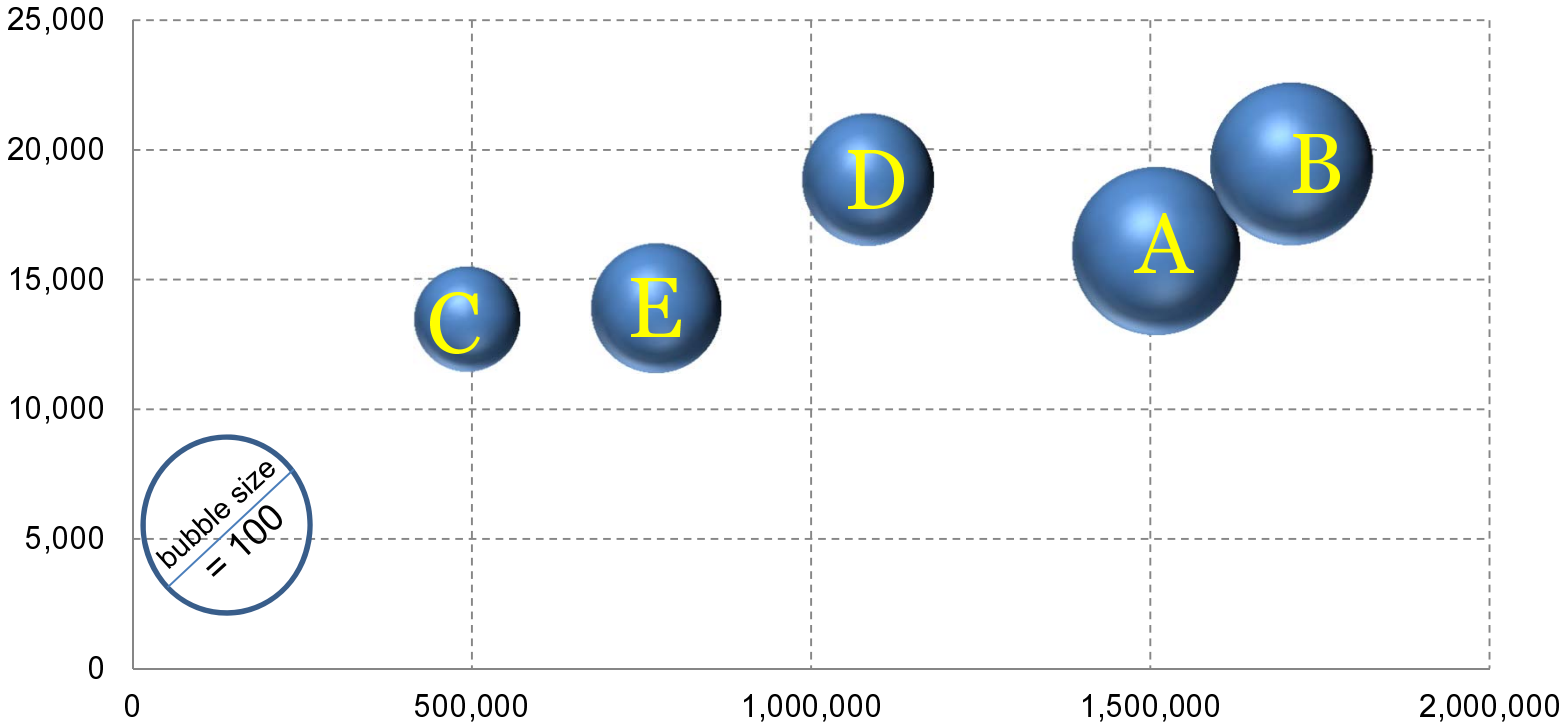
This graph illustrates:



a. Power draw of an educational building that has photovoltaic panels and exterior parking lot lighting.
b. Light levels in a restroom with an occupancy sensor.
c. CO_2 levels in a movie theater.
d. Temperature in a refrigerated warehouse.
e. Power draw of a chiller used for thermal storage.

Mystery Graph 10

This graph illustrates:



a. Cooling capacity in BTU/hr, total condenser fan CFM and the nominal tonnage for a selection of air-cooled chillers.

b. Annual energy use in kBTU, square footage and Energy Usage Intensity (EUI) for five mixed-use buildings within a single portfolio.

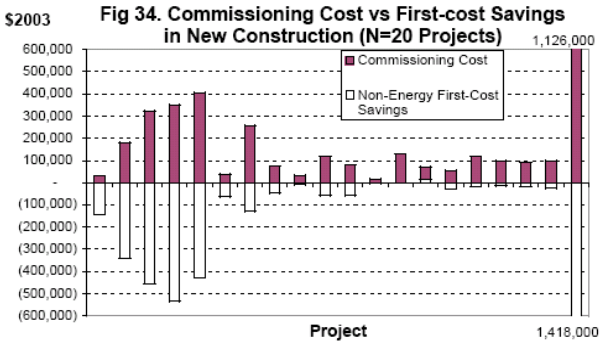
c. Heating capacity in BTU/hr, flow rate at vessel in GPM and the thermal efficiency for a several industrial boilers.

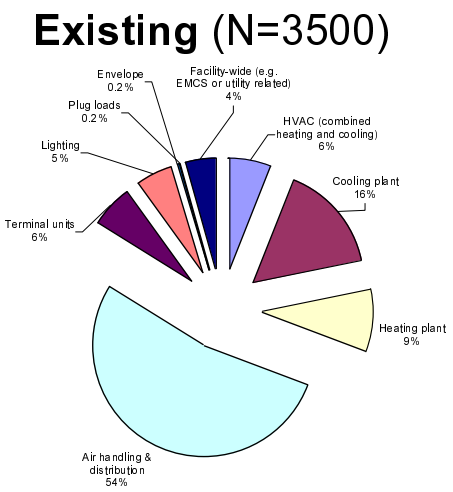
d. Annual energy cost in $, square footage and the Energy Star Portfolio manager score for 5 grocery stores.

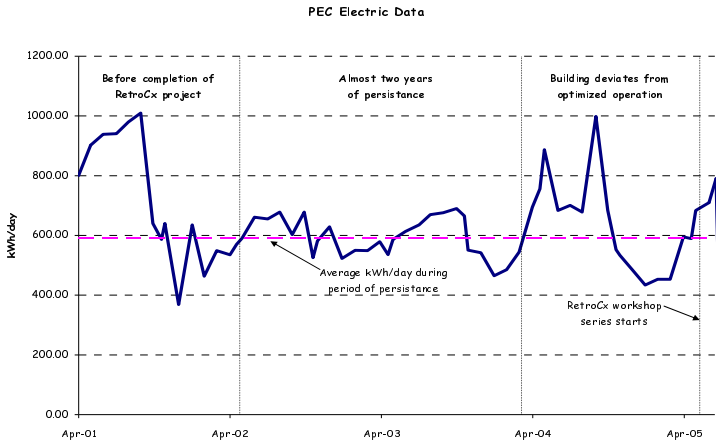
e. Number of people, total cooling load in BTU/hr and the total CFM ventilation requirement for 5 theaters at a multiplex.

The Intention of the Graphic Representation of Data

- Graphs are a means of communication
  - Identify Cx Issues
  - Savings data
- Data visualization helps us think and encourages better decisions
  - Identify correlations between variables
  - “Let the data set change your mind set” - Hans Rosling
- Knowledge compression (more information with fewer bits)
  - One image can represent thousands of data points
  - Annotation and other tools help to highlight specific phenomena







Data Sources

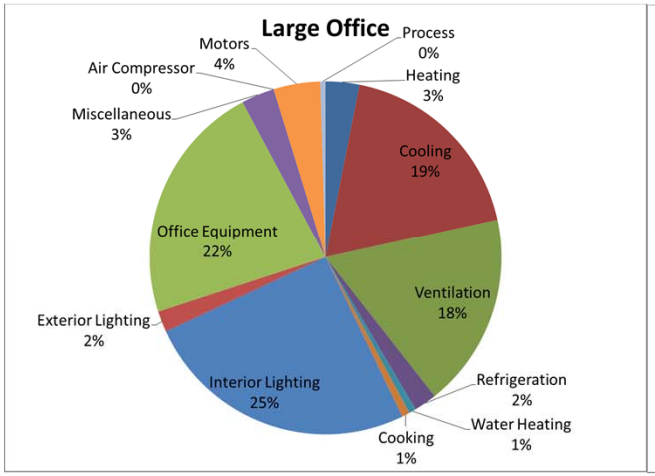
- **Quantitative**
  - Climate stations: air temperature, relative humidity, wind speed, wind direction, solar radiation, precipitation…
  - Utility meters: electrical (kWh), natural gas (therms), water (CCF), steam (BTU), chilled water (BTU)…
  - Energy Management Systems: air pressure & flow, liquid pressure & flow, damper position…
  - Data loggers: surface temperature, amps, volts, power factor, power, CO_2, CO, occupancy, illuminance…
  - Financial: energy costs, energy savings, incentive values, interest rates, implementation costs, sales…
  - Other: hours of operation, square footage, vacancy rates, storage life, capacity, quantity of equipment…
  - Time: year, month, week, day, hour, minute, second…

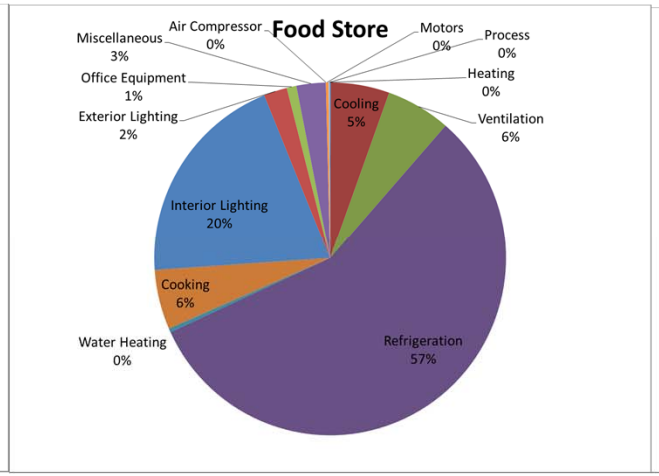
- **Categorical**
  - Building type: office, retail, grocery, restaurant, lodging, warehouse, university, K-12, health care…
  - Location: address, city, state, zip code, climate zone, altitude, latitude, longitude, country…
  - End-use type: space heating, space cooling, water heating, lighting, refrigeration, electronics, ventilation…
  - Fuel type: petroleum, natural gas, coal, nuclear, biomass, hydro-electric, wind, solar, geothermal…
  - Deficiency type: VAV box set-point analysis, air-side economizer, lighting controls, equipment scheduling…
  - Persistence strategy: metering total building energy use, comfort stability reporting, trend data analysis…

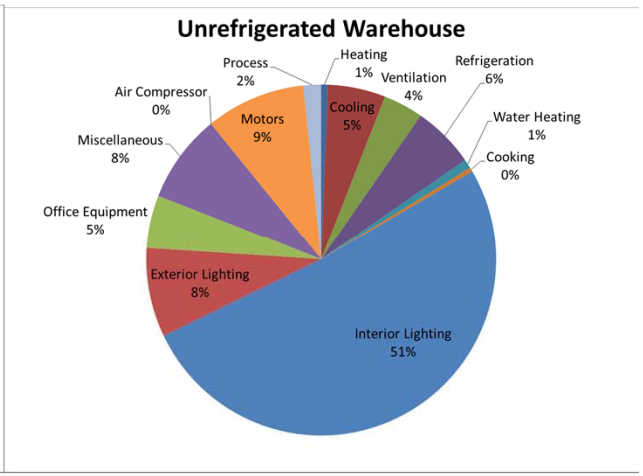
Graph Types and Applications

Pie Chart

- Also known as a Circle graph
- Used to provide percentage breakdown of one categorical variable
- Benefits:
  - Easy to compare relative percentage of categorical variables
  - Simple (may even oversimplify)

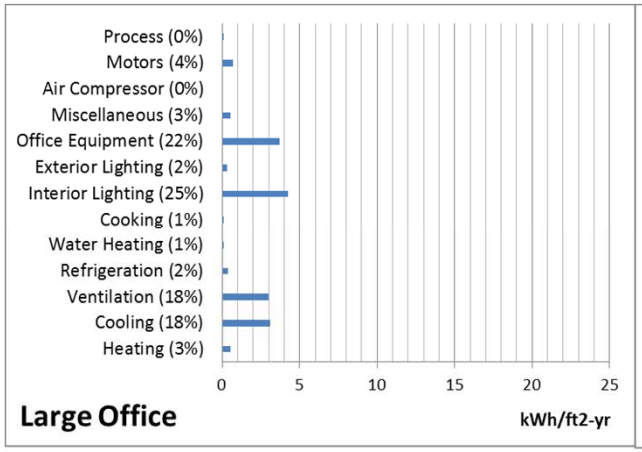


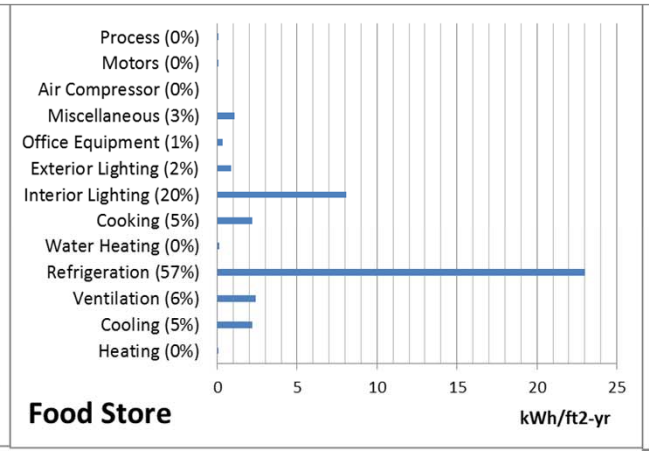


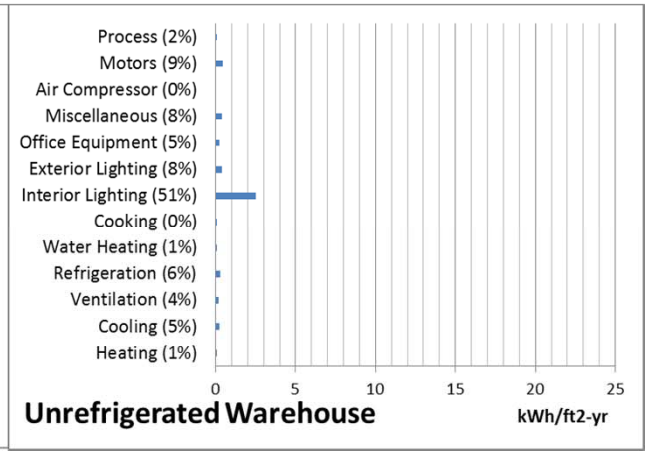


Bar Chart

- Also known as Column Chart
- Used to plot quantitative variables against categorical variables
- Benefits:
  - Easy to compare relative magnitude of categorical variables
  - Preferred by many over Pie chart
  - Can be layered with other quantitative data
  - Bars can be “stacked” (see Gantt chart)
  - Easy to understand

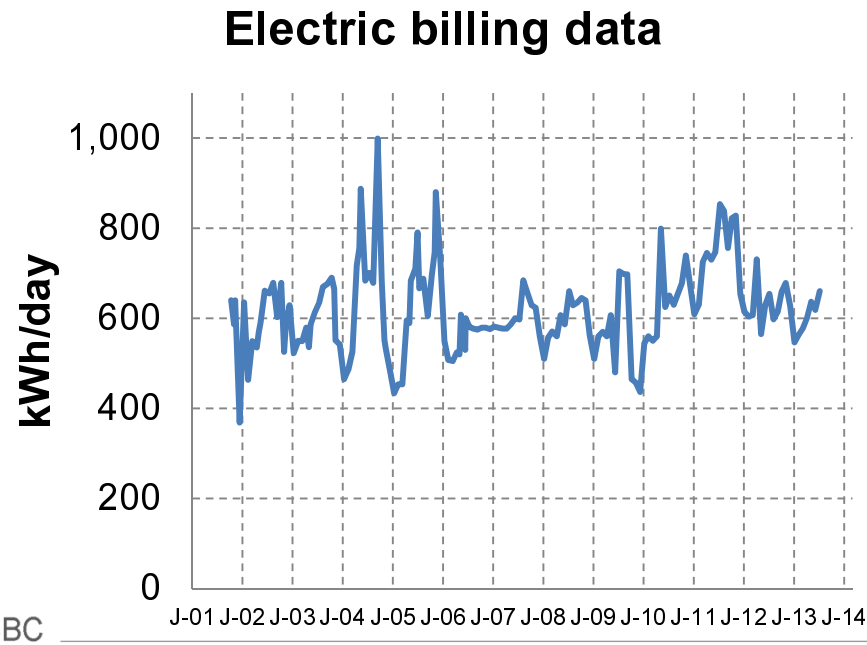


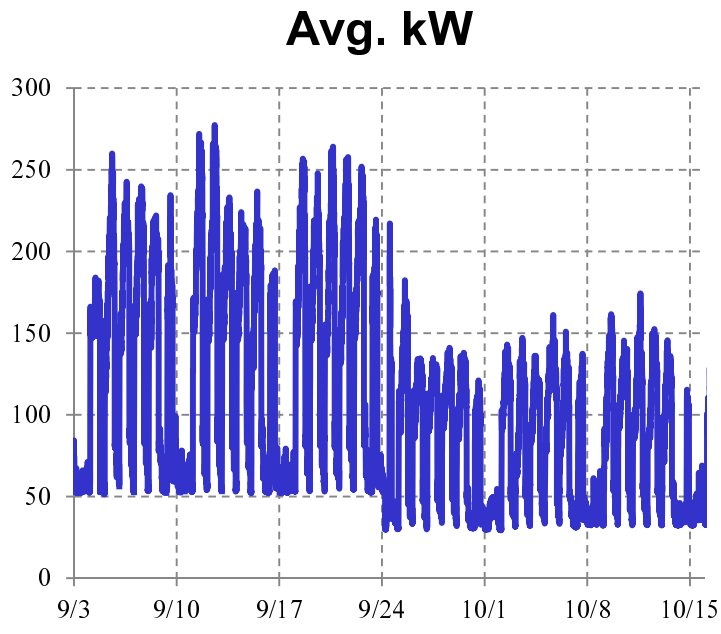




Time Series Chart

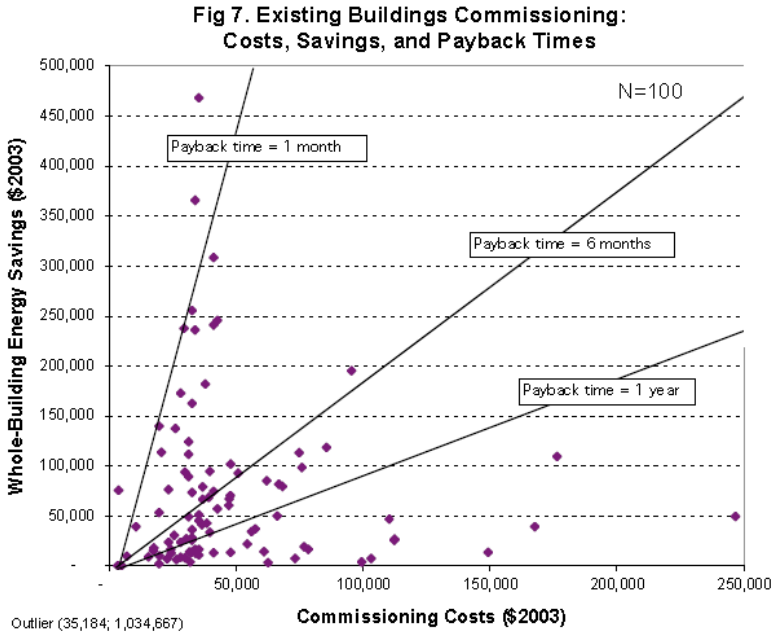
- Also known as Line Chart
- Depicts quantitative variables over time
- Benefits:
  - Easy to visualize variations over time
  - Multiple quantitative variables can be included in chart
  - Familiar

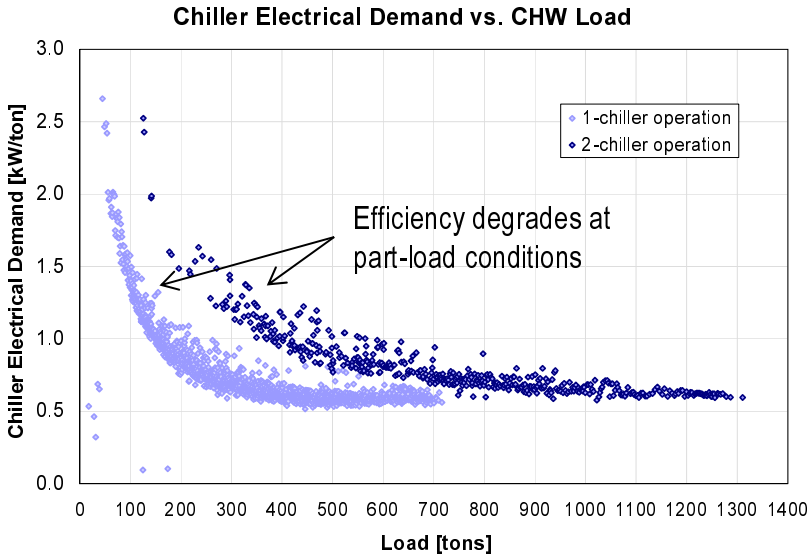




Scatter Plot

- Depicts two quantitative variables
- Time is not a represented variable and data is not depicted chronologically
- Benefits:
  - Easy to see data correlations and develop regressions
  - Can layer on other information that also corresponds to two axis

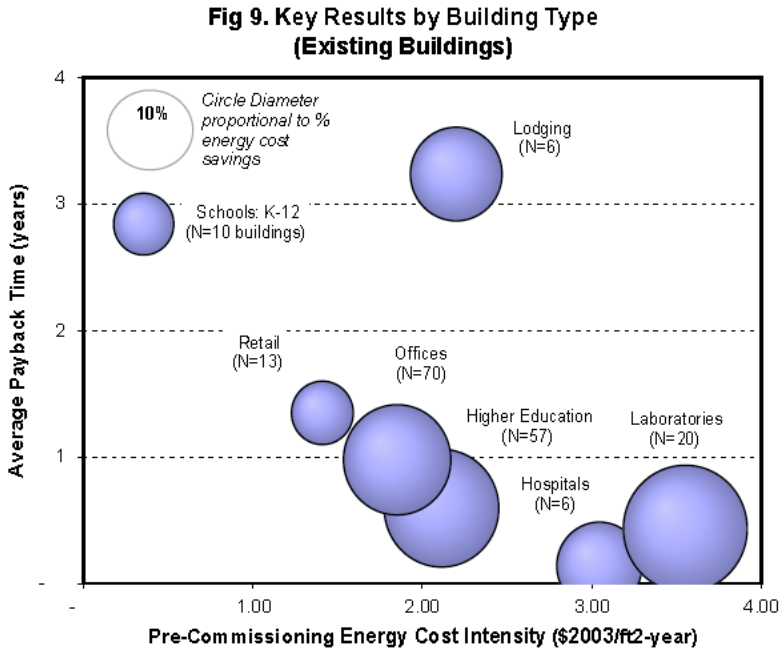




THE COST-EFFECTIVENESS OF COMMERCIAL BUILDINGS COMMISSIONING
Evan Mills, 2004

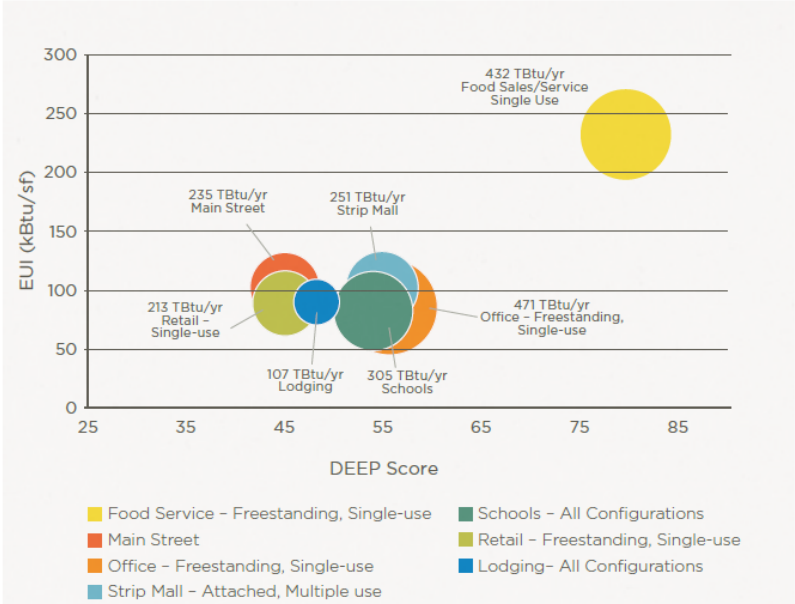
Bubble Chart

- Depicts three quantitative variables
- Enhanced scatter plot with bubble size as third quantitative variable
- Benefits:
  - Allows a third variable to be expressed without introducing third axis
  - Can be compelling if correlations with three variables are consistent



THE COST-EFFECTIVENESS OF COMMERCIAL BUILDINGS COMMISSIONING
Evan Mills, 2004

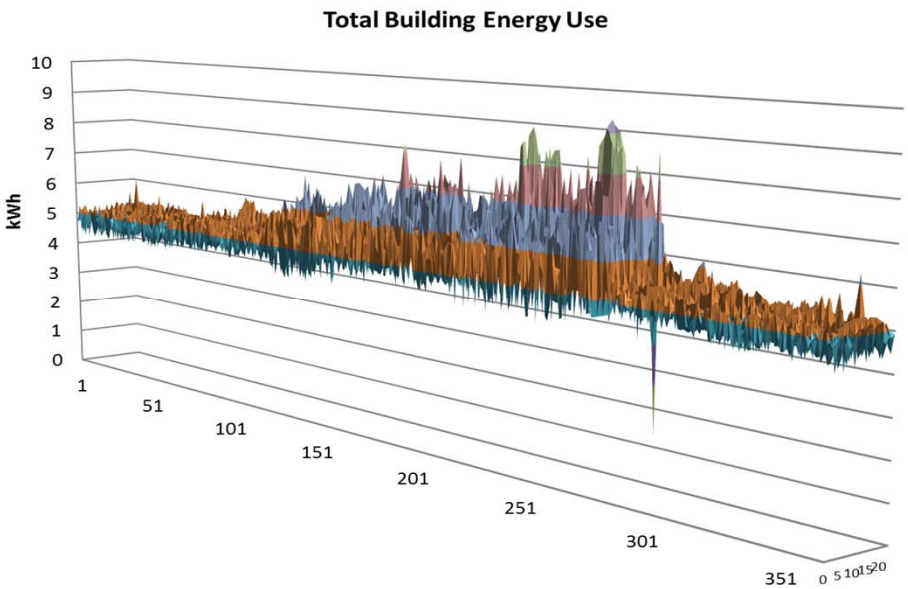
Figure 6: Deep Energy Efficiency Potential (DEEP) Rating for Target Building Types

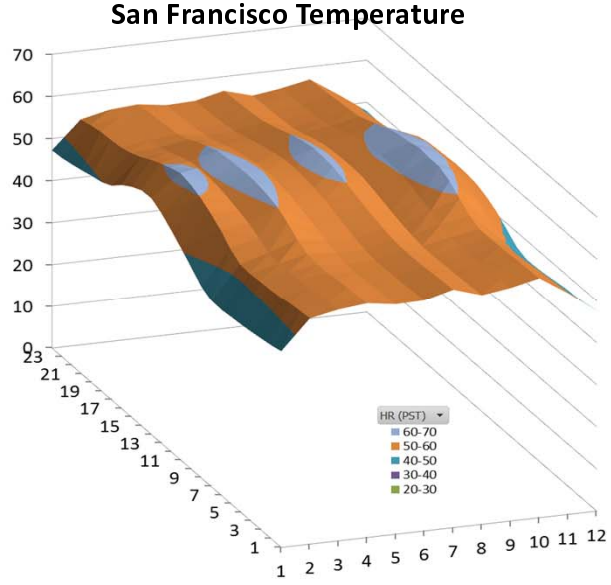


REALIZING THE ENERGY EFFICIENCY POTENTIAL OF SMALL BUILDINGS
New Buildings Institute, 2013

Surface Plot

- Depicts three quantitative variables
- Third quantitative variable plotted on third axis (three-dimensional chart)
- Benefits:
  - Allows a third variable to be expressed
  - Can be compelling if the data warrants the application





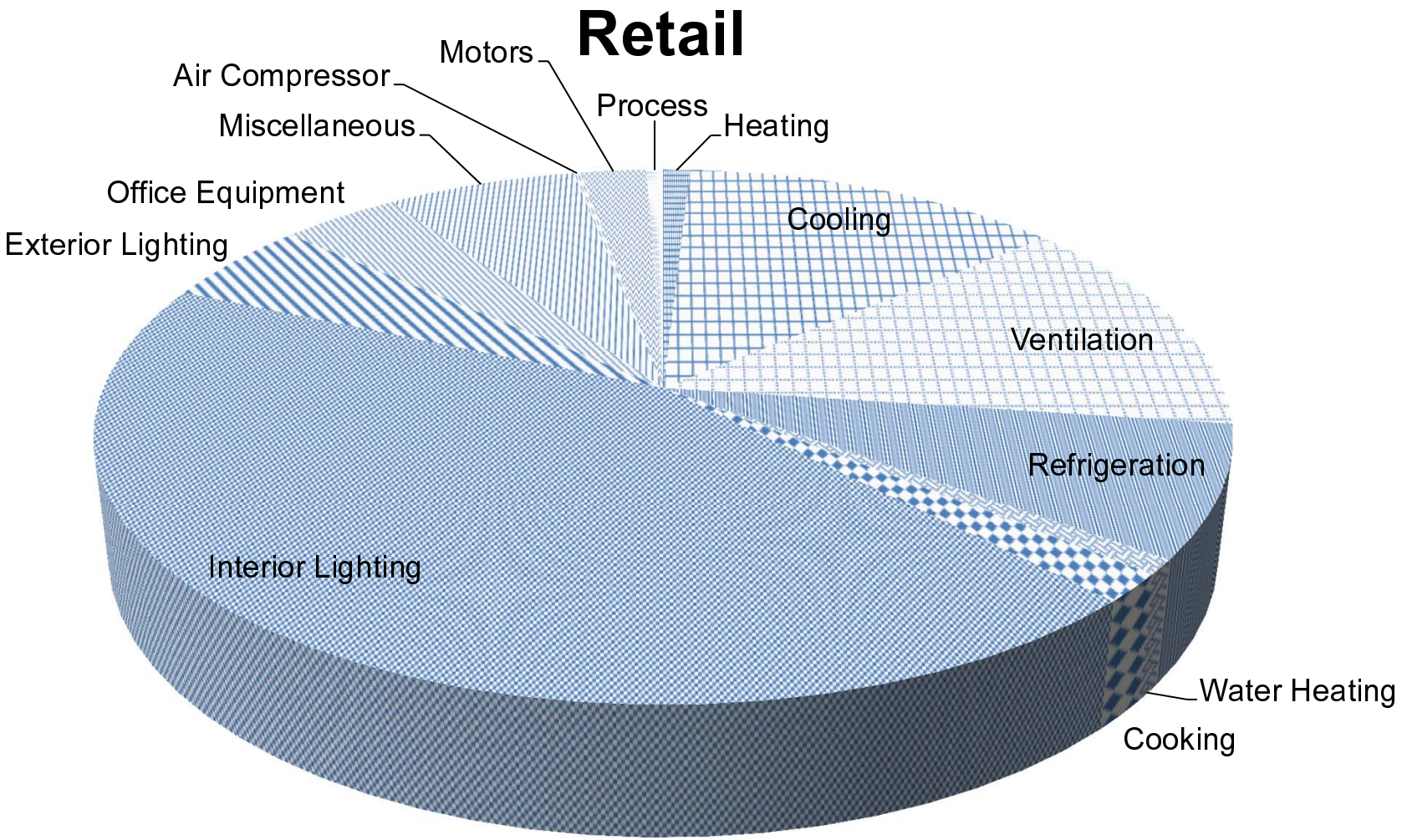
Tabular Data

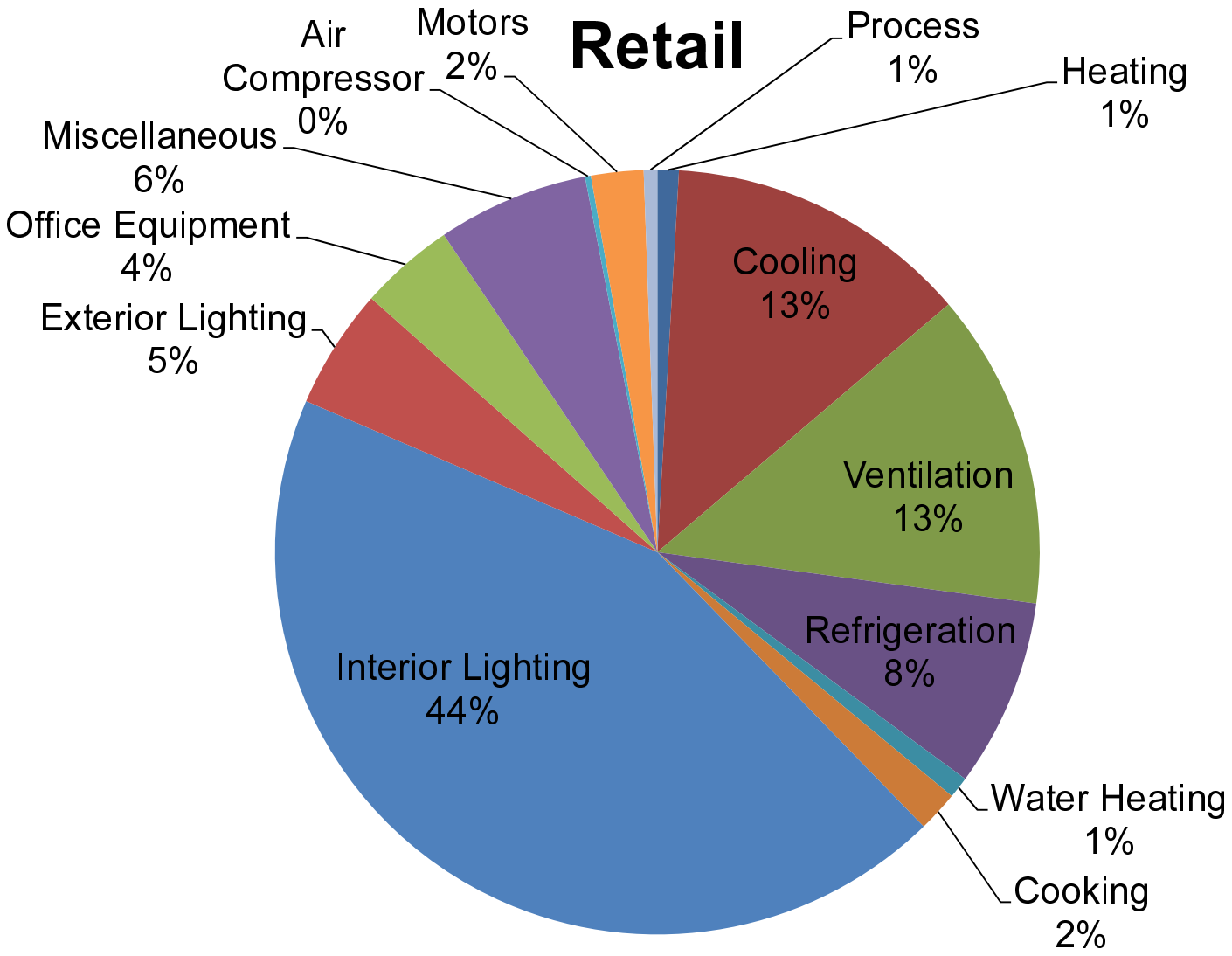
- Depicts many quantitative variables
- Best approach for some data sets
- Benefits:
  - Allows a many variables to be expressed
  - Can be compelling if the data warrants the application

Setpoint Analysis												
Box	% of box score	RESULT Value Score	Lower Value Result	Upper Value Result	% Time Under Lower Setpoint	% Time Over Upper Setpoint	Time Under Lower Setpoint	Time Over Upper Setpoint	Average Value Under Lower Setpoint	Average Value Over Upper Setpoint	Minimum Value	Maximum Value
VAV2-3	18%	2.5	2.5	0	90.9	0.1	63270	45	2.7	2.1	65	79.7
VAV2-5	11%	1.6	1.6	0	64.7	0	45060	0	2.5	0	63	77.9
VAV2-7	10%	1.4	1.4	0	46	0	32055	0	3.1	0	62	75.9
VAV2-3	9%	1.3	1.3	0	47.1	0	32805	0	2.8	0	64	73
VAV2-1	9%	1.3	1.3	0	47.8	0	33285	0	2.7	0	63	74.8
VAV1-3	9%	1.2	1.2	0	65.4	0	45285	0	1.8	0	66	72
VAV1-5	7%	1	1	0	42.9	0	29745	0	2.3	0	66	77.5
VAV2-6	7%	1	1	0	39.9	0	27765	0	2.4	0	66	78.4
VAV2-2	6%	0.9	0.9	0	39.9	0	27765	0	2.2	0	65	78.9
VAV1-6	4%	0.5	0.1	0.4	6.5	20.9	4530	14550	1.8	2	64.5	80.3
VAV1-4	3%	0.4	0.4	0	15.2	0	10560	0	2.6	0	67	74
VAV1-8	3%	0.4	0.3	0	17.7	2.7	12300	1860	1.9	1	65	76.2
VAV1-2	2%	0.3	0.3	0	19.2	0.1	13320	60	1.6	1	68	78.5
VAV1-1	1%	0.2	0.2	0	13.2	0	9120	15	1.9	0.5	69	78.2
VAV1-7	1%	0.1	0.1	0	6	2.5	4185	1710	1.6	1.1	66	79.4

Graphic Excellence

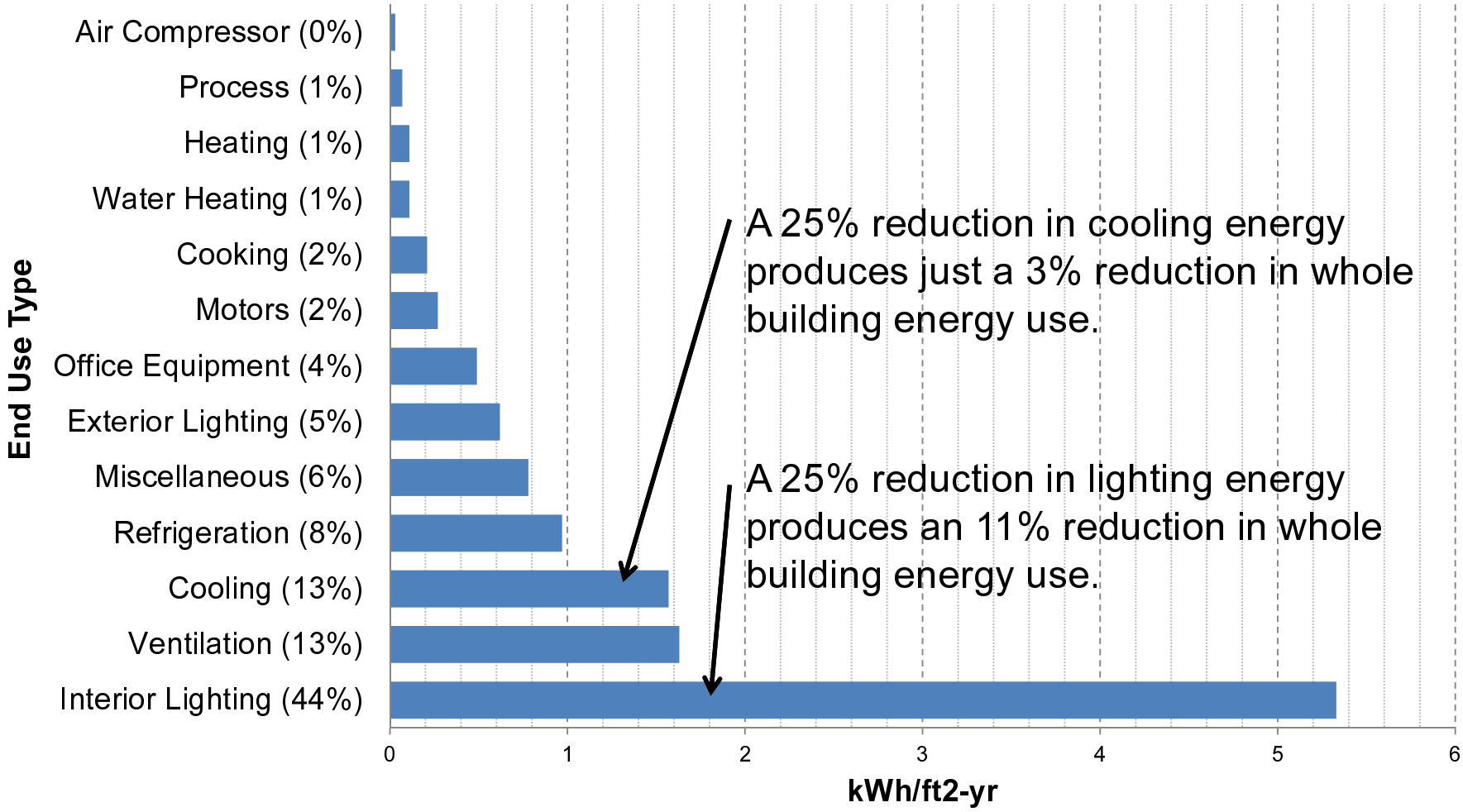
Spot the Graph Issues #1





CALIFORNIA COMMERCIAL END-USE SURVEY, March 2003, PG&E Data, pg. 188

Retail



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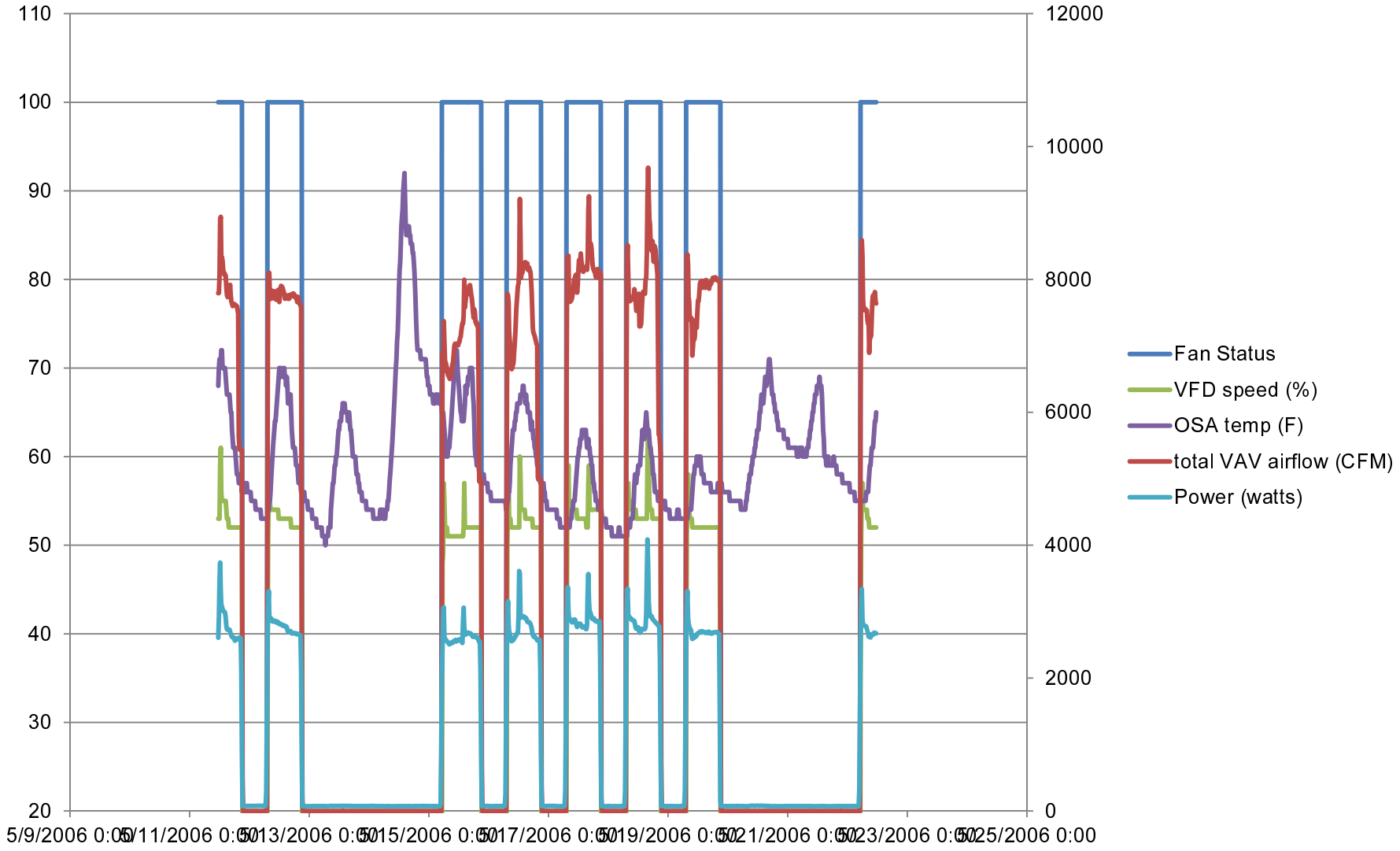
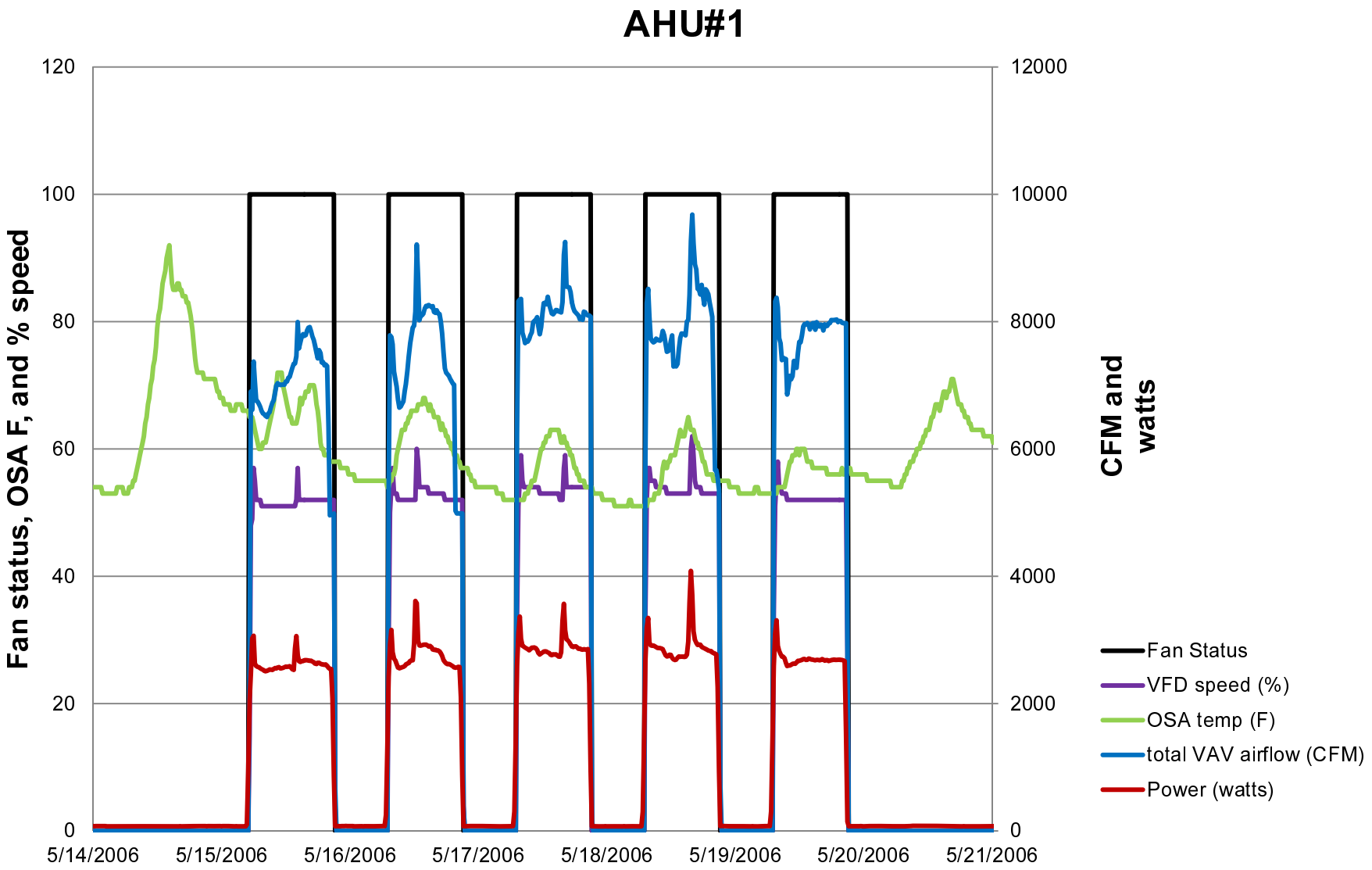
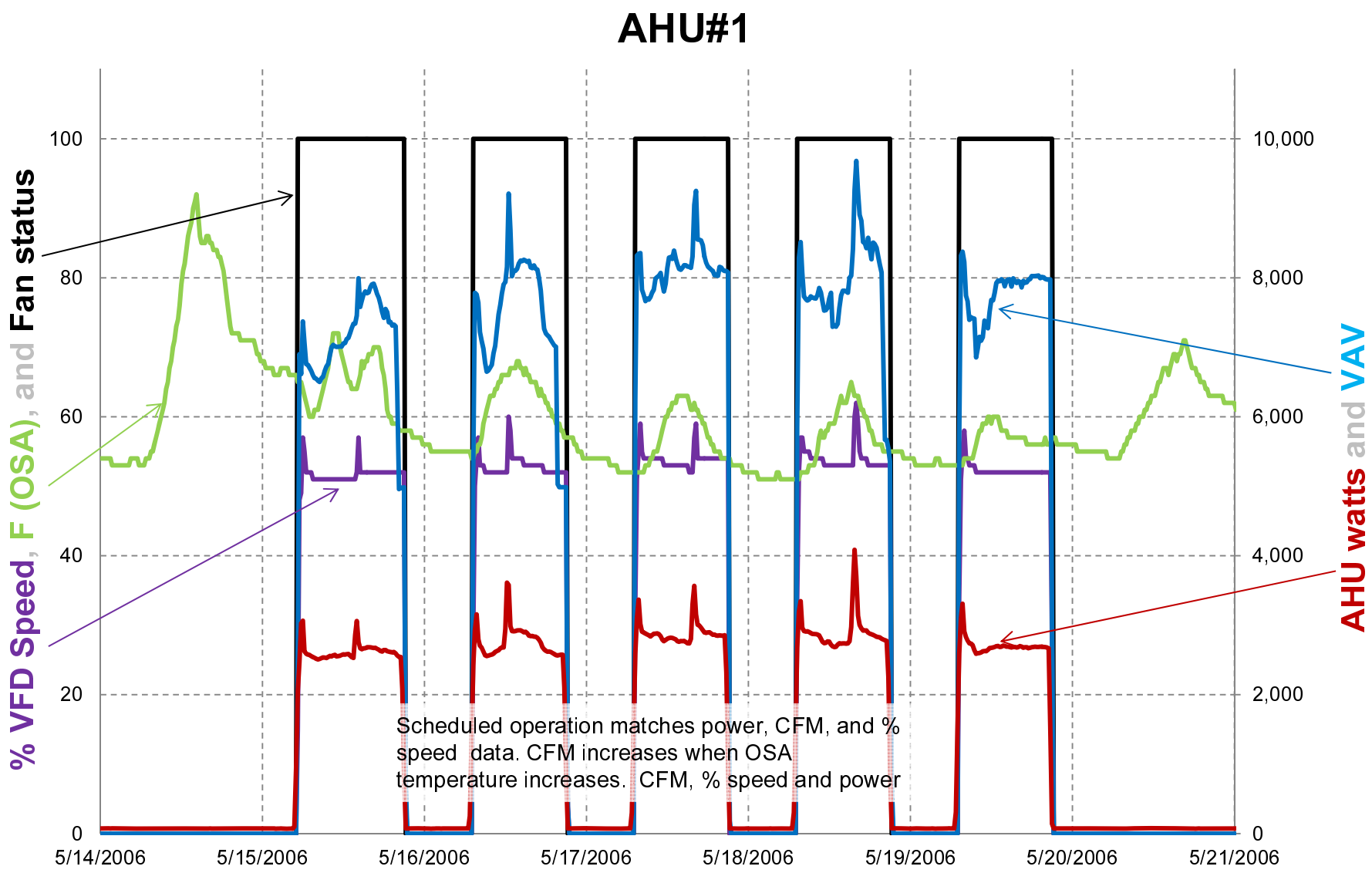
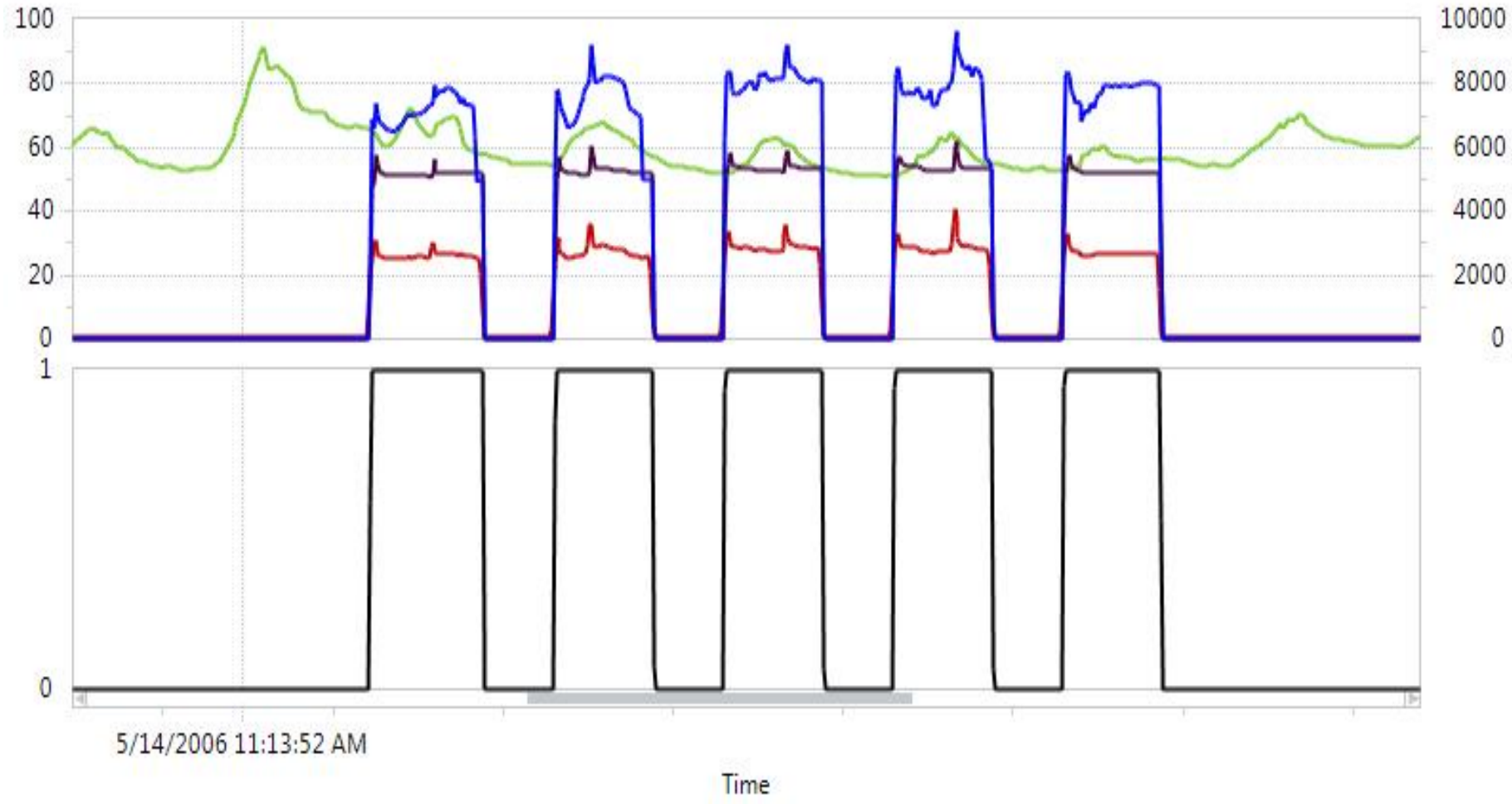
Spot the Graph Issues #2




AHU#1
Fan status, OSA F, and % speed
CFM and watts
120
100
80
60
40
20
0
12000
10000
8000
6000
4000
2000
0
5/14/2006
5/15/2006
5/16/2006
5/17/2006
5/18/2006
5/19/2006
5/20/2006
5/21/2006
Fan Status
VFD speed (%)
OSA temp (F)
total VAV airflow (CFM)
Power (watts)


AHU#1
% VFD Speed, F (OSA), and Fan status
AHU watts and VAV
100
80
60
40
20
0
10,000
8,000
6,000
4,000
2,000
0
5/14/2006
5/15/2006
5/16/2006
5/17/2006
5/18/2006
5/19/2006
5/20/2006
5/21/2006
Scheduled operation matches power, CFM, and % speed data. CFM increases when OSA temperature increases. CFM, % speed and power

Graph Output from UT Software



Use Pre-attentive Attributes

Exercise: count all the fives in the following string of numbers:

80123219484330589997761638344092969120944615788393236339524232366360198433444671059226283489086225893034995710332105261099112682126719279447773600760076080427298708029026792847592494601388717226228769442758085

Use Pre-attentive Attributes

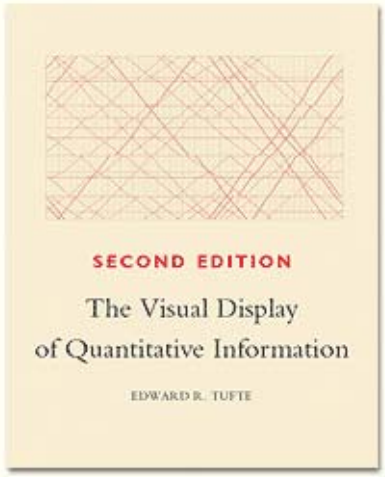
Exercise: count all the fives in the following string of numbers:

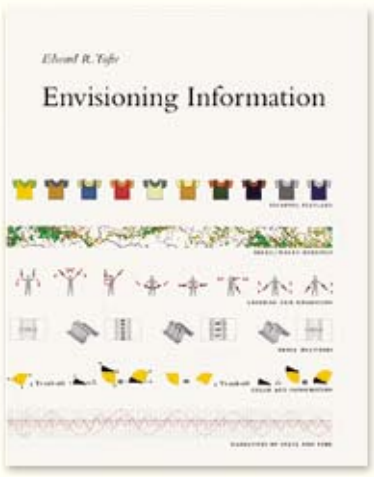
8012321948433058999776163834409296912094461578839323
6339524232366360198433444671059226283489086225893034
99571033210526109911268212671927944773600760076080 4
27298708029026792847592494601388717226228769442758 08

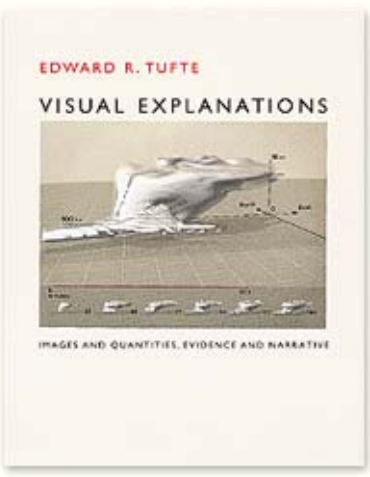
The point: Pre-attentive processing occurs below the level of consciousness at an extremely high speed. When utilized, the audience is able to decipher data more quickly than when this device is not utilized.
- from “Show Me the Numbers” by Stephen Few.

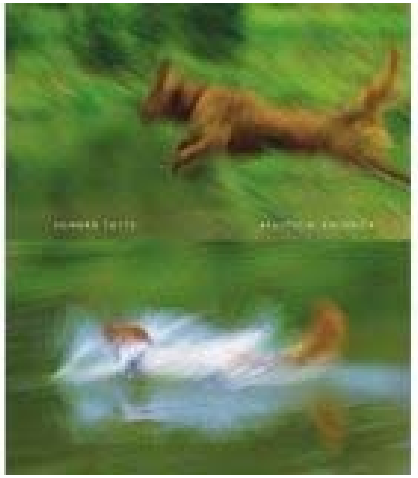
Ed Tufte's Principles of Graphical Excellence

- Graphical Excellence is the well-designed presentation of interesting data… a matter of *substance*, *statistics* and *design.*
- Graphical Excellence consists of complex ideas communicated with clarity, precision and efficiency.
- Graphical Excellence is that which gives to the viewer the greatest number of ideas in the shortest time with the least ink in the smallest space.
- Graphical Excellence is nearly always multivariate.
- Graphical Excellence requires telling the truth about data.









Do’s and Don'ts of Graphic Representation

- **Do’s**
  - when time is a quantitative variable; always **place** it along horizontal axis
  - **include** the 0-axis on all graphs and **use** this to distinguish positive and negative values.
  - **orient** charts horizontally and **maximize** the chart area on the page.
  - **apply** annotations to your graphs that identify the variables and explain the results.
  - **configure** annotations and labels so they are oriented consistently.
  - to facilitate comparisons, **order** data in a hierarchical order when using bar charts
  - **utilize** multiple graph panes and axis to separate objects in a crowded chart.
  - **correlate** color of data to axis label when using multiple vertical axis
  - **consider** that tabular data may be appropriate for some situations

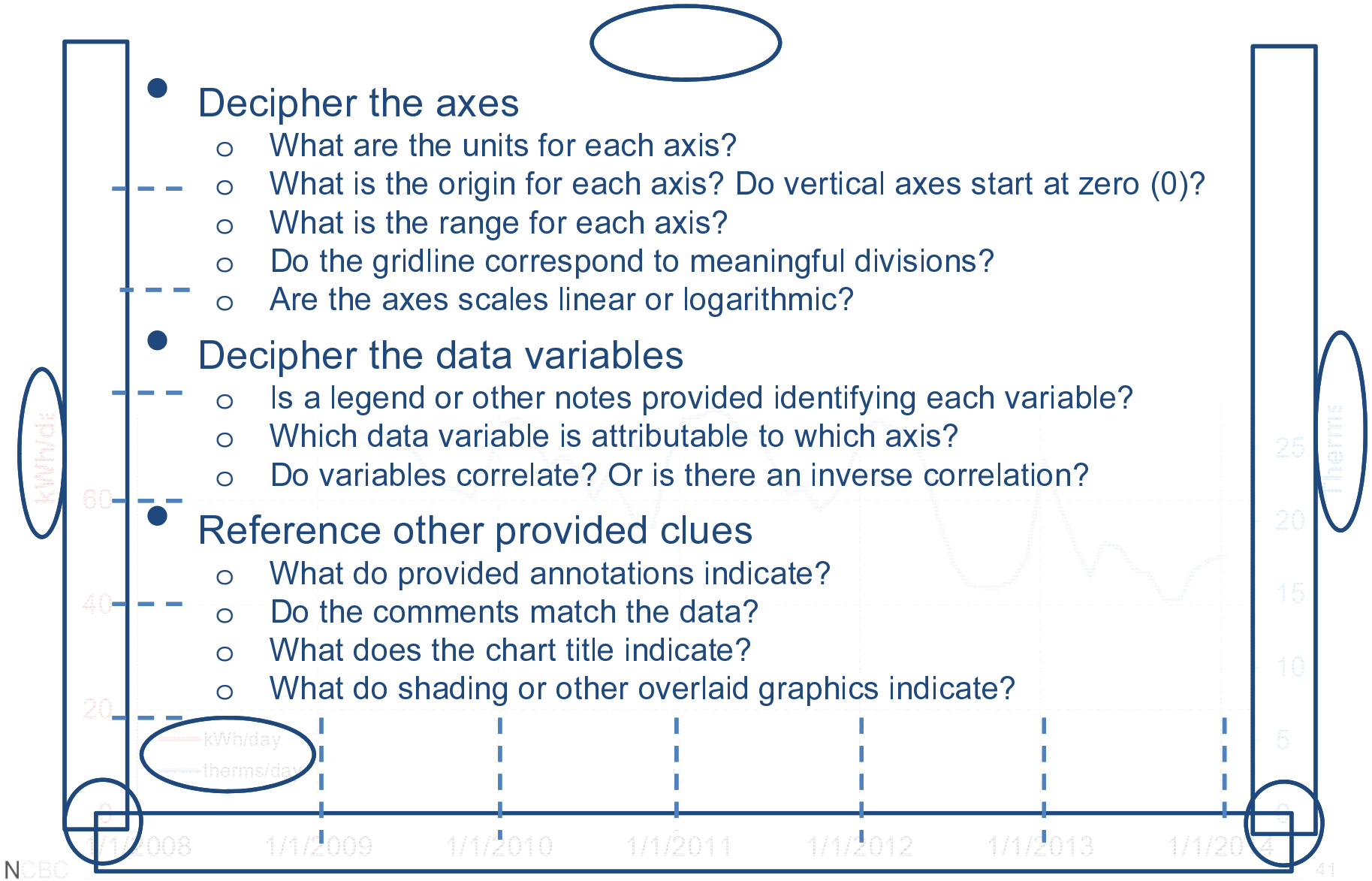
- **Don’ts**
  - avoid using chart junk including fill patterns, shading, heavy grid lines and borders
  - avoid 3-D graphic representations of data; this approach is rarely helpful.
  - avoid using red and green colors together in a single chart.
  - eliminate the legend if possible.
  - do not compromise the ability to interpret data with an overwhelming amount of text

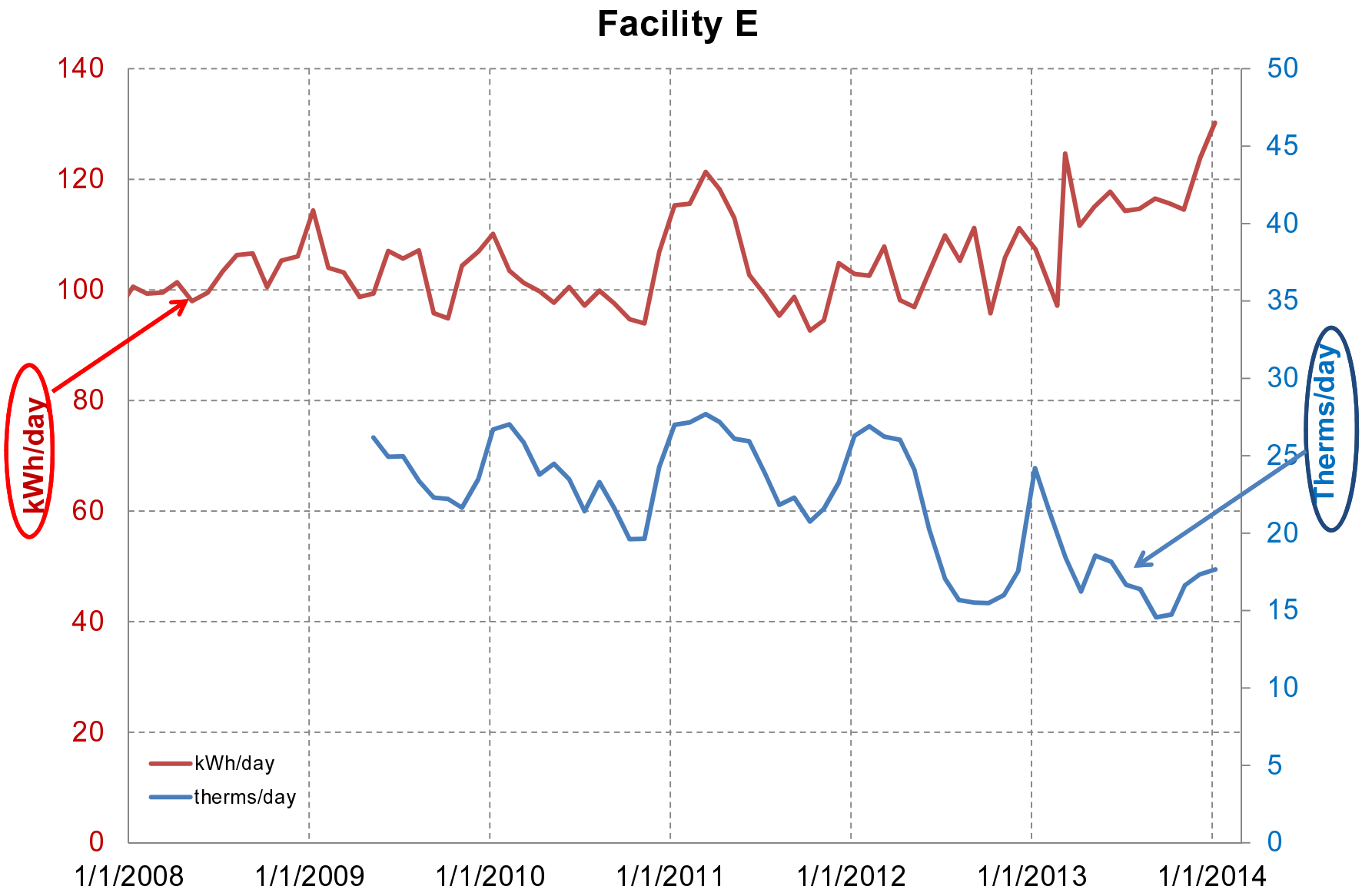
Graph Interpretation Clues


The Sky is Blue

A Cynic's List of What to Look for When Deciphering Graphs

- Decipher the axes
  - What are the units for each axis?
  - What is the origin for each axis? Do vertical axes start at zero (0)?
  - What is the range for each axis?
  - Do the gridline correspond to meaningful divisions?
  - Are the axes scales linear or logarithmic?
- Decipher the data variables
  - Is a legend or other notes provided identifying each variable?
  - Which data variable is attributable to which axis?
  - Do variables correlate? Or is there an inverse correlation?
- Reference other provided clues
  - What do provided annotations indicate?
  - Do the comments match the data?
  - What does the chart title indicate?
  - What do shading or other overlaid graphics indicate?

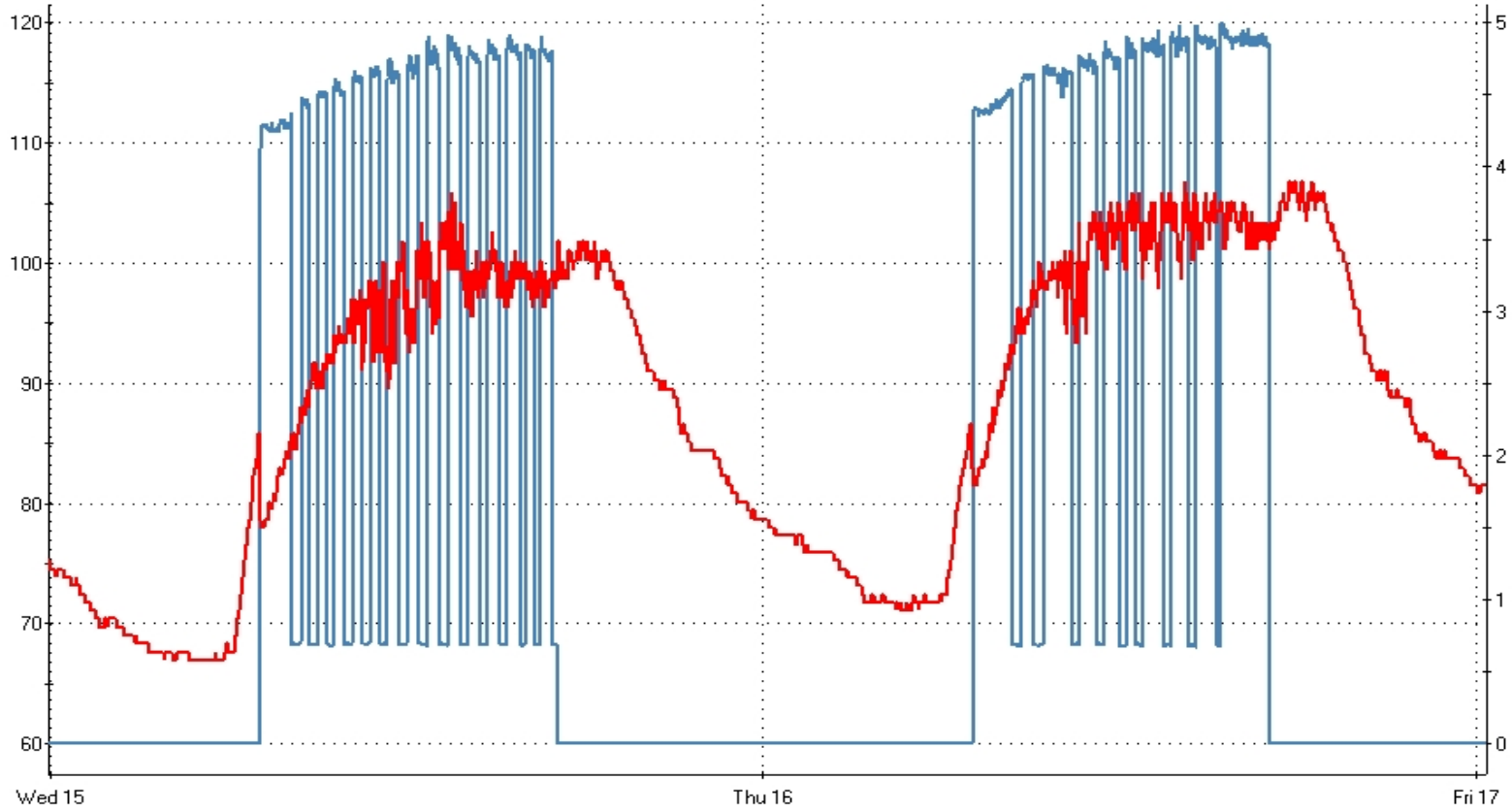



Facility E
140
120
100
80
60
40
20
0
50
45
40
35
30
25
20
15
10
5
0
kWh/day
Therms/day
kWh/day
therms/day
1/1/2008
1/1/2009
1/1/2010
1/1/2011
1/1/2012
1/1/2013
1/1/2014

Mystery Graphs Answers

Mystery Graph 1

This graph illustrates:



a. Leaving boiler temperature (L) and pump amps (R) for a boiler loop used for space heating

b. Exterior illuminance (L) and interior illuminance (R) in klux for a warehouse with skylights.

c. Outside air temperature (L) and power draw (R) for a packaged unit with a single-stage of cooling.

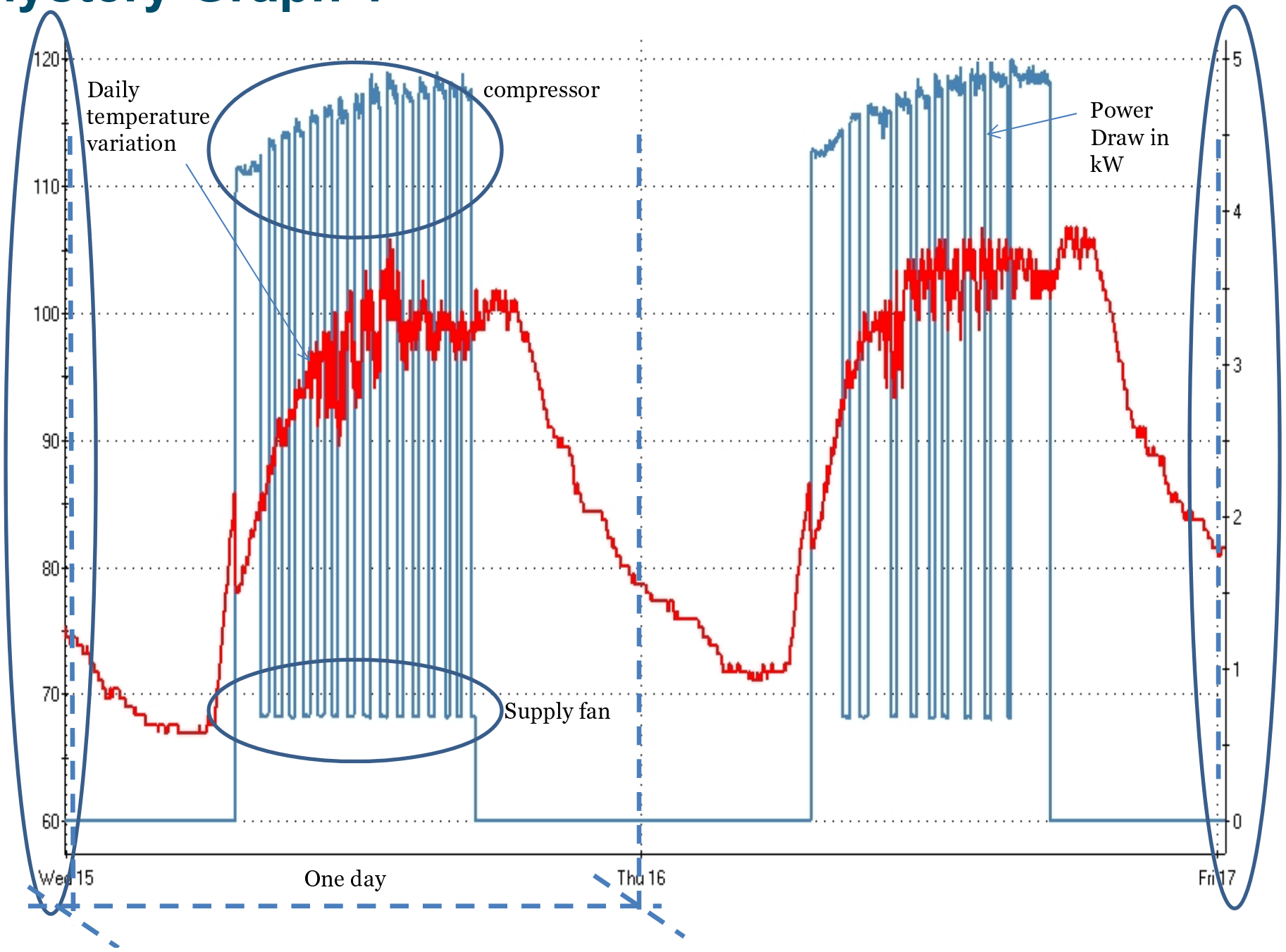
d. CO2 levels (L) and amps for the lighting systems (R) at a movie theater.

e. % load (L) and amps (R) for a motor used for ventilating a restroom in an airport terminal.

(L) = variable references left axis

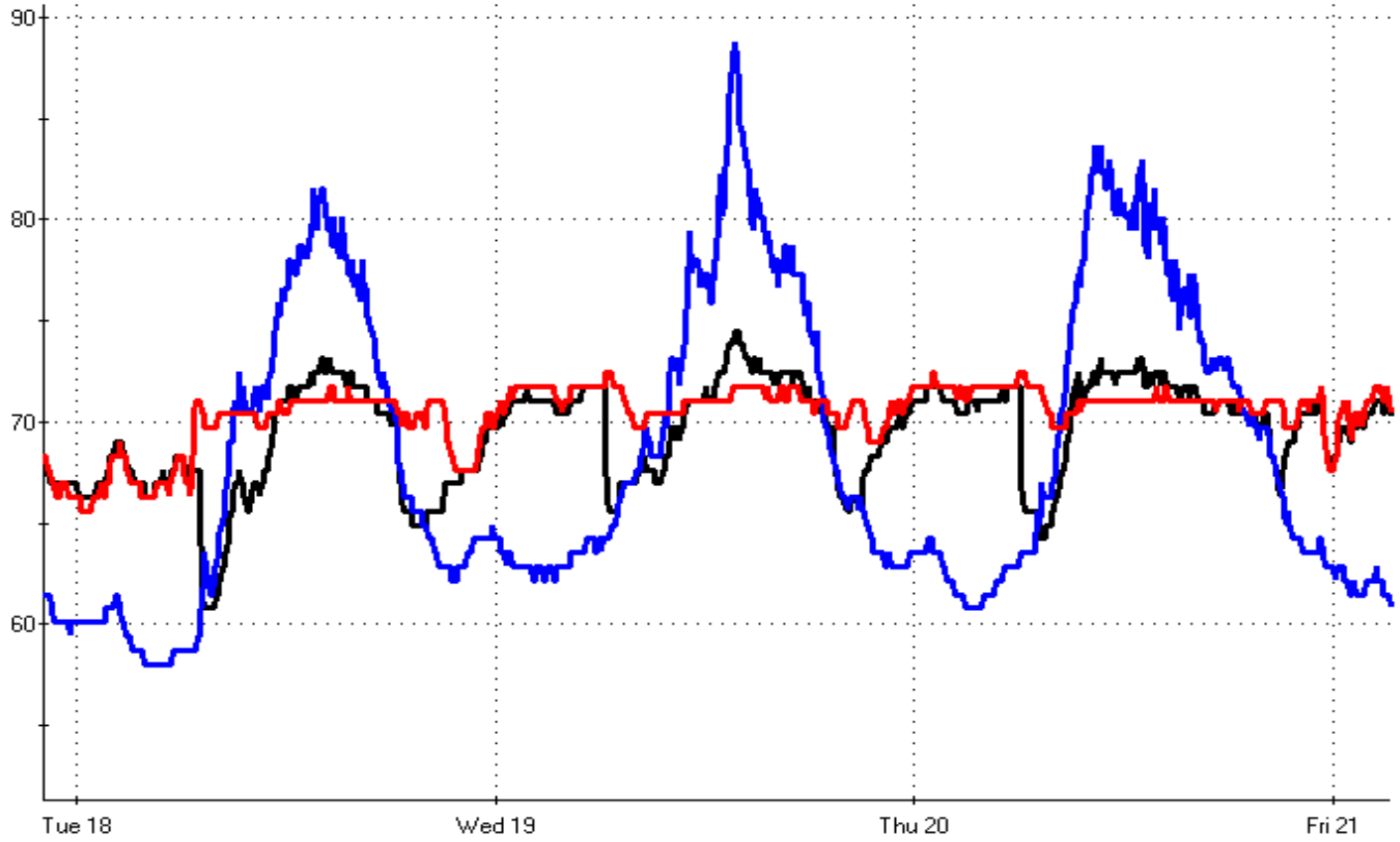
(R) = variable references right axis

Mystery Graph 1



Mystery Graph 2

The three variables illustrated in the graph depicted here are?



a. daily electricity, natural gas and water use.

b. outside air, mixed air and return air temperatures at an air handler with a working economizer

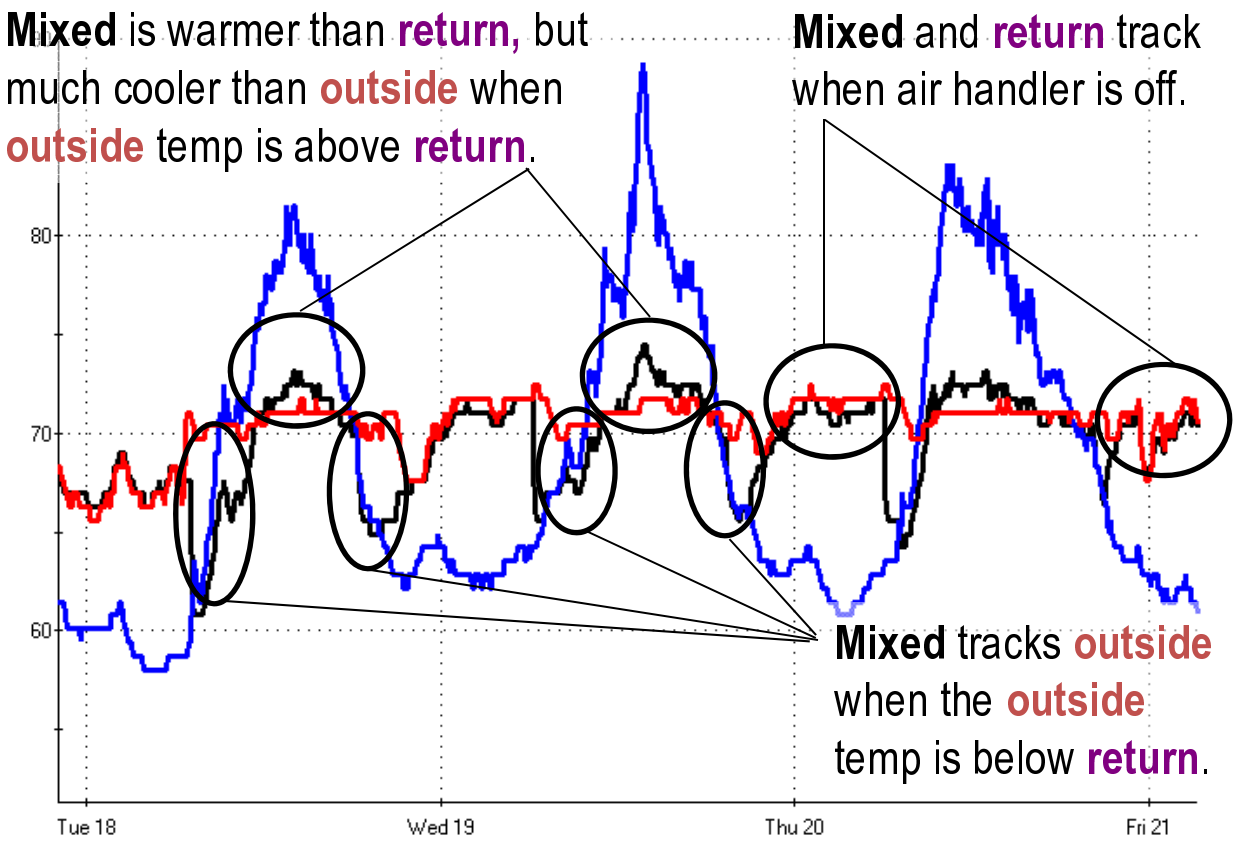
c. space temperature, air flow and damper position for a working VAV box.

d. temperature, relative humidity and dew point of an air volume.

e. chilled water flow, chilled water supply temperature and condenser water supply temperature for an optimized chiller.

Mystery Graph 2

The three variables illustrated in the graph depicted here are?



a. daily electricity, natural gas and water use.

b. outside air, mixed air and return air temperatures at an air handler with a working economizer

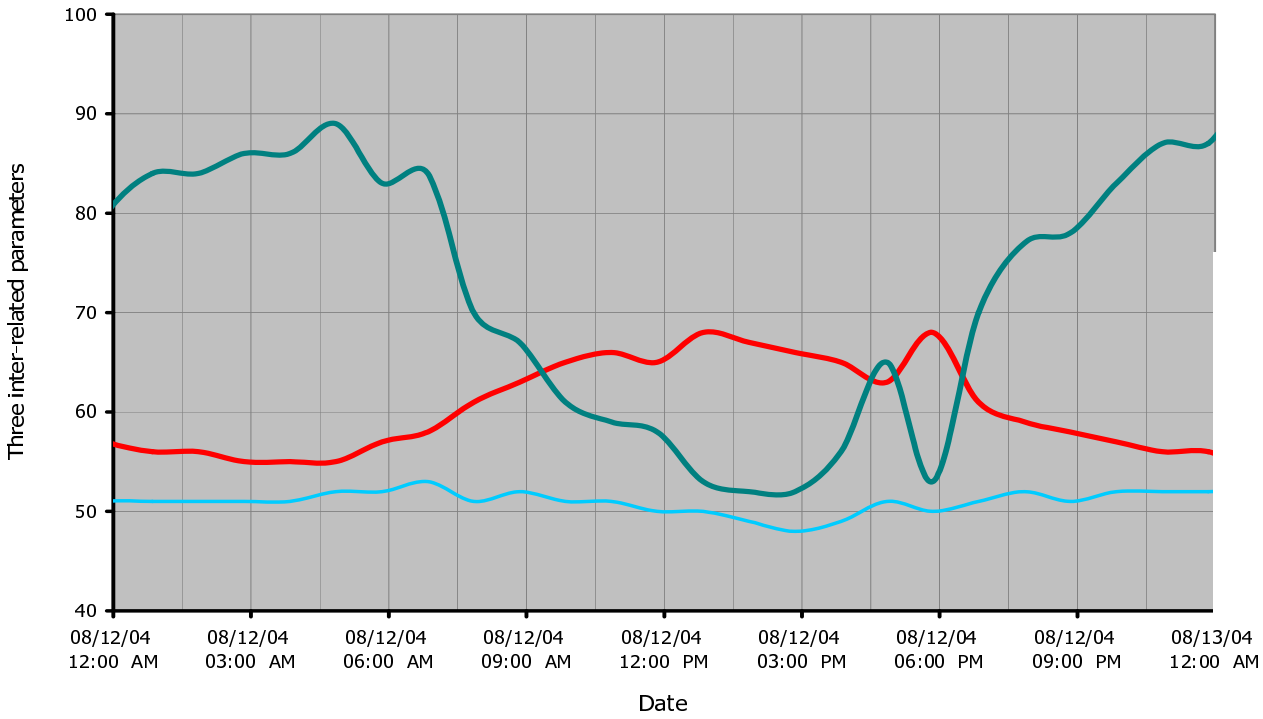
c. space temperature, air flow and damper position for a working VAV box.

d. temperature, relative humidity and dew point of an air volume.

e. chilled water flow, chilled water supply temperature and condenser water supply temperature for an optimized chiller.

Mystery Graph 3

This graph illustrates:



a. Voltage, amperage and power factor for a server room.

b. space temperature, air flow and damper position for a working VAV box.

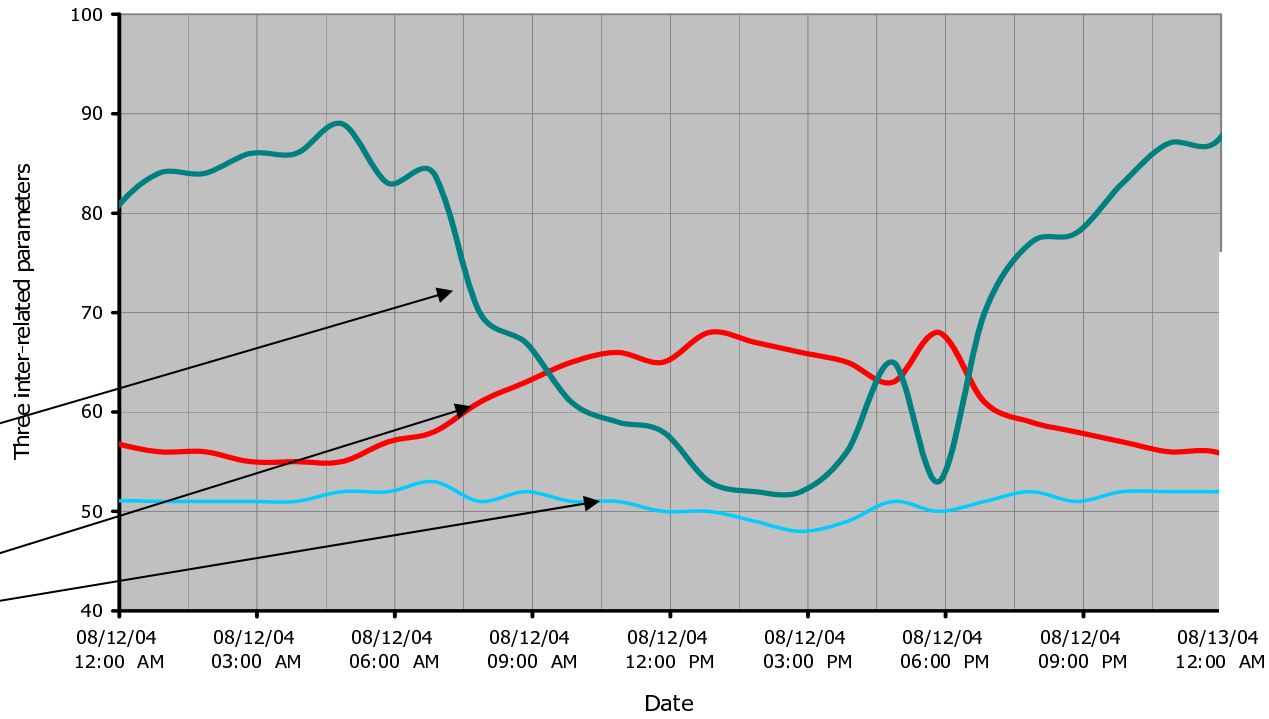
c. outside air, mixed air and return air temperatures at an air handler with an economizer

d. Temperature, relative humidity and dew point of an air volume

e. chilled water flow, chilled water supply temperature and condenser water supply temperature for an optimized chiller.

Mystery Graph 3

This graph illustrates:

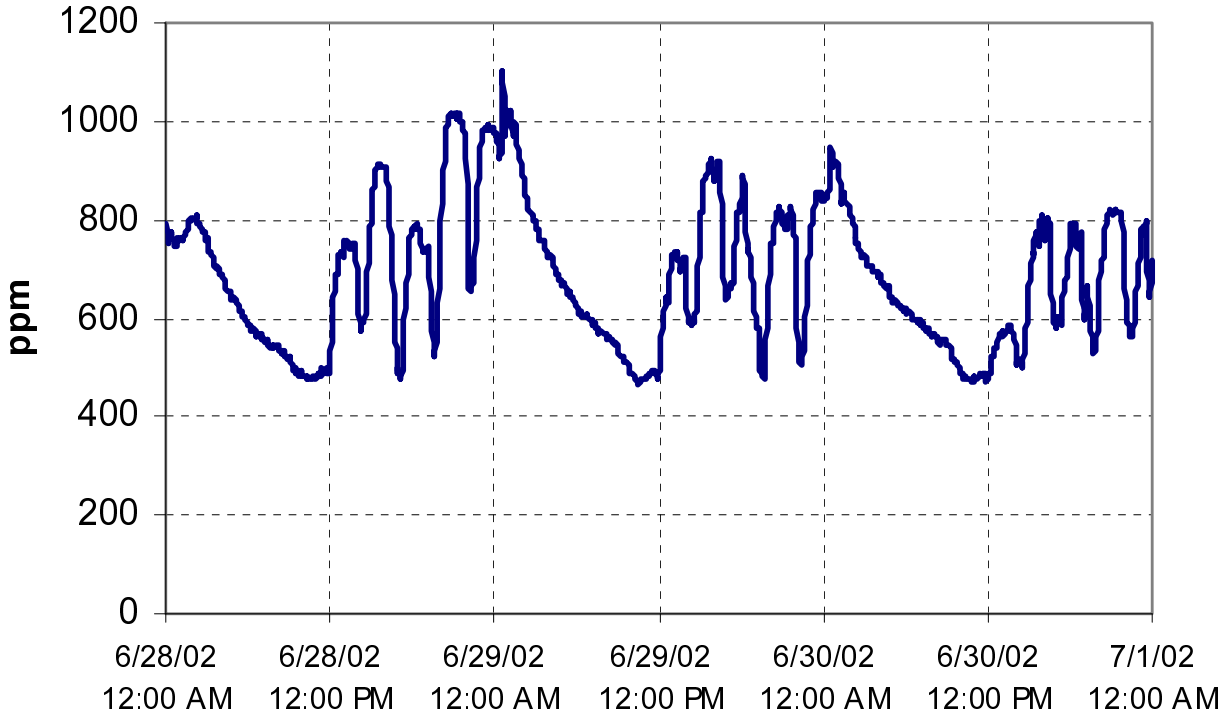


RH drops as temperature rises and dew point stays relatively constant

a. Voltage, amperage and power factor for a server room.
b. space temperature, air flow and damper position for a working VAV box.
c. outside air, mixed air and return air temperatures at an air handler with an economizer
d. Temperature, relative humidity and dew point of an air volume
e. chilled water flow, chilled water supply temperature and condenser water supply temperature for an optimized chiller.

Mystery Graph 4

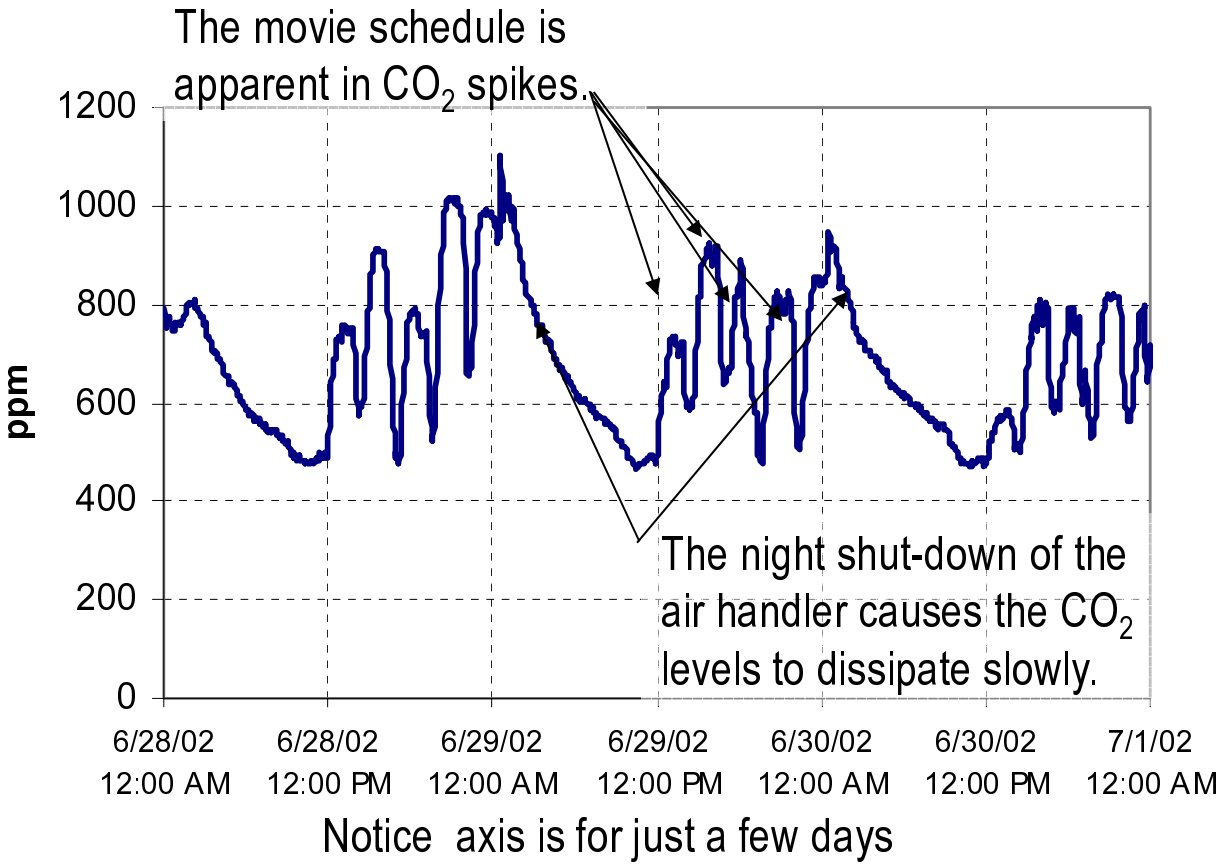
The data shown to the right is an indication of which condition?



a. Total dissolved solids in condenser water for a cooling tower.
b. Volatile organic compounds (VOC) levels during construction of an office building.
c. CO levels in a parking garage.
d. CO_2 levels in the open office area of a law office.
e. CO_2 levels in a movie theater.

Mystery Graph 4

The data shown to the right is an indication of which condition?



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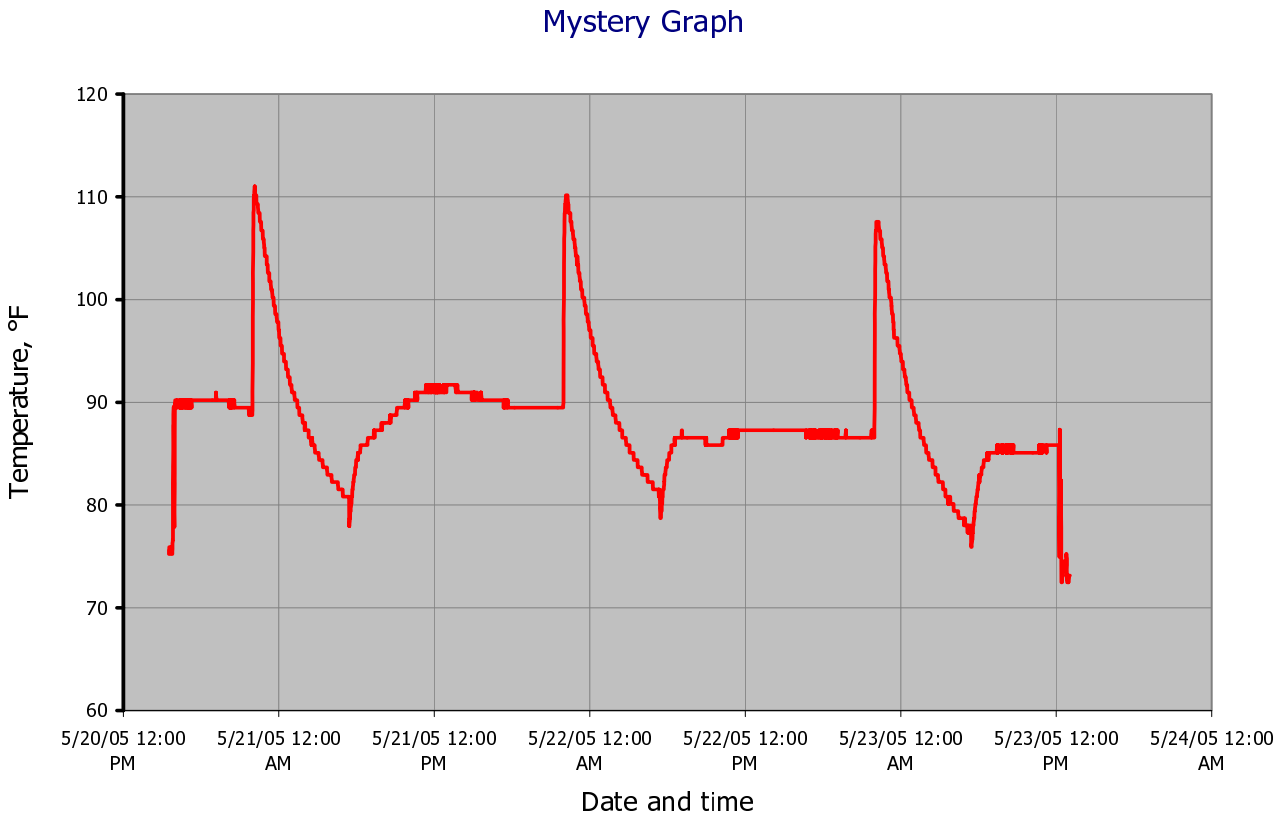
c. CO levels in a parking garage.
d. CO_2 levels in the open office area of a law office.
e. CO_2 levels in a movie theater.

Mystery Graph 5

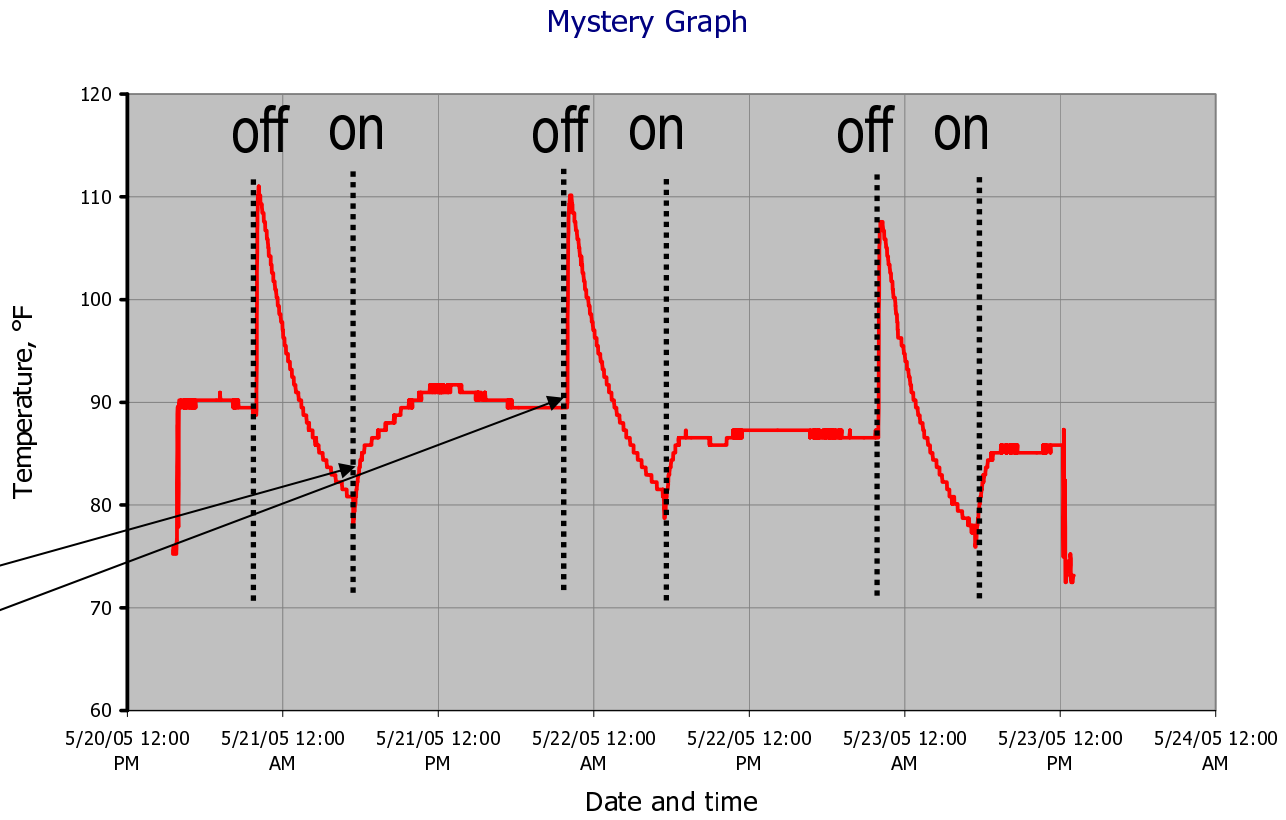
This graph illustrates:



a. light levels from daylight in a library.
b. run time data for a light fixture
c. Space temperature in an unconditioned warehouse.
d. the scheduled operation of a motor
e. flue temperature for a non-condensing heating hot water boiler.

Mystery Graph 5

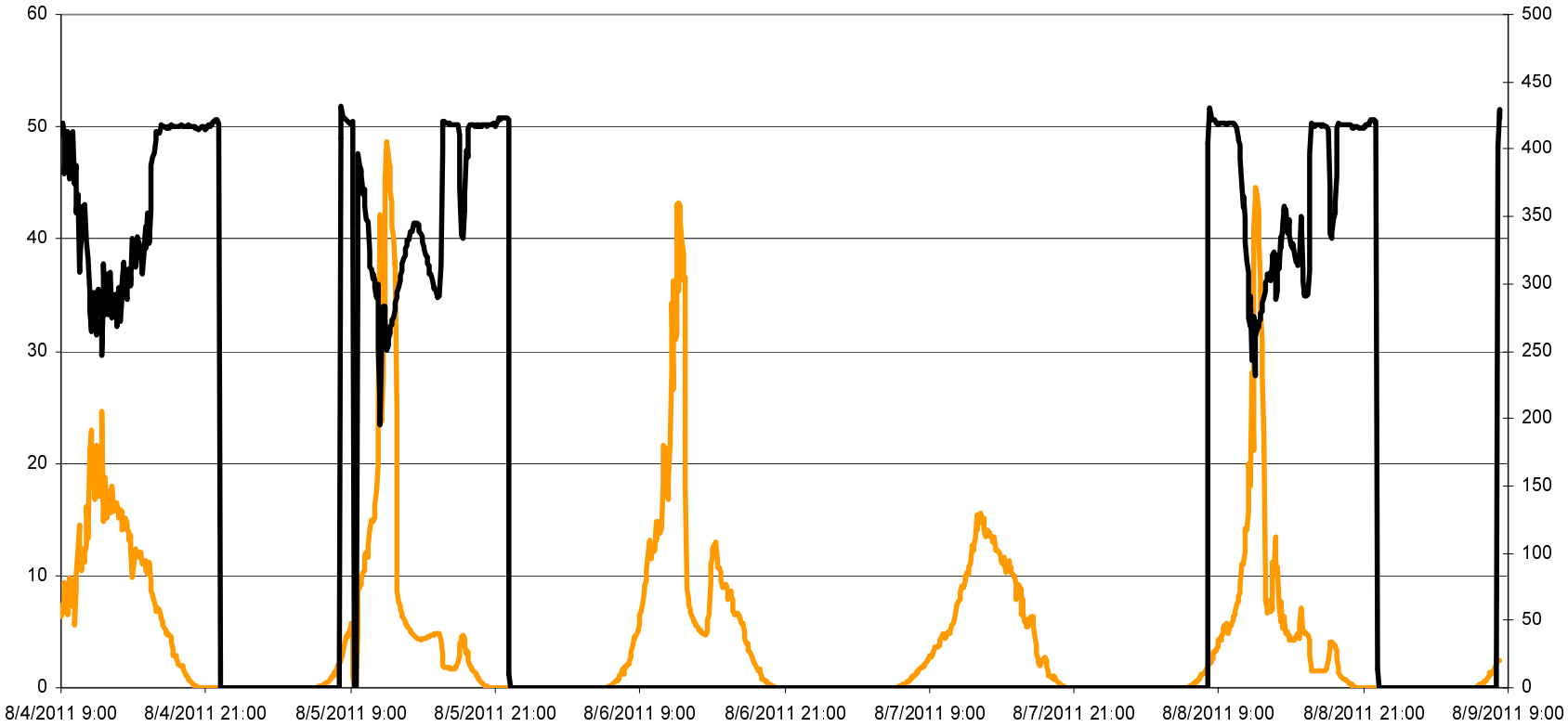
This graph illustrates:



Motor heats up at start up. Motor temp spikes when it shuts down as fan is no longer running.

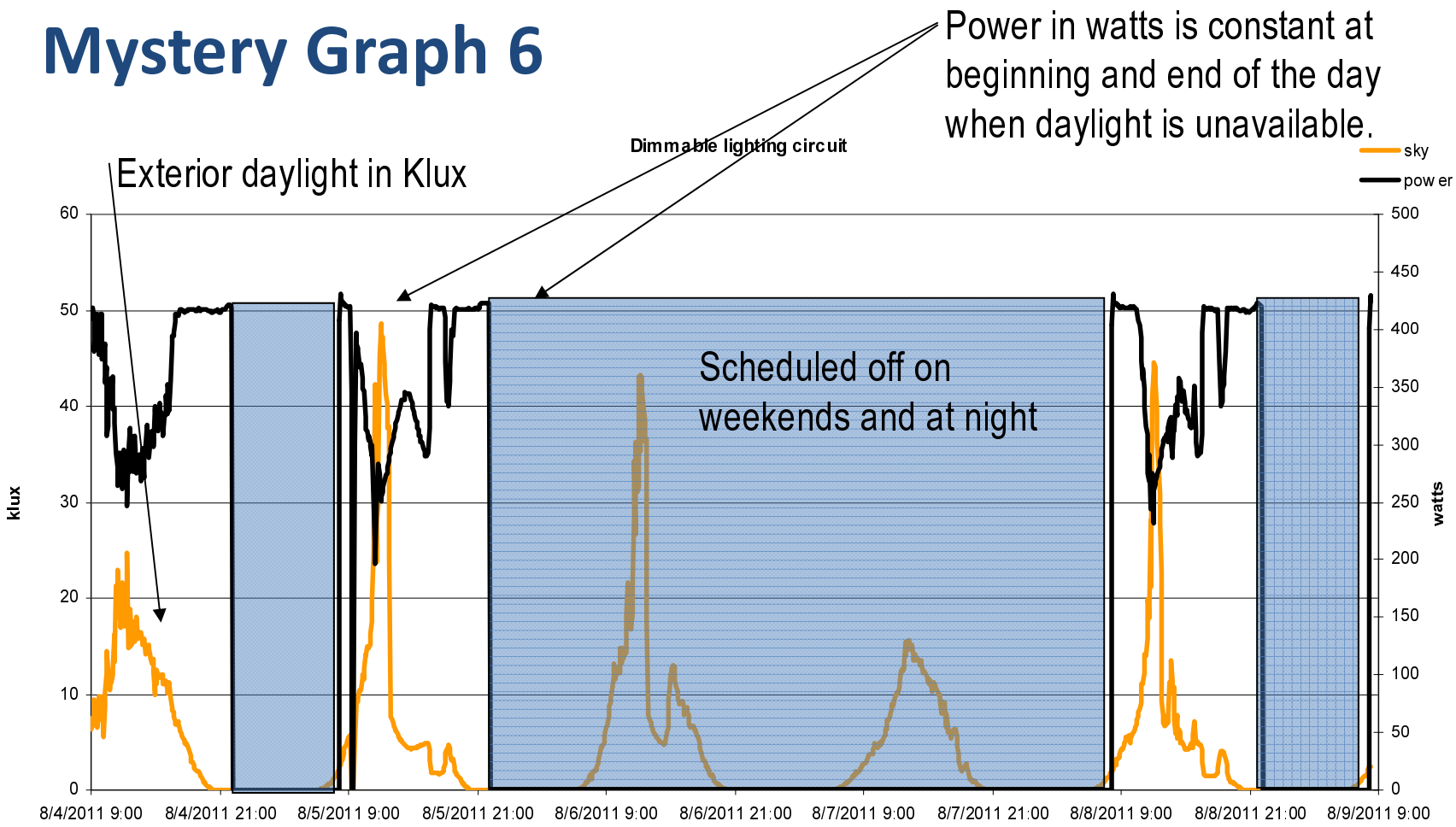
a. light levels from daylight in a library.
b. run time data for a light fixture
c. Space temperature in an unconditioned warehouse.
d. the scheduled operation of a motor
e. flue temperature for a non-condensing heating hot water boiler.

Mystery Graph 6



a. Temperature and humidity data for a lab.
b. Occupancy and light data for an office.
c. Temperature and therm use for a boiler on a schedule control at a warehouse.
d. Wattage and exterior daylight levels for corridor lights controlled by both a photo-sensor and schedule.
e. Zone temperature and air flow for a VAV box serving a classroom.

Mystery Graph 6



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b. Occupancy and light data for an office.

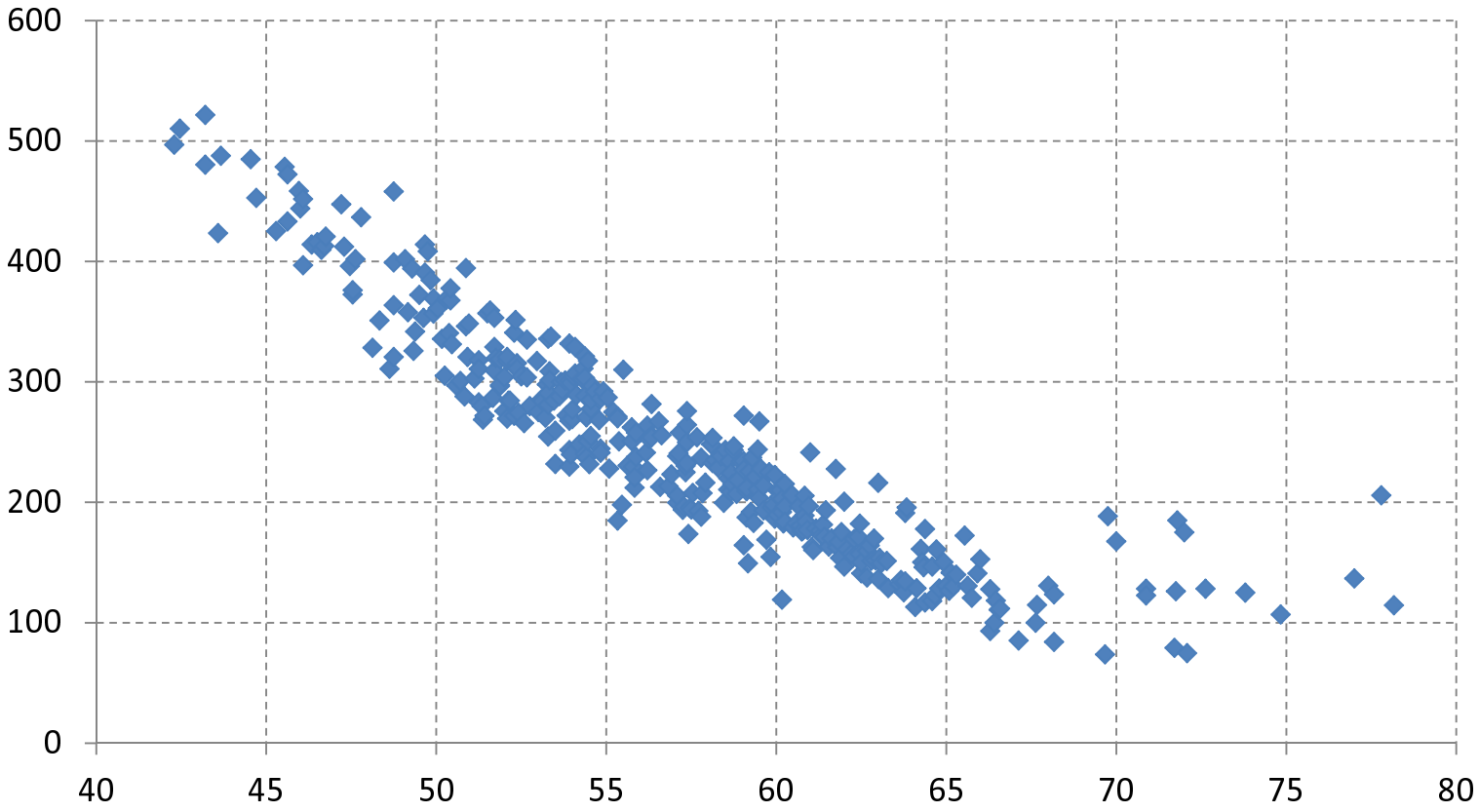
c. Temperature and therm use for a boiler on a schedule control at a warehouse.

d. Wattage and exterior daylight levels for corridor lights controlled by both a photo-sensor and schedule.

e. Zone temperature and air flow for a VAV box serving a classroom.

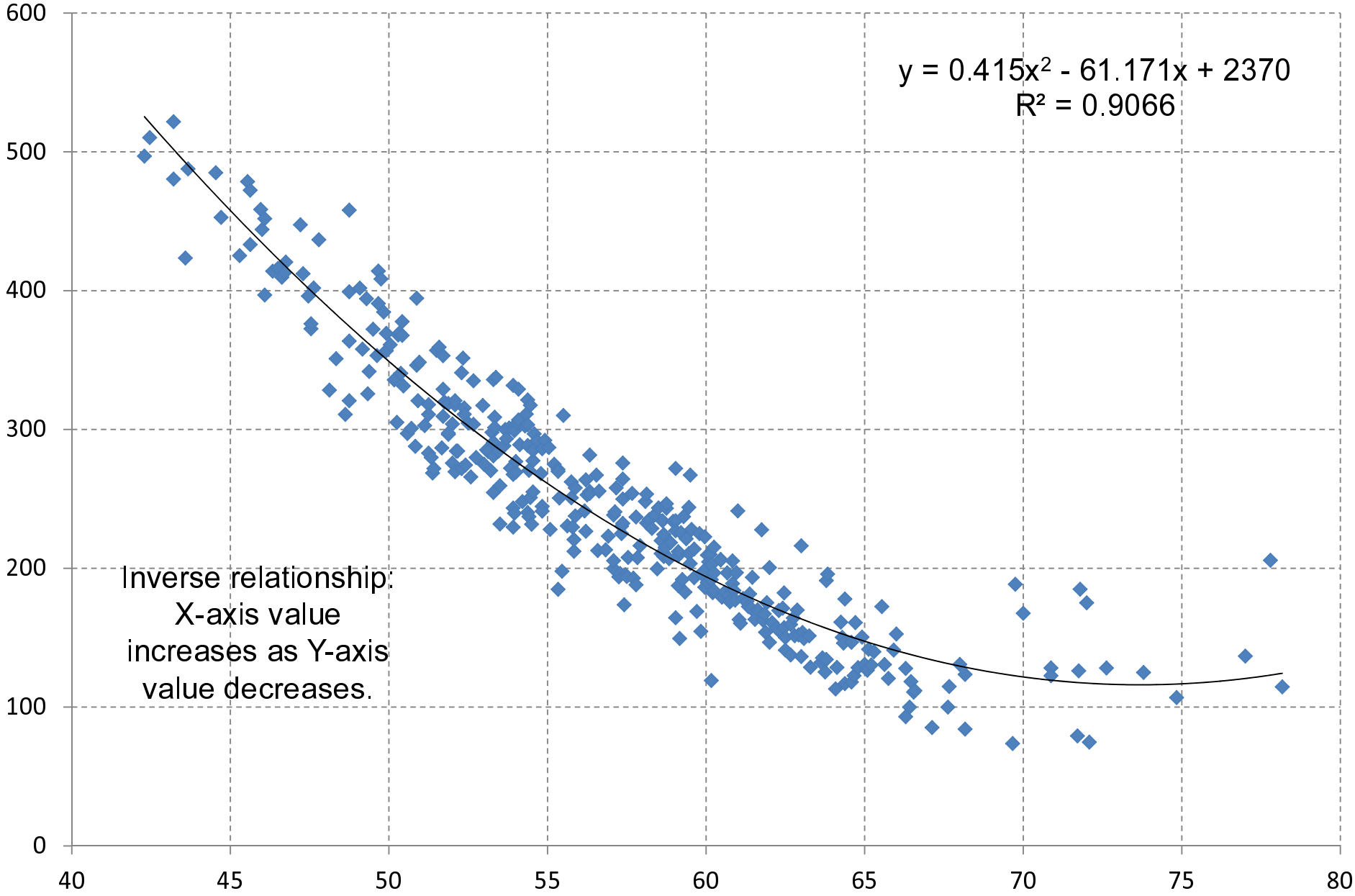
Mystery Graph 7

This graph illustrates the relationship between:



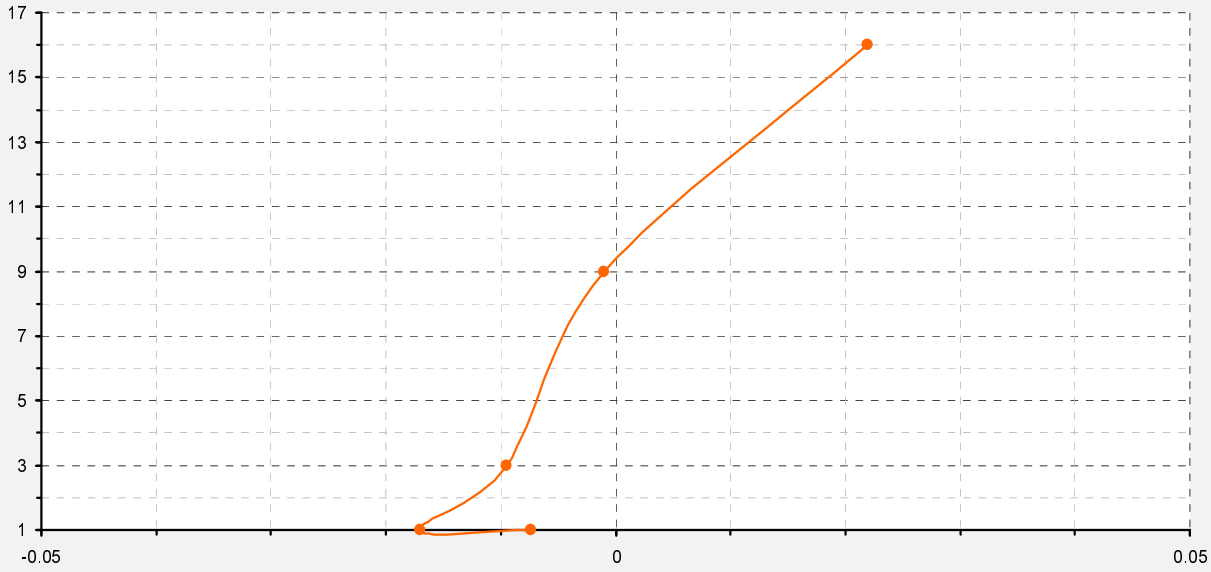
a. the percent load and power draw in watts for a motor.
b. the cooling load in kWh per day and the average zone temperature per day for a hospital.
c. the VFD speed in hertz and power in watts for a packaged unit supply air fan.
d. the humidity and enthalpy for air downstream from a direct evaporative cooling system.
e. the heating load for a building in therms per day and the average outside temperature per day.

Mystery Graph 7



Mystery Graph 8

This graph illustrates:



a. Pressure differential across filters relative to months installed.

b. The building pressure (in WG) relative to outside for a 16 storey building under normal operating conditions on a 60F day.

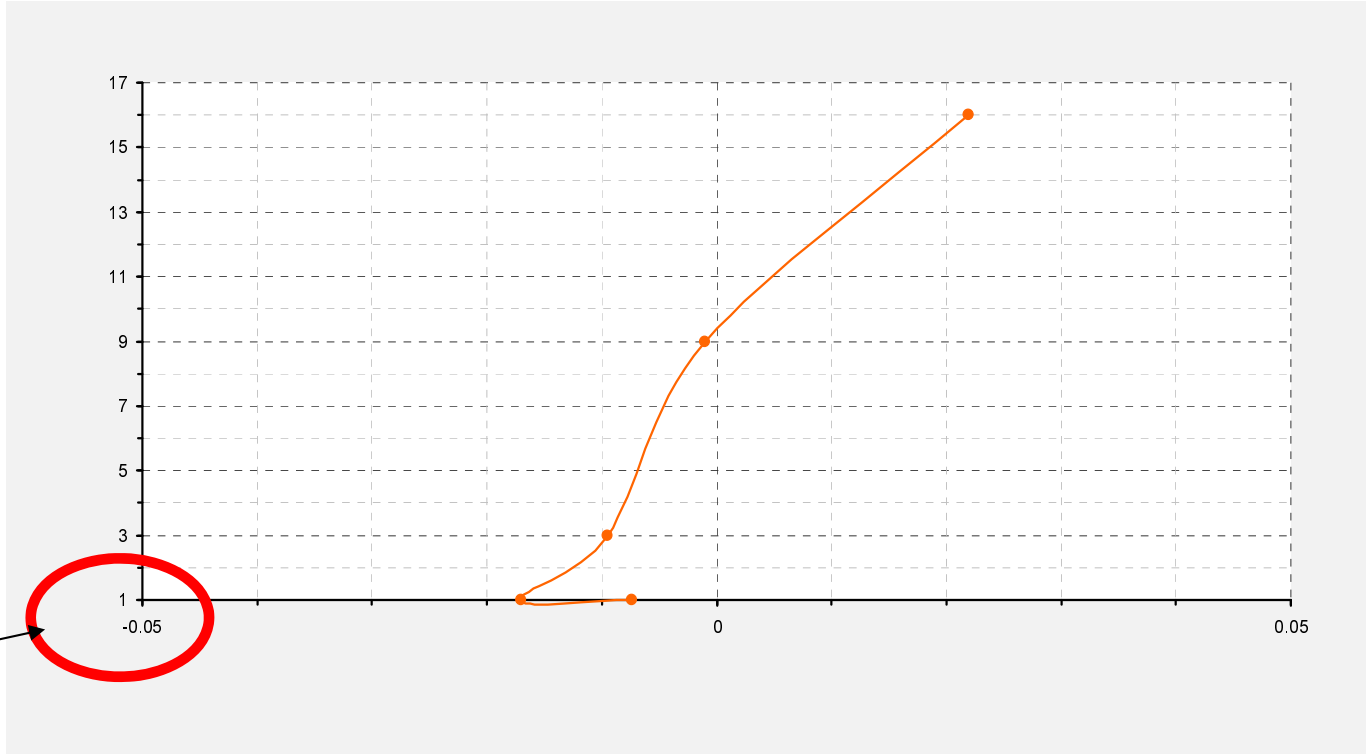
c. The relationship between wind speed (MPH) and altitude (100 ft) in an open field.

d. Wind pressure on the down-wind face of a building with a steady 10 mph wind blowing.

e. Supply static pressure relative to height for a 2 story building.

Mystery Graph 8

This graph illustrates:



Negative value and relative magnitude of the numbers on this axis are your biggest clues

a. Pressure differential across filters relative to months installed.

b. The building pressure (inWG) relative to outside for a 16 storey building under normal operating conditions on a 60F day

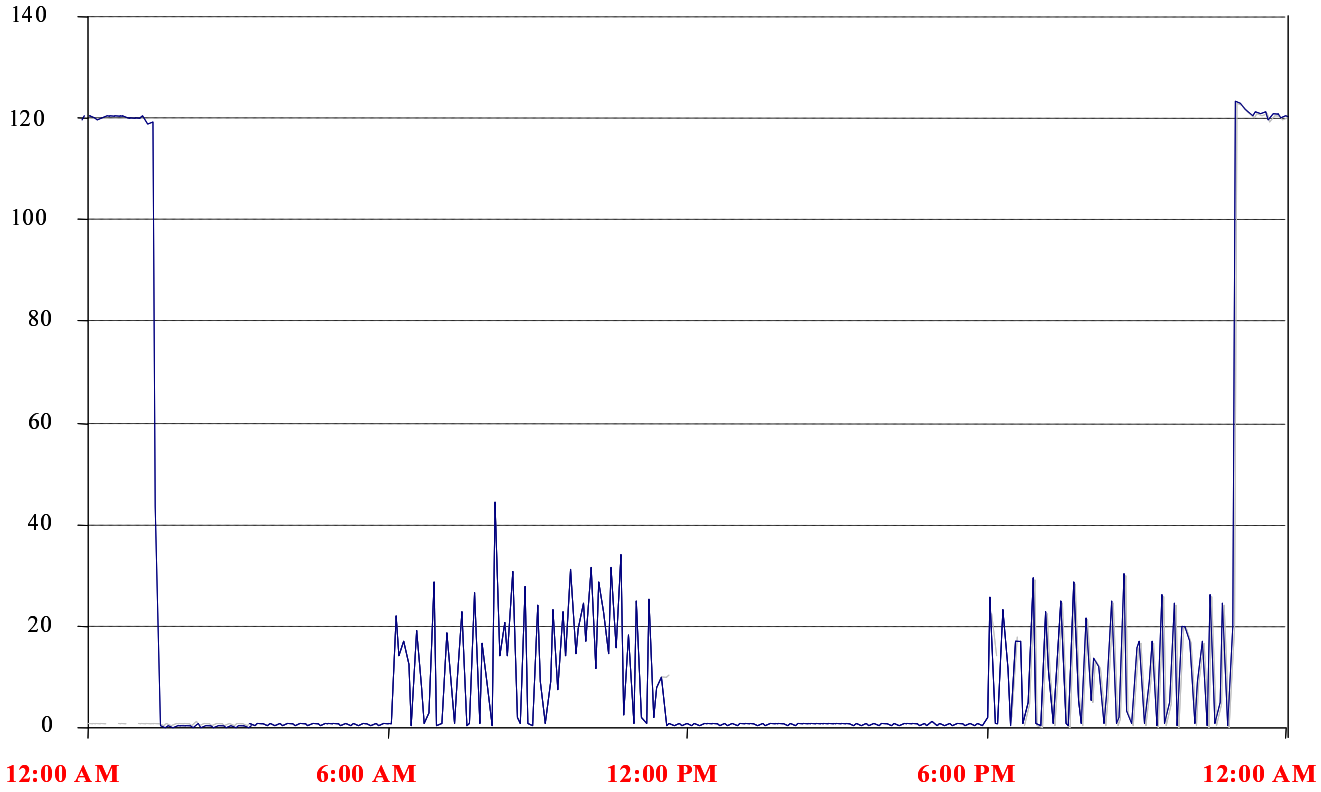
c. The relationship between wind speed (MPH) and altitude (100 ft) in an open field.

d. Wind pressure on the down-wind face of a building with a steady 10 mph wind blowing.

e. Supply static pressure relative to height for a 2 story building.

Mystery Graph 9

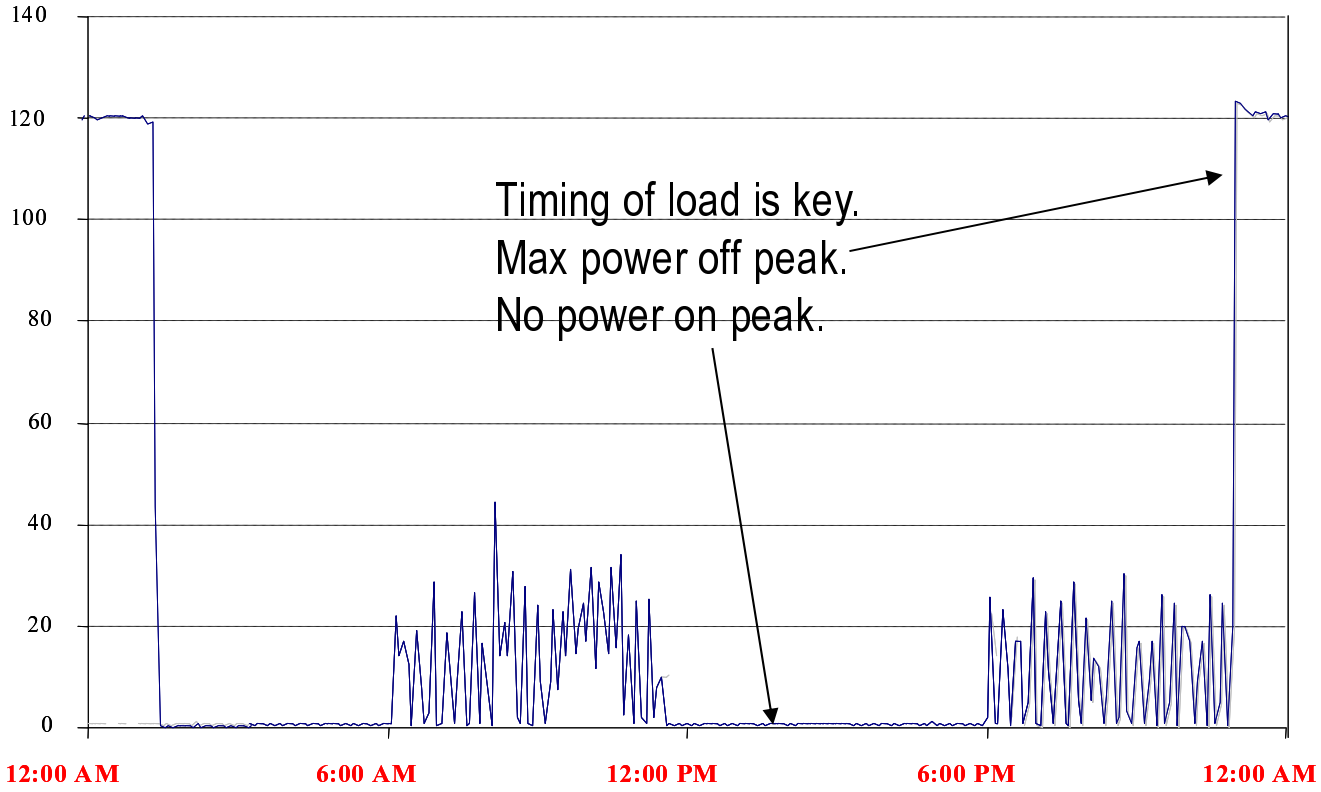
This graph illustrates:



a. Power draw of an educational building that has photovoltaic panels and exterior parking lot lighting.
b. Light levels in a restroom with an occupancy sensor.
c. CO_2 levels in a movie theater.
d. Temperature in a refrigerated warehouse.
e. Power draw of a chiller used for thermal storage.

Mystery Graph 9

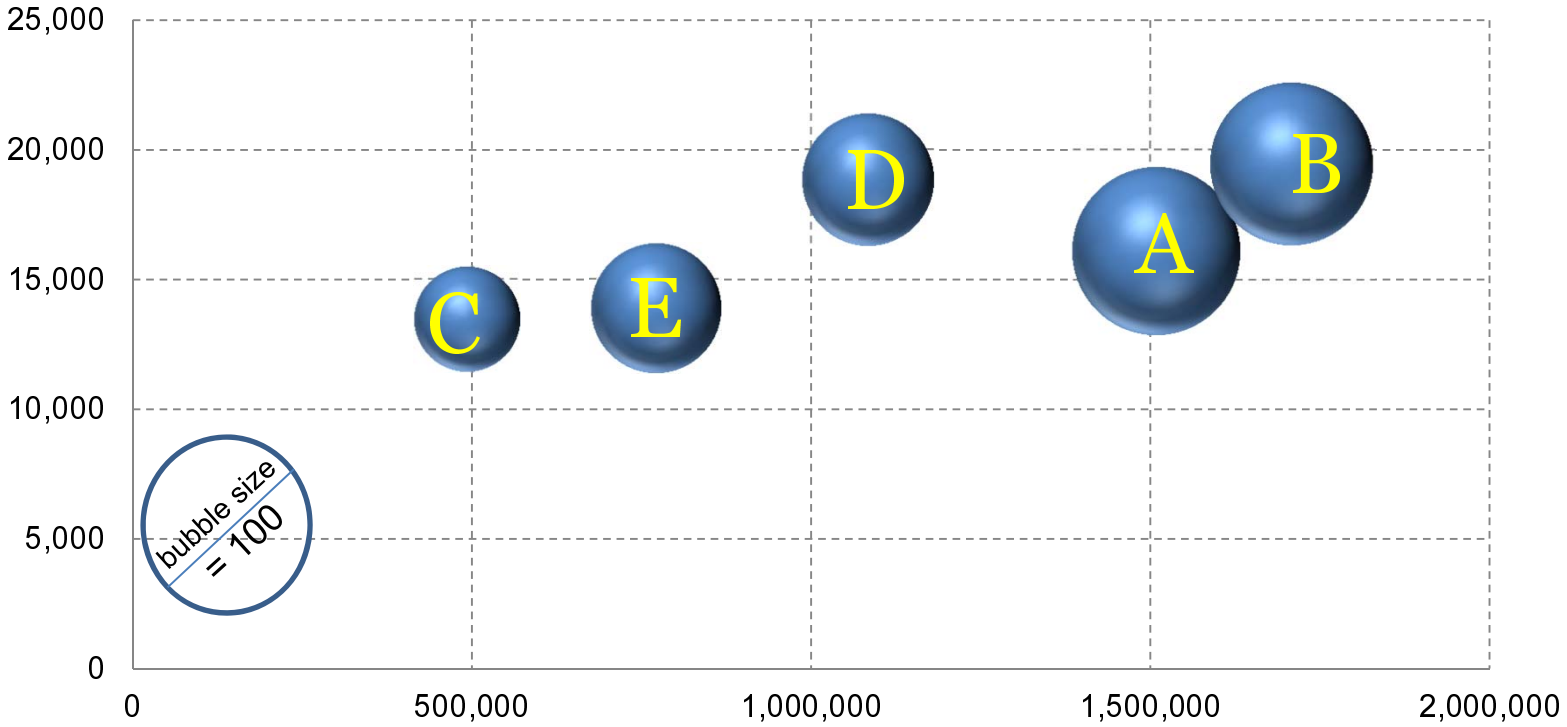
This graph illustrates:



a. Power draw of an educational building that has photovoltaic panels and exterior parking lot lighting.
b. Light levels in a restroom with an occupancy sensor.
c. CO_2 levels in a movie theater.
d. Temperature in a refrigerated warehouse.
e. Power draw of a chiller used for thermal storage.

Mystery Graph 10

This graph illustrates:



a. Cooling capacity in BTU/hr, total condenser fan CFM and the nominal tonnage for a selection of air-cooled chillers.

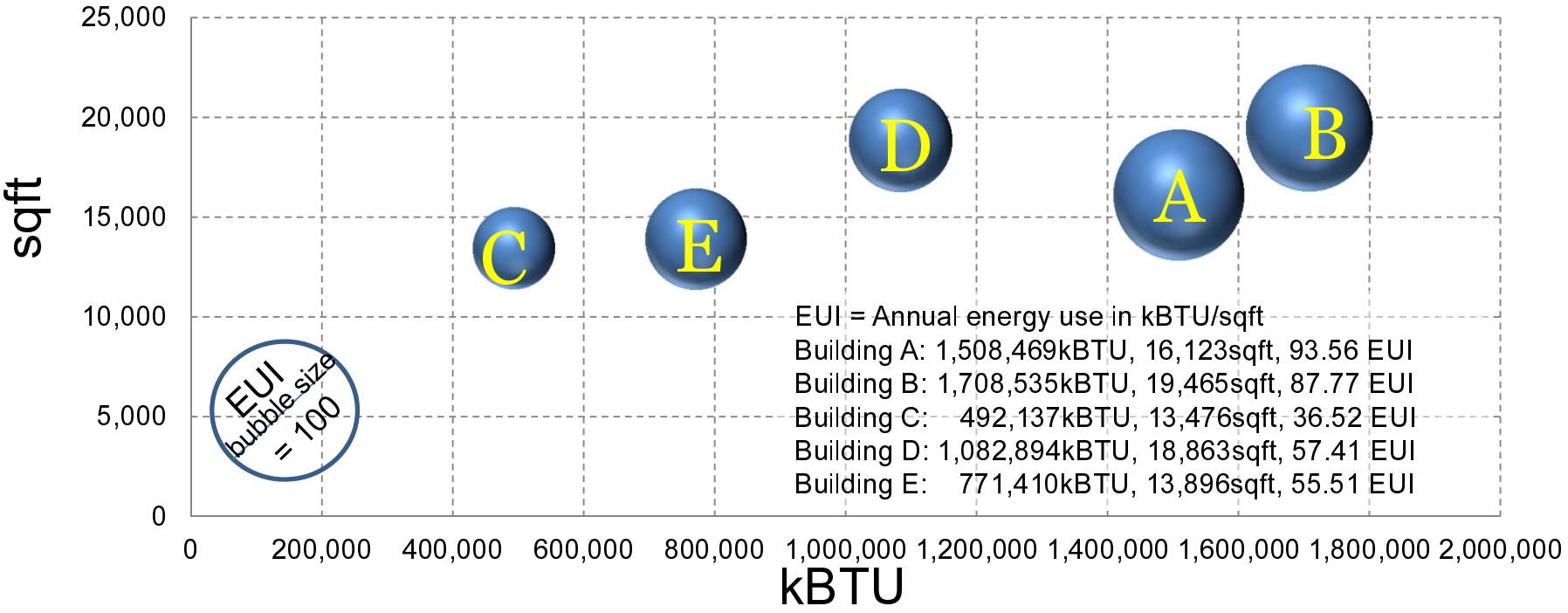
b. Annual energy use in kBTU, square footage and Energy Usage Intensity (EUI) for five mixed-use buildings within a single portfolio.

c. Heating capacity in BTU/hr, flow rate at vessel in GPM and the thermal efficiency for a several industrial boilers.

d. Annual energy cost in $, square footage and the Energy Star Portfolio manager score for 5 grocery stores.

e. Number of people, total cooling load in BTU/hr and the total CFM ventilation requirement for 5 theaters at a multiplex.

Mystery Graph 10



a. Cooling capacity in BTU/hr, total condenser fan CFM and the nominal tonnage for a selection of air-cooled chillers.

b. Annual energy use in kBTU, square footage and Energy Usage Intensity (EUI) for five mixed-use buildings within a single portfolio.

c. Heating capacity in BTU/hr, flow rate at vessel in GPM and the thermal efficiency for a several industrial boilers.

d. Annual energy cost in $, square footage and the Energy Star Portfolio manager score for 5 grocery stores.

e. Number of people, total cooling load in BTU/hr and the total CFM ventilation requirement for 5 theaters at a multiplex.

Resources/Bibliography

Related Publications

Graphic Excellence for the Commissioning Profession: Strategies for Representing Building Performance Data
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Few, Stephen. *Show Me the Numbers: Designing Tables and Graphs to Enlighten*. Oakland: Analytics Press, 2004

Few, Stephen. *Now You See It: Simple Visualization Techniques for Quantitative Analysis*. Oakland: Analytics Press, 2009

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Tufte, Edward R. *Envisioning Information*. Connecticut: Graphics Press, 1990.

Tufte, Edward R. *Visual Explanations: Images and Quantities, Evidence and Narrative*. Connecticut: Graphics Press, 1997.

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Ware, Colin: *Information Visualization: Perception for Design*, 3 edition. Morgan Kaufmann, 2012

Yau, Nathan. *Visualize This: The FlowingData Guide to Design, Visualization, and Statistics*. Wiley, 2011.

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Early Results and Fields Tests of an Information Monitoring and Diagnostic System for Commercial Buildings
Lawrence Berkeley National Laboratory,1998
http://poet.lbl.gov/phase2/phs2rpt.pdf

e-Handbook of Statistical Methods
NIST/SEMATECH, 2012
http://www.itl.nist.gov/div898/handbook

7 Common Graphs in Statistics
Courtney Taylor
http://statistics.about.com/od/HelpandTutorials/a/7-Common-Graphs-In-Statistics.htm

Nuts and Bolts of Chart & Graph Types
Daniel Waisberg
http://online-behavior.com/analytics/chart-types

when-numbers-bleed-freeze-starve-and-die-on-a-battlefield-the-dark-poetry-of-data
Robert Krulwich
http://www.npr.org/blogs/krulwich/2014/05/16/312839051/when-numbers-bleed-freeze-starve-and-die-on-a-battlefield-the-dark-poetry-of-dat

Online Videos

Data Visualization: See the story in the Data and Learning to Effectively Communicate it to Others
Tyler Rinker
https://www.youtube.com/watch?v=IHIPQ4VhucY

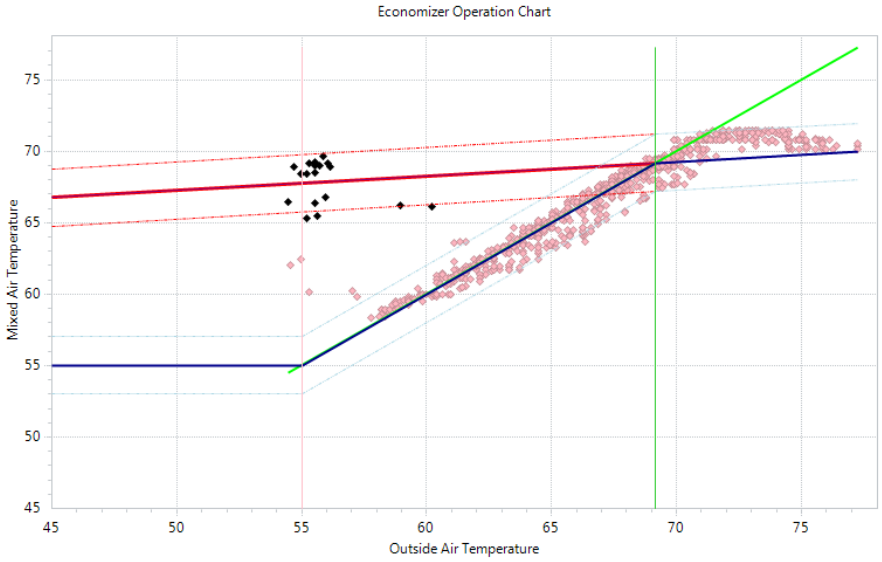
I Like Pretty Graphs: Best Practices for Data Visualization Assignments
University of Wisconsin Design Lab
https://www.youtube.com/watch?v=pD_OvRtH0aY

Ted Talks: The Beauty of Data Visualization
David McCandless:
https://www.youtube.com/watch?v=cWZ16PqiRQ8

Anything with Hans Rosling like these
https://www.youtube.com/watch?v=jbkSRLYSojo
https://www.youtube.com/watch?v=hVimVzgtD6w
https://www.youtube.com/watch?v=BkSO9pOVpRM

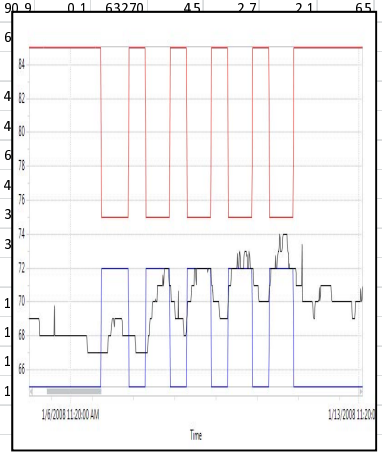
Universal Translator (Free) Software: www.utonline.org

- Data management
  - Resampling
  - Time shift
  - Slope and offset adjustments
  - Data filters
  - Calculated data channels
  - Psychrometric channels
- Data analysis
  - Line graph
  - Scatter plots
- Diagnostics
  - Air side economizer
  - Dual duct AHU fault detection
  - Fans and system curves
  - Fan coil fault detection
  - Light load
  - Measurement and verification
  - Plug load
  - Set point analysis
  - Single duct AHU fault detection
  - Statistics



Setpoint Analysis

Channel Folder Name	Channel Name	RESULT Value Score	Lower Value Result	Upper Value Result	% Time Under Lower Setpoint	% Time Over Upper Setpoint	Time Under Lower Setpoint	Time Over Upper Setpoint	Average Value Under Lower Setpoint	Average Value Over Upper Setpoint	Minimum Value	Maximum Value
VAV2-3	VAV 2-3_VAV-2-3 EXHIBITHALL-4 ZoneTemperature	2.5	2.5	0	90.9	0.1	63270	45	2.7	2.1	65	79.7
VAV2-5	VAV 2-5_VAV-2-5 EXHIBITHALL-1 ZoneTemperature	1.6	1.6	0	6							77.9
VAV2-7	VAV 2-7_VAV-2-7 TECHOFFICE ZoneTemperature	1.4	1.4	0								75.9
VAV2-4	VAV 2-4_VAV-2-4 EXHIBITHALL-3 ZoneTemperature	1.3	1.3	0	4							73
VAV2-1	VAV 2-1_VAV-2-1 ADMIN-OFFICE-1 ZoneTemperature	1.3	1.3	0	4							74.8
VAV1-3	VAV 1-3_VAV-1-3 BASEMENT ZoneTemperature	1.2	1.2	0	6							72
VAV1-5	VAV 1-5_VAV-1-5 BIRDIE-ROOM ZoneTemperature	1	1	0	4							77.5
VAV2-6	VAV 2-6_VAV-2-6 EXHIBITHALL-2 ZoneTemperature	1	1	0	3							78.4
VAV2-2	VAV 2-2_VAV-2-2 ADMIN-OFFICE-2 ZoneTemperature	0.9	0.9	0	3							78.9
VAV1-6	VAV 1-6_VAV-1-6 KITCHEN ZoneTemperature	0.5	0.1	0.4								80.3
VAV1-4	VAV 1-4_VAV-1-4 LOBBY-2 ZoneTemperature	0.4	0.4	0	1							74
VAV1-8	VAV 1-8_VAV-1-8 CONFERENCE-RM-2 ZoneTemperature	0.4	0.3	0	1							76.2
VAV1-2	VAV 1-2_VAV-1-2 LIGHTING-RM ZoneTemperature	0.3	0.3	0	1							78.5
VAV1-1	VAV 1-1_VAV-1-1 LOBBY ZoneTemperature	0.2	0.2	0	1							78.2
VAV1-7	VAV 1-7_VAV-1-7 CONFERENCE-RM-1 ZoneTemperature	0.1	0.1	0								79.4



PEC's Free Trainings on Building Commissioning

- **Design Performance and Commissioning Series**
  - Airside Economizers
  - Variable Air Volume (VAV) Systems
  - Pumps
  - Chilled and Condenser Water Systems
  - Heating Hot Water and Steam Systems
  - Controls
  - Fans, Ducts and AHUs
  - Variable Speed Drives (VSDs)

Each of these are simulcast over the Internet.

- **Other Commissioning Trainings**
  - Existing Building Commissioning Workshop Series
  - RCx 101: Identifying and Assessing Common Retrocommissioning Opportunities
  - Logic Diagrams and Control Sequences
  - System Diagram Workshop
  - Commissioning Lighting Controls
- **Related Training Topics**
  - Basic Excel for Energy Analysts
  - Universal Translator Training
  - Optimizing the Design and Control of Data Centers
  - Optimizing the Design and Control of Chilled Water Plants
  - Building Measurement classes

Full list of classes and registration links:
http://www.pge.com/energyclasses

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- Tools loaned for **FREE** for **energy efficiency, demand reduction and demand response** projects for public utility rate payers in California.
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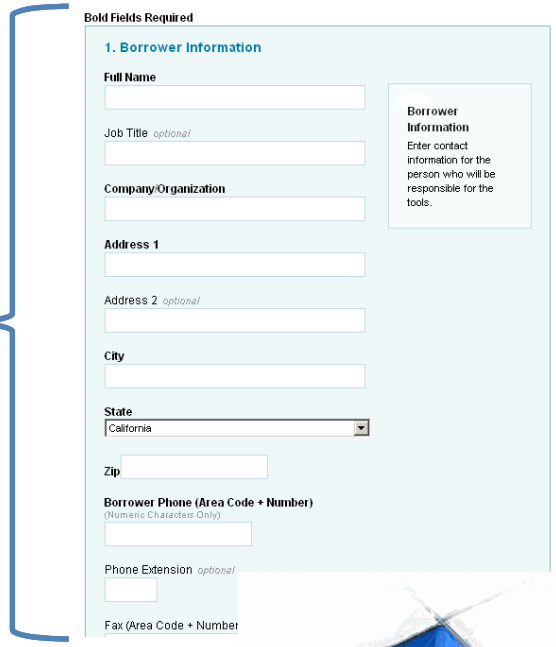
  - Borrower information
  - Project information
  - Specifics on tools requested
- Online catalog of available equipment
- Application notes with step-by-step instructions
- Over 5000 diagnostic measurement tools and accessories in the lending library.




CO2 Meter


Strobe Tachometer


Temp/RH Meter


Ultrasonic Flow Meter


Drywell Calibrator

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Ryan Stroupe, Building Performance Program Coordinator

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