Pacific Northwest NATIONAL LABORATORY

Proudly Operated by **Battelle** *Since 1965*

Influence of Occupancy on Building Energy Use and Use of an Occupancy-Adjusted Performance Metric

ABINESH SELVACANABADY AND KATHLEEN JUDD, PNNL

November 17, 2016

Presentation to the Green Building Advisory Council

U.S. DEPARTMENT OF ENERGY

Study Objectives

Pacific Northwest NATIONAL LABORATORY
Proudly Operated by Battelle Since 1965

- To further develop the concept, DOE-FEMP sponsored PNNL to conduct an exploratory study to:
  - Assess the influence of occupancy on building energy use and EUI in a “typical” office building, where occupancy is based on concept of full time equivalent occupancy (FTEO)

$$FTEO = \frac{Total\ Annual\ Occupied\ Person\ Hours}{1645\ Hours}$$

  - If warranted, provide a factor for accounting for the influence of changes in occupant density in planning decisions

Study Approach (1)

Pacific Northwest NATIONAL LABORATORY
Proudly Operated by **Battelle** *Since 1965*

- Literature review on occupancy impact on building energy use
- Review of simulation and benchmarking tools
- Identified two GSA buildings to explore occupancy-EUI correlation
  - GSA Headquarters, 1800 F St NW, Washington, DC
  - Byron Rogers Federal Building and U.S. Courthouse, Denver, CO
- Data collection and processing
  - 15-minute electric demand data was converted to hourly and daily energy use
  - Hourly steam and 15-minute natural gas data were converted to daily energy use
  - Occupancy data using prox card swipe-in logs (and swipe-out in one building)
  - 1-hour interval weather data from NOAA

Study Approach (2)

Pacific Northwest NATIONAL LABORATORY
Proudly Operated by **Battelle** *Since 1965*

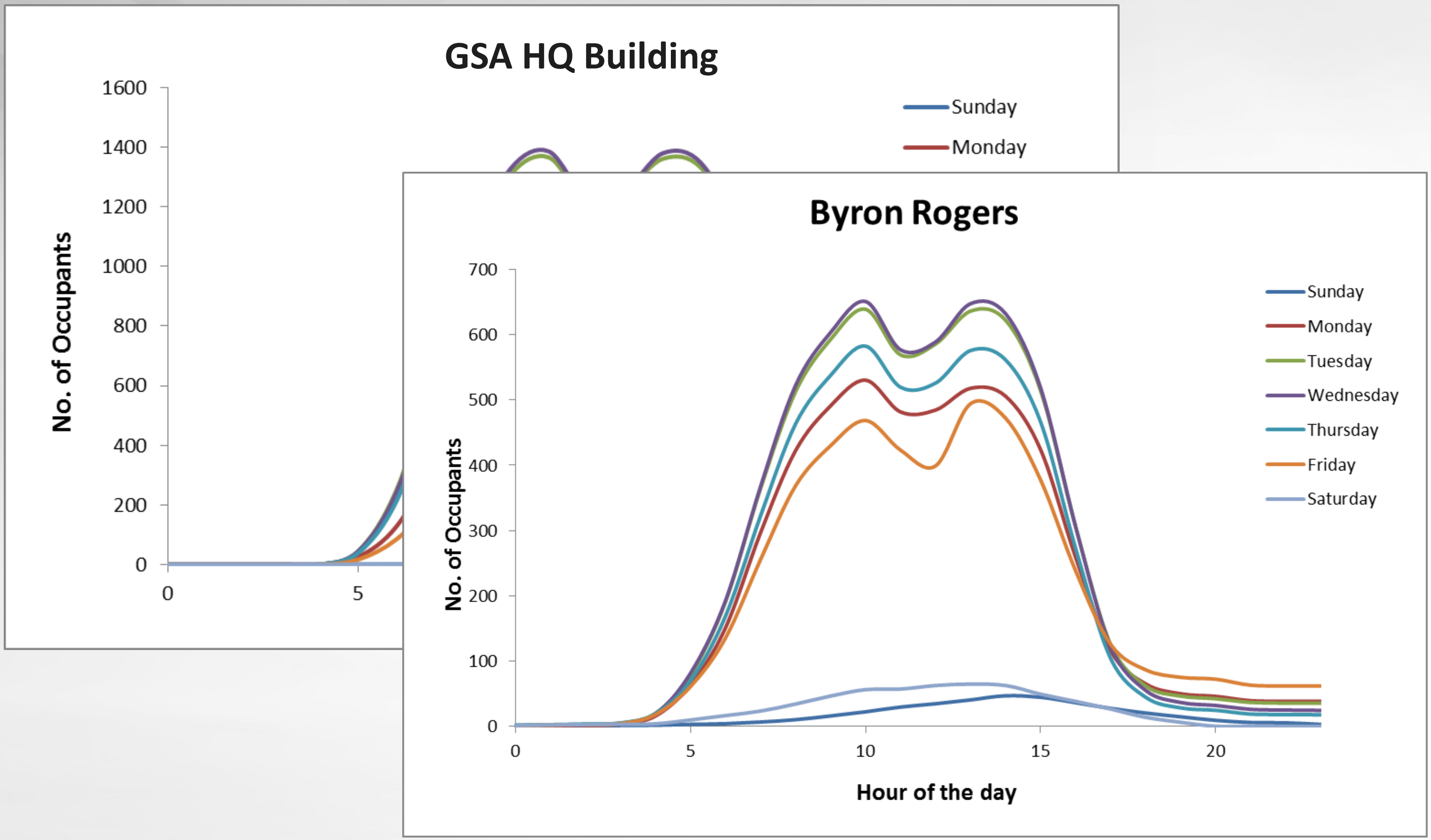
- Data analysis
  - Correlated building energy use to average daily outdoor temperature
  - Correlated building energy use to estimated daily FTEO
  - Created a multivariate regression model to assess the impact of both independent variables (weather and person-hours) on the dependent variable (energy use)
  - Studied sensitivity of traditional EUI, occupancy-based EUI and energy consumption for various occupancy levels
- Validation
  - DOE Building Performance Database to correlate occupant density with EUI
  - Bottom-up estimate of energy use from non-weather related occupant loads

Building Data Limitations

- GSA Headquarters
  - Electricity interval data could only be acquired for a portion of the building (accounted for 20-25% of the billed monthly consumption)
  - Developed adjustment factor based on ratio of metered to billed energy use for each month and prorated daily kWhs using factors to fill in missing data
  - Disclaimer: Missing data could pertain to loads influenced by occupancy (e.g. plug loads) and the effects would not be captured accurately in this analysis

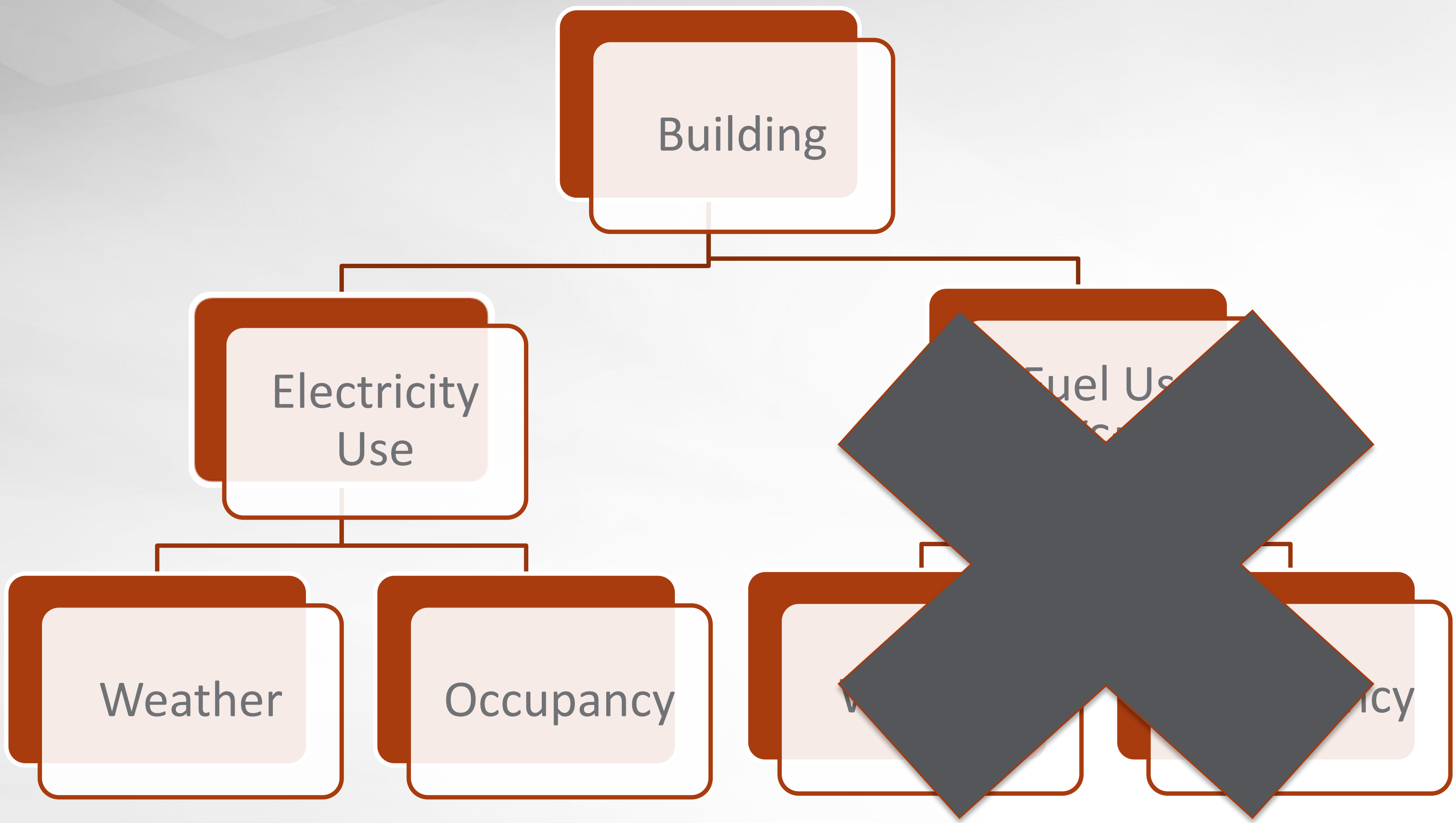
- Byron Rogers Federal Building
  - Prox access system logs entry swipe-ins and not exits
  - Hourly occupancy was estimated based on occupancy trends from GSA HQ building

Occupancy Profiles



Analysis Approach

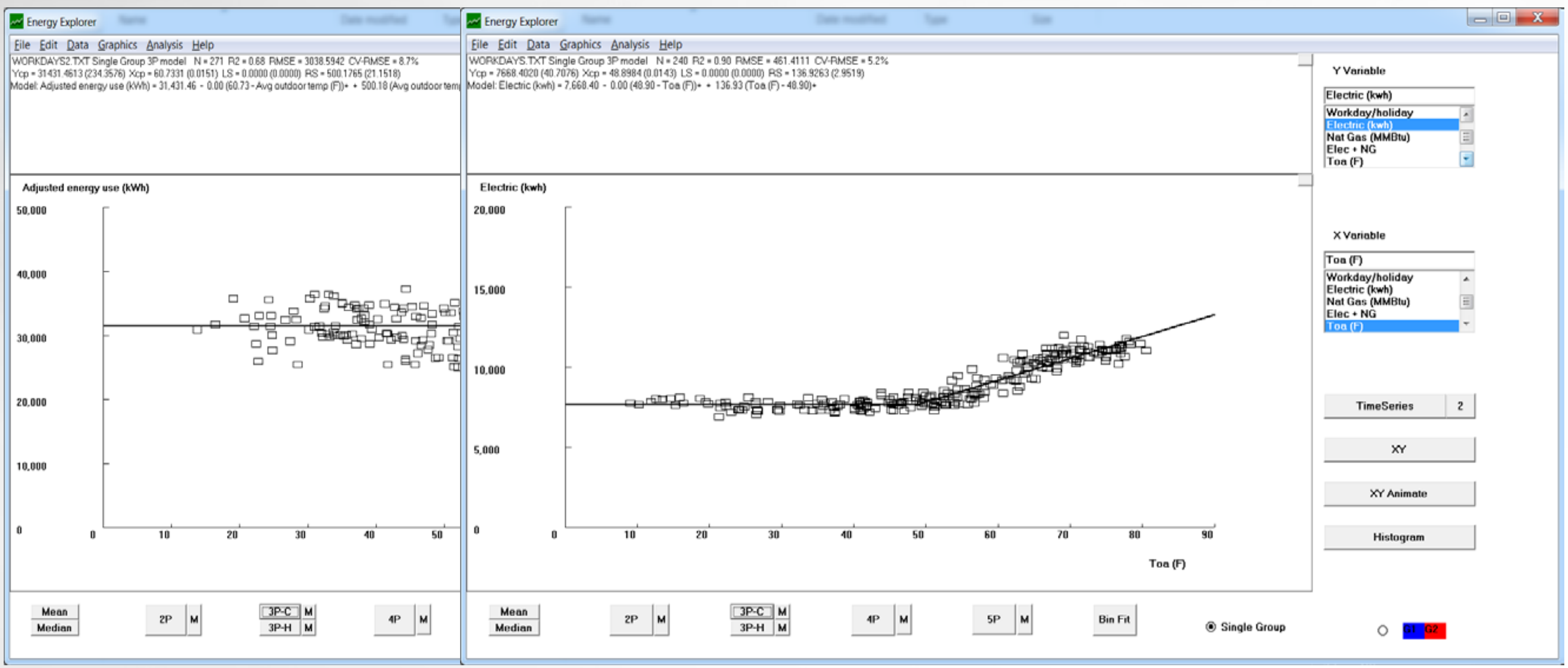
Pacific Northwest
NATIONAL LABORATORY
Proudly Operated by **Battelle** *Since 1965*



Findings:
Analysis for Weather Influence

Pacific Northwest
NATIONAL LABORATORY
Proudly Operated by **Battelle** *Since 1965*

- Weekday Daily Electricity Use vs. Daily Average Temperature
  - GSA HQ: Strong Correlation R2=0.68
  - Byron Rogers: Strong Correlation R2=0.90



Findings:
Analysis for Occupancy Influence

Initial Approach

- Does occupancy influence a building's energy consumption?
  - All data points were plotted together and occupancy correlation was evaluated
  - A distinct clustering pattern was noticed in the data for Byron Rogers, which warranted a modified approach

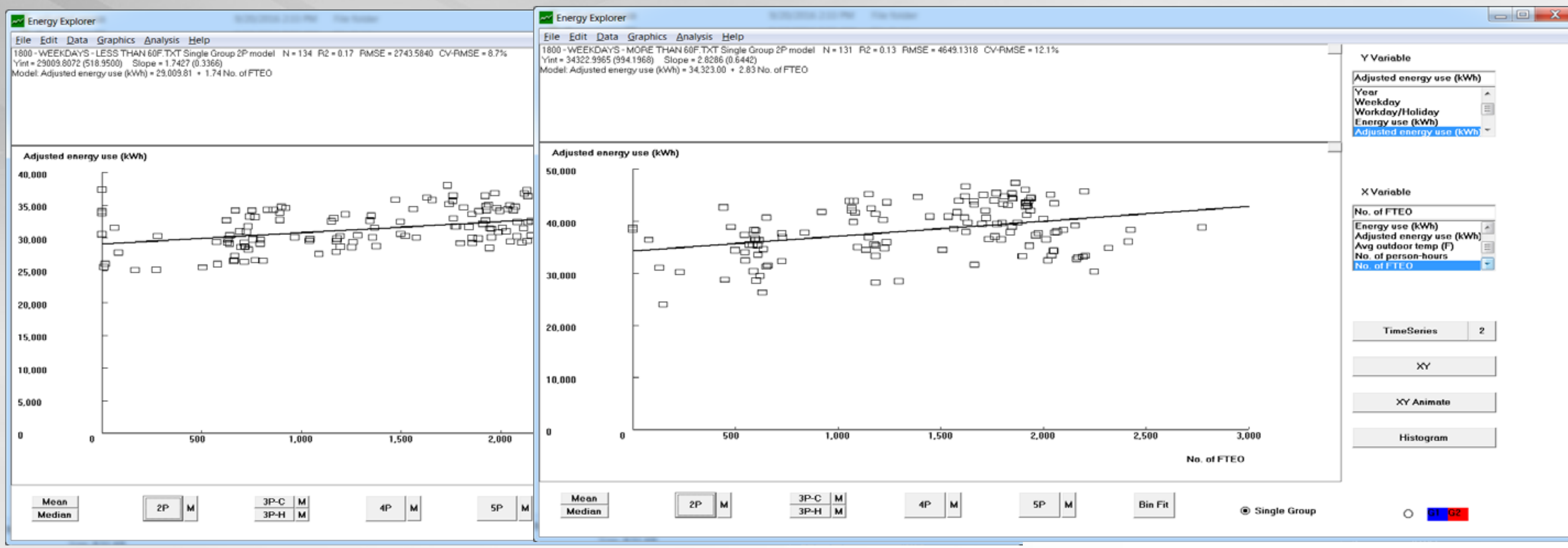
Modified Approach

- Does occupancy have different levels of influence on plug load- and HVAC-related energy use?
  - Dataset divided into 2 groups based on the temperature change point on the electricity vs. outdoor air temperature correlation graph
  - Occupancy correlation (slope) was calculated for each dataset
  - Slopes were weighted based on the number of data points analyzed

- Approach did impact results for Byron Rogers building

Findings: GSA HQ Building
Electricity Use Analysis using Modified Approach

Pacific Northwest
NATIONAL LABORATORY
Proudly Operated by **Battelle** *Since 1965*

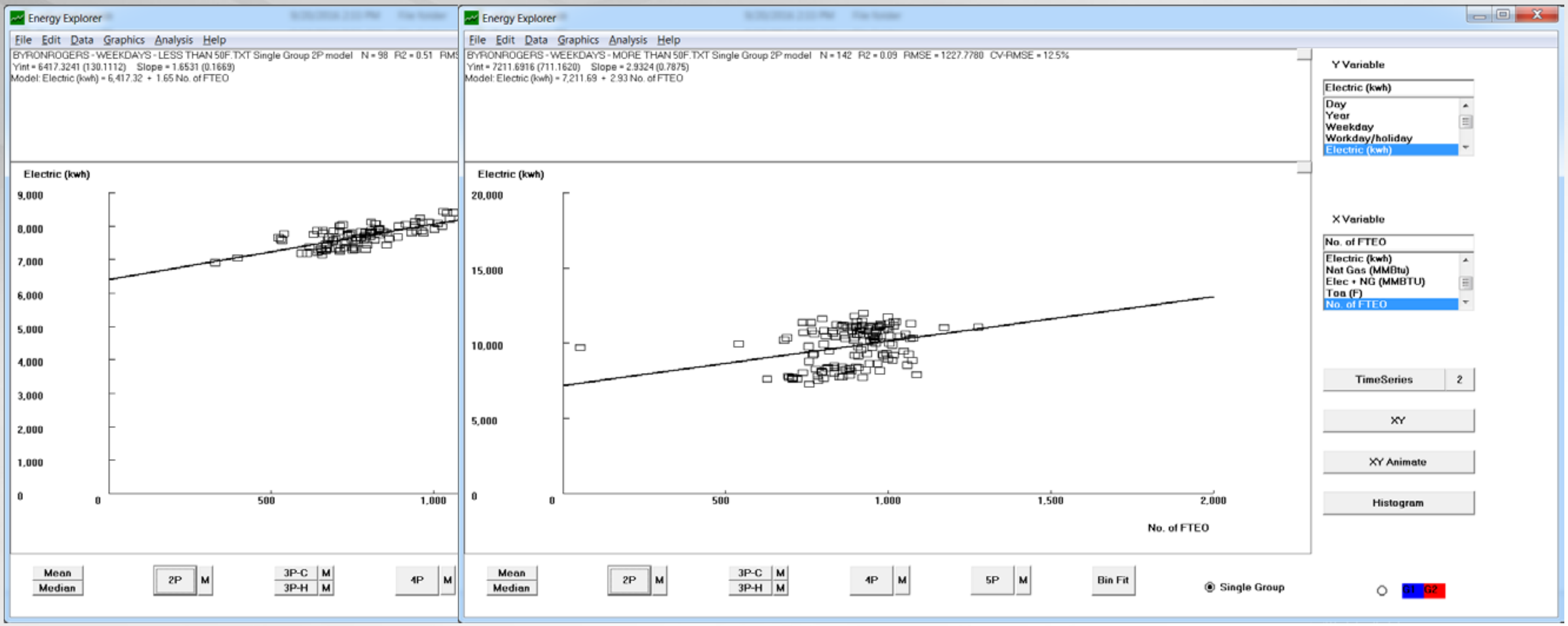


Outdoor Temperature Change Point	R2	# Datapoints	kWh/day/FTEO
Less than 60F	0.17	134	1.74
Greater Than 60 F	0.13	131	2.83

- Weighted slope = 2.28 kWh/day/FTEO

Findings: Byron Rogers Building
Electricity Use Analysis using Modified Approach

Pacific Northwest
NATIONAL LABORATORY
Proudly Operated by Battelle *Since 1965*



Outdoor Temperature Change Point	R2	# Datapoints	kWh/day/FTEO
Less than 50F	0.51	98	1.65
Greater than 50F	0.09	142	2.93

- Weighted slope = 2.41 kWh/day/FTEO

Validation: Buildings Performance Database

Pacific Northwest NATIONAL LABORATORY
Proudly Operated by Battelle *Since 1965*

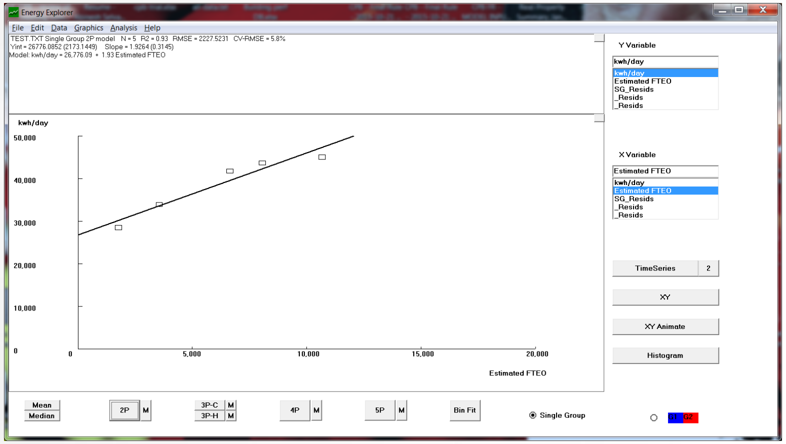
- Plotted site Electricity EUI vs. Occupant Density
- Data not accessible to run a true regression, so cluster means were visually identified to run a quasi-regression

Occ density (Ppl/1000SF) Bin-Low	Occ density (Ppl/1000SF) Bin-High	Occ density (Ppl/1000SF) Cluster Mean	Mean Electric EUI (kBtu/SF/year)
0	2	1.5	47.36
2	4	3	56.39
4	6	5.6	69.39
6	8	6.8	72.54
8	10	9	74.84

Findings: Buildings Performance Database

Pacific Northwest NATIONAL LABORATORY
Proudly Operated by **Battelle** *Since 1965*

Building Electric Use (kWh/day)	Estimated FTEO
28521	1778
33960	3556
41788	6638
43685	8061
45071	10669



Slope = 1.93 kWh/day-FTEO

Findings: Bottom-up Estimate Typical Personal Loads

Pacific Northwest NATIONAL LABORATORY
Proudly Operated by Battelle Since 1965

Typical Personal Loads	% of occupants using equipment daily	Watt-hrs / occupant-day
Desktop Computer (EStar)	50%	181
Laptop computer (EStar)	50%	24
LCD Monitor (EStar)	100%	73
Computer speakers (Estar)	50%	3
Mobile phone charger	50%	19
Phone: analog	75%	20
Phone: VOIP (EStar)	25%	12
Task lighting	25%	16
Personal printer: laser	13%	13
Personal printer: inkjet	13%	11
Coffee maker	6%	22
Space heater	2%	2
Compact refrigerator (2.3 cu.ft Estar)	5%	34
	All loads	**0.43 kWh/occ-day**

With less conservative assumptions, use from all loads approached 1 kWh/occ-day

Summary: Impact of Occupancy

Pacific Northwest NATIONAL LABORATORY
Proudly Operated by **Battelle** *Since 1965*

- Occupancy appears to have relatively minor impact on energy use based on regression analyses in these two office buildings

- Estimates of per occupant impact were within the same general range

Analysis	Estimated Impact on Building Energy Use
GSA HQ building data	2.28 kWh/day-FTEO
Byron Rogers building data	2.41 kWh/day-FTEO
DOE Building Performance Database	1.93 kWh/day-FTEO
Bottom-up analysis	0.43 to 0.94 kWh/day-occupant (plug loads only)

Sensitivity of EUI to Occupancy Changes

Pacific Northwest NATIONAL LABORATORY
Proudly Operated by Battelle Since 1965

	Peak Occupancy Increase	FTEO Adjustment Factor (actual hrs logged/FTEO hrs)	Difference in Predicted Electric EUIs (kWh/SF-yr)	Occupant-adjusted Electric EUI (kWh/FTEO-yr)
GSA HQ 1800 F St NW, Washington, DC	76% (2500 to 4400 heads)	0.55	+7%	-39%
Byron Rogers, Denver, CO	50% (1000 to 1500 heads)	0.78	+14%	-24%

Note: Predicted changes in electric EUI are based on building-specific regression curves. It would not be appropriate to apply these to other buildings.

Conclusions

- Based on a limited analysis of occupancy influence on building energy using daily-scale data in two office buildings, and estimated impacts using less granular data:
  - Each FTEO appears to contribute ***~2kWh/day*** to building loads
  - Influence was small compared to weather but statistically significant

- Occupancy-adjusted EUI could be tracked as a supplemental metric to help understand
  - Actual energy use per occupant
  - Impact of adding shifts or changes in telework use
  - How building consolidation efforts affect energy use
  - How facility utilization is influencing whole building energy use

Conclusions

Pacific Northwest NATIONAL LABORATORY
Proudly Operated by Battelle *Since 1965*

- Calculating occupancy-adjusted EUI requires accurate occupancy logs and the level of data processing is non-trivial

- The estimated electricity use/FTEO-day documented in this study could be used to assess general impacts of occupancy changes, *however*
  - Actual impact will depend on building specific operations; the methodology established in this study could be replicated to estimate impacts of building consolidation efforts in a specific building

Further Research

- We recommend expanding this study to larger number and type of buildings to see if results are similar
  - Use modified analysis approach, separating energy use data into two bins based on outdoor air temperatures / HVAC change point.
  - The analysis has the potential to differentiate between occupancy-based non-weather-dependent loads (plug loads, common lighting) and occupancy-based weather-dependent loads (HVAC loads), which has been a challenging problem to solve by itself.
  - This could be useful in the case of high performance buildings with tight building envelopes and very high HVAC component to the occupancy-based energy use.
- Use of updated Portfolio Manager regression curve to develop an adjustment factor to the traditional EUI based on occupancy change, for buildings without access to occupancy data

Backup slides

Pacific Northwest
NATIONAL LABORATORY
Proudly Operated by **Battelle** *Since 1965*

Findings: Literature Review

Pacific Northwest NATIONAL LABORATORY
Proudly Operated by Battelle *Since 1965*

- Reviewed dozens of studies and found few publications on the subject
- Clevenger, et al (2006)
  - Looked at ~1000 SF classroom in CA; studied influence of occupants on various schedules (lighting, equipment, fraction of people in the building) as well as various associated loads
  - Found relatively small change in EUI of 7-10% when occupant density more than doubled from 10 to 25 people/1000 SF
- Azar, et all (2012)
  - Identified existing simulation parameters that related occupant's behavior to total building energy. Looked at small office building (1000-5000 ft2) and varied parameters such as baseload, lighting, heating and cooling set points during the occupied and unoccupied hours to quantify the influence on energy use
  - Not directly useful but the influence parameter gave a sense for a ball park estimate

Background

Pacific Northwest NATIONAL LABORATORY
Proudly Operated by Battelle Since 1965

- Energy use intensity (EUI) is the primary metric used to evaluate federal building performance

- Recent efforts to consolidate the federal building footprint have raised questions about the impact of increasing occupancy on building EUI
  - Administration's 2015 Reduce the Footprint policy
  - GSA goals to reduce per-employee office space allocations

- Green Building Advisory Committee (GBAC) established EUI Task Group to investigate merits of an EUI metric that accounts for occupant density
  - White paper outlined an "occupancy-based EUI" based on the concept of full time equivalent occupancy, to allow a more accurate estimation of energy use per occupant

Findings: Simulation Tool Review

Pacific Northwest NATIONAL LABORATORY
Proudly Operated by Battelle Since 1965

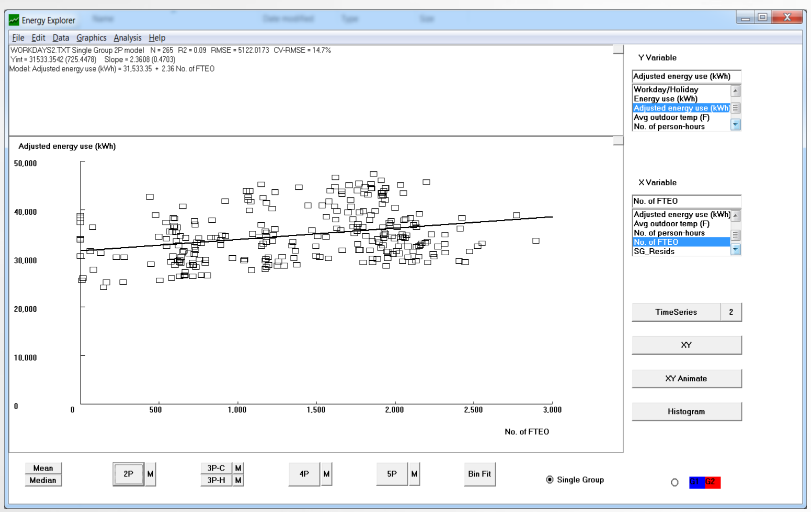
- Energy Plus, EQuest, and FEDS tools
  - All account for occupants but as an HVAC load contributing factor only
  - Other loads (plug loads, lighting) use power density values and their operation assumed as typical and not influenced by the occupant density

- Energy Star Portfolio Manager
  - Ranks building relative to peers for benchmarking based on CBECS 2003
  - Considers “workers per 1000 SF ” and “computers” as independent variables and predicts an EUI
  - Provides regression curve coefficients for variables
    - Workers per 1000 SF : 10.34
    - Computers per 1000 SF: 17.28
  - Could be used as a simplified alternative to FTEO come up with an adjustment factor for traditional EUI, e.g.
    - When the workers and computers increases by 20%, the EUI increases by 1% and 4% respectively

Findings: GSA HQ Building
Electricity Use Analysis

Pacific Northwest
NATIONAL LABORATORY
Proudly Operated by Battelle *Since 1965*

- Weekday Daily Energy Use vs. Number of FTEOs
  - Weak correlation R2 = 0.09
- For the energy use vs. occupancy regression analysis
  - Baseload (non-variable) energy is 31,533 kWh/day
  - Occupant-dependent energy use is 2.36 kWh/FTEO
  - $Energy\ use\ (kWh/day) = 2.36\ \frac{kWh/day}{FTEO} \times [\#FTEO] + 31{,}533\ kWh/day$
  - Slope of 2.36 kWh/day/FTEO tested statistically significant
  - Weather seems to be the primary driver for this building



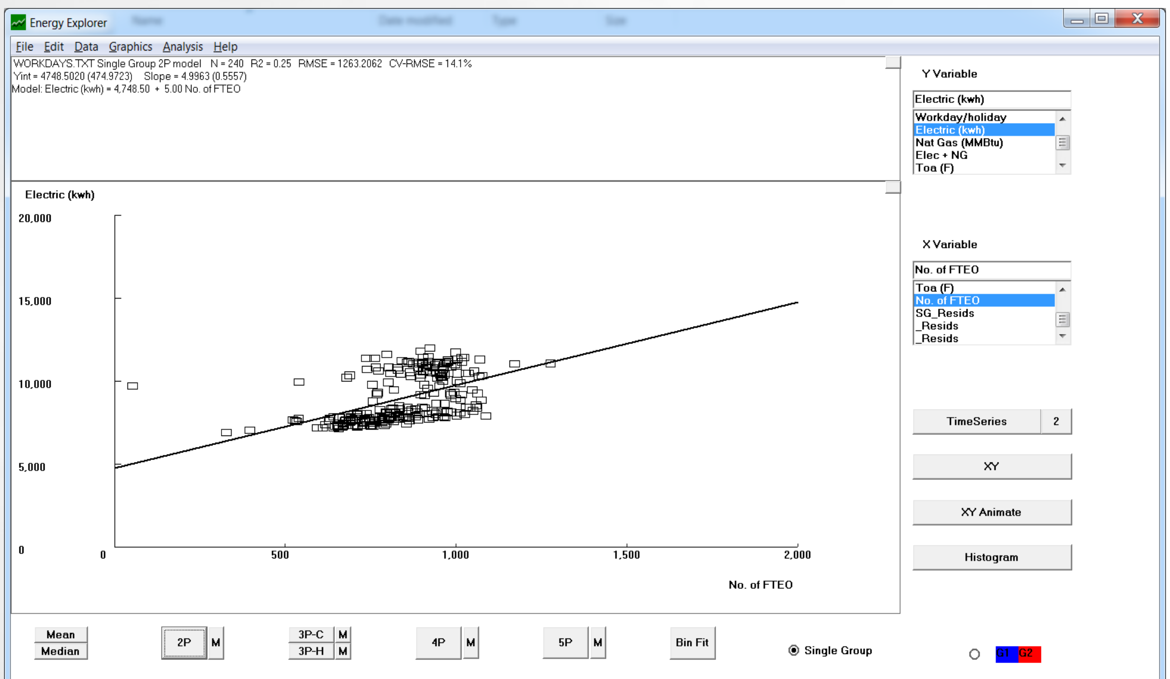
Findings: Byron Rogers Building
Electricity Use Analysis

Pacific Northwest
NATIONAL LABORATORY
Proudly Operated by **Battelle** *Since 1965*

- Weekday Daily Electricity Use vs. # FTEOs
  - Weak correlation R2 = 0.25

$$Energy\ use\ (kWh/day) = 5\frac{kWh/day}{FTEO} \times [\#FTEO] + 4{,}748.50\ kWh/day$$

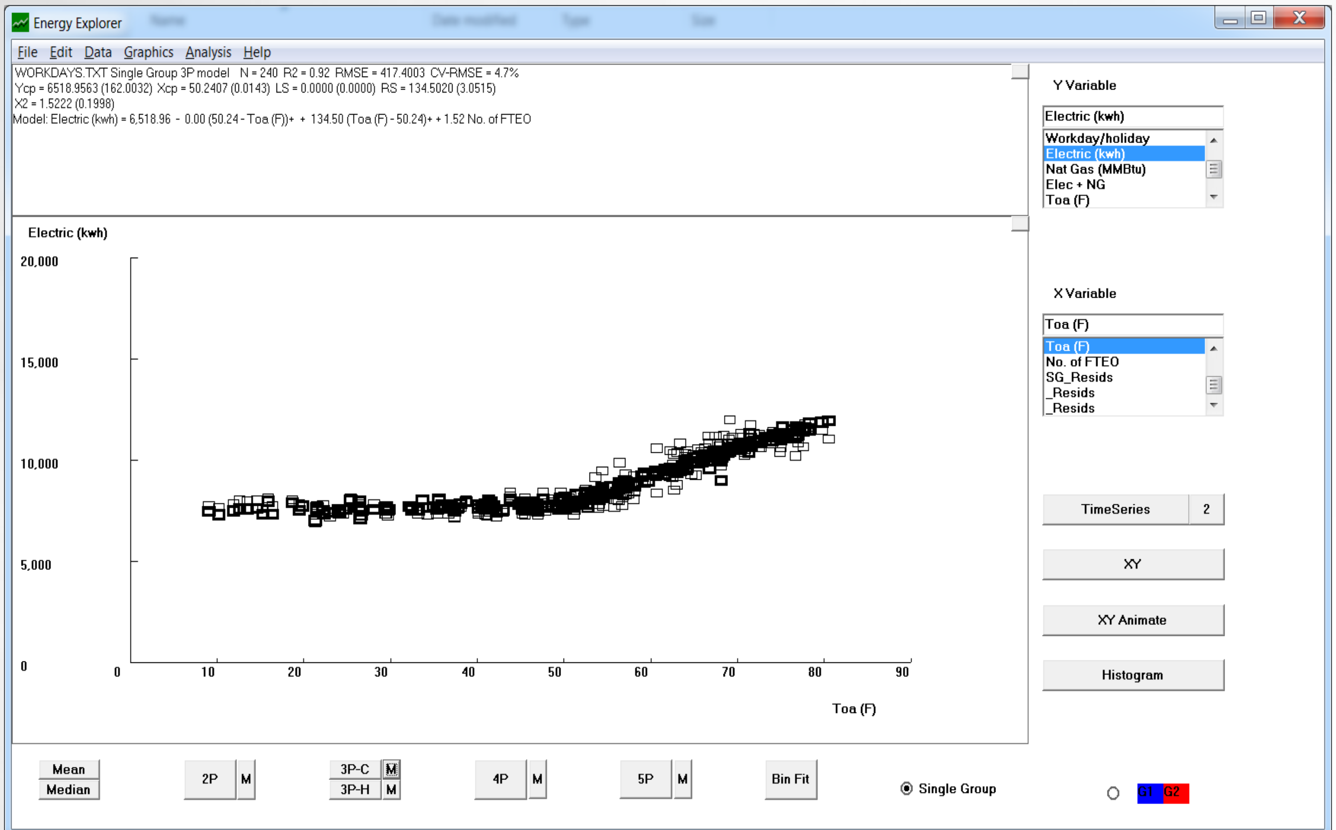
  - Slope of 5 kWh/day/FTEO tested statistically significant
  - Weather seems to be the primary driver for building energy use



Findings: Byron Rogers Building
Electricity Use Analysis

Pacific Northwest
NATIONAL LABORATORY
Proudly Operated by **Battelle** *Since 1965*

- Weekday Daily Electricity Use vs. # FTEOs and Temperature
  - In the multivariate regression, the R2 only went up to 0.92 (from 0.9 for the energy vs. weather correlation) further suggesting a weak link to occupancy



DRAFT

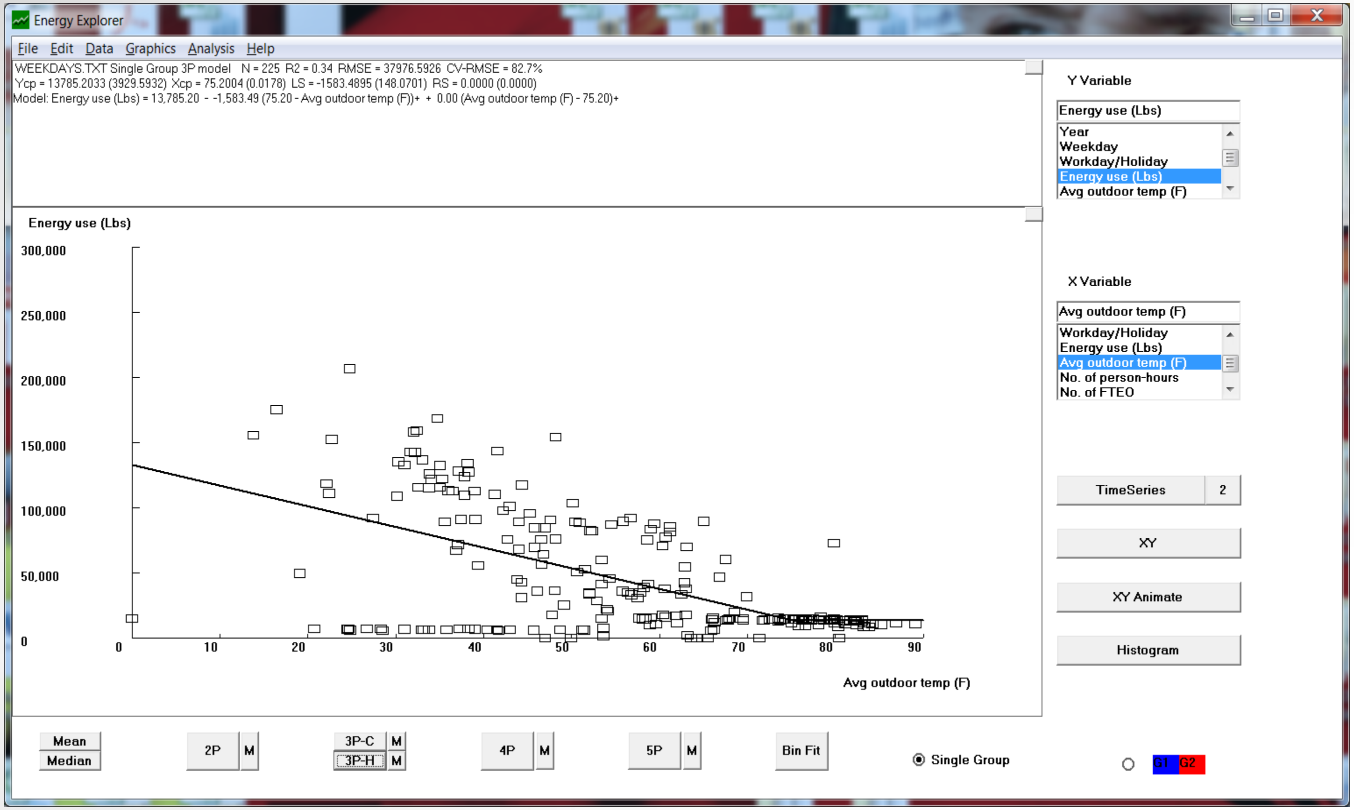
Findings: GSA HQ Building

Steam Use Analysis

Pacific Northwest NATIONAL LABORATORY

Proudly Operated by **Battelle** *Since 1965*

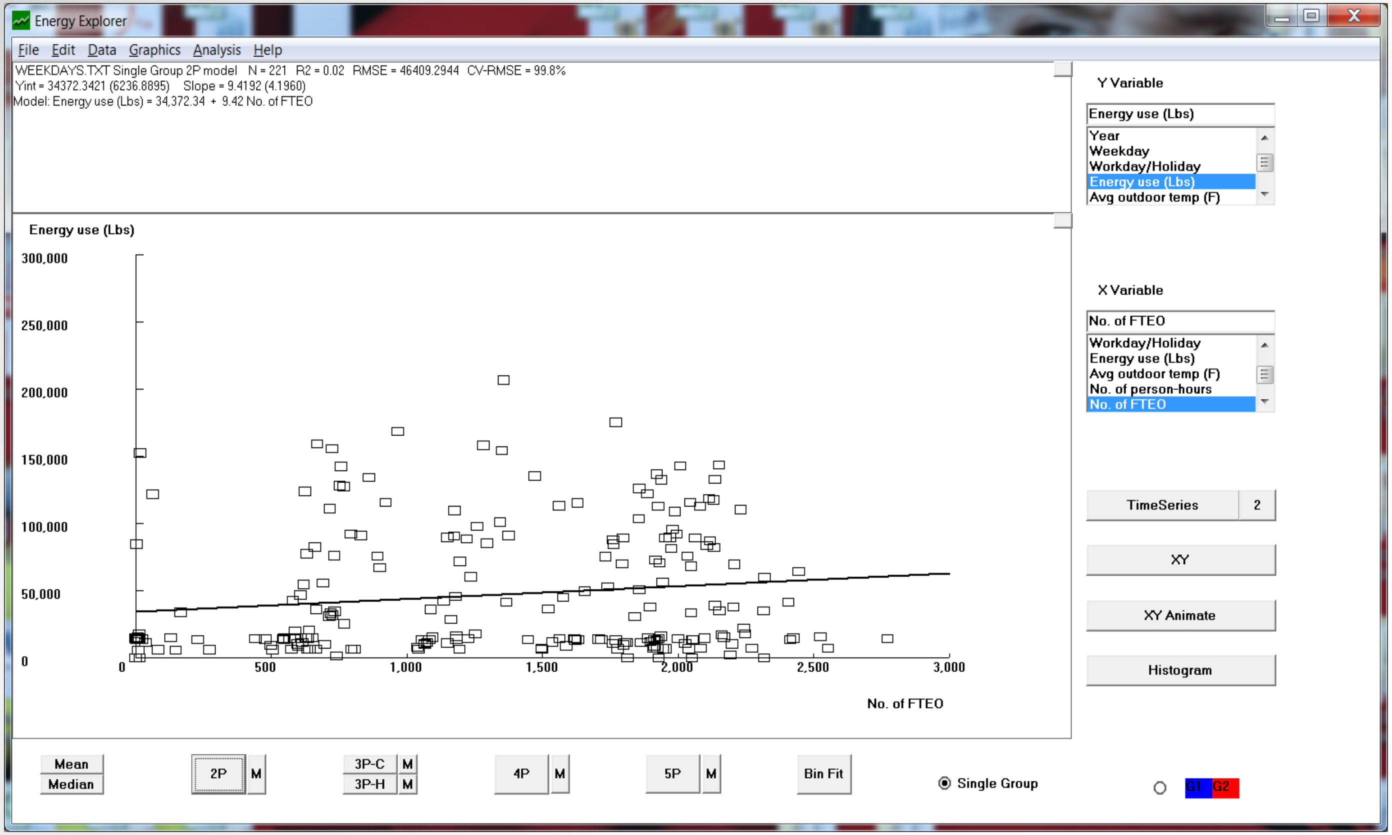
- Weekday Daily Steam Use vs. Daily Average Temperature
  - Weak Correlation R^2=0.34



Findings: GSA HQ Building
Steam Use Analysis

Pacific Northwest
NATIONAL LABORATORY
Proudly Operated by **Battelle** *Since 1965*

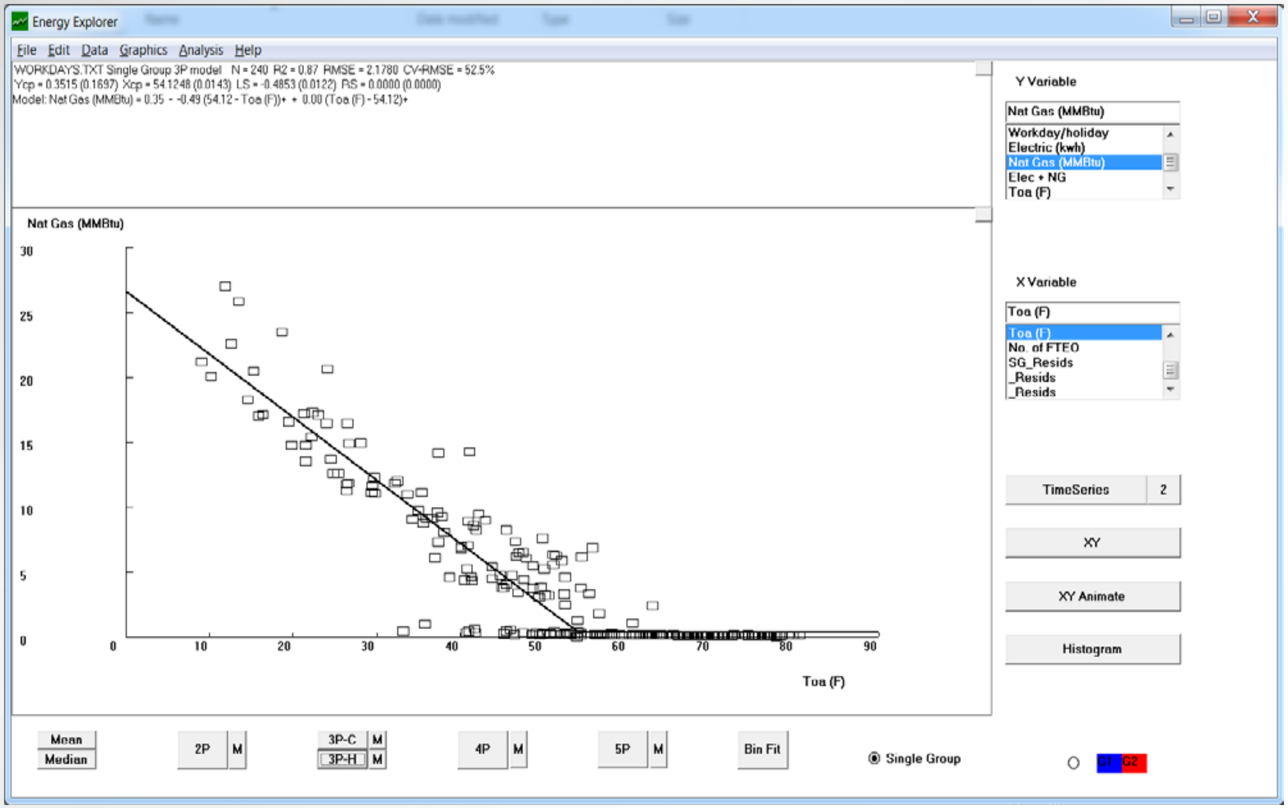
- Weekday Daily Steam Use vs. # of FTEOs
  - Very Weak / No Correlation R2 = 0.02



Findings: Byron Rogers Building
Natural Gas Use Analysis

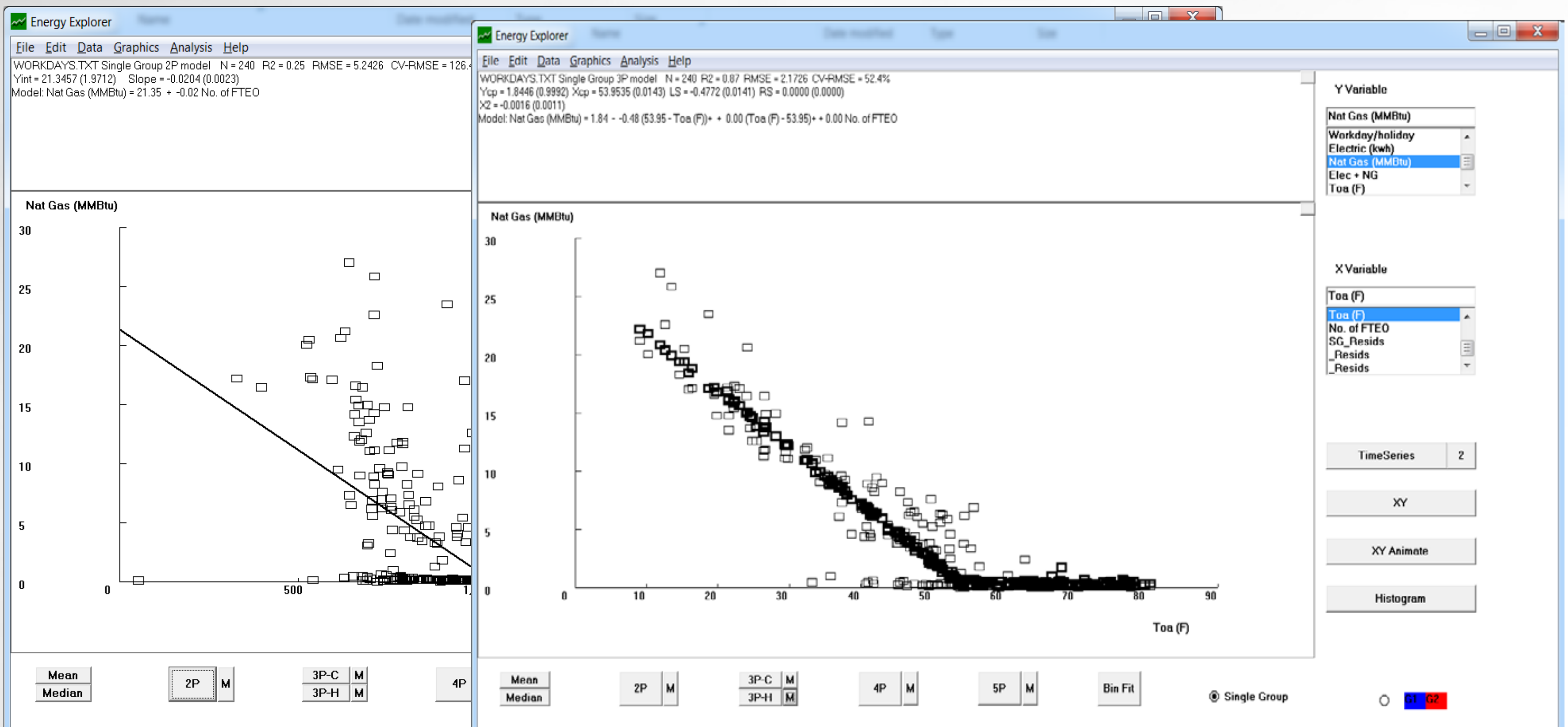
Pacific Northwest
NATIONAL LABORATORY
Proudly Operated by **Battelle** *Since 1965*

- Weekday Daily Natural Gas vs. Daily Average Temperature
  - Strong Correlation R2=0.87



Findings: Byron Rogers Building
Natural Gas Use Analysis

- Weekday Daily Natural Gas vs. FTEOs
  - Weak correlation R2 = 0.25, similar to electricity
  - Multivariate regression with temperature and FTEO did not improve, R2=0.85

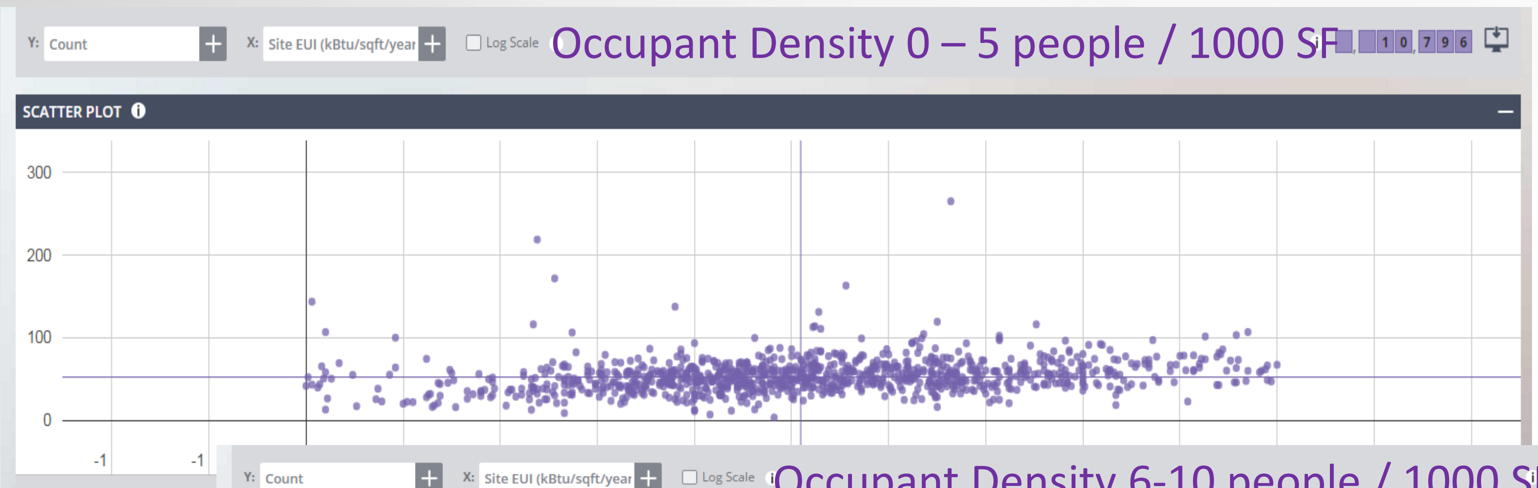


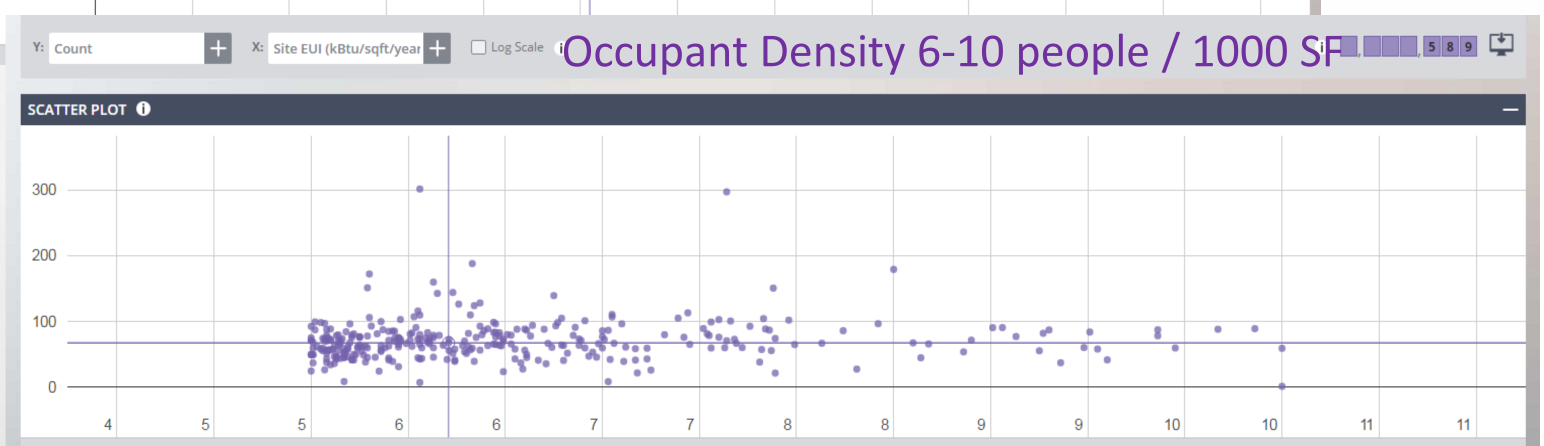
Pacific Northwest NATIONAL LABORATORY
Proudly Operated by Battelle *Since 1965*

Findings: Buildings Performance Database

Pacific Northwest NATIONAL LABORATORY
Proudly Operated by Battelle *Since 1965*

- Plotted site Electricity EUI vs. Occupant Density
- Data not accessible to run a regression, but visually there appears to be a slight upward trend, similar to the GSA building analysis results

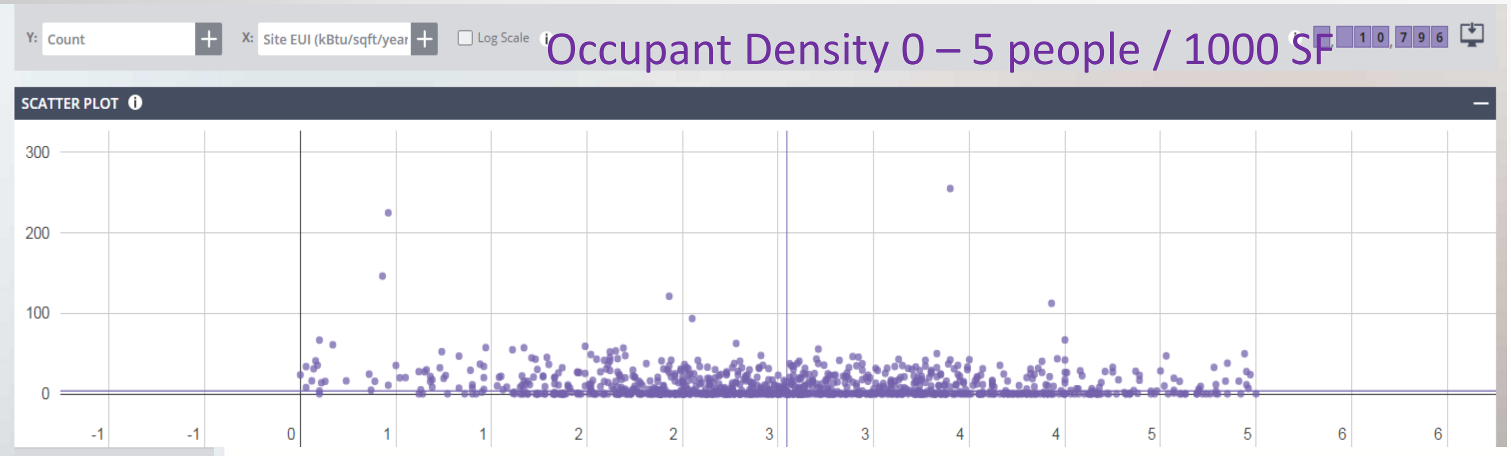


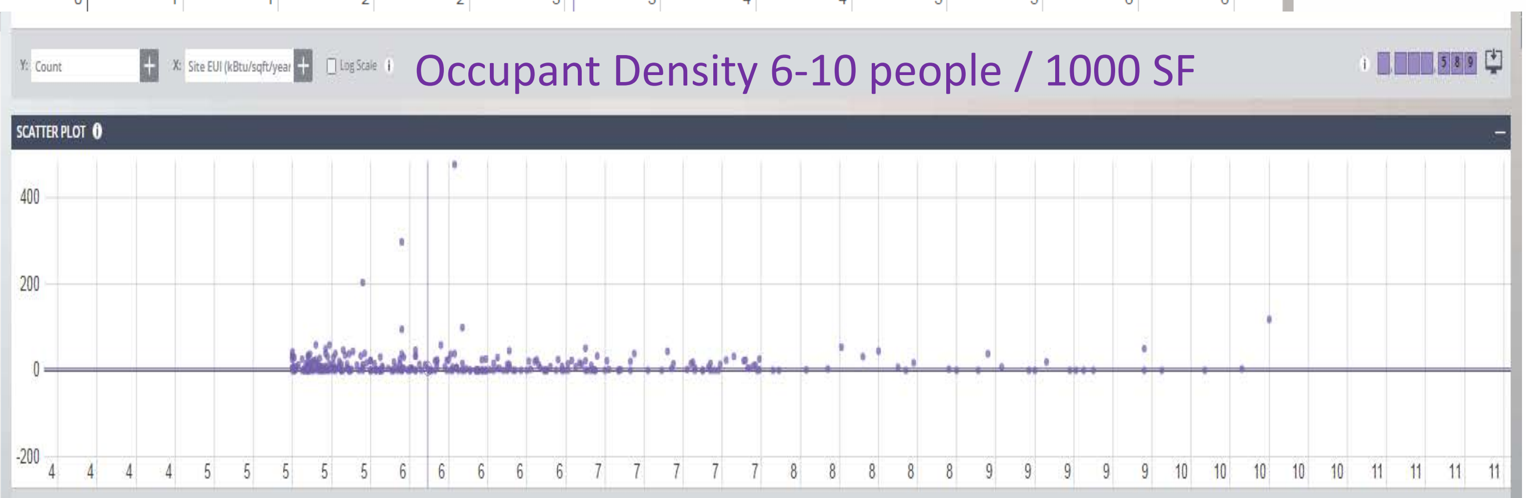


Pacific Northwest NATIONAL LABORATORY
Proudly Operated by **Battelle** *Since 1965*

Findings: Buildings Performance Database

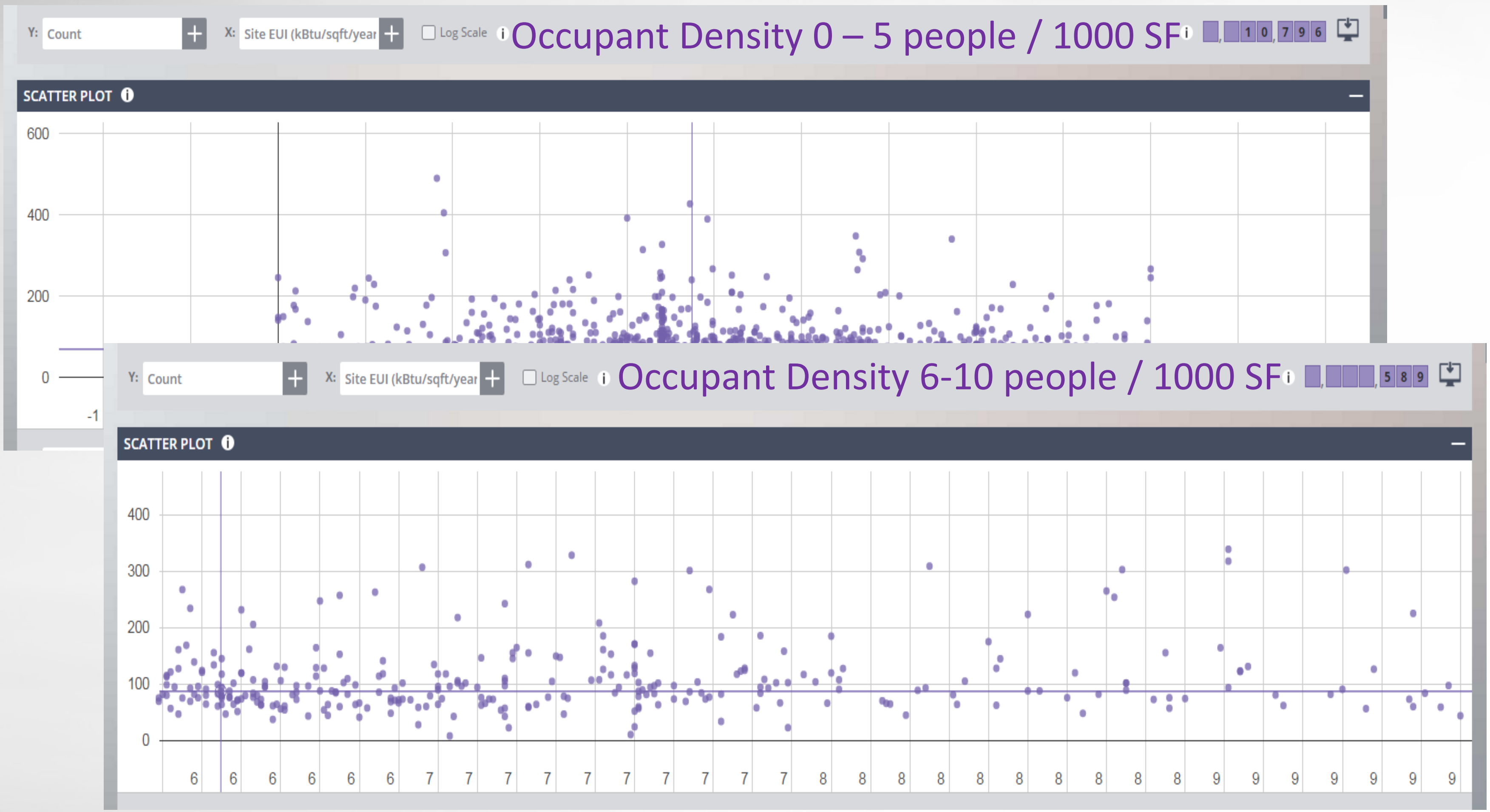
- Plotted site Fuel Use EUI vs. Occupant Density
- Visually, little to no observable correlation





Findings: Buildings Performance Database

- Plotted site Total EUI (Elect + Fuel) vs. Occupant Density
- Visually, little to no observable correlation



Findings: Assumptions about Typical Personal Loads in an Office Building

Pacific Northwest NATIONAL LABORATORY
Proudly Operated by **Battelle** *Since 1965*

	Average Watts			Duty cycle		
Blue = most have Yellow = some have	**On (w)**	**Off (w)**	**Standby (w)**	**hrs of/day "on"**	**hrs/day off**	**hrs/day in standby**
Desktop Computer (EStar)	46		2	7.2	1.7	15
Laptop computer (EStar)	14	0	1	2.4	6.2	15
LCD Monitor (EStar)	15	0.2	0.5	4.3	5.3	14
Computer speakers (Estar)	4.1		1	1.7	22.3	
Mobile phone charger	3.7	2.24	0.26	0.5	15.4	8.2
Phone: analog	1.1			24		
Phone: VOIP (EStar)	2.0			24		
Task lighting	36	0		1.8		22
Personal printer (laser)	131	1.58		0.5	24	
Personal printer (inkjet)	9	5.26		0.5	16	
Coffee maker	464	1.25		0.7	23.3	
Space heater	1,500		1.03	0.1		23.9
Compact refrigerator (Estar)	28			24	-	

Adjustment Factor to Traditional EUI based on Occupancy

Pacific Northwest NATIONAL LABORATORY
Proudly Operated by **Battelle** *Since 1965*