NREL
NATIONAL RENEWABLE ENERGY LABORATORY

Innovation for Our Energy Future

NREL's Research Support Facility: Plug Load Efficiency Strategies in Meeting Net Zero Energy Goals

Shanti Pless, LEED AP
Senior Research Engineer

NREL Commercial Buildings Research Group

January 29, 2013

NREL
NATIONAL RENEWABLE ENERGY LABORATORY

Overview | Owners | Occupants | Facility Managers

Assessing and Reducing Plug and Process Loads in Office Buildings

Overview

Plug and process loads (PPLs) in commercial buildings account for almost 5% of U.S. primary energy consumption (McKenney et al. 2010). Minimizing these loads is a primary challenge in the design and operation of an energy-efficient building. PPLs are not related to general lighting, heating, ventilation, cooling, and water heating, and typically do not provide comfort to the occupants. They use an increasingly large fraction of the building energy use pie because the number and variety of electrical devices have increased along with building system efficiency. Reducing PPLs is difficult because energy efficiency opportunities and the equipment needed to address PPL energy use in office spaces are poorly understood.

Purpose of This Document ▼

The results of plug load audits and long-term PPL studies, conducted by the U.S. Department of Energy's National Renewable Energy Laboratory, have yielded the following process and strategies. These PPLs are some of the largest that are typically found in office buildings and are the most likely to have a high energy savings potential.

This document provides an overview of PPLs and provides strategies for building owners, occupants, and facility managers to reduce PPLs. It is also intended to guide the procurement of new equipment.

Plug and Process Loads Reduction Process ▼

The following steps provide a guide to reduce PPLs in an office building.

Step 1: Establish a Plug and Process Loads Champion

The first step in addressing PPLs in a low-energy building is to establish a PPL champion (or a team of champions) to initiate and help with the process. This person needs to understand technical energy efficiency opportunities and design strategies and be able to independently and objectively apply business model cost justifications. He or she must be willing and able to question the owner's operations, institutional policies, and procurement processes.

Step 2: Develop a Business Case for Addressing Plug and Process Loads

To gain buy-in from all parties involved, especially the building owner, the champion must develop a business case for addressing PPLs.

In most projects, the business case will be the energy and energy cost savings associated with each strategy. The business case gives all parties a financial incentive to investigate PPLs and pay close attention to mass-distributed items and large load, low quantity, continuous use items.

Step 3: Benchmark Current Equipment and Operations

An energy audit needs to be performed to establish a baseline of PPLs and operations. It can be carried out, in part, with many commercially available PPL power meters. If PPLs cannot be studied with conventional meters, a combination of submetering and manufacturers' specification sheets can be used. Once the data from the audit are collected, they can be used to understand when equipment is used and highlight opportunities to turn off the equipment when it is not in use.

National Renewable Energy Laboratory
1617 Cole Boulevard, Golden, Colorado 80401
303-275-3000 • www.nrel.gov

NREL is a national laboratory of the U.S. Department of Energy
Office of Energy Efficiency and Renewable Energy
Operated by the Alliance for Sustainable Energy, LLC

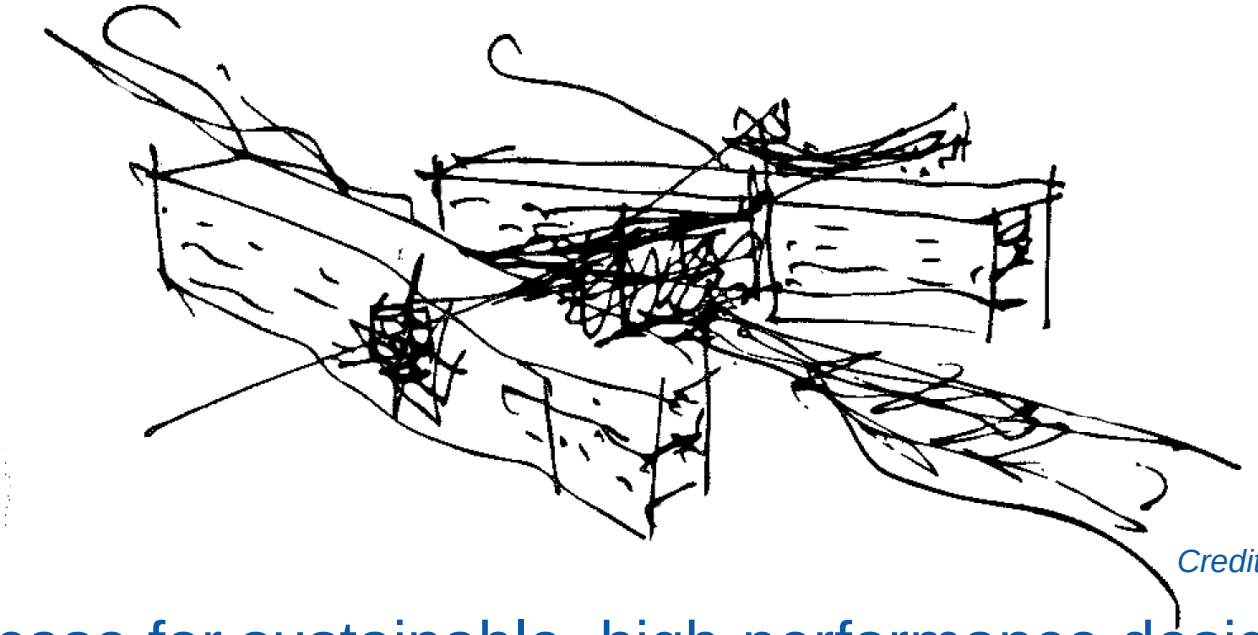
NREL/BR-5500-51199 • June 2011

http://www.nrel.gov/docs/fy11osti/51199.pdf

NREL: 2006

Used with Permission from Haselden

Research Support Facility Vision



Credit: RNL

- A showcase for sustainable, high-performance design
  - Incorporates the best in energy efficiency, environmental performance, and advanced controls using a “whole-building” integrated design process
- Serves as a model for cost-competitive, high-performance commercial buildings for the nation’s design construction, operation, and financing communities

NREL: Today

DOE/NREL Research Support Facility: Project Goals

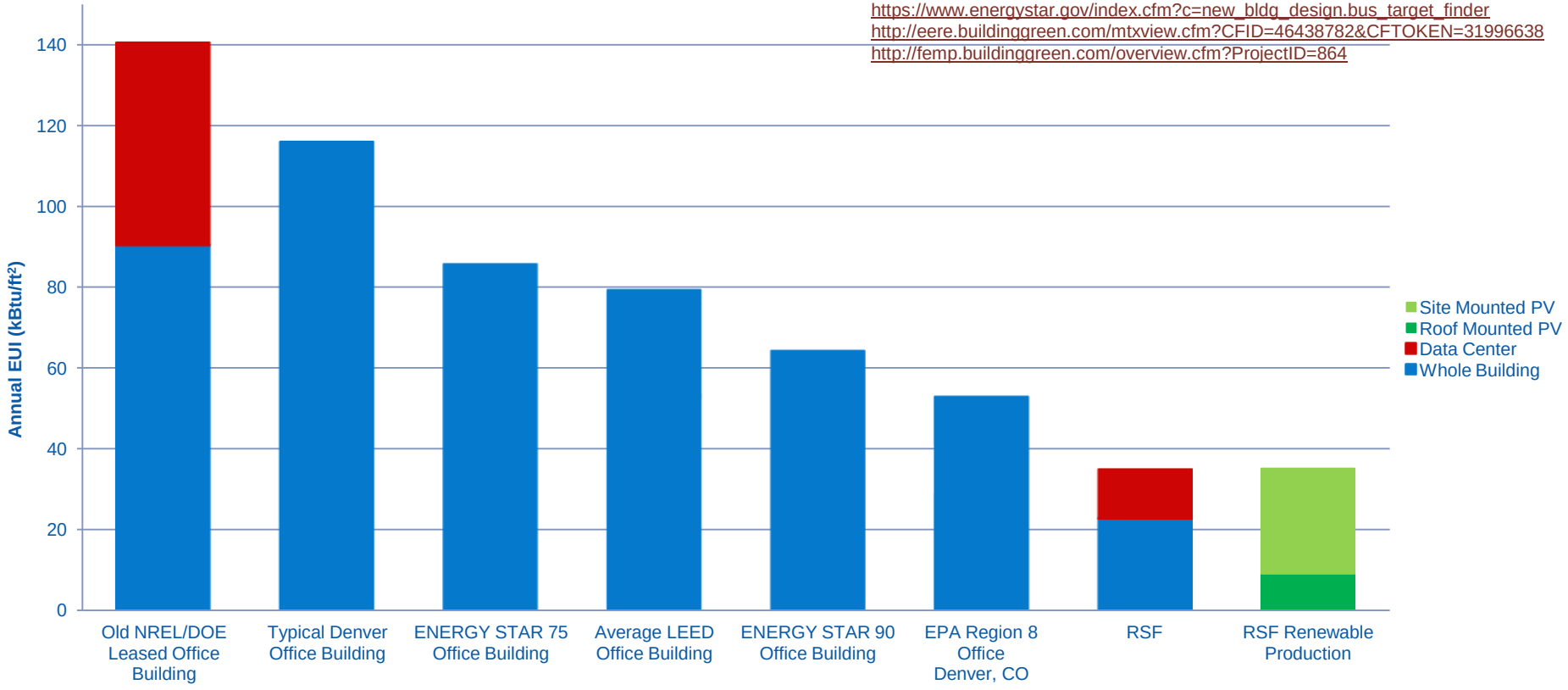
- More than 800 people in DOE office space on NREL's campus
- 220,000 ft^2
- Design/build process with required energy goals
  - 25 kBtu/ft^2
  - 50% energy savings
  - LEED Platinum
- Replicable
  - Process
  - Technologies
  - Cost
- Site, source, carbon, cost ZEB:B
  - Includes plugs loads and datacenter
- Firm fixed price of ~$64 million
  - $259/ft^2 construction cost (not including $27/ft^2 for PV from PPA/ARRA)
- Open first phase June 10, 2010

Credit: Haselden Construction

Energy Efficiency Design Requirements

- 25 kBtu/ft^2/yr for standard office space occupant density and data center loads
  - Demand side energy use goal, not including renewables
  - Normalized up to 35.1 kBtu/ft^2/yr for better space efficiency and to account for full data center load
- On site renewables sized to offset site energy use to reach net zero annual use

References:
https://www.energystar.gov/index.cfm?c=new_bldg_design.bus_target_finder
http://eere.buildinggreen.com/mtxview.cfm?CFID=46438782&CFTOKEN=31996638
http://femp.buildinggreen.com/overview.cfm?ProjectID=864

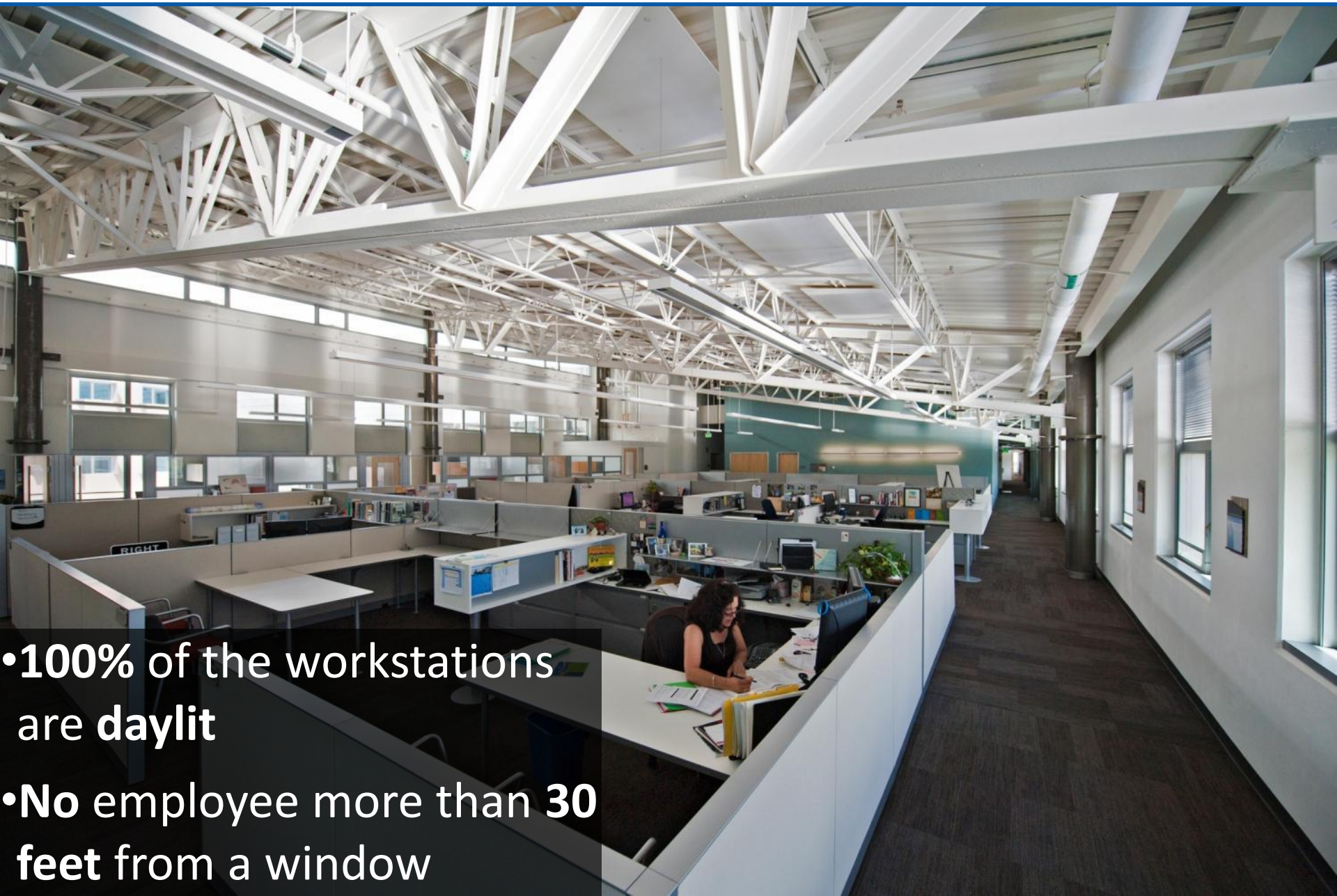


Credit: Chad Lobato/NREL

Key Design Strategies

- Optimal orientation and office space layout
- Fully daylit office wings with high-performance electrical lighting
- Continuous insulation precast wall panels with thermal mass
- Operable windows for natural ventilation
- Radiant heating and cooling
- Outdoor air preheating
  - Transpired solar collector
  - Data Center waste heat
  - Exhaust air heat recovery
  - Crawl space thermal storage
- Aggressive plug load control strategies
- Data Center outdoor air economizer with hot aisle containment
- Roof top- and parking lot-based PV

Daylighting

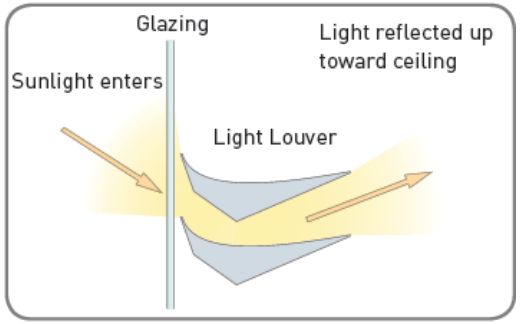


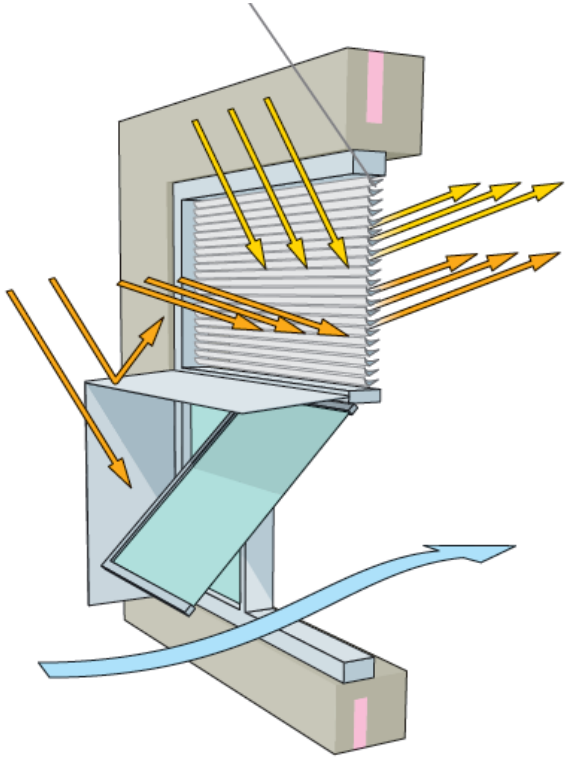
- **100%** of the workstations are **daylit**
- **No** employee more than **30 feet** from a window

Daylighting: Glare Control

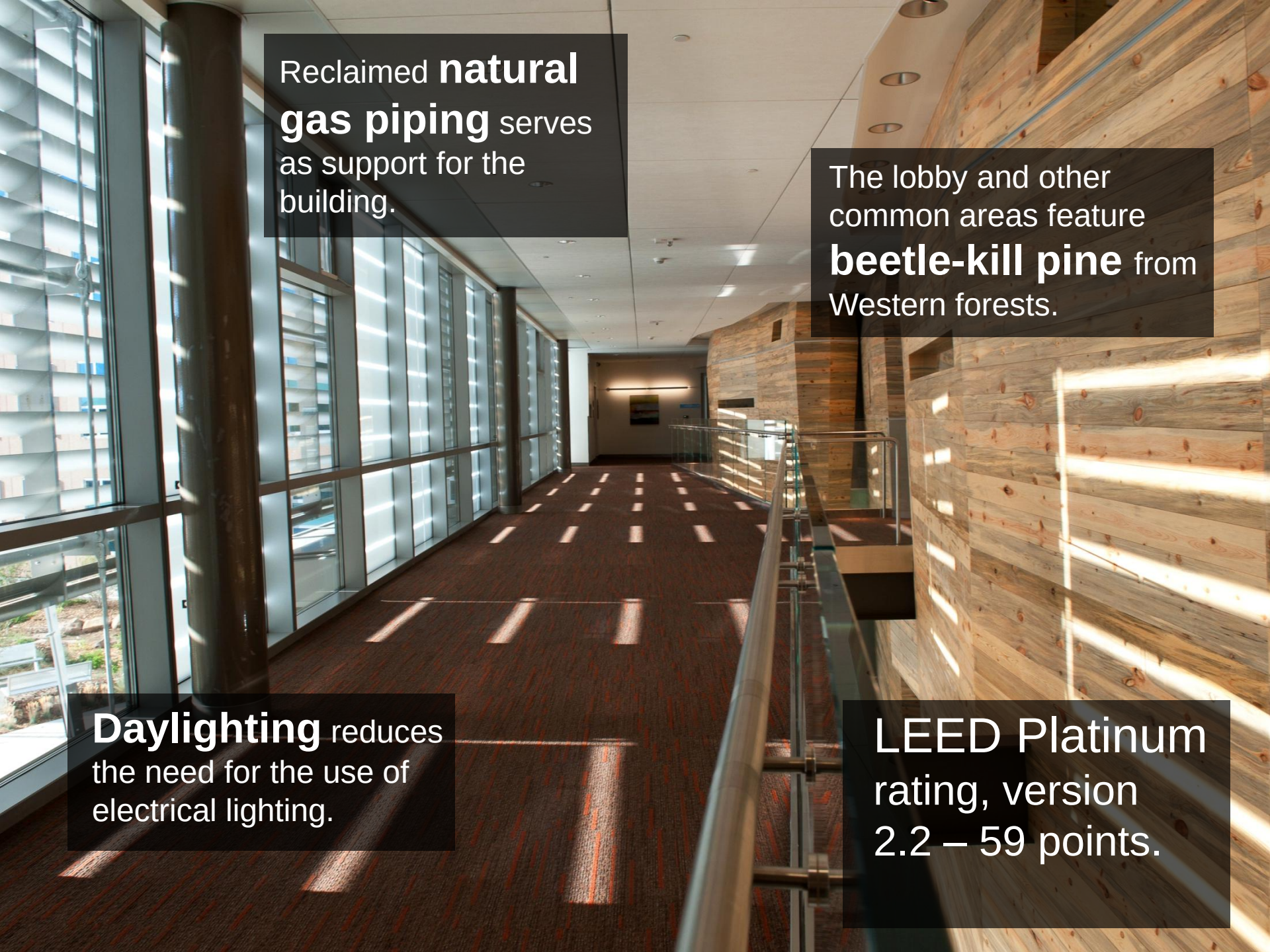
A light redirecting device reflects sunlight to the ceiling, creating an indirect lighting effect.

Fixed sunshades limit excess light and glare.



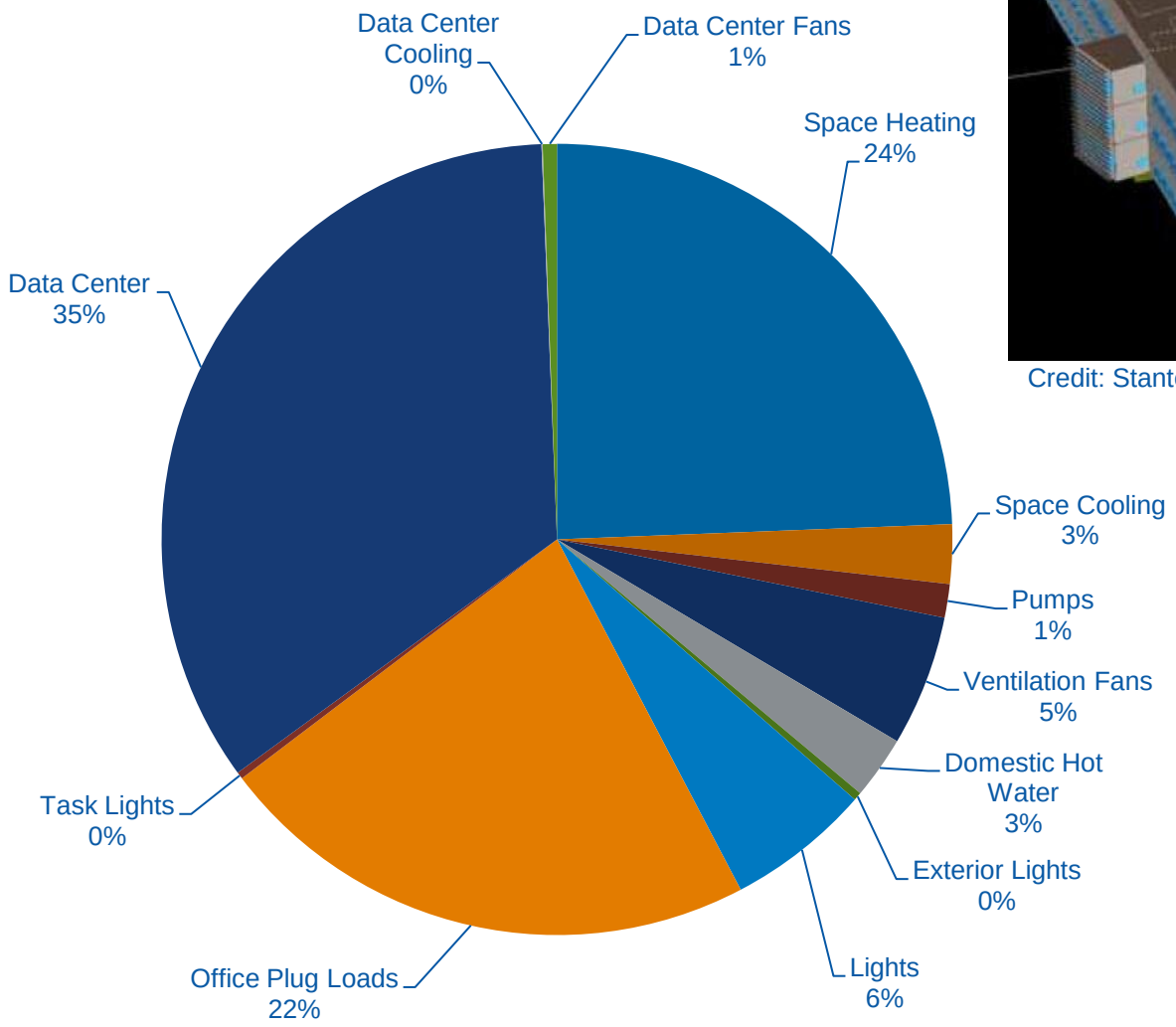


Credit: RNL

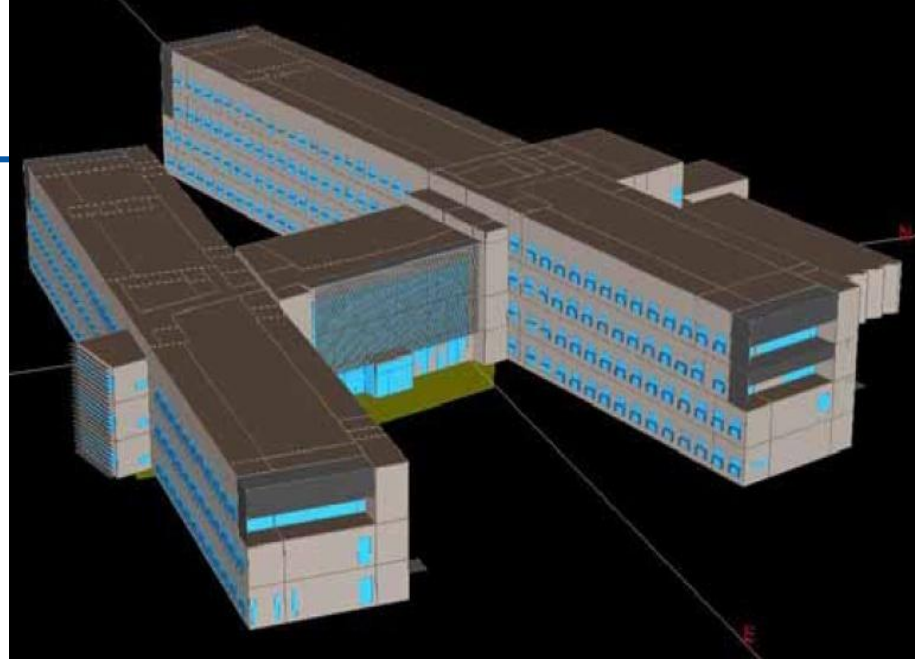

Reclaimed **natural gas piping** serves as support for the building.
The lobby and other common areas feature **beetle-kill pine** from Western forests.
Daylighting reduces the need for the use of electrical lighting.
LEED Platinum rating, version 2.2 – 59 points.

Energy Modeling

NREL RSF Energy Use Breakdown



Credit: Chad Lobato/NREL



Credit: Stantec

End Use	kBtu/ft²
Space Heating	8.58
Space Cooling	0.85
Pumps	0.48
Ventilation Fans	1.88
Domestic Hot Water	0.90
Exterior Lights	0.12
Lights	2.07
Office Plug Loads	7.87
Task Lights	0.10
Data Center	12.11
Data Center Cooling	0.02
Data Center Fans	0.20

Living in a ZEB: Every Watt Counts

- Whole building energy use = 283 Watts continuous per occupant
  - 4-5 incandescent light bulbs per occupant continuous
  - $8500 of PV per occupant
- For every 1 watt continuous we save, we avoid $33 of PV needed to offset this 1 watt
- Every watt counts!

Day vs. Night Plug and Process Loads

Only occupied about ⅓ of the time

-Nights Unoccupied

-Weekends Unoccupied

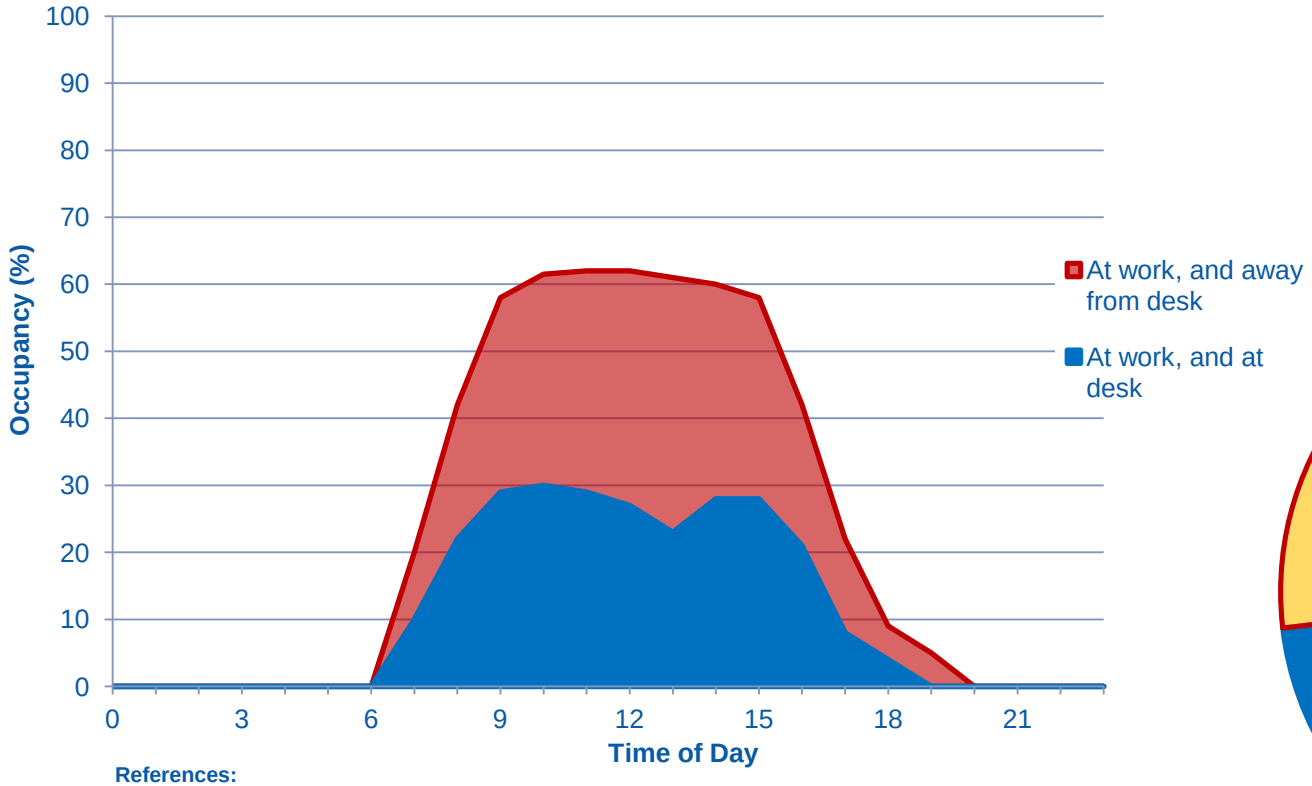
-Holidays Unoccupied

Annual Plug Load Energy Use Intensity (kBtu/ft²)

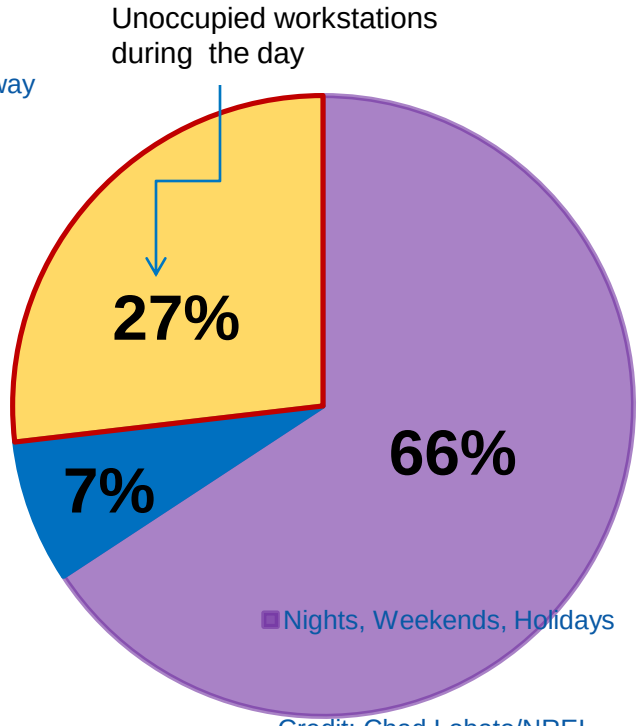
Occupied Hours Power Density (W/ft²) \ Unoccupied Hours Power Density (W/ft²)	0.10	0.20	0.30	0.40	0.50	0.60	0.70	0.80	0.90	1.00	1.10	1.20	1.30	1.40	1.50
0.10	3.0	5.2	7.4	9.7	11.9	14.1	16.3	18.6	20.8	23.0	25.2	27.4	29.7	31.9	34.1
0.20	3.8	6.0	8.2	10.4	12.7	14.9	17.1	19.3	21.5	23.8	26.0	28.2	30.4	32.7	34.9
0.30	4.5	6.8	9.0	11.2	13.4	15.6	17.9	20.1	22.3	24.5	26.8	29.0	31.2	33.4	35.6
0.40	5.3	7.5	9.7	12.0	14.2	16.4	18.6	20.9	23.1	25.3	27.5	29.7	32.0	34.2	36.4
0.50	6.1	8.3	10.5	12.7	15.0	17.2	19.4	21.6	23.8	26.1	28.3	30.5	32.7	35.0	37.2
0.60	6.8	9.1	11.3	13.5	15.7	17.9	20.2	22.4	24.6	26.8	29.1	31.3	33.5	35.7	38.0
0.70	7.6	9.8	12.0	14.3	16.5	18.7	20.9	23.2	25.4	27.6	29.8	32.1	34.3	36.5	38.7
0.80	8.4	10.6	12.8	15.0	17.3	19.5	21.7	23.9	26.2	28.4	30.6	32.8	35.0	37.3	39.5
0.90	9.1	11.4	13.6	15.8	18.0	20.3	22.5	24.7	26.9	29.1	31.4	33.6	35.8	38.0	40.3
1.00	9.9	12.1	14.4	16.6	18.8	21.0	23.2	25.5	27.7	29.9	32.1	34.4	36.6	38.8	41.0
1.10	10.7	12.9	15.1	17.3	19.6	21.8	24.0	26.2	28.5	30.7	32.9	35.1	37.3	39.6	41.8
1.20	11.4	13.7	15.9	18.1	20.3	22.6	24.8	27.0	29.2	31.4	33.7	35.9	38.1	40.3	42.6
1.30	12.2	14.4	16.7	18.9	21.1	23.3	25.5	27.8	30.0	32.2	34.4	36.7	38.9	41.1	43.3
1.40	13.0	15.2	17.4	19.6	21.9	24.1	26.3	28.5	30.8	33.0	35.2	37.4	39.7	41.9	44.1
1.50	13.7	16.0	18.2	20.4	22.6	24.9	27.1	29.3	31.5	33.8	36.0	38.2	40.4	42.6	44.9

Annual Occupied Hours

- Nights, weekends, and holidays account for 66% of the year
  - A typical office building is unoccupied during this time
- During a typical work day, building occupants are only at their desk less than 30% of the time
  - Workstations are vacant and should be powered down during more than 70% of business hours
- Workstations should only be powered 7% of the year!



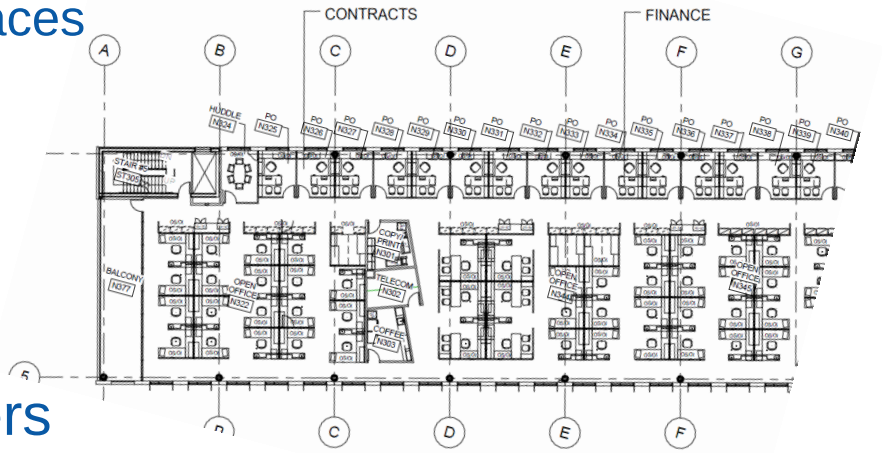
References:
http://www.gsa.gov/graphics/pbs/WorkPlace_Matters_FINAL508_lowres.pdf



Credit: Chad Lobato/NREL

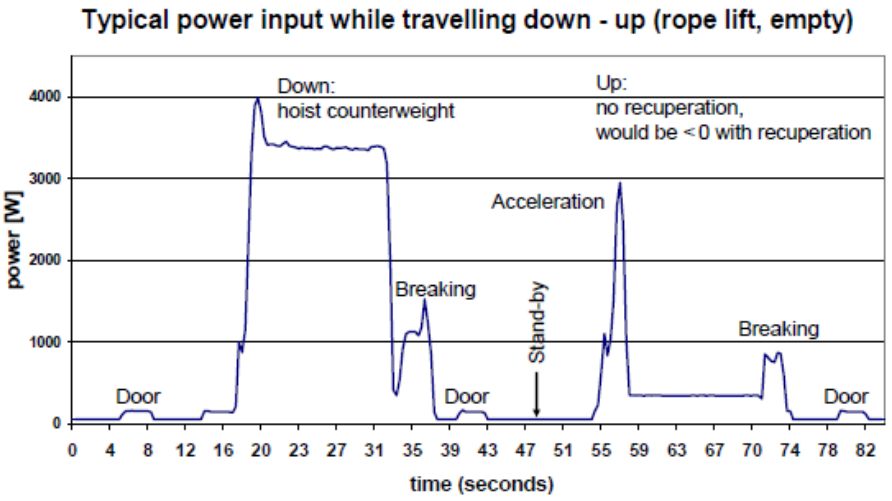
Plug and Process Load Opportunities:
Design Team Opportunities

- How can space efficiency reduce office equipment?
  - Maximize use of commons spaces
    - Copy rooms
    - Break rooms
- Design to use stairs
  - Regenerative elevators
    - Slower is ok
- Minimize distribution transformers
- Exhaust transfer air for cooling of network/switch rooms
- Opportunities to turn off parasitic office equipment
  - Occupancy sensor power strips
  - Scheduled outlets
- Integrated datacenter cooling
  - Air side economizer
  - Evaporative cooling
  - Waste heat recovery



Elevators

- Regenerative Traction Elevators
  - Machine Room Less Elevator
  - Space Savings
  - Recovers breaking energy and converts it to AC electricity
- Change elevator lighting to energy efficient fluorescent lighting or LEDs
- Turn off lighting and fans when the elevator is unoccupied



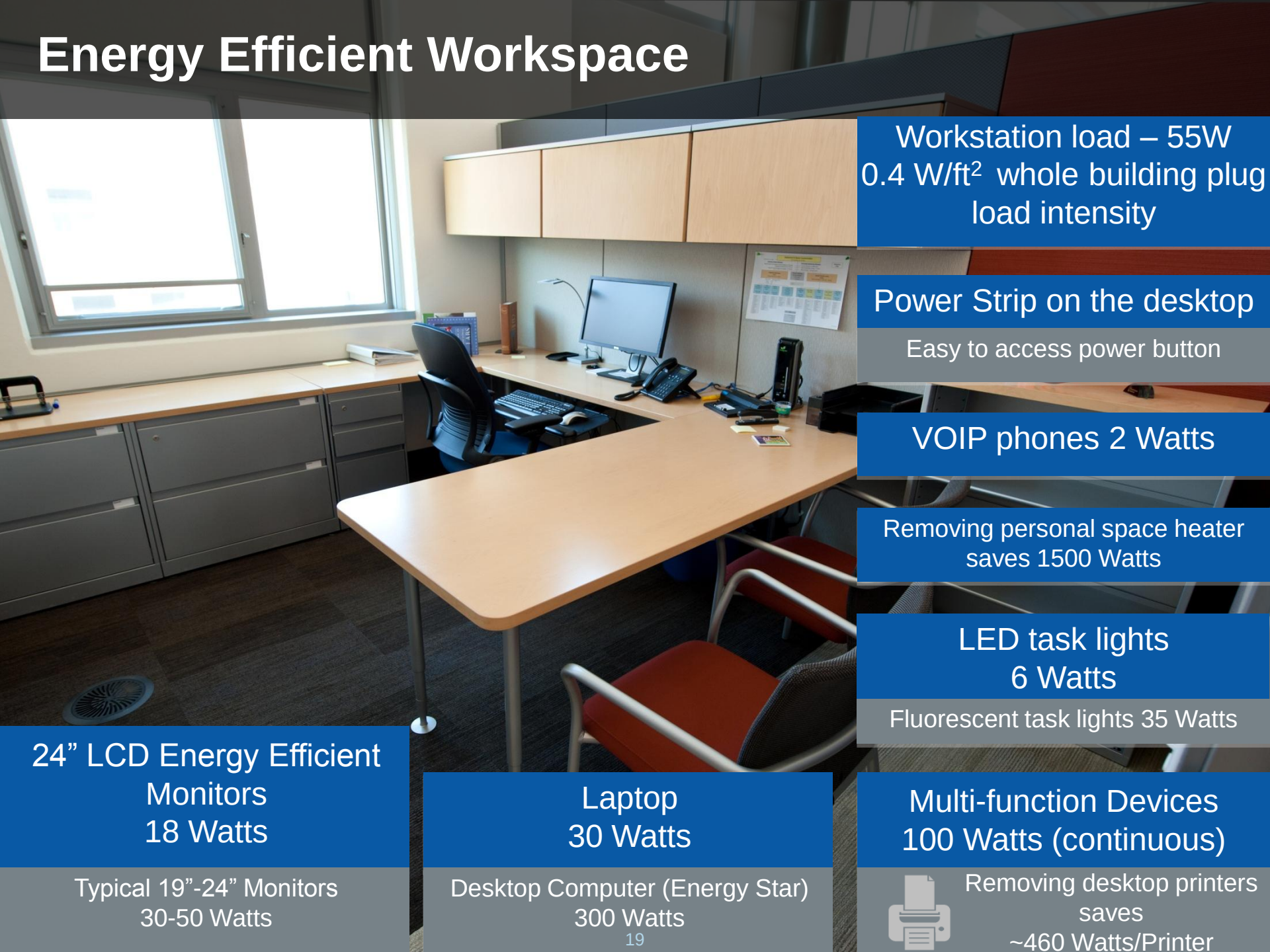
Credit: Jürg Nipkow, Swiss Agency for Efficient Energy Use

Plug and Process Load Opportunities:
Owner Opportunities

- Document current space efficiency and plug load profiles
- Multifunction Devices
  - 75% less printers
- Workstation
  - Laptops, VOIP 2 W phones, 6 W LED task lights
- Efficiency datacenter operations
  - Blade servers with virtualization
  - ASHRAE temperature Guidelines
  - Fully contained hot aisle
- All the other “STUFF”
  - EnergyStar only a starting point
  - Hand operated compact shelving
  - Minimize individual stuff
  - Question all operations!

Workstation Type	Power	Savings
Standard PC	400w	0%
Energy Star PC	300w	25%
Laptop	60w	85%
Thin Client	35w	91%

Energy Efficient Workspace



Workstation load – 55W
0.4 W/ft^2 whole building plug load intensity

Power Strip on the desktop

Easy to access power button

VOIP phones 2 Watts

Removing personal space heater saves 1500 Watts

LED task lights
6 Watts

Fluorescent task lights 35 Watts

24” LCD Energy Efficient Monitors
18 Watts

Typical 19”-24” Monitors
30-50 Watts

Laptop
30 Watts

Desktop Computer (Energy Star)
300 Watts

Multi-function Devices
100 Watts (continuous)

Removing desktop printers saves
~460 Watts/Printer

Multifunction Devices

- Multifunction energy-star 4.0 compliant devices
- Lower Maintenance
- Higher performance
- Reduce number of network printers by 75%
- Strong justification will be required for personal printers
- Do not use banner pages
- Default to duplex printing
- Business processes are becoming increasing paperless
- Use recycled materials

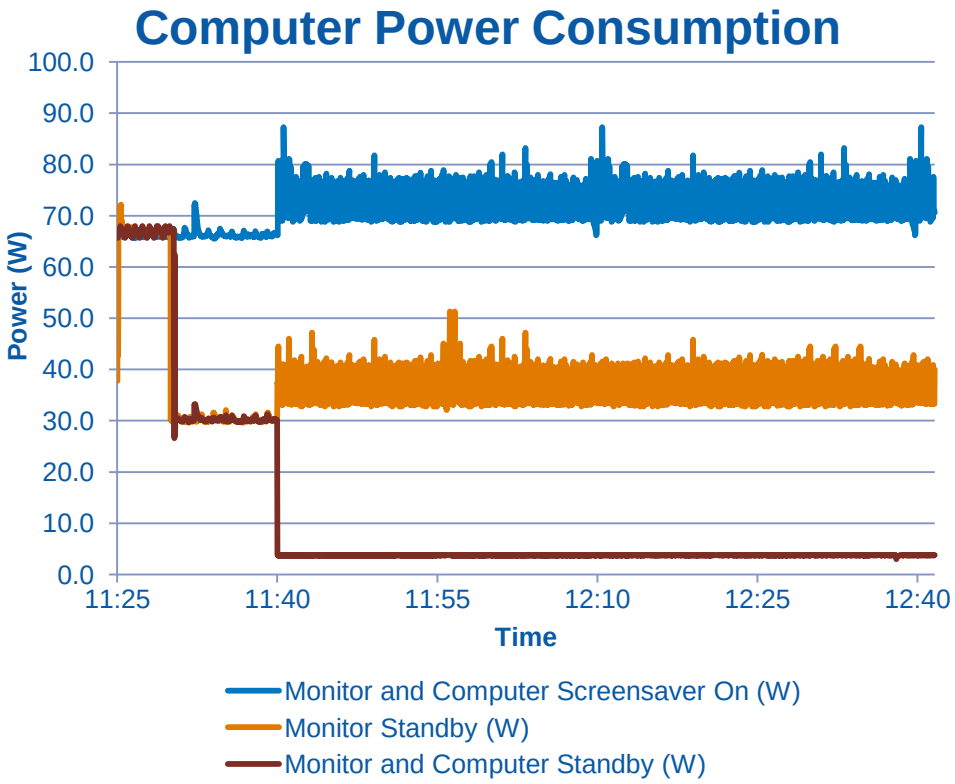
Functions?

- Printing
- Copying
- Scan to mailbox
- Standard fax
- Fax from desktop

NREL Cyber-Security Policy

Evaluate policies and operations to ensure effectiveness

- NREL currently used a screensaver to lock unused computers
  - The screensaver consumes on average 5W more than an idle computer
- Instead of a screensaver, if the monitors and computers went into standby there would be a savings of 70W per person
- ~$500,000 of PV saved
- Anything multiplied by 800 is a lot!



NREL Old Coffee Car Daily Load Profile

RSF Data Center

Moving towards high-density blade servers

- Highly efficient power supplies
- Variable speed fans
- Wake-on-LAN

Server virtualization

- Ratio: 4-8 to 1

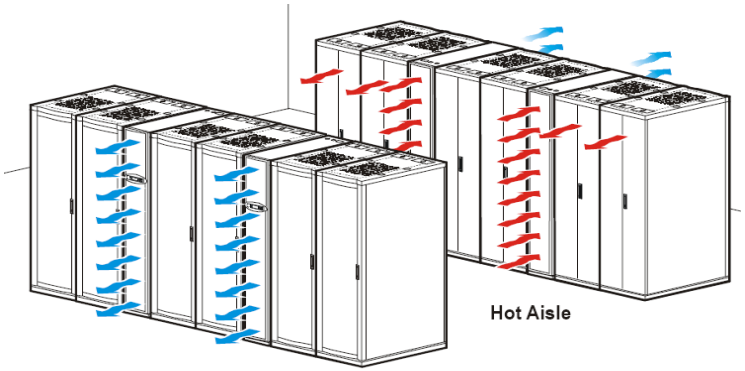
Dynamic Workload management

- Server resources go from “always on” to “always available”
- Resources are powered up or down as resources are needed

Hot aisle containment with airside economizer and evaporative cooling

Target PUE of 1.1 vs. legacy PUE of 2.5

Expected reduction of 65% in total data center power consumption



RSF Plug Load Reduction Strategies

Elevators
- Use energy efficient traction elevators
- Change elevator lighting to energy efficient fluorescent lighting
- Turn off elevator lighting when the elevator is unoccupied

Break Rooms
- Increase the number of people that use each break room from approximately 40 to 60
- Eliminate the cooler on the drinking fountain

Task Lights
- Move from 35W fluorescent task lights to 6W LED task lights

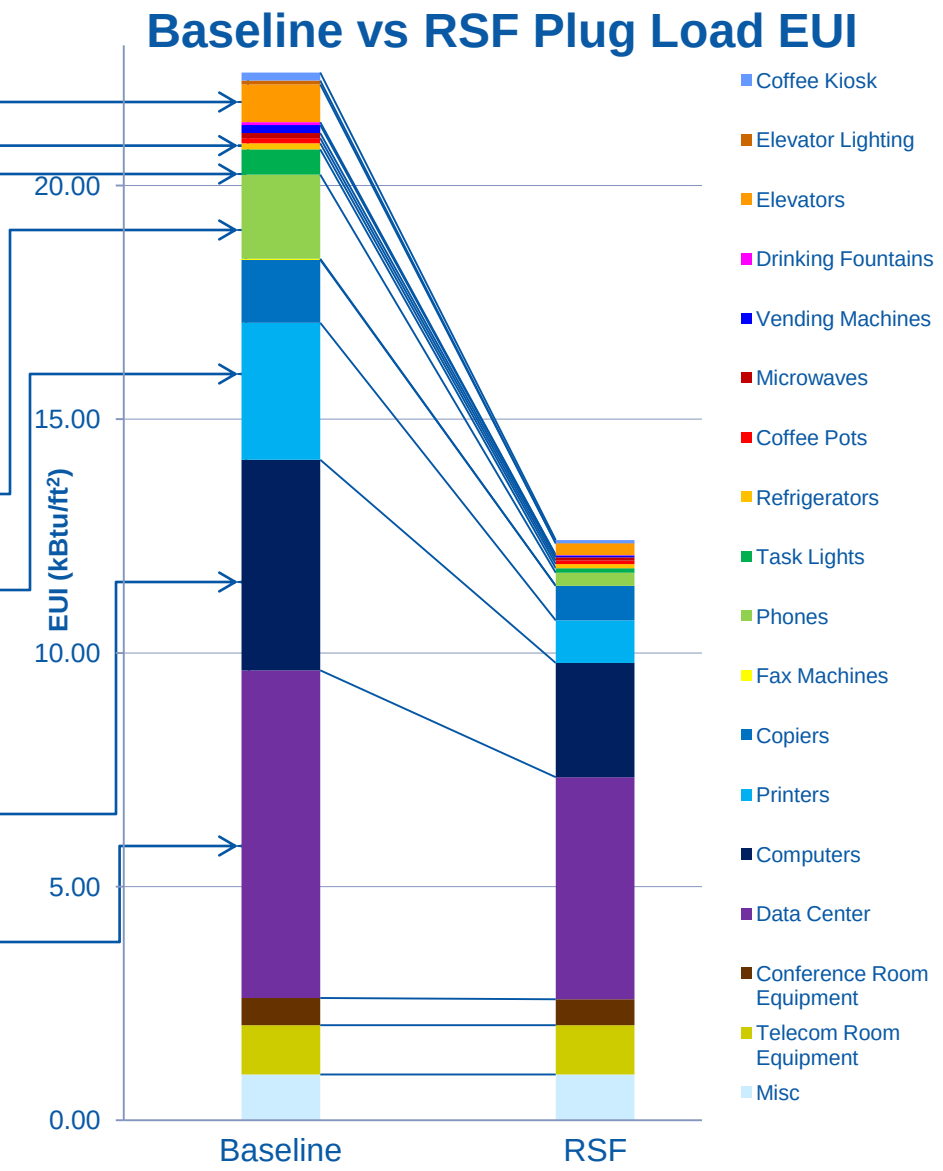
Phones
- Go from 1000 standard phones to 1000 VOIP phone that consumes 2W each

Copiers, Printers, Fax Machines
- Decrease the number people that use individual copiers, printers and fax machines
- Increase the number of people that use common, or group, copiers, printers and fax machines from 15 to 20
- Increase the use of all-in-one machines

Computers
- Go from approximately 260 laptops, 33% of staff, to 720, 90% of staff, ensure standby mode works for all workstations

Data Center
- Blade Servers with Virtualization
- High efficiency UPS
- 65W/employee current to 48W/employee in RSF

The result of these strategies is a 47% reduction in plug loads



October 2010 – August 2011 Plug Load Power Density

Credit: Marjorie Schott/NREL

Power Density (W/ft²)

Time of Day

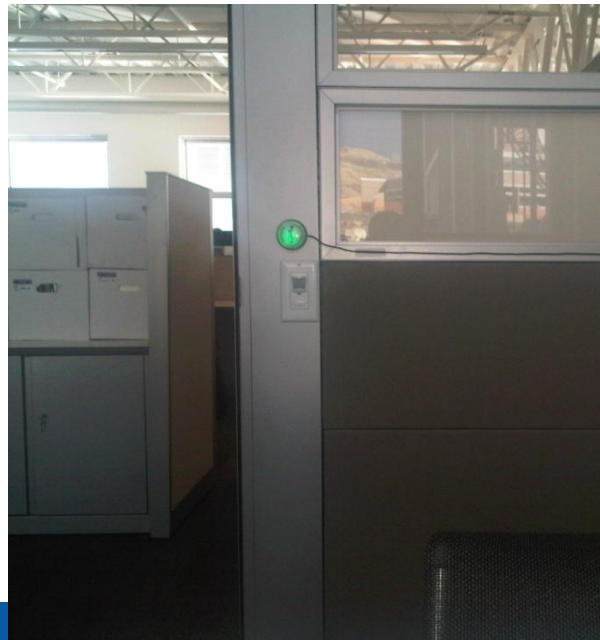
Model Average
October 2010
November 2010
December 2010
January 2011
February 2011
March 2011
April 2011
May 2011
June 2011
July 2011
August 2011

Credit: Chad Lobato/NREL

Note: The elevators are included in the plug loads

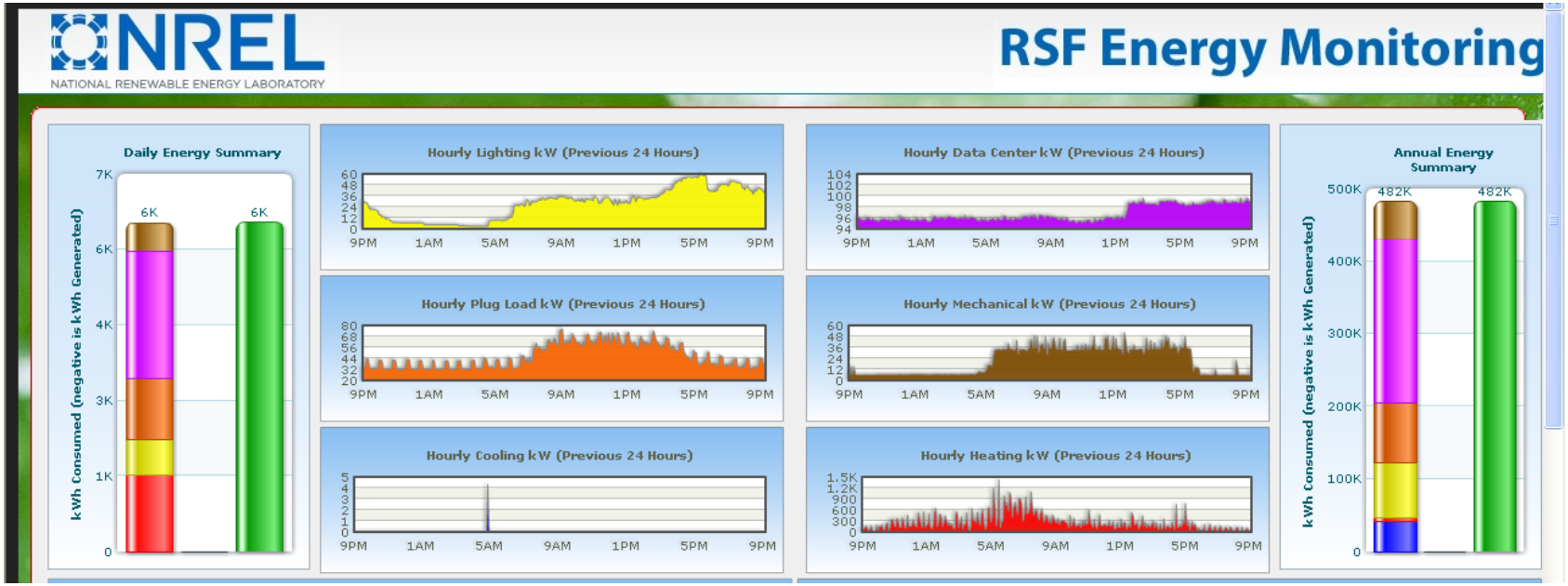
Operations Lessons – Plug loads

- Daytime loads lower than predicted
  - Model did not account for actual occupancy
    - Only ~75% of occupants actually at their desk any given day
- Nighttime loads still difficult
  - Programmable outlets added after the fact
  - Automatic Laptop standby/hibernate functionality deployed system-wide
    - Monitors go to sleep well
    - Laptops have insomnia (except Macs)
    - Need a forced standby function and not rely on integrated windows standby
    - Ensure Wake-On-LAN functionality
  - Staff have not fully utilized desktop based power strip controls
- Continued staff educational programs
- Need to develop an optimal workstation plug load control system
  - Programmable power strips to disconnect all plugs at night?
  - Easy to use office plug load disconnect switch?



Operations Lessons – Plug loads Cont..

- 2 Refrigerators per break room sometimes excessive
  - Some groups unplug and don't use second refrigerator
- Utilize more switched outlets or controllable outlets
  - Or allow for programmable plugs
  - Energy Monitoring Displays on all night…

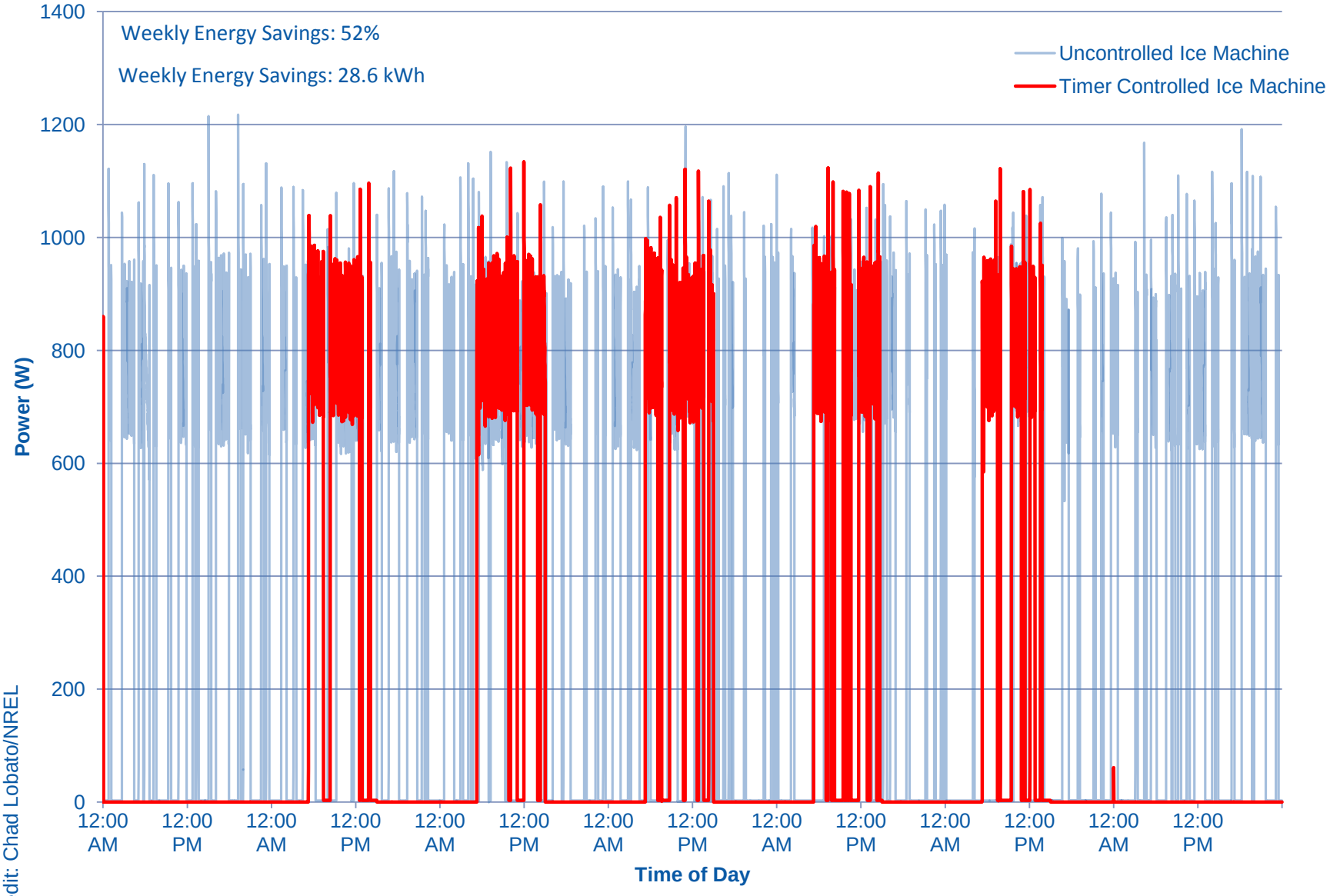


Ice Machine Timed Outlet

- The devil is in the details…
- Saved 52% energy use on an ENERGY STAR® ice machine with a $15 programmable outlet

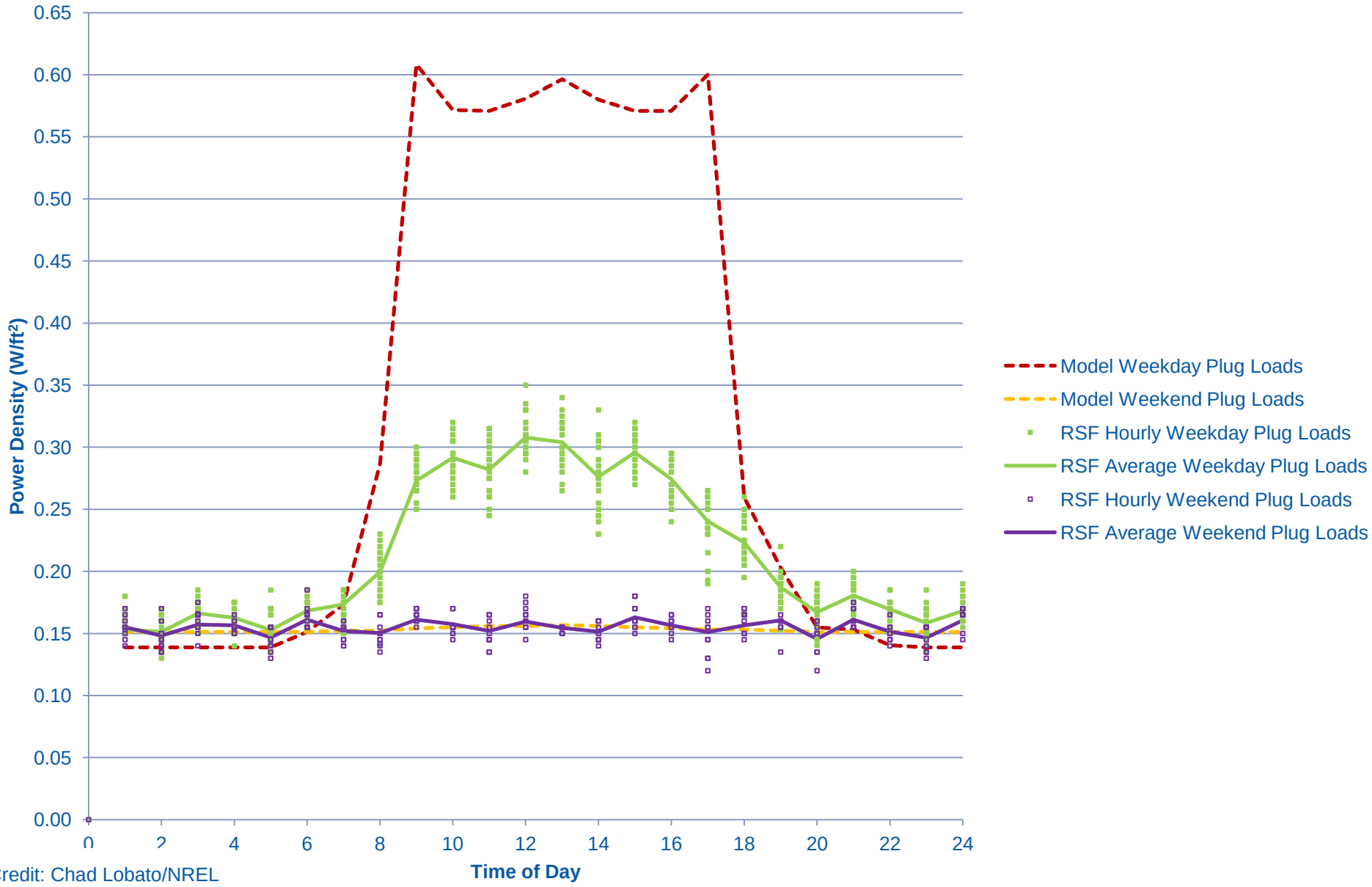
Credit: Chad Lobato/NREL

Ice Machine Timed Outlet



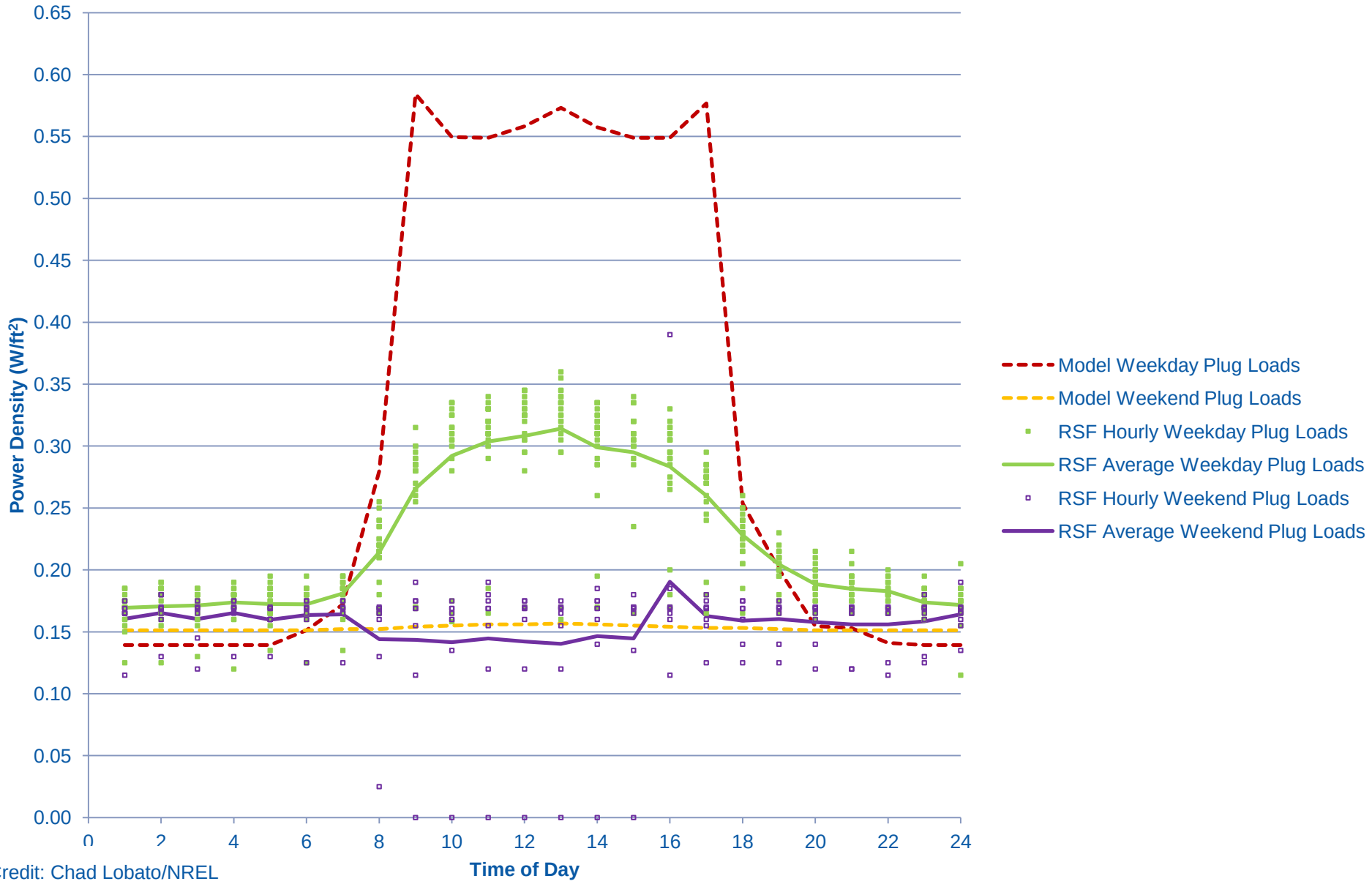
Credit: Chad Lobato/NREL

October 2010 Plug Load Power Density



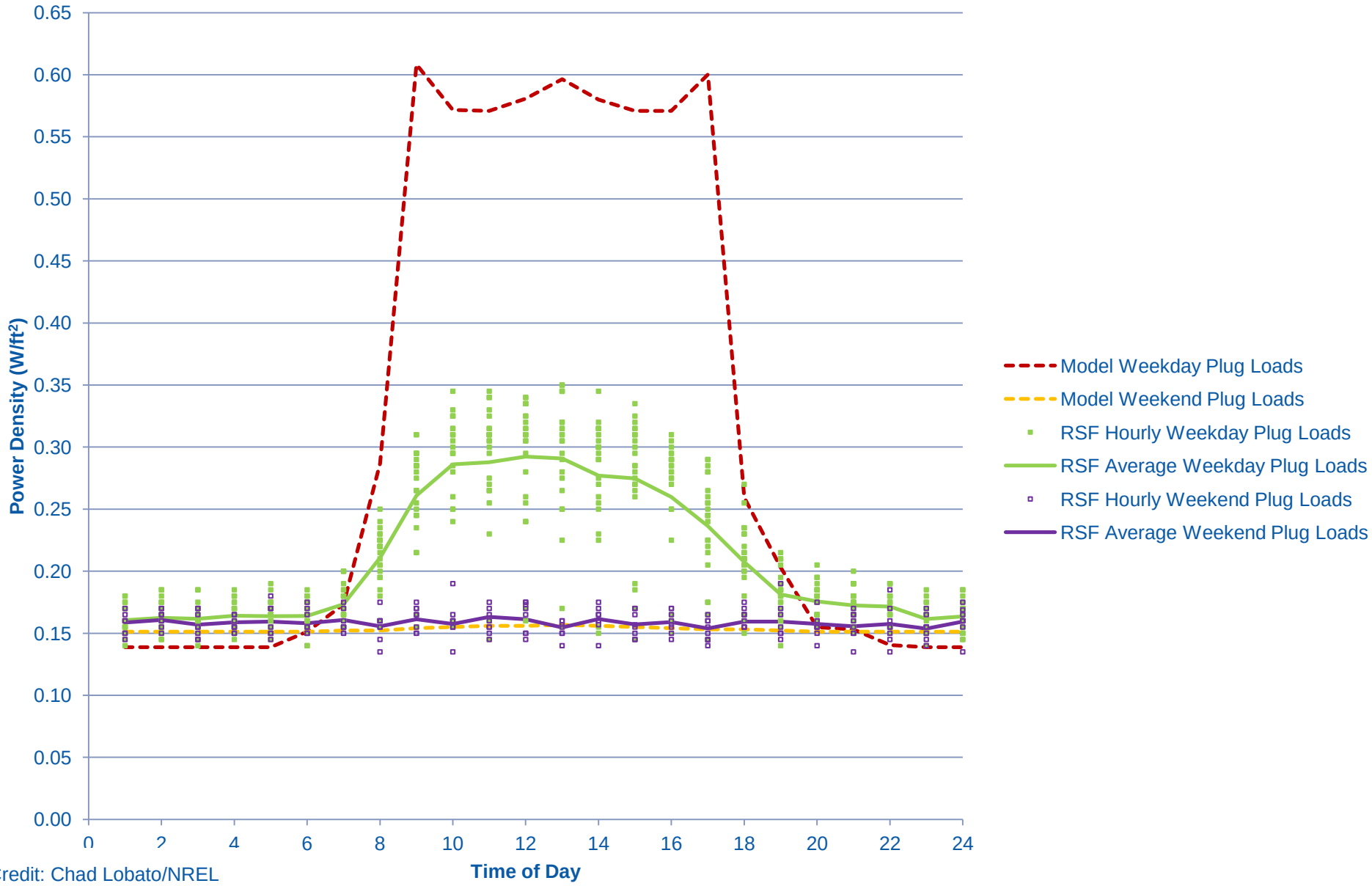
Credit: Chad Lobato/NREL

November 2010 Plug Load Power Density



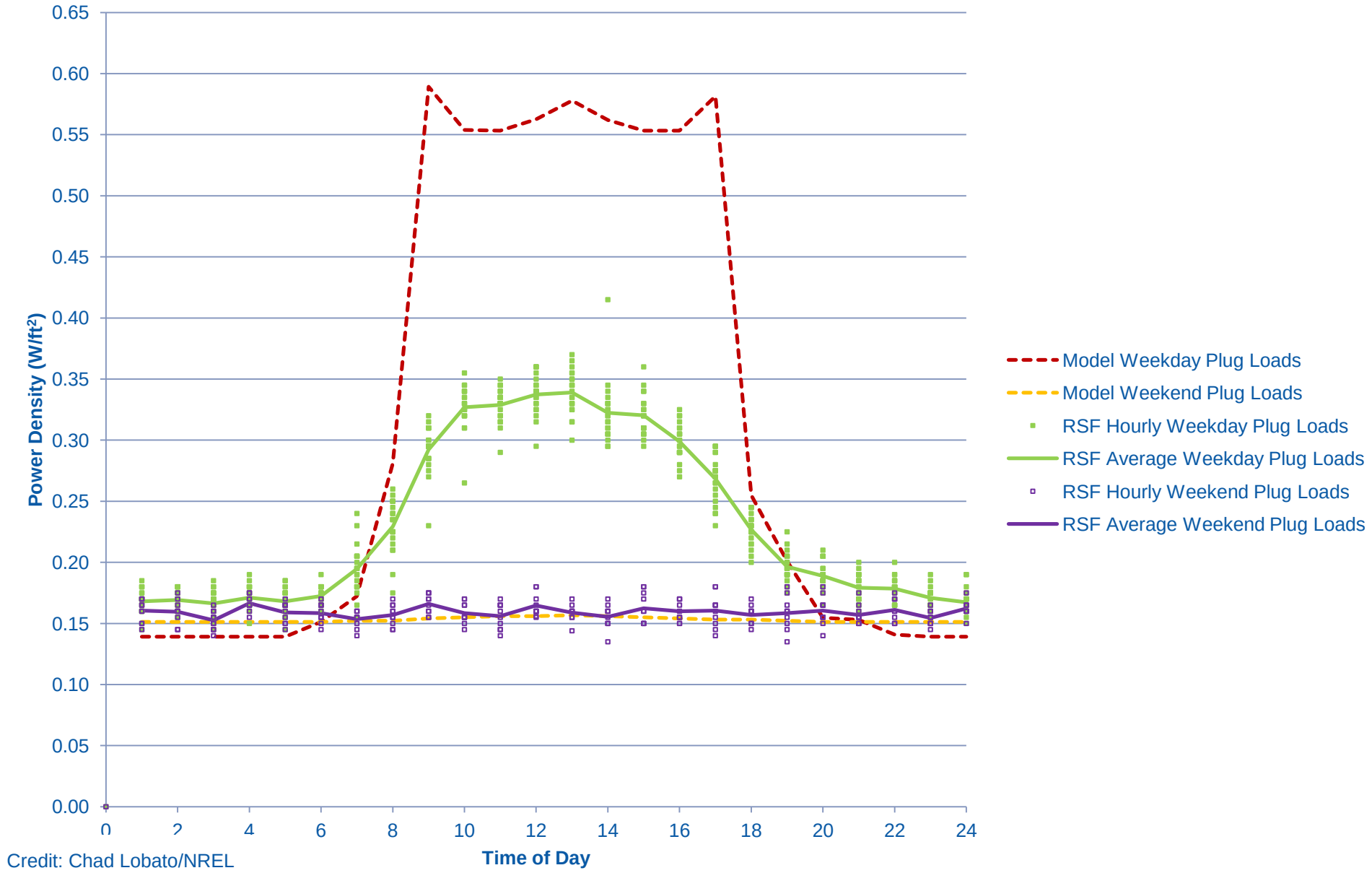
Credit: Chad Lobato/NREL

December 2010 Plug Load Power Density



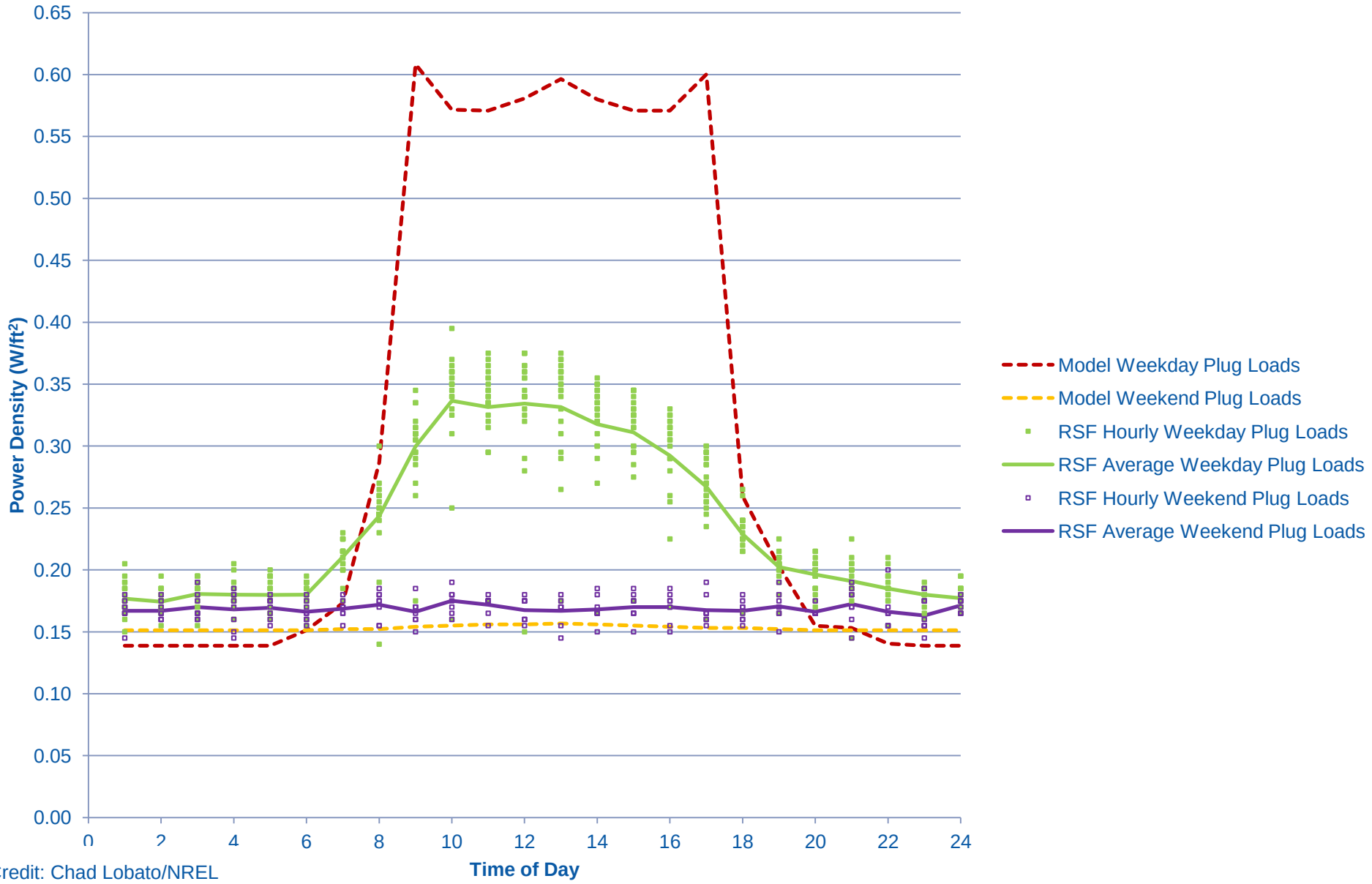
Credit: Chad Lobato/NREL

January 2011 Plug Load Power Density



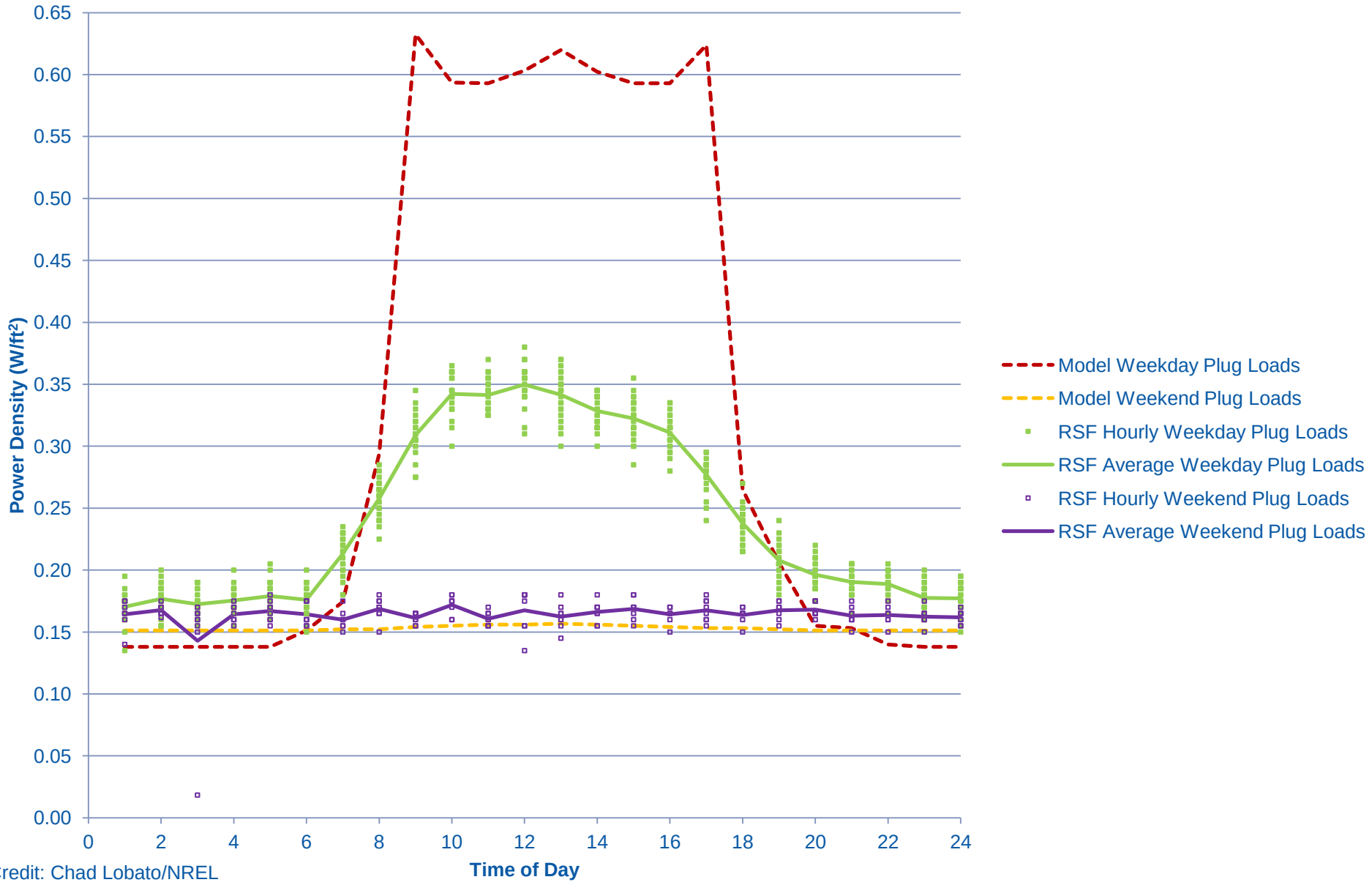
Credit: Chad Lobato/NREL

February 2011 Plug Load Power Density



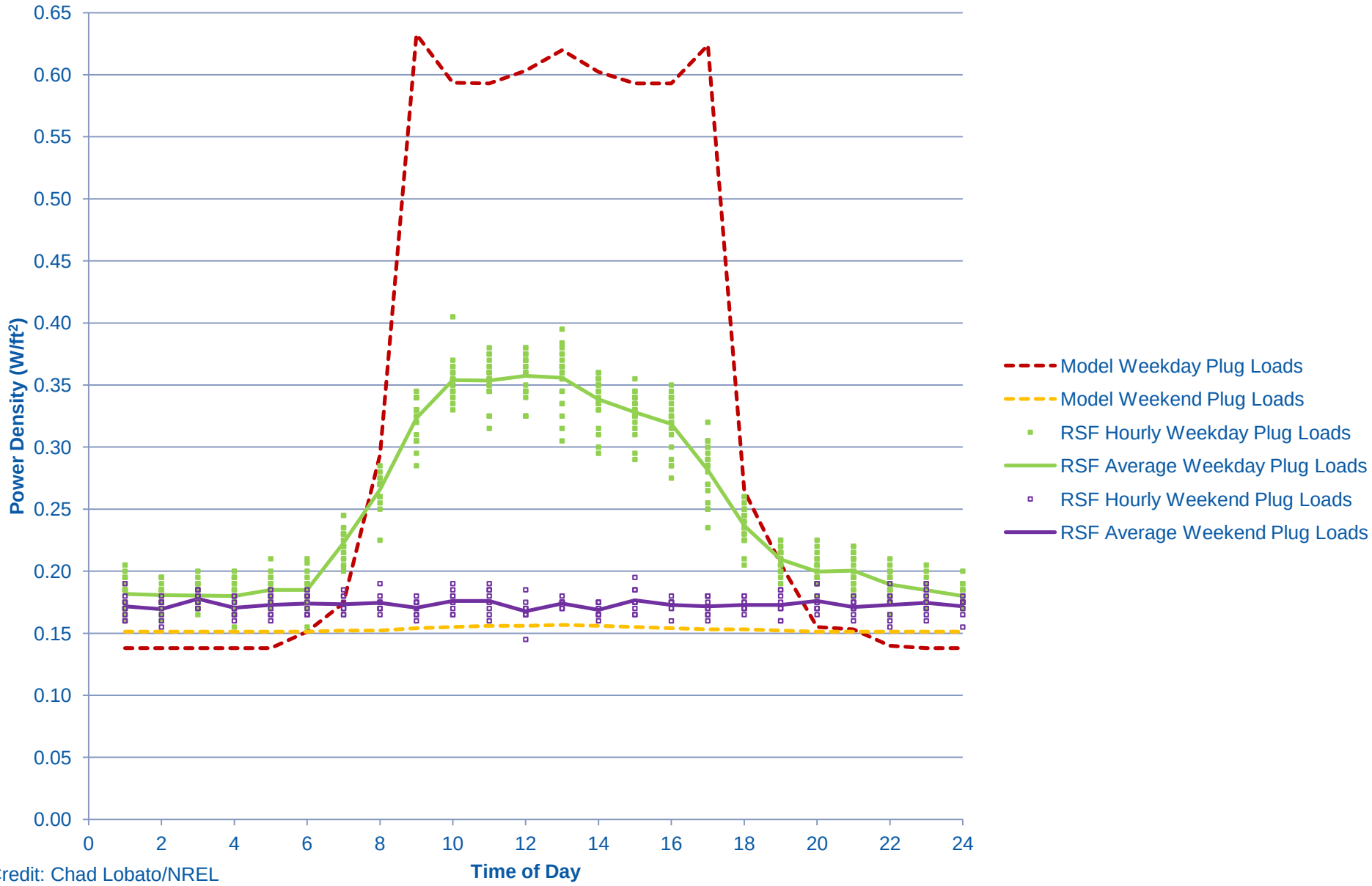
Credit: Chad Lobato/NREL

March 2011 Plug Load Power Density



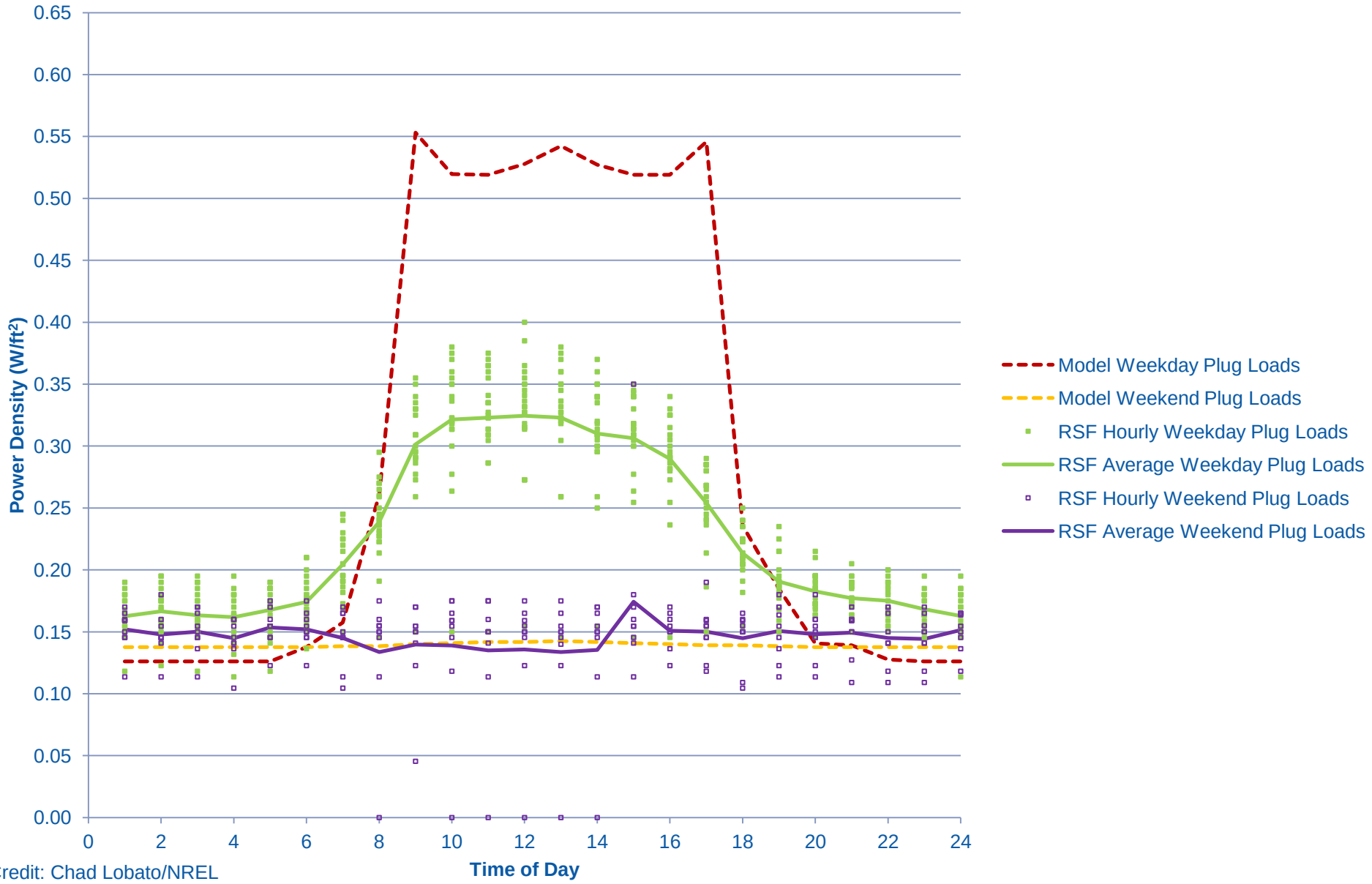
Credit: Chad Lobato/NREL

April 2011 Plug Load Power Density



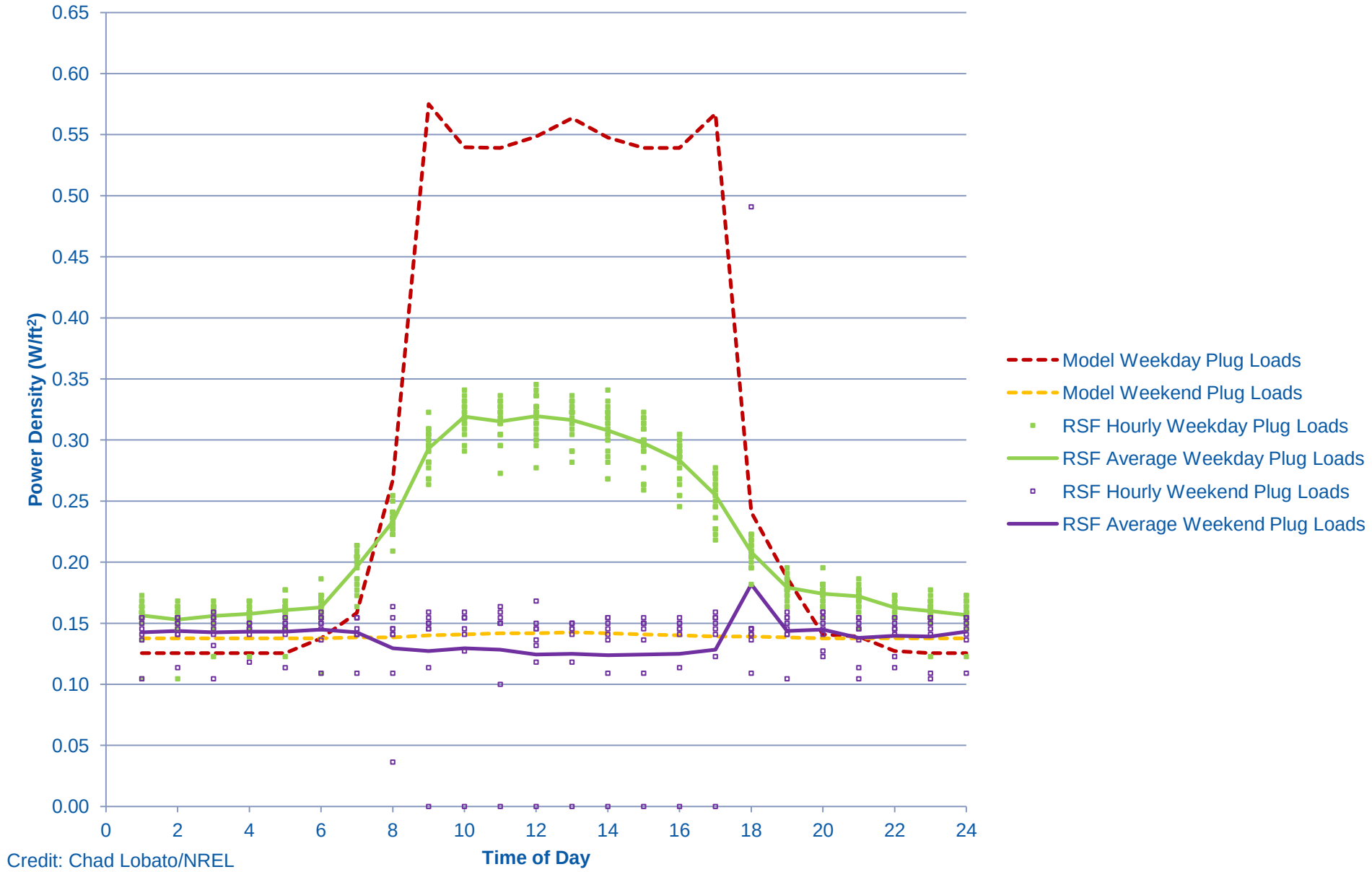
Credit: Chad Lobato/NREL

May 2011 Plug Load Power Density



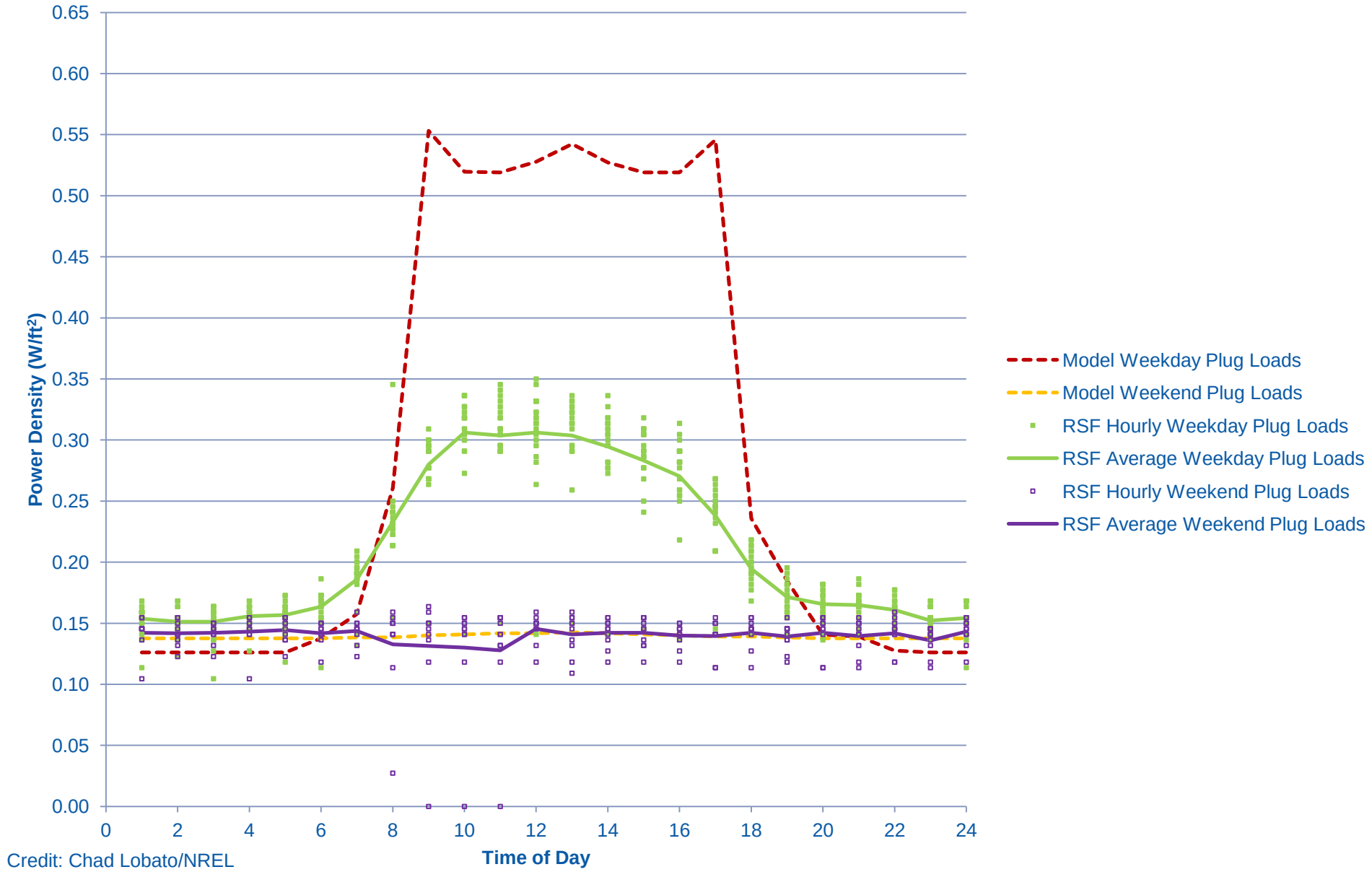
Credit: Chad Lobato/NREL

June 2011 Plug Load Power Density



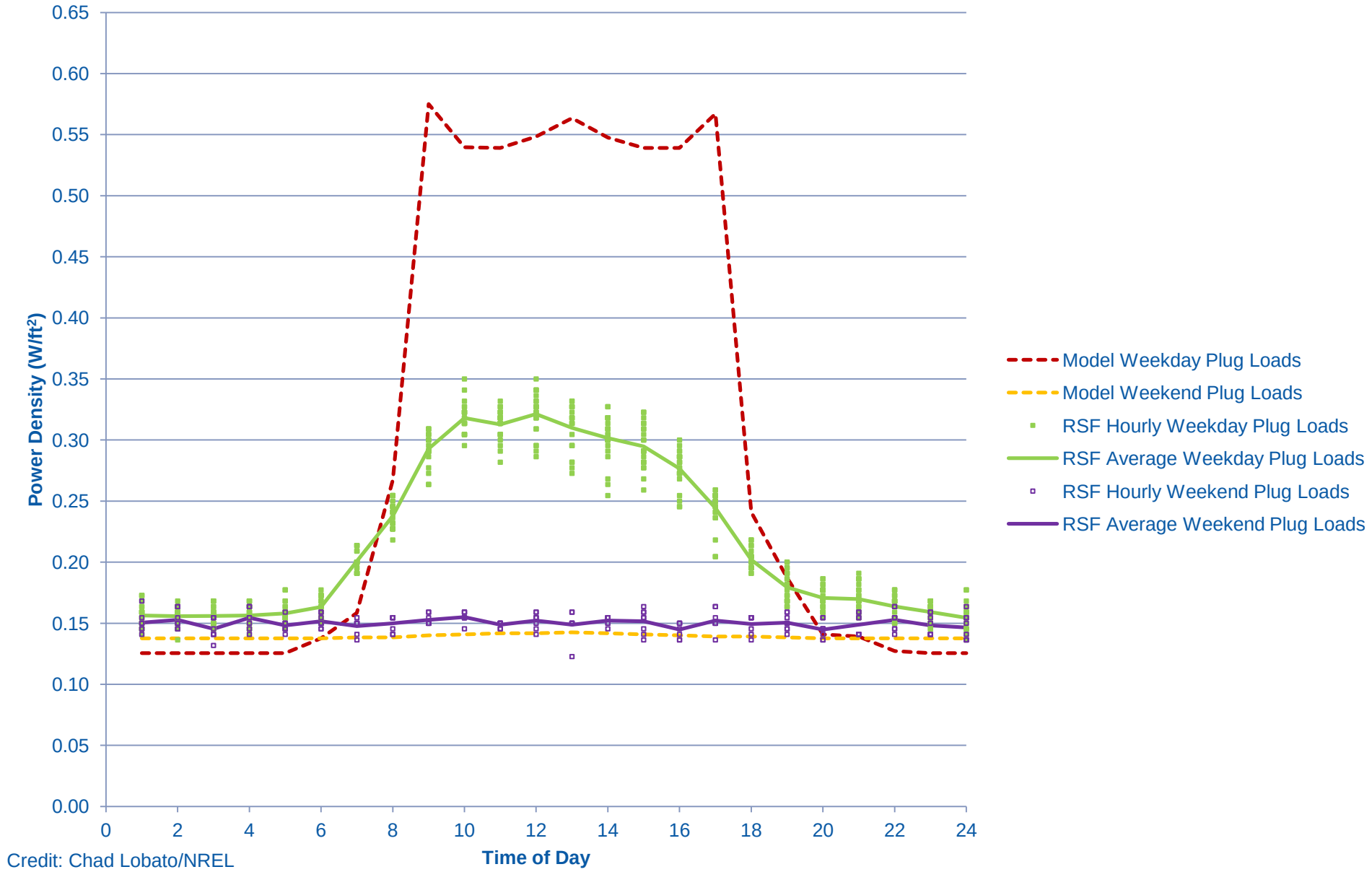
Credit: Chad Lobato/NREL

July 2011 Plug Load Power Density



Credit: Chad Lobato/NREL

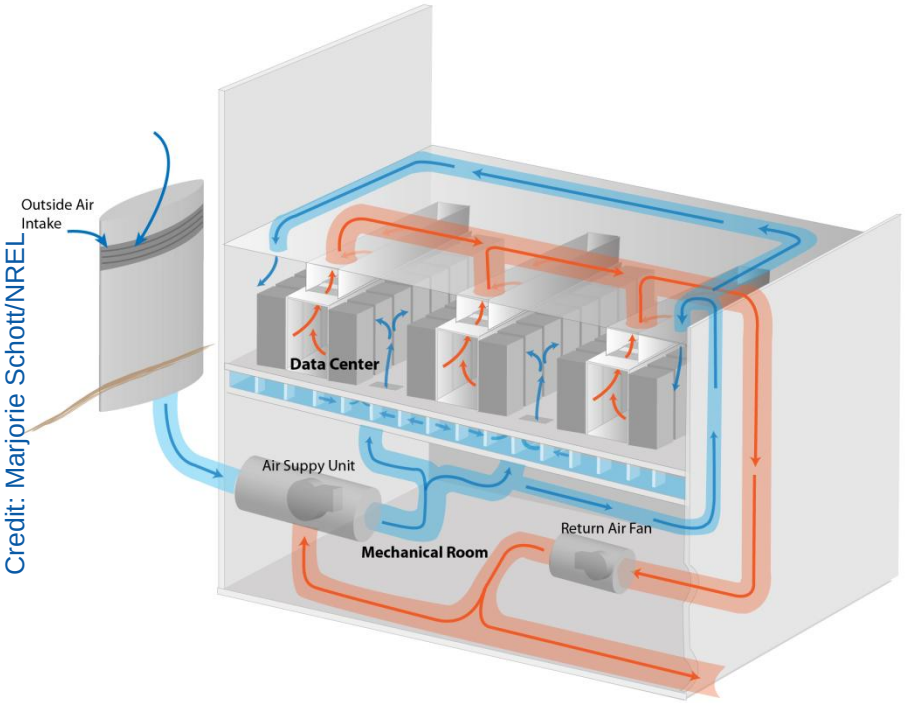
August 2011 Plug Load Power Density



Credit: Chad Lobato/NREL

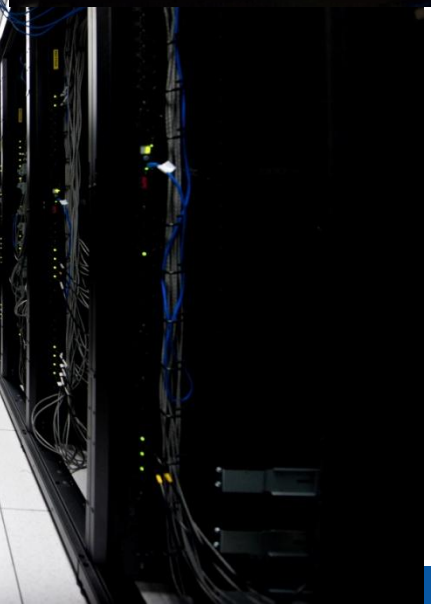
Operational Lessons- Datacenter

- Fully containing hot aisle difficult
  - Custom aisle floor and door seals
  - Ensure equipment designed for cold aisle containment
    - And installed to pull cold air
      - Not hot air…
- Have run ~1.1-1.15 PUE
  - A few hot spots were driving up PUE…
  - Summer time PUE of 1.20 because of increased cooling
- Starting to control hot aisle based on return temperature of ~80F
- 65 Watts/person to 38 Watts/person
  - But NREL has doubled in size
  - Modeled 65 watts/person for 1200 people
  - Using 38 watts/person for 2300 people

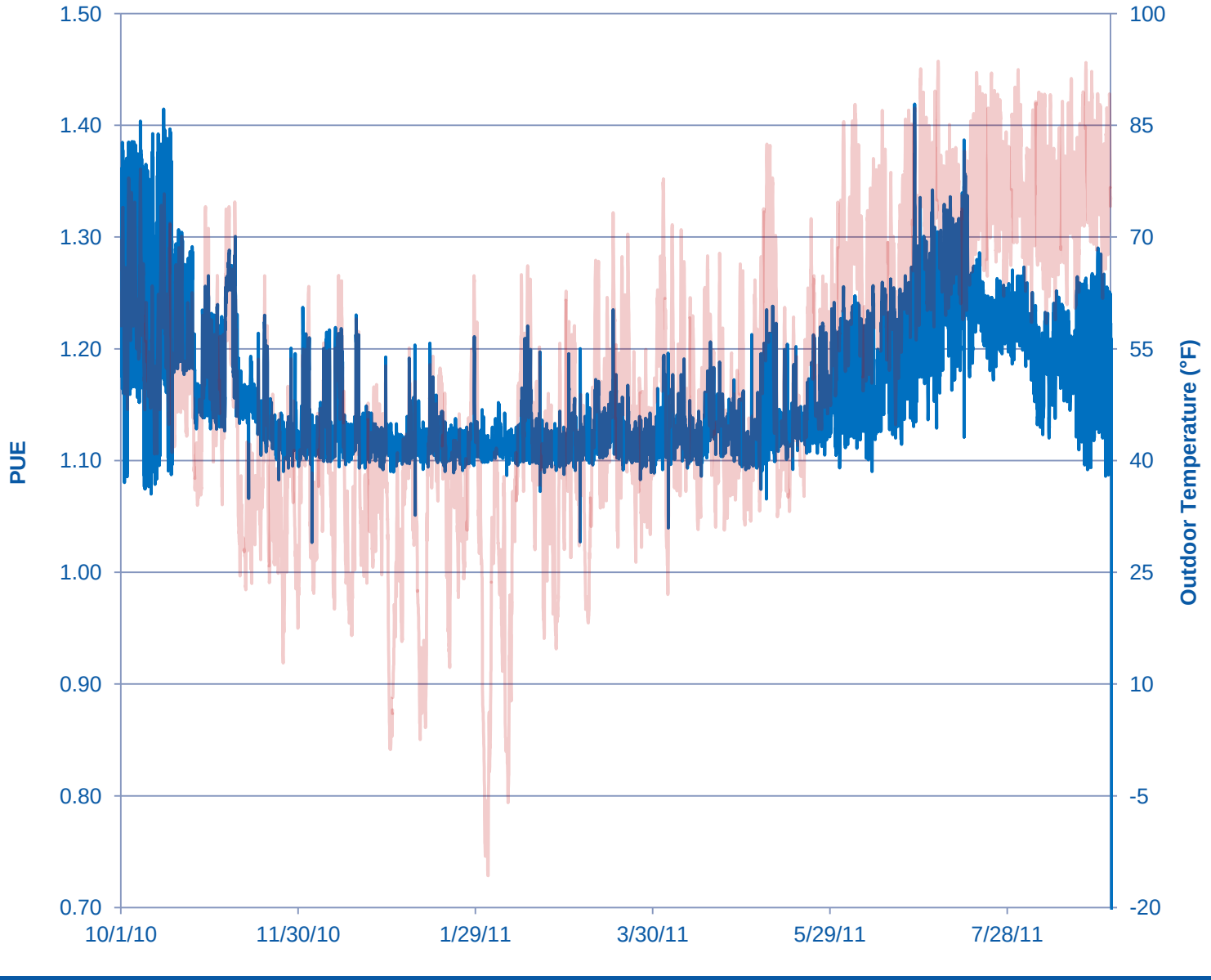


Credit: Marjorie Schott/NREL

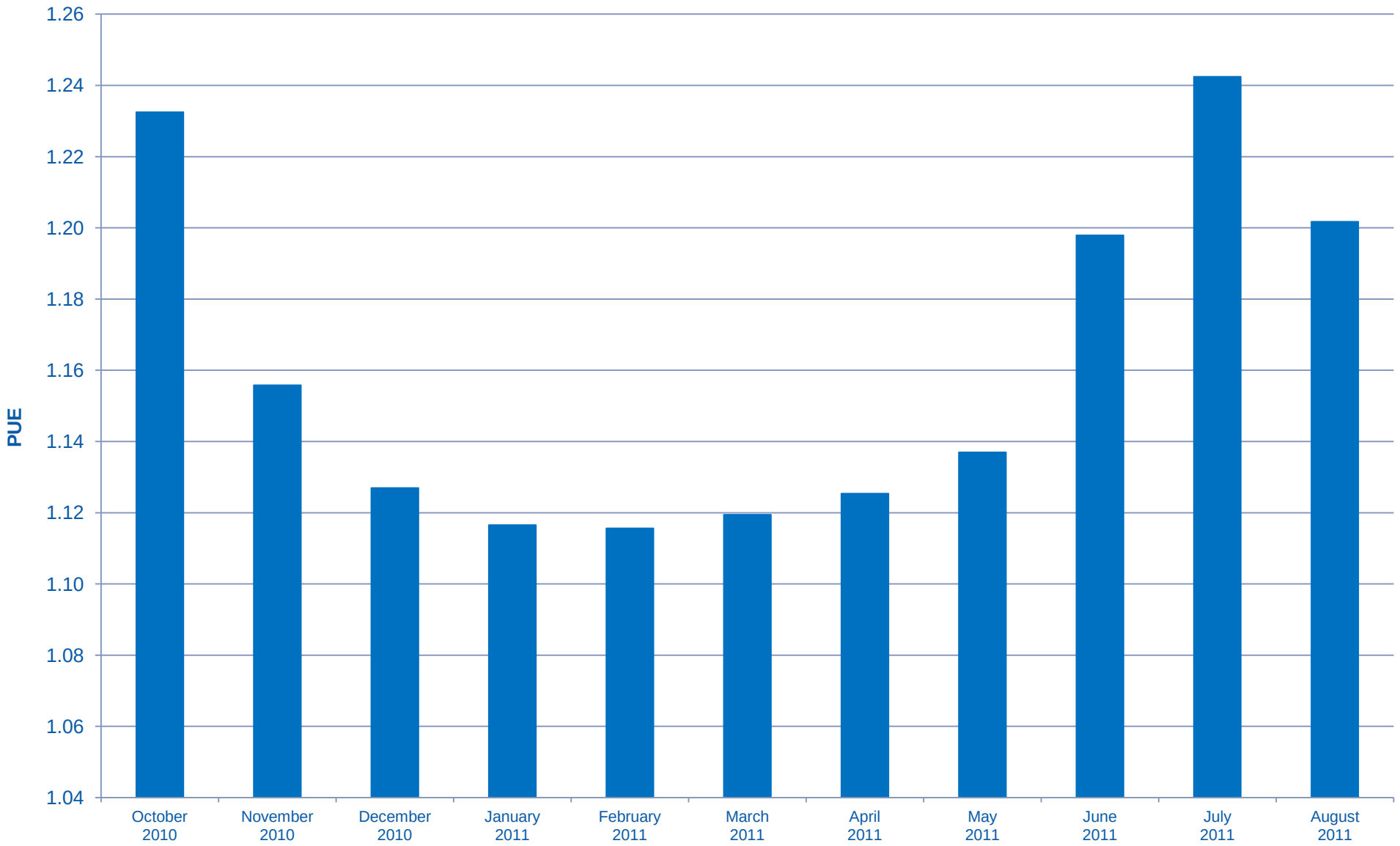
NREL/PIX 17897



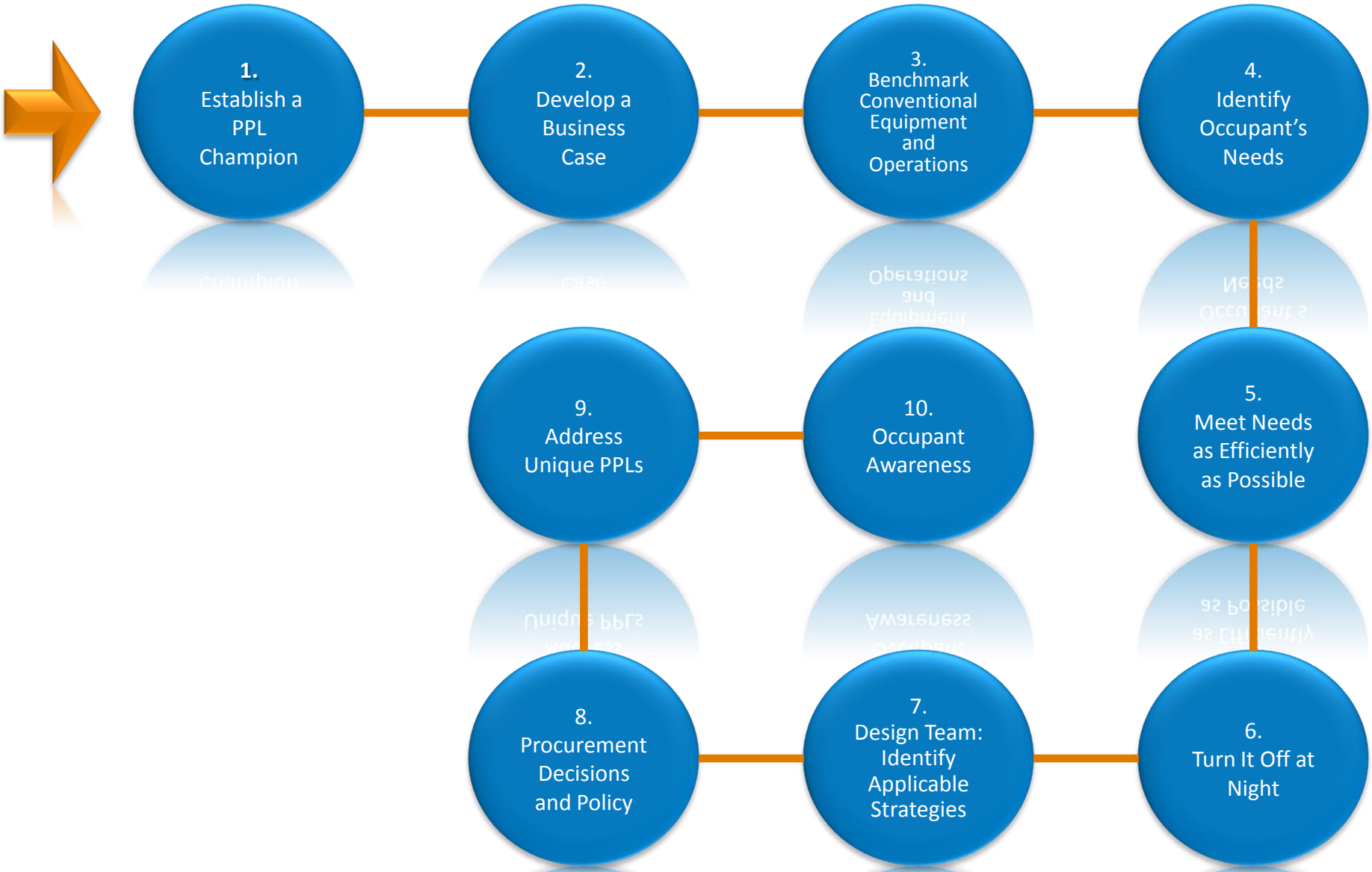
Data Center PUE



Monthly Average PUE



10 Steps to Address PPLs



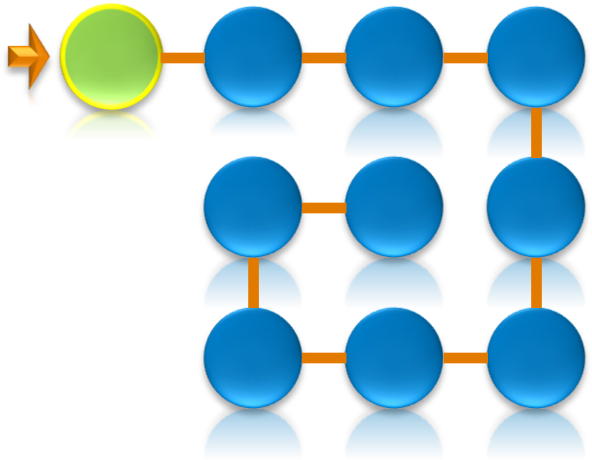
Step 1: Establish a PPL Champion

Purpose:

To initiate and help implement PPL strategies.

Skills needed:

- Understanding of:
  - technical energy efficiency opportunities
  - design strategies
- Ability to:
  - apply business model
  - question operations, institutional policies, and procurement processes



Step 2: Develop a business case for addressing PPLs

Avoided Cost of Renewables (ACR):

Equates the cost of PPL efficiency measures to avoided renewable costs.

Gives all parties a financial incentive to investigate PPLs.

ACR for the RSF:

Used to justify demand-side efficiency measures.

1 Watt continuous saved = $33 worth of PV was avoided. Additional loads must be offset with renewables.

The PV cost avoided by PPL reductions exceeded **$4 million.**

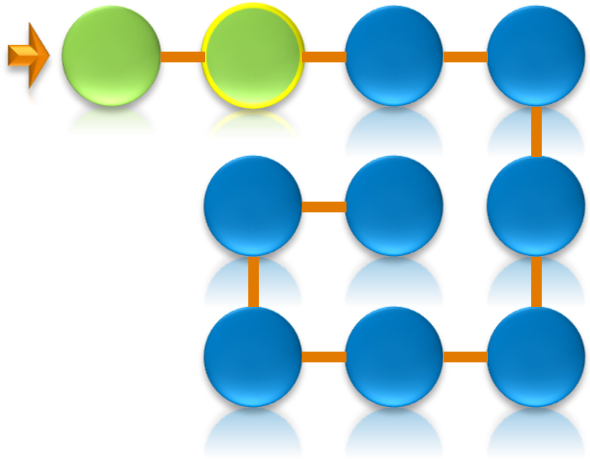


Photo Credit: Dennis Schroeder, PIX 17842

Step 3: Benchmark your conventional equipment and operations

Methods:

- Submeter panels (if properly organized)
- PPL power meters
- Combination of submetering and equip. spec. sheets can be used

Data:

- Understand when equipment is used
- Highlight opportunities to turn off
- Basis of comparison for financial calculations

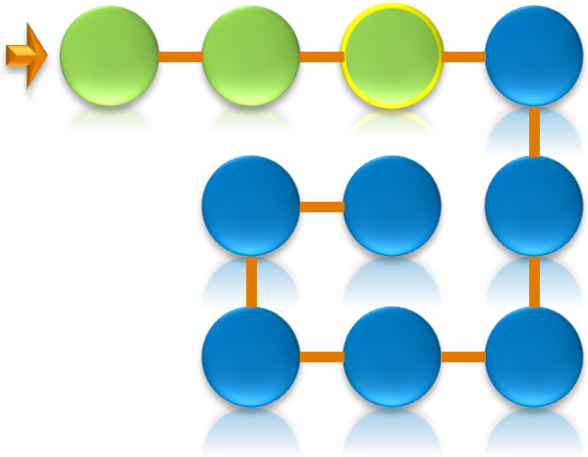


Figure Credit: Microsoft Clip Art

Step 4: Be willing to identify occupants' true needs

True need:

Equipment or procedure required to achieve a given business goal or an assigned task.

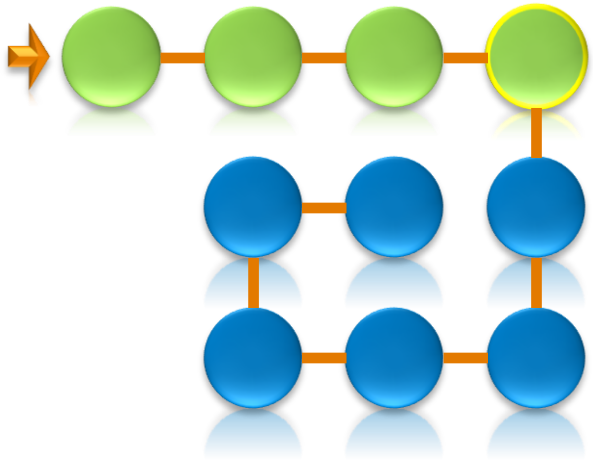
Understand:

What do occupants produce as part of their jobs and what tools do they require?

Every occupant, including those working in sensitive operations must be accounted for.

Nonessential equipment:

•A business case must be made for continued use.

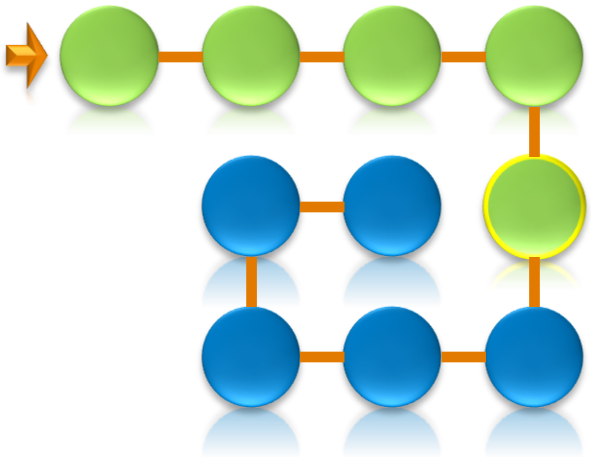


Step 5: Meet needs as efficiently as possible

Search energy efficient equipment databases.

Nonrated equipment:
- Investigate the most efficient model
- Turn off when not in use (if possible)

Pay attention to parasitic loads.



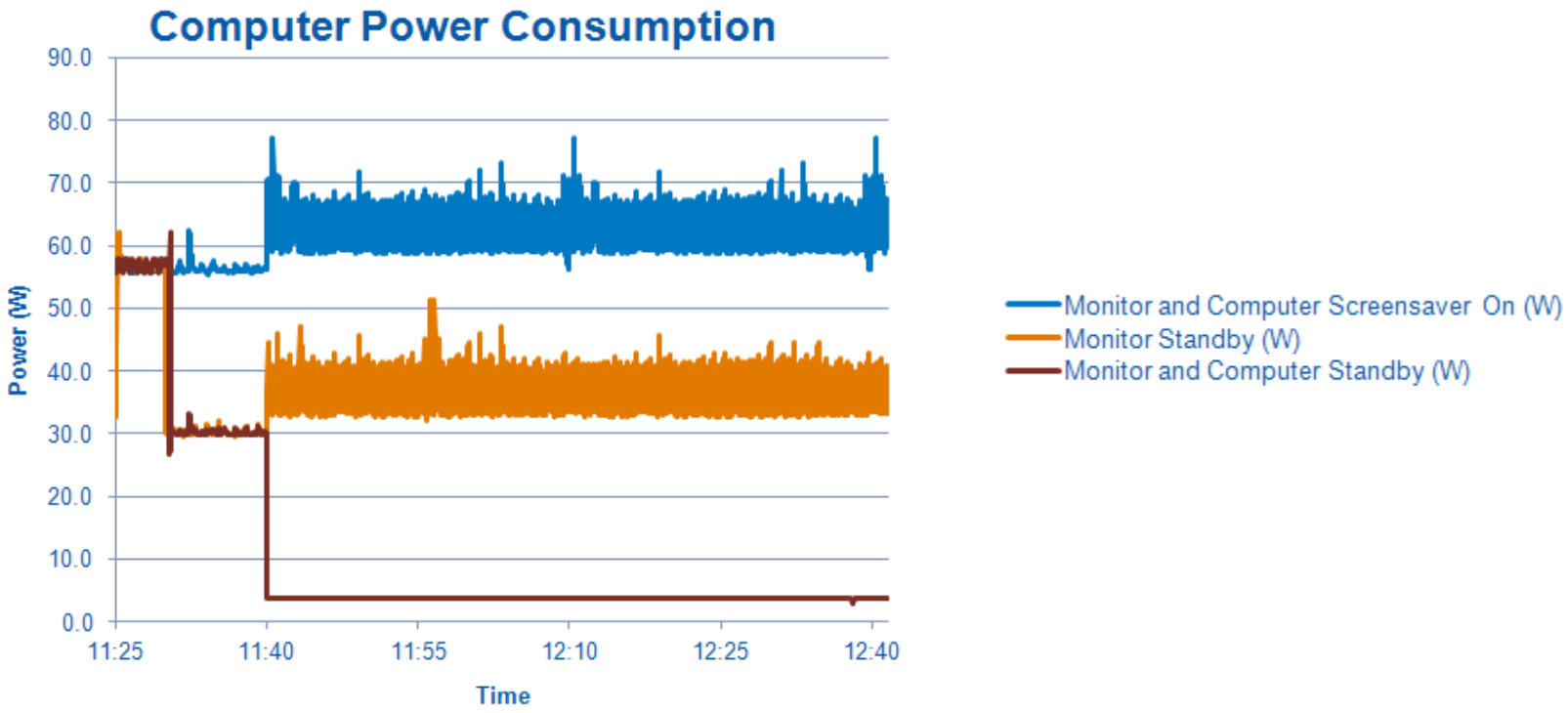


Photo Credit: Chad Lobato

Step 6: Turning it all off

Office buildings are typically unoccupied **66%** of year.

KEY: Reduce power density during nonbusiness hours.

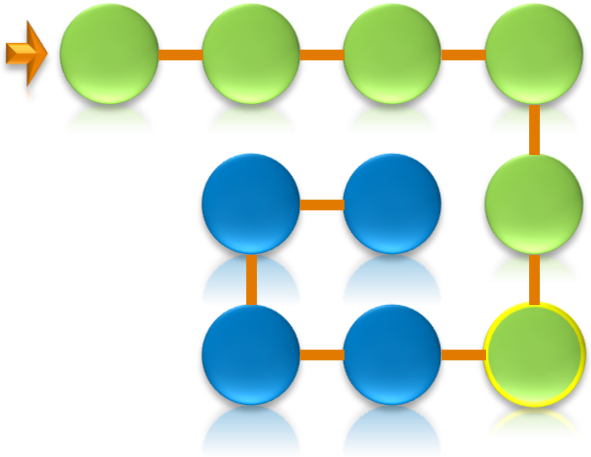


Photo Credit: Jennifer Schieb

Step 7: Encourage the design team to identify all applicable PPL strategies

Question standard specifications, operations, and design standards.

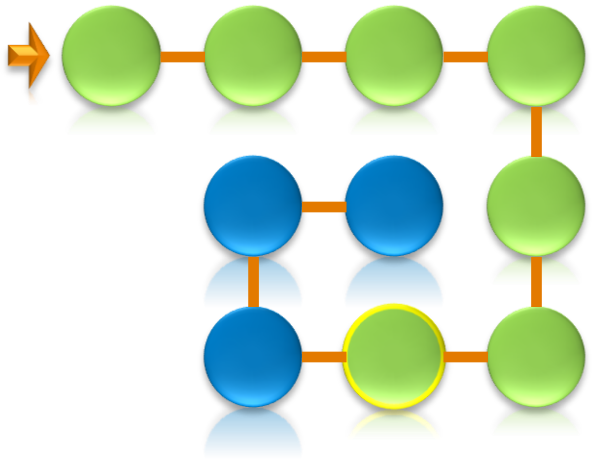
Maximize space efficiency.

Integrate PPL control strategies into the building's electrical system:

- Switches
- Vacancy sensors
- Timed disconnects for outlets
- Controlling outlets through the Building Management System (BMS)

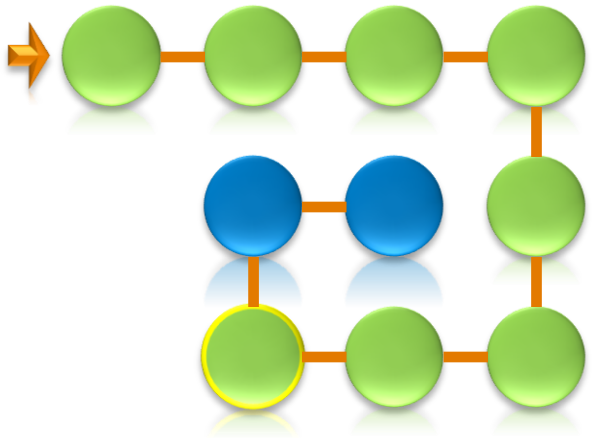
Other loads:

- Elevators
- Transformers
- Process cooling systems
- Data centers



Step 8: Institutionalize procurement decisions and policy programs

Day-to-day energy efficiency: Depends on the decisions of occupants, facility managers, and owners.



Identify decision makers who can:

- Institutionalize PPL measures through procurement decisions and policy programs.
- Promote buy-in.
- Identify unbreakable and unchangeable policies.

Step 9: Address unique miscellaneous PPLs

EXAMPLE: Contractors and food service areas.

Building owner can *contractually require* or *provide* the most efficient equipment available.

Case-by-case evaluation:

- Energy-efficient equipment may not be available and may be restricted from being turned off (e.g. ATM)
- Manufacturers may be able to recommend alternatives.

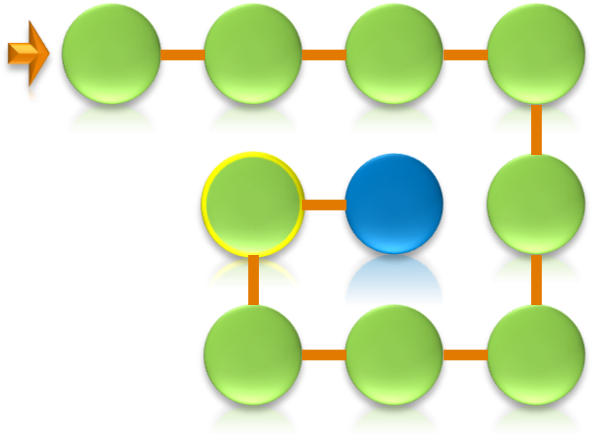


Photo Credit: Chad Lobato

Step 10: Occupant awareness

Encourage and allow to “do good”.

PPL strategies should counteract “bad users.”

Emphasize importance of turning off personal electronics when leaving a workspace.

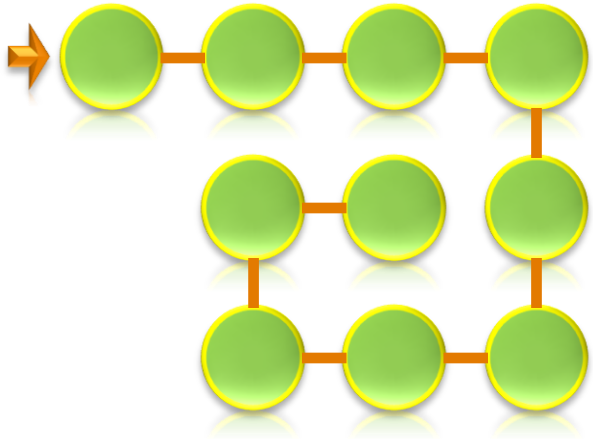
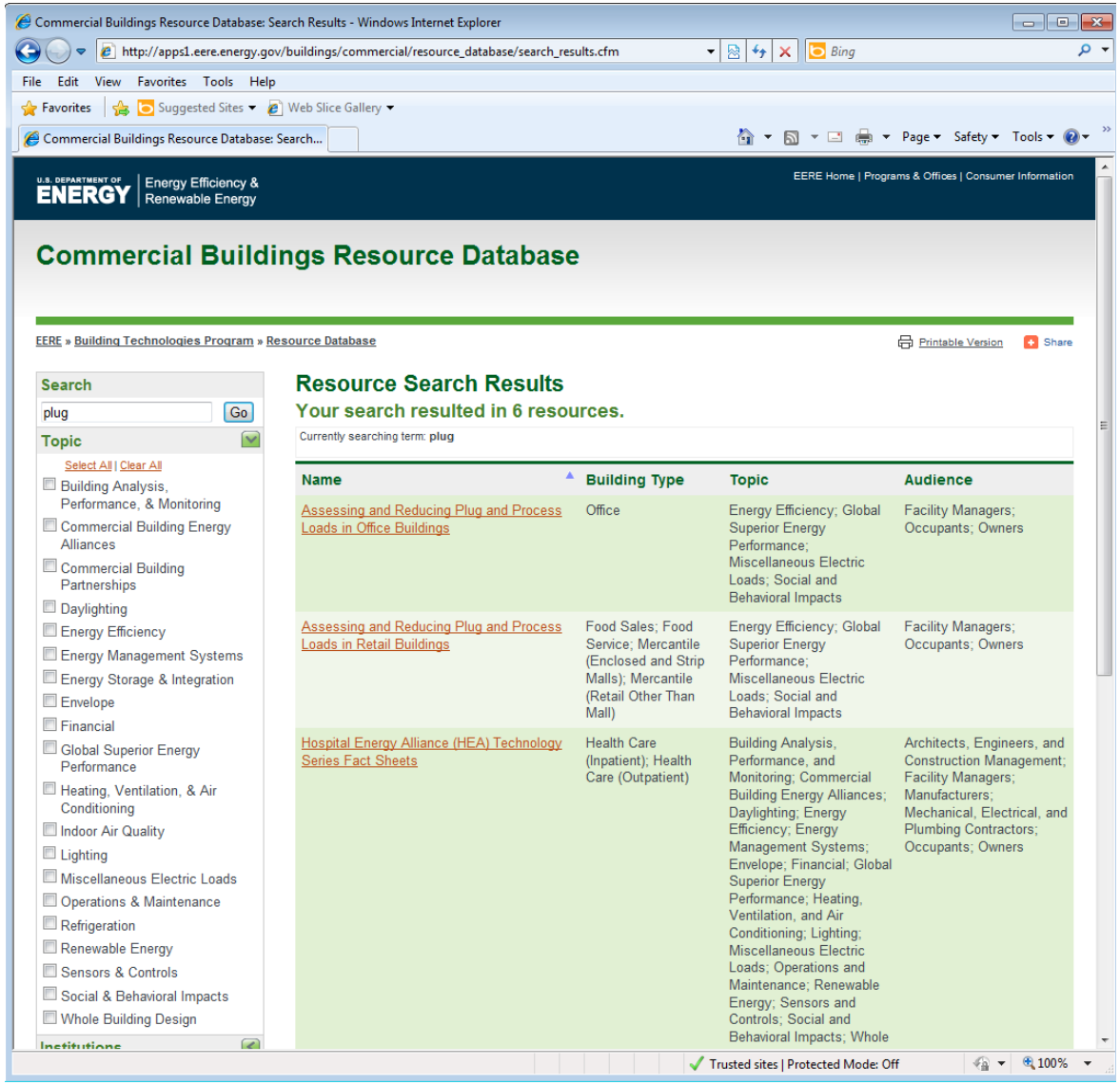


Photo Credit: Jennifer Scheib

DOE Commercial Buildings Resource Database: Additional Plug Load Guidance

http://apps1.eere.energy.gov/buildings/commercial/resource_database/



Search for:

- Plug or Miscellaneous Electric Load
- Datacenter

Thanks and Questions

Shanti Pless

Shanti.pless@nrel.gov

www.nrel.gov/rsf