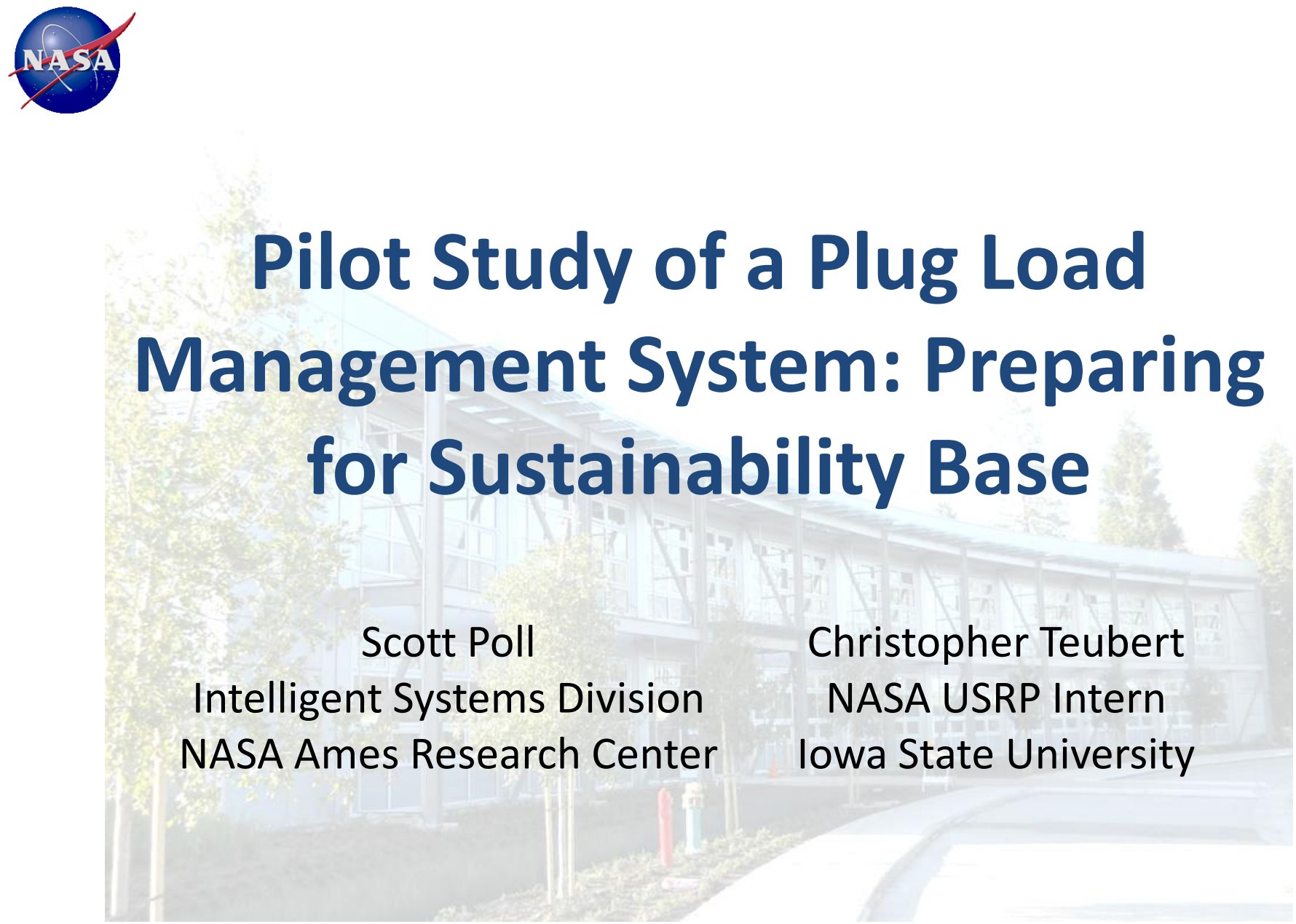

Pilot Study of a Plug Load Management System: Preparing for Sustainability Base

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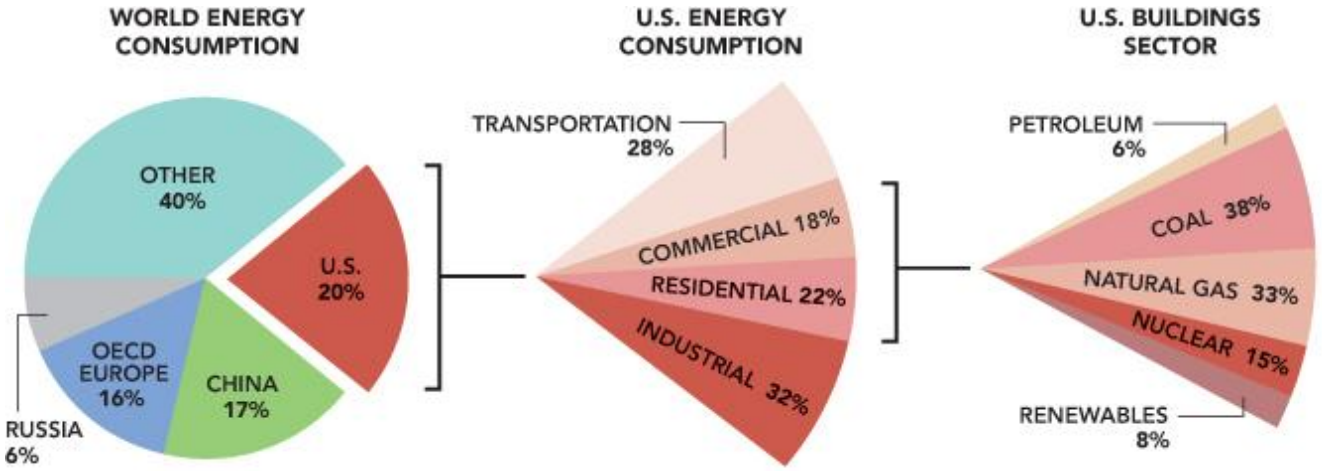
Overview

- Motivation
- Pilot Study
  - Goals
  - Plug load management system
  - Device allocation
  - Test sequence
- Results
  - Overall
  - Workstation/Workspace
  - Copy Room
  - Break Room
- Recommendations
- Current Status / Future Work

Motivation (1)

- Buildings are ubiquitous
  - 130 million residential housing units in 2009[1] and 5 million commercial buildings as of 2003[2]
  - In 2007, residential and commercial building construction and renovation was estimated to cost 1.2 trillion dollars, over 8% of the U.S. gross domestic product
- Buildings have impacts
  - 40% of total U.S. primary energy consumption[3]
  - 72% of electricity consumption[3]
  - 40% of carbon dioxide emissions[4]



Data source http://buildingsdatabook.eren.doe.gov/ChapterIntro1.aspx

[1] "American housing survey for the united states: 2009," US Department of Housing and Urban Development: US Department of Commerce Economics and Statistics Administration, H150/09, 2011.
[2] "Commercial buildings energy consumption survey," Department of Energy: US Energy Information Administration, 2003.
[3] "2009 buildings energy data book," U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, 2009.
[4] "Emissions of greenhouse gasses in the united states 2009," US Department of Energy: US Energy Information Administration, 2011.

Motivation (2)

- Plug loads, a.k.a. Miscellaneous Electrical Loads (MELs), may account for more than 50% of total energy consumption in high performance buildings[5]
- Preparing for plug load management system deployment to Sustainability Base
  - 50,000 sq ft office building
  - Fully occupied as of March, 2012
  - LEED Platinum certified

Image Courtesy of William McDonough + Partners

[5] C. Lobato, S. Pless, M. Sheppy, and P. Torcellini, "Reducing plug and process loads for a large scale, low energy office building: NREL's research support facility," National Renewable Energy Laboratory, NREL/CP-5500-49002, 2011.

Goals

- Collect representative plug load data in reference office building
- Deploy system for plug load devices anticipated in Sustainability Base
- Make preliminary assessment as to effectiveness of controlling selected loads
- Identify malfunctioning or inefficient equipment
- Evaluate utility of plug load management system chosen for study

Plug Load Management System

Enmetric Systems Power Port

- 4 channels (outlets/ports), 15 amps total
- Meters and controls per channel
- Manual override per channel
- Parasitic draw: ~0.8 W (off state), ~1.8 W (on state)
- Communicates wirelessly (802.15.4), default rate 1 Hz
  - Wattage, Voltage*, Amperage*, Frequency*, Power factor* (*not available during pilot study)

Power Port

Bridge

- Communicates with up to 50 Power Ports
- 1000 feet (unimpeded line of sight), 2.4 GHz
- Connects to LAN with rj45 Ethernet port
- Parasitic draw ~1.1 W

Bridge

Cloud-based Data Service

- Data archived once per minute
  - minimum, mean, maximum power draw over each one minute interval recorded

http://www.enmetric.com/

Device Allocation

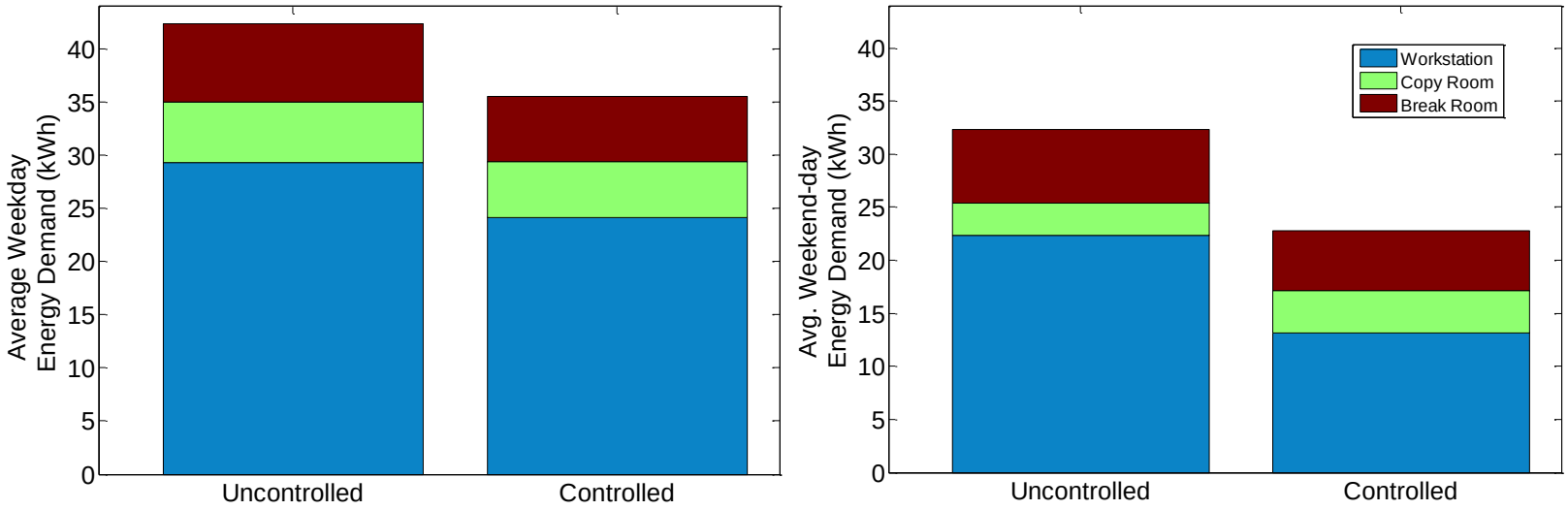
- 15 Power Ports deployed to variety of spaces in reference office building
  - Workstations (workspaces), copy room, break room
  - Administrative, financial, project management, technical personnel

Location	Device	Number
Workstations (7)	Desktop Computers	6
	Laptop Computers	3
	Monitors	7
	Printers	5
	Phones	2
	Shredders	2
	Speakers	3
	Scanners	3
	Other	10
Copy Room (1)	Printers	2
	Copier	1
	Shredder	1
Break Room (1)	Refrigerator	1
	Vending Machines	2
	Microwave	1
	Coffee Maker	1

Test Sequence

- Pilot study conducted at NASA Ames campus during spring and summer 2011
- Baseline (uncontrolled) data acquired for approximately 5 weeks
- Employed schedule-based rules over the course of several weeks, final set of rules put in place for approximately 9 weeks
  - Conservative rule timings, not optimized; same timing used for weekdays and weekends
- Also made changes to equipment energy saver settings during controlled portion of testing

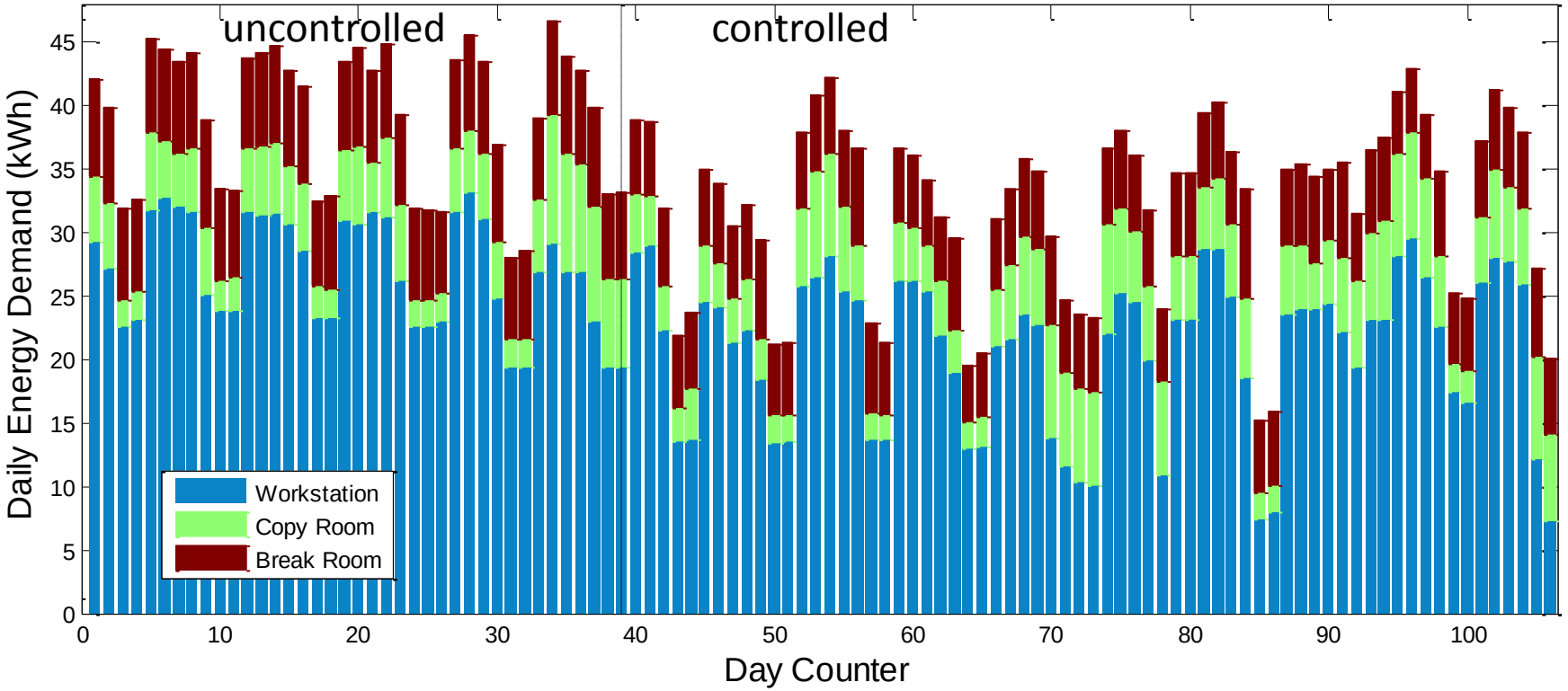
Results (1)



a) Weekdays b) Weekends

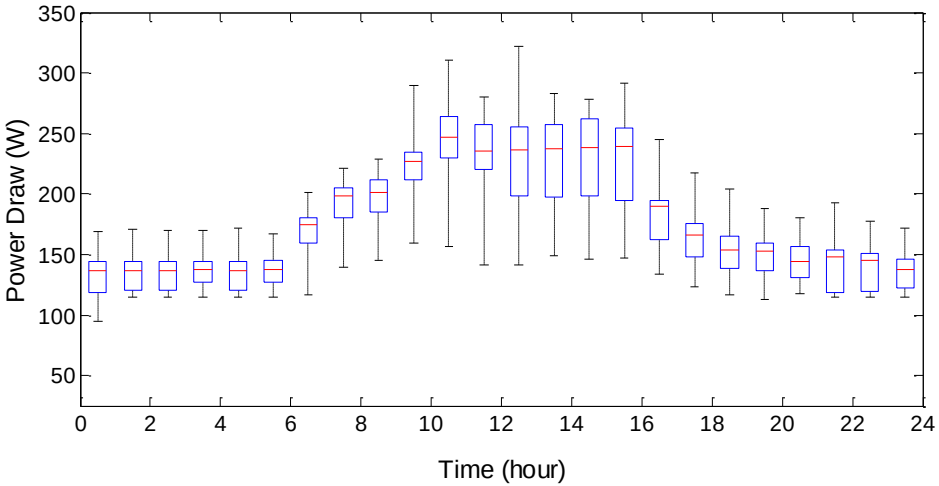
- Controlled energy consumption includes contribution from plug load management system
- Average energy savings for employing schedule-based rules and changing energy policy changes:
  - 6.8 kWh/day (16%) for weekdays
  - 9.6 kWh/day (30%) for weekends
- Copy room power draw affected by malfunctioning copier

Results (2)

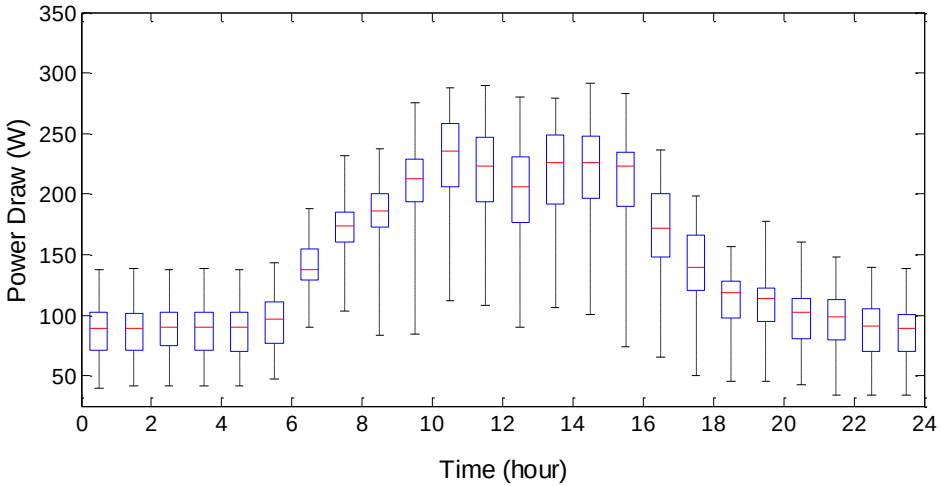


- Uncontrolled and controlled to left and right of dotted line (day 39), respectively
- 11 of 50 channels did not employ schedule-based rules
  - 6 channels were not de-energized to prevent computer data loss
  - 1 channel connected to refrigerator
  - 1 channel connected to bridge
  - 1 channel (copier) did not return to ready-to-use state
  - 2 channels consumed more energy with rules in place

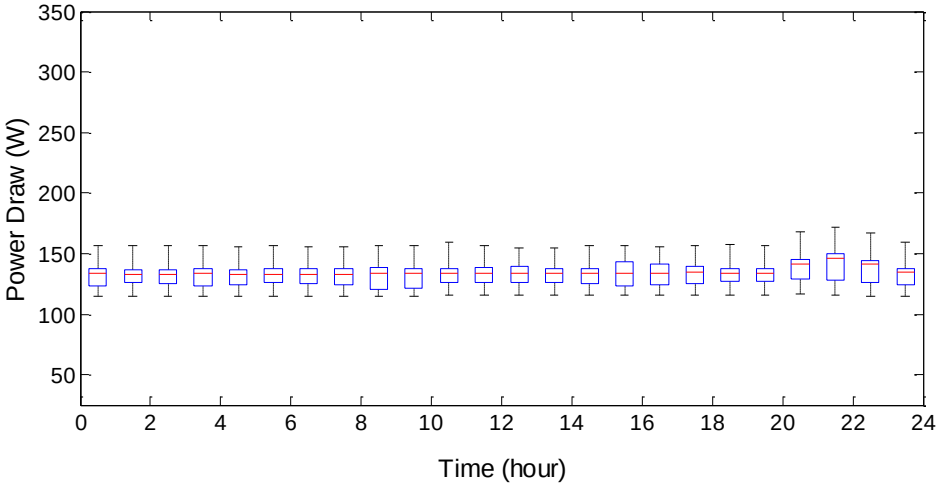
Workstation (1)



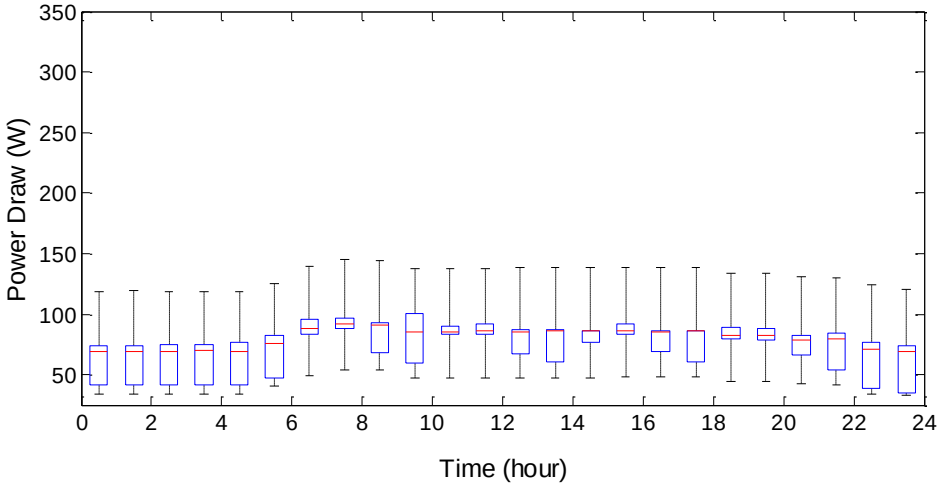
a) Weekday-Uncontrolled



b) Weekday-Controlled



c) Weekend-Uncontrolled

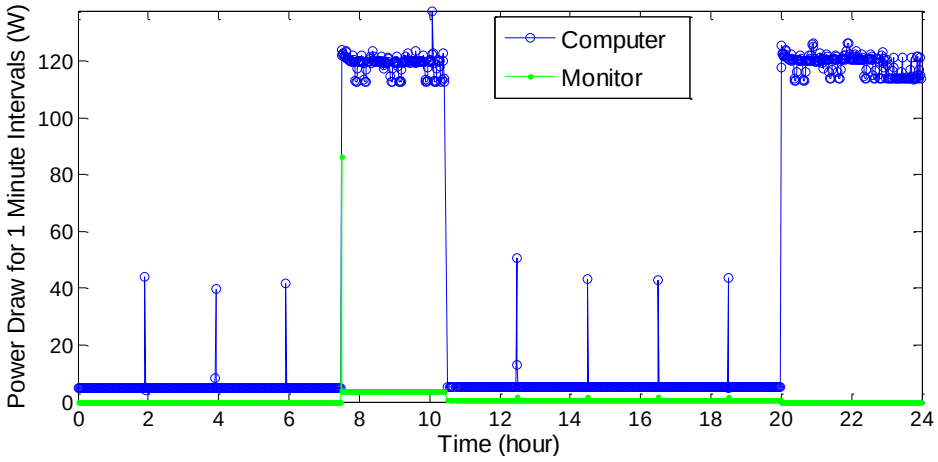


d) Weekend-Controlled

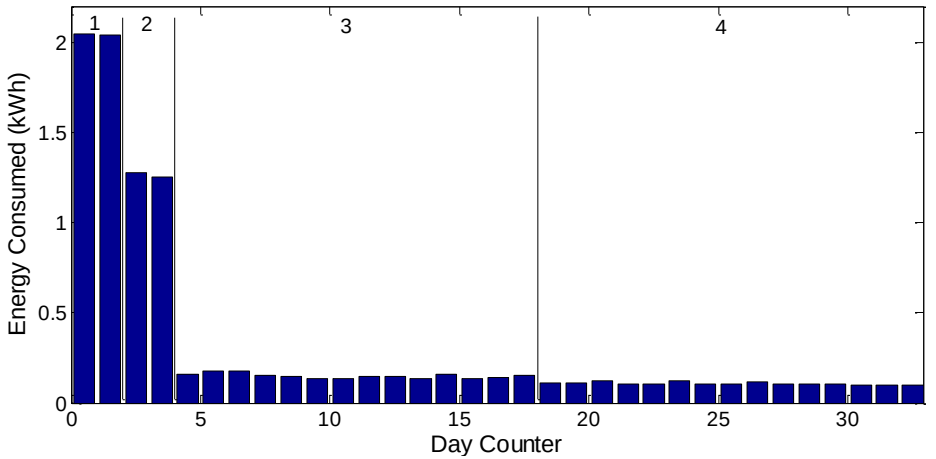
27 kWh/week Uncontrolled

21 kWh/week Controlled

Workstation (2)



Computer and Monitor Coupling

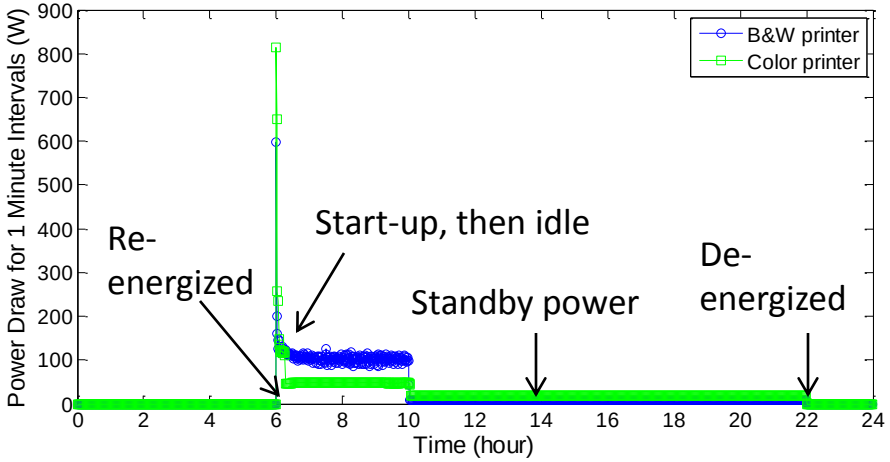


30” Monitor Energy Consumption

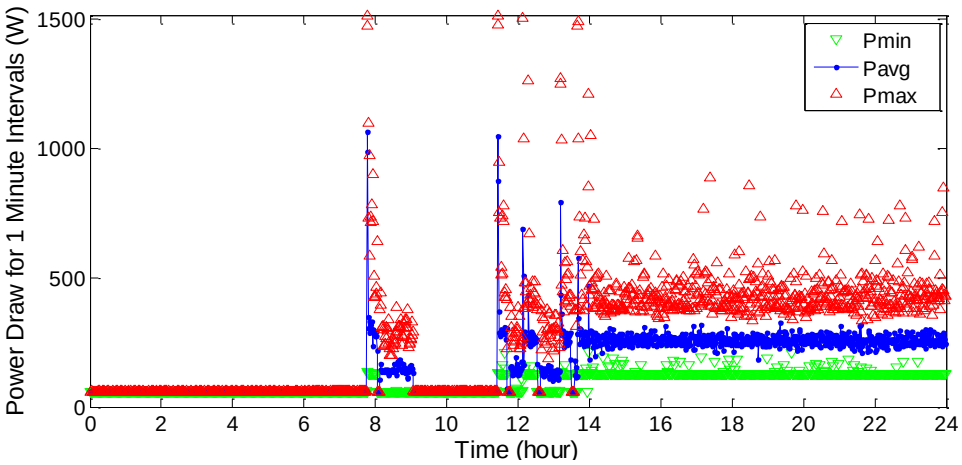
- Original computer power management settings did not use built-in power management control
- Even after enabling built-in control, not all computers consistently entered low power modes
- For one workstation, turning off monitor caused connected computer to wake (see figure above), resulting in higher energy use for system

- Most effective way to save energy is to use built-in power management control
  - Zone 1: uncontrolled, screen saver displaying pictures 24/7
  - Zone 2: controlled (de-energized from 10 pm to 6 am)
  - Zone 3: uncontrolled, but with screen saver changed to turn off display after 10 min
  - Zone 4: new screen saver setting + de-energized from 10 pm to 6 am

Copy Room



Shared Printers

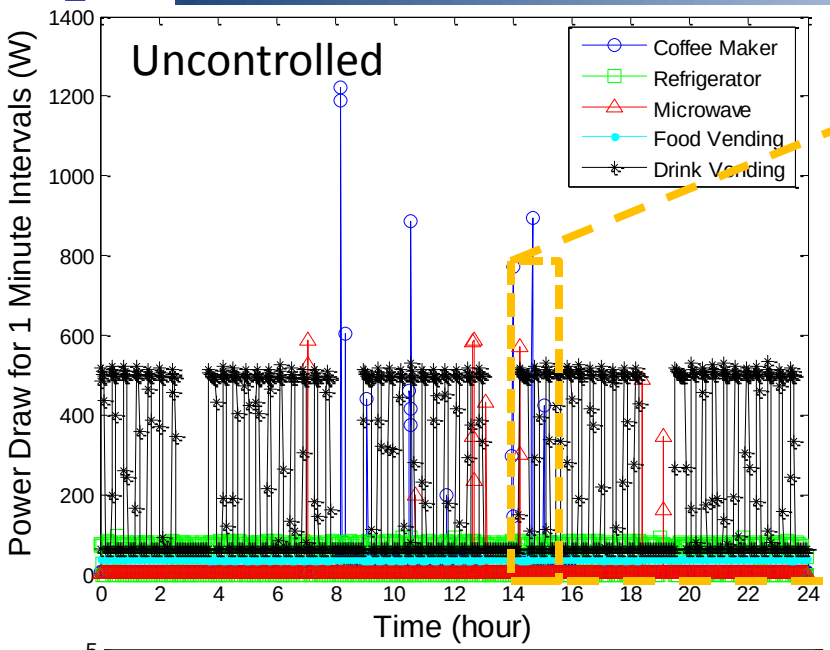


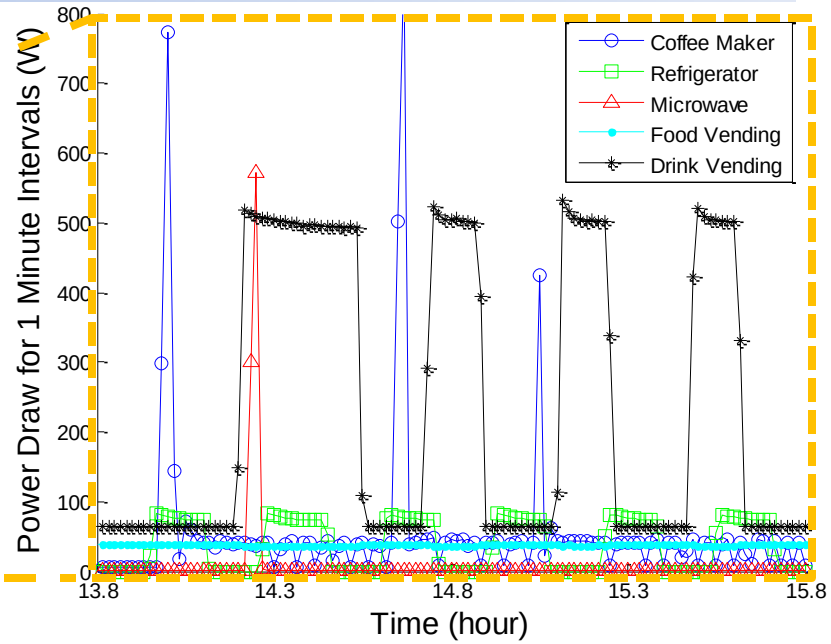
Copier Power Draw

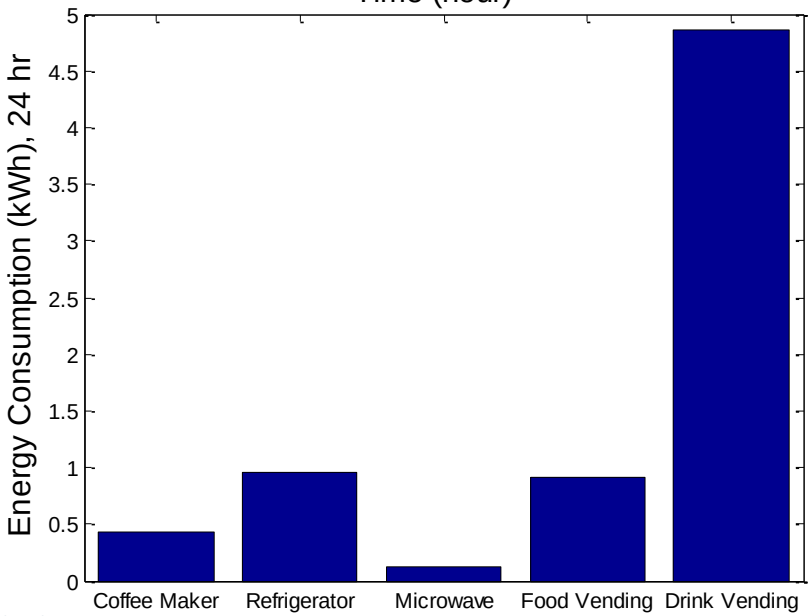
- Original time to standby was 4 hours for shared printers
- Even after changing to 1 hour, B&W printer used more energy during warm up compared to leaving on in standby mode (9 W) => de-energizing ineffective
- Color printer had higher standby power draw (18 W) but lower overall power draw during start-up and idle modes => de-energizing effective

- Copier did not re-energize to ready to use state
- High standby power draw of 60 W
- Copier ceased to transition to standby mode consistently
- Idle mode power draw more than 4 times standby power draw
- Note bands of min, avg, max reflects oscillating power draw during 1 minute intervals

Break Room







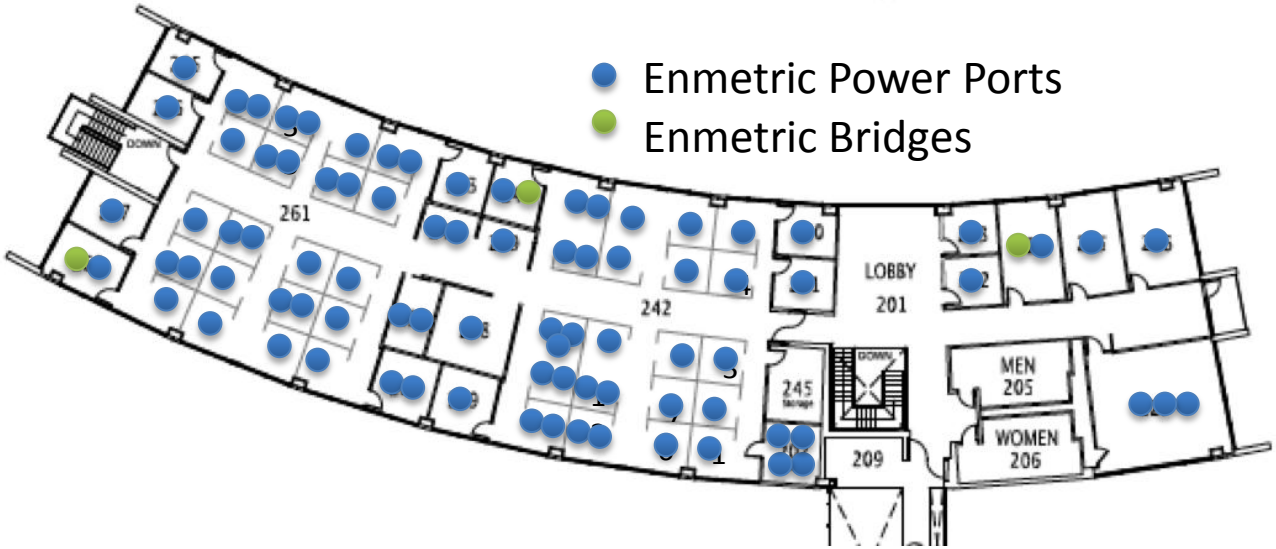
- Drink vending machine consumed most energy of break room loads and had second highest average daily energy consumption overall
- Coffee maker and microwave had high peak power draw but low standby power draw
- Food vending machine had light which remained on 24/7 during uncontrolled portion of testing

Recommendations

- Choose energy efficient equipment
  - Choose devices with low power draw, efficient power saver modes, and desirable re-energize characteristics
  - Use shared instead of personal devices (printers, refrigerators, etc.)
- Set effective energy policies
  - Employ short time to standby on devices when practical
  - Monitor plug loads to indicate when policies fail
- Promote beneficial occupant behavior
  - Provide personal energy feedback to occupants, allowing them to monitor and customize control of their own plug loads
  - Incentivize friendly competitions among building "neighborhoods"
- Employ plug load controls
  - Turn off devices during non business hours when effective
  - Instruct occupants on use of manual override for occasional work outside of typical hours

Current Status / Future Work

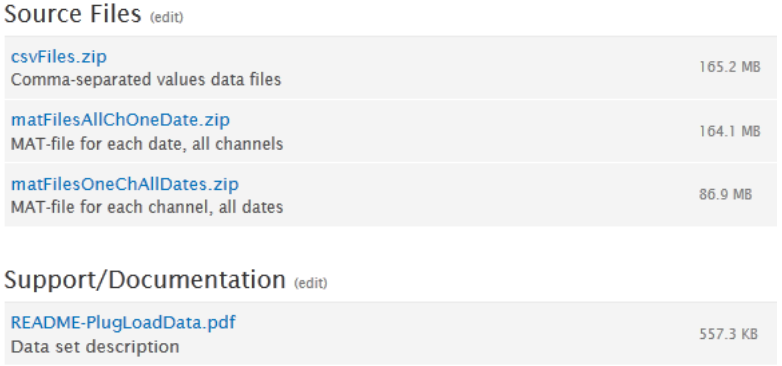
- 86 Power Ports deployed in Sustainability Base, 2nd floor of North building



- Working to provide personal energy dashboards to occupants and assess impact
- Exploring additional plug load control strategies
- Installing sub-metering at panel level
- Investigating other plug load management systems

Pilot Study Data

- .csv and .mat files of raw pilot study data available at https://c3.nasa.gov/dashlink/resources/500/
- README provided



Source Files (edit)

csvFiles.zip Comma-separated values data files	165.2 MB
matFilesAllChOneDate.zip MAT-file for each date, all channels	164.1 MB
matFilesOneChAllDates.zip MAT-file for each channel, all dates	86.9 MB

Support/Documentation (edit)

README-PlugLoadData.pdf Data set description	557.3 KB

README for Plug Load Data

We provide MATLAB binary files (.mat) and comma separated values files of data collected from a pilot study of a plug load management system that allows for the metering and control of individual electrical plug loads. The study included 15 power strips, each containing 4 channels (receptacles), which wirelessly transmitted power consumption data approximately once per second to 3 bridges. The bridges were connected to a building local area network which relayed data to a cloud-based service. Data were archived once per minute with the minimum, mean, and maximum power draw over each one minute interval recorded. The uncontrolled portion of the testing spanned approximately five weeks and established a baseline energy consumption. The controlled portion of the testing employed schedule-based rules for turning off selected loads during non-business hours; it also modified the energy saver policies for certain devices.

Three folders are provided: "matFilesAllChOneDate" provides a MAT-file for each date, each file has all channels; "matFilesOneChAllDates" provides a MAT-file for each channel, each file has all dates; "csvFiles" provides comma separated values files for each date (note that because of data export size limitations, there are 10 csv files for each date). Each folder has the same data; there is no practical difference in content, only the way in which it is organized.

The MAT-file format is similar in both folders. Each file contains two variables: 'data' and 'header'; 'header' is a description of the columns in 'data'. The MAT-files in "OneChAllDates" also has a variable 'fileInd', which is an array that contains the row indices of 'data' that mark a new date (e.g., data(fileInd(1):fileInd(2)-1,:) is all data for the first date). Here are the column headers with a description and example:

Column Header	Description	Example
Time	Serial date number	7.345540013888888e+5 (2/20/2011, 12:02 am)
nodeHid	Node (power strip) identifier (1-15)	4
channelNumber	Channel (receptacle) identifier (0-3)	0
powerAvg	Average power draw over 1 minute interval	9.42
powerMin	Minimum power draw over 1 minute interval	9.35
powerMax	Maximum power draw over 1 minute interval	9.50
powerSum	Summation of power counts received by data server over 1 minute interval	565.08
numMeasurements	Number of measurements received by data server over 1 minute interval (Note: powerAvg = powerSum / numMeasurements)	60