PI System for Improved Educational Outcomes: Research, Coursework, and Career Development

Presented by **Vivian Loftness**

Bertrand Lasternas

Background: Carnegie Mellon University

Founded in 1900 by Andrew Carnegie

12,991 Students (6223 undergrad)

CMU annual utility budget over $20M

That's over $1,600 per year per student!

Goal of the Oakland 2030 District:
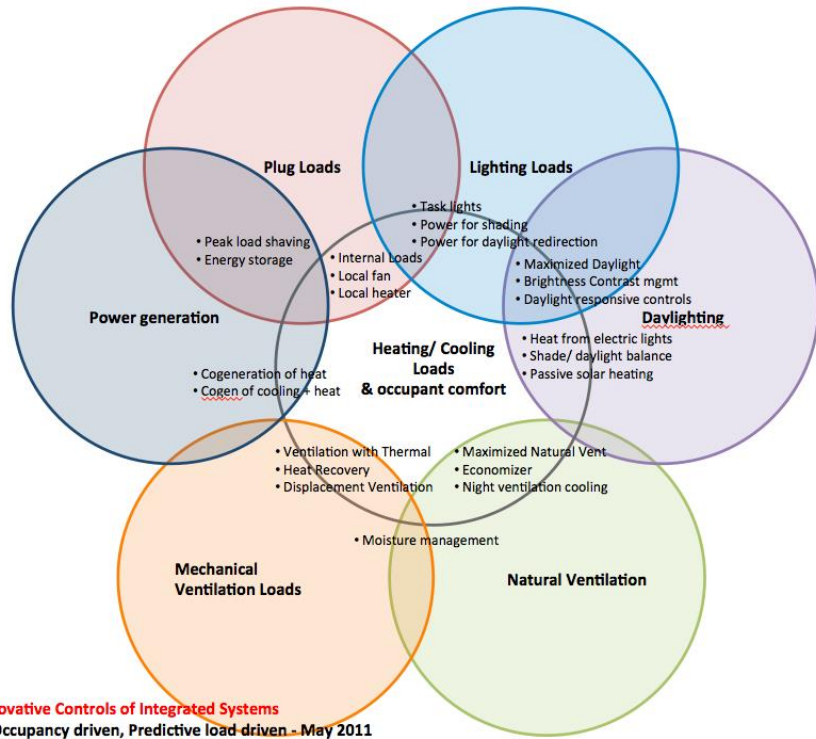
50% Energy Savings by 2030
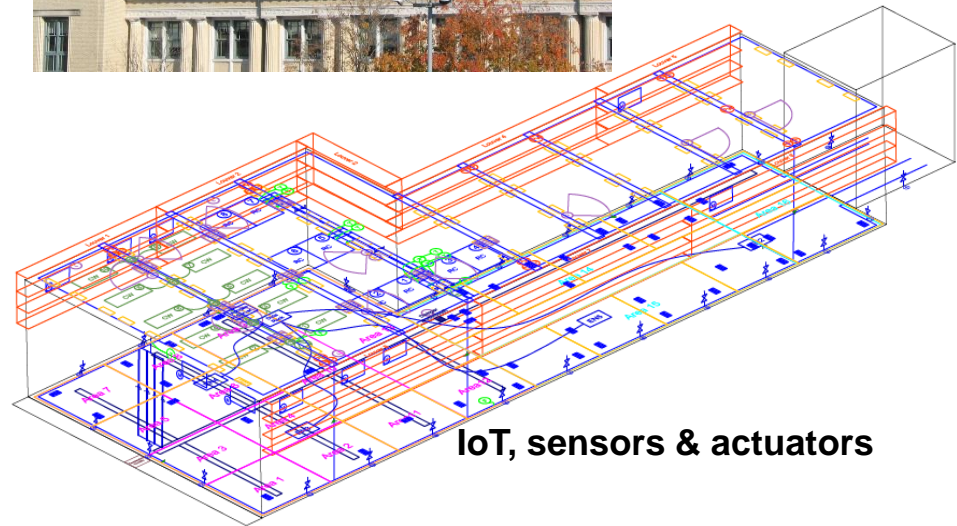
~ 6,500,000 sqft
65 + Buildings
80,000 data points

Pittsburgh, PA

The Intelligent Workplace: a Living Laboratory

Plug Loads

Lighting Loads

- Task lights
- Power for shading
- Power for daylight redirection

- Peak load shaving
- Energy storage

- Internal loads
- Local fan
- Local heater

- Maximized Daylight
- Brightness Contrast mgmt
- Daylight responsive controls

Power generation

Daylighting

Heating/ Cooling Loads & occupant comfort

- Heat from electric lights
- Shade/ daylight balance
- Passive solar heating

- Cogeneration of heat
- Cogen of cooling + heat

- Ventilation with Thermal
- Heat Recovery
- Displacement Ventilation

- Maximized Natural Vent
- Economizer
- Night ventilation cooling

- Moisture management

Mechanical Ventilation Loads

Natural Ventilation

ovative Controls of Integrated Systems
ccupancy driven, Predictive load driven - May 2011

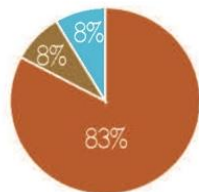**IoT, sensors & actuators**

ID-C

Intelligent Dashboards for Corporate and Campus Portfolio Managers

With Monthly Electric, Gas and Water Bills

2013 Utility Consumption Executive Summary

1 In 2013, ___ spent a total of:

$59 million
on utilities

- **$5 million on water**
- **$5 million on gas**
- **$49 million on electricity**

83%
8%
8%

total utility spending by resource consumption

2 In 2013, ___ consumed:

403 Million Gallons of Water — ...which is enough to provide **clean drinking water for the entire population of Somalia for almost 3 months**

472 Million kBTU of Gas — ...which is enough to heat **over 5,000 average households for a year**

586 Million kWh of Electricity — ...which is enough to power **almost 54,000 average homes in the United States for a year**

3 By building type, ___ spent:

	Retail	Office	Other
Million $ spent	$34 million	$19 million	$6 million
at:	$2.39/sf	$1.22/sf	$3.33/sf
Size Million GSF	14.2	15.6	1.8
Number of Buildings	3,206	419	163

4 Rank of Potential for Saving by Resource Type and Building Type

#1 Office Energy (Electricity + Gas)
potential savings of: **$2.3 million** from top 25 energy expenditure buildings

#2 Retail Energy (Electricity + Gas)
potential savings of: **$452 thousand** from top 25 energy expenditure buildings

#3 Office Water
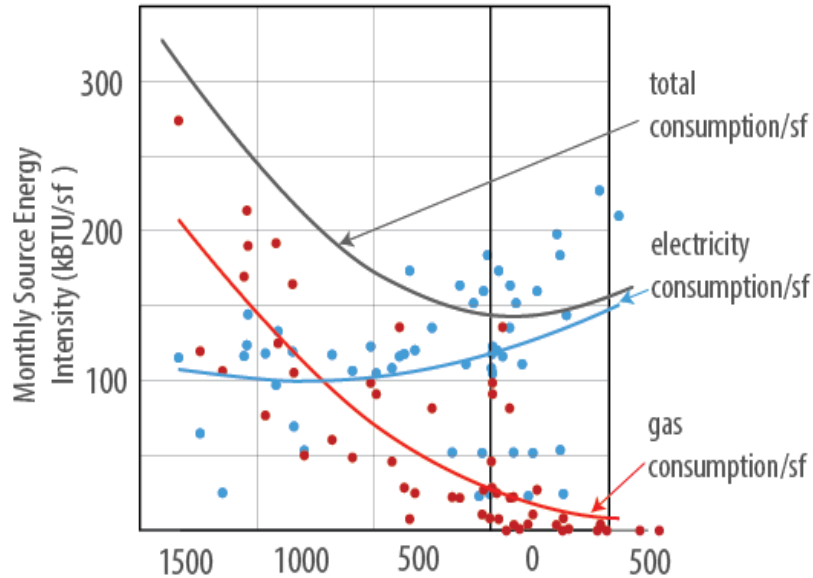potential savings of: **$287 thousand** from top 25 water expenditure buildings

#4 Retail Water
potential savings of: **$250 thousand** from top 25 water expenditure buildings

Engaging Stakeholders in Building Energy and Water Reduction
Kai-Wei Hsu & Ting Wang
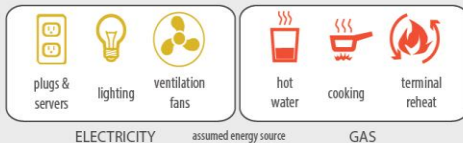
Monthly utility consumption: Lean Analysis

Base loads are estimated from averaging energy intensity in the **lowest cooling an**
heating degree day months, assuming there is no heating or cooling during tho
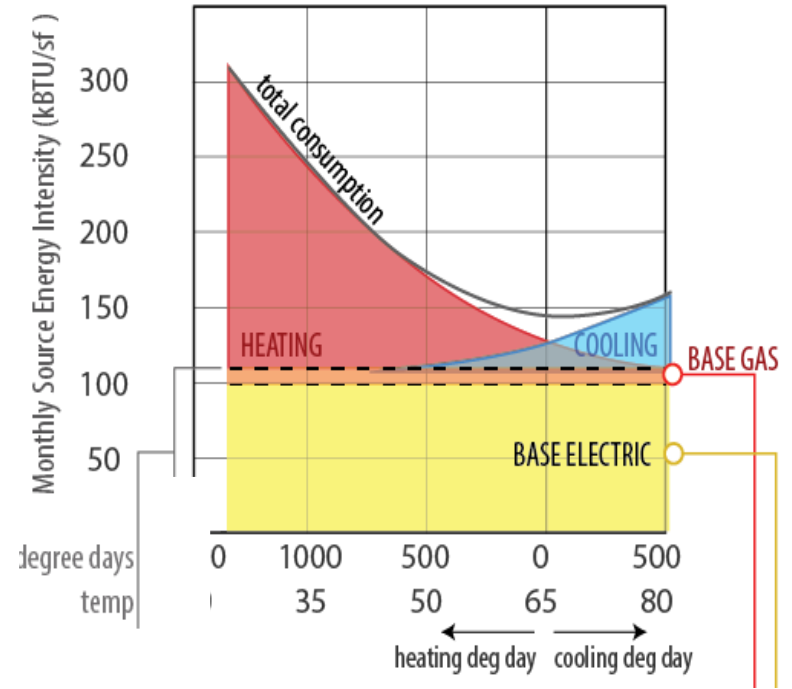
2011-13 OFFICE BASE LOADS
of PNC's 25 Highest Energy Use Intensities
Office Source Gas & Electric

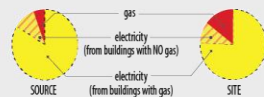1 Base loads MAY entail loads from:

plugs & servers | lighting | ventilation fans
ELECTRICITY | assumed energy source

hot water | cooking | terminal reheat
GAS

2 Out of the top 25 energy intense office buildings, **2 do not use gas**.

base loads in buildings without gas may include:

3 **Electric base loads** dominate PNC (top 25 energy intense) office base loads-- in both site and source energy.

gas
electricity (from buildings with NO gas)
electricity (from buildings with gas)
SOURCE | SITE

C2

4 The source **base loads** for these office buildings need to be addressed:

temp equivalent: 65
degree day: 0
heating cooling
deg day deg day

WORST 5

base gas: 0.13 | base gas: 0.18 | | base gas: 2.46 | base gas: 0.16 | base gas: 4.75 | base gas: 0.06 | base gas: 0.04

source load (kBTU/sf)

29 | 26 | 26 | 26 | 25 | 25 | 23 | 23 | 23

7 Miamisburg Bldg 1, OH | 2 Naperville South Office, IL | 21 205 Datura-W. Palm Beach, FL* | 1 East Brunswick - 710 Turnpike, NJ | 3 Dupont-DC | 4 Cincinnati-925 Annex, OH | 22 Highland Hills, OH | 16 Midway Operations Center, IL | 11 Clarendon Hills Office, IL

total baseload
energy intensity rank

base gas: 0.5 | base gas: 0.01 | base gas: 0.01 | base gas: 0.73 | base gas: 0.60 | base gas: 1.51 | base gas: 1.14 | base gas: 3.88 | base gas: 3.26

source load (kBTU/sf)

21 | 19 | 18 | 18 | 16 | 15 | 15 | 15 | 14

13 Westchester Office, IL | 15 Hanover Admin Center, PA | 23 Miamisburg Bldg 5, OH | 19 Aerospace-2000, OH | 20 Liberty Commons - CLC, PA | 5 Greensburg South Main St, PA | 6 Towne Centre - Saginaw, MI | Northeast Main-Libertyville, IL | 17 Valley Plaza - Indiana, IN

base gas: 0.12 | base gas: 3.26 | base gas: 1.67 | base gas: 0.25 | base gas: 0.79 | base gas: 0.05 | base gas: 0.17

source load (kBTU/sf)

15 | 12 | 11 | 11 | 11 | 10 | 5

10 Crawfordsville Road, IN | 9 Champaign Main Office, IL | 25 Traverse City Main Office, MI | 12 Westminster-Admin, MD | 18 Plymouth MI Main Office, MI | 24 Bay City MI - Traxler Court, MI | 14 Warren -201 Liberty St, PA

Energy Signature
all electric buildings | buildings with gas consumption

cooling
electric heating | heating
base gas load
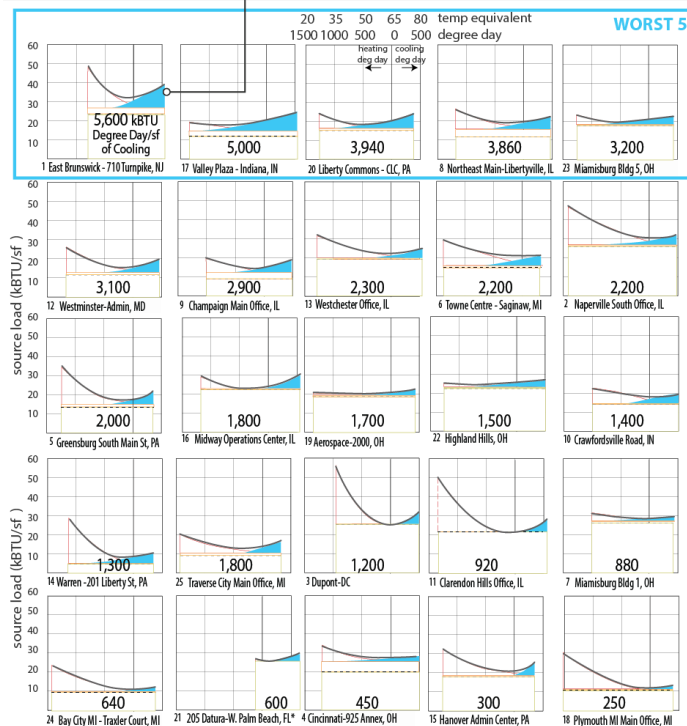base load | base electric load
total consumption

Engaging Stakeholders in Building Energy and Water Reduction
Kai-Wei Hsu & Ting Wang

2011-13 OFFICE COOLING
of PNC's 25 Highest Energy Use Intensities
Office Source Electricity

C3

1 High cooling **MAY** be due to a building's:
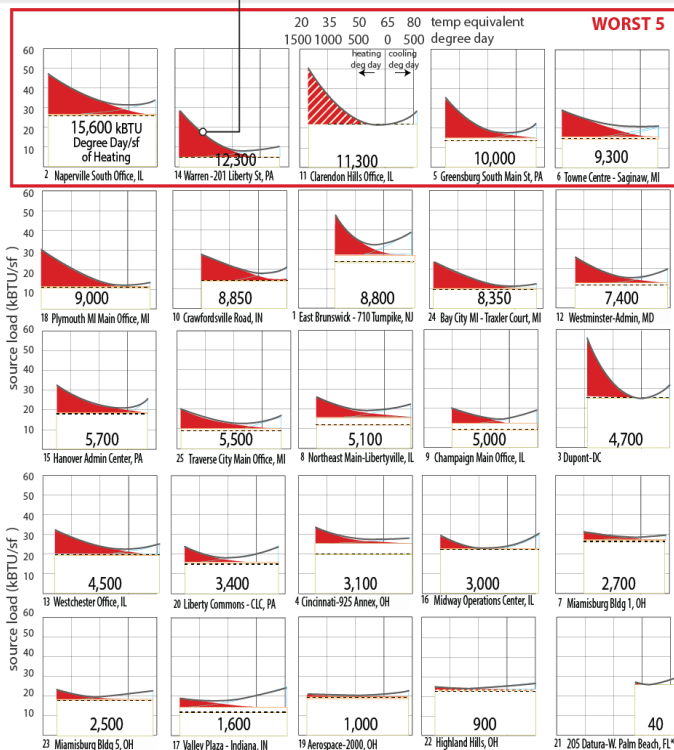
- Poor Envelope
- Insufficient Shading
- Air Conditioning Inefficiency
- Poor Seasonal Operation

2 Cooling electricity (area under the curve) needs to be addressed in these buildings:

WORST 5

20 35 50 65 80   temp equivalent
1500 1000 500 0 500 degree day

heating deg day → cooling deg day

- 5,600 kBTU Degree Day/sf of Cooling — 1 East Brunswick - 710 Turnpike, NJ
- 5,000 — 17 Valley Plaza - Indiana, IN
- 3,940 — 20 Liberty Commons - CLC, PA
- 3,860 — 8 Northeast Main-Libertyville, IL
- 3,200 — 23 Miamisburg Bldg 5, OH

source load (kBTU/sf)

- 3,100 — 12 Westminster-Admin, MD
- 2,900 — 9 Champaign Main Office, IL
- 2,300 — 13 Westchester Office, IL
- 2,200 — 6 Towne Centre - Saginaw, MI
- 2,200 — 2 Naperville South Office, IL

- 2,000 — 5 Greensburg South Main St, PA
- 1,800 — 16 Midway Operations Center, IL
- 1,700 — 19 Aerospace-2000, OH
- 1,500 — 22 Highland Hills, OH
- 1,400 — 10 Crawfordsville Road, IN

- 1,300 — 14 Warren -201 Liberty St, PA
- 1,800 — 25 Traverse City Main Office, MI
- 1,200 — 3 Dupont-DC
- 920 — 11 Clarendon Hills Office, IL
- 880 — 7 Miamisburg Bldg 1, OH

- 640 — 24 Bay City MI - Traxler Court, MI
- 600 — 21 205 Datura-W. Palm Beach, FL*
- 450 — 4 Cincinnati-925 Annex, OH
- 300 — 15 Hanover Admin Center, PA
- 250 — 18 Plymouth MI Main Office, MI
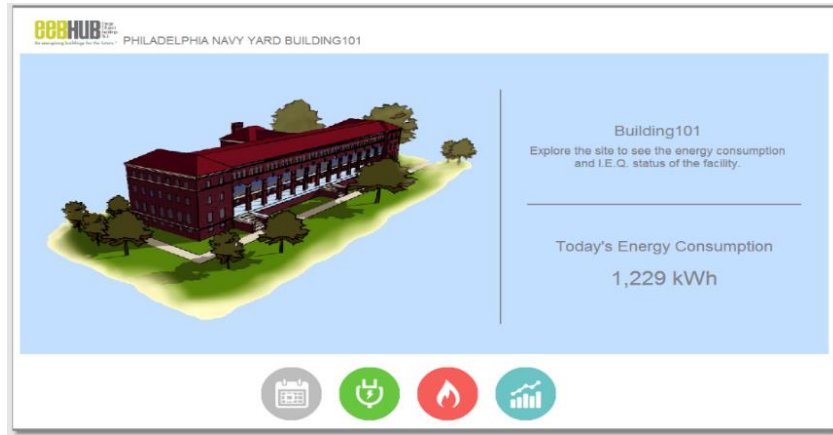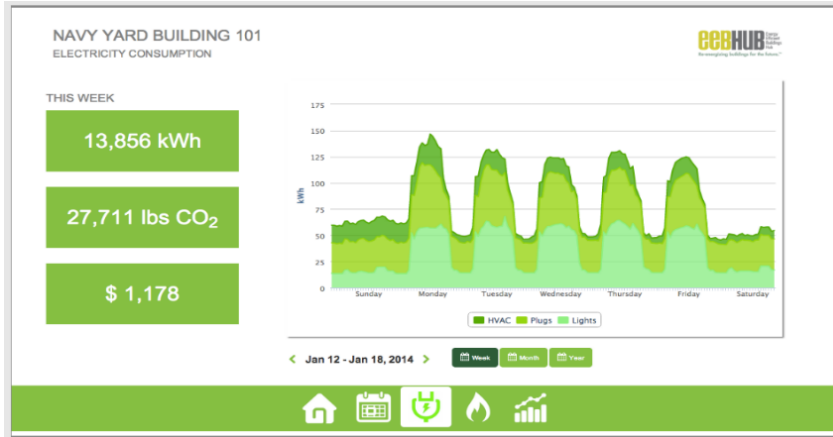
3 A CLOSER LOOK: Highest cooling loads of the 5 worst cooling buildings determined by the slope of the curve

source load above baseload (kBTU/sf)

+10

East Brunswick
Valley Plaza
Liberty Commons

+5

North East Main

Miamisburg Bldg 5

at baseload

20 35 50 65 80   temp equivalent (°F)
1500 1000 500 0 500 degree day

Worst Seasonal Operation

Liberty Commons, PA
cooling until ~26°F

Valley Plaza, IN
cooling until ~35°F

Worst buildings in terms of Envelope, Insufficient Shading, or Air Conditioning Inefficiency

East Brunswick, NJ
using ~7 kBTU/sf for 15°F of temperature change

North East Main, IL
using ~3 kBTU/sf for 15°F of temperature change

	approx. cooling until:	per 15°F temp change:	Energy Signature all electric buildings	buildings with gas consumption
Liberty Commons, PA	29°F	~2 kBTU/sf		cooling
Valley Plaza, IN	35°F	~2 kBTU/sf	electric heating	heating
Miamisburg Bldg 5, OH	41°F	~2 kBTU/sf		base gas load
Nort East Main, IL	46°F	~3 kBTU/sf	base load	base electric load
East Brunswick, NJ	59°F	~7 kBTU/sf		total consumption

Engaging Stakeholders in Building Energy and Water Reduction
Kai-Wei Hsu & Ting Wang

2011-13 OFFICE HEATING
of PNC's 25 Highest Energy Use Intensities
Bank Branches Source Electricity & Gas

1 **High heating load MAY be due to a building's:**

Poor Envelope | Heating System Inefficiency | Poor Seasonal Operation

2 **Heating** (area under the curve) needs to be addressed in these buildings:

20 35 50 65 80 temp equivalent degree day
1500 1000 500 0 500

heating deg day | cooling deg day

WORST 5

15,600 kBTU Degree Day/sf of Heating

15,600 — 2 Naperville South Office, IL	12,300 — 14 Warren -201 Liberty St, PA	11,300 — 11 Clarendon Hills Office, IL	10,000 — 5 Greensburg South Main St, PA	9,300 — 6 Towne Centre - Saginaw, MI
9,000 — 18 Plymouth MI Main Office, MI	8,850 — 10 Crawfordsville Road, IN	8,800 — 1 East Brunswick - 710 Tumpike, NJ	8,350 — 24 Bay City MI - Traxler Court, MI	7,400 — 12 Westminster-Admin, MD
5,700 — 15 Hanover Admin Center, PA	5,500 — 25 Traverse City Main Office, MI	5,100 — 8 Northeast Main-Libertyville, IL	5,000 — 9 Champaign Main Office, IL	4,700 — 3 Dupont-DC
4,500 — 13 Westchester Office, IL	3,400 — 20 Liberty Commons - CLC, PA	3,100 — 4 Cincinnati-925 Annex, OH	3,000 — 16 Midway Operations Center, IL	2,700 — 7 Miamisburg Bldg 1, OH
2,500 — 23 Miamisburg Bldg 5, OH	1,600 — 17 Valley Plaza - Indiana, IN	1,000 — 19 Aerospace-2000, OH	900 — 22 Highland Hills, OH	40 — 21 205 Datura-W. Palm Beach, FL*

source load (kBTU/sf)

3 **A CLOSER LOOK: Highest heating loads** of the 5 worst heating buildings determined by the **slope of the curve**

Clarendon Hills
Warren-201 Liberty St.
Naperville South
Greensburg S Main St.
Towne Centre - Saginaw

+30
+20
+10

source load above baseline (kBTU/sf)

at baseload

temp equivalent (°F) 20   35   50   65   80
degree day   1500 1000 500   0   500

Worst Seasonal Operation

Warren-201 Liberty St., PA heating until ~72 °F | Naperville South Office, IL heating until ~79 °F

Worst buildings in terms of Envelope, or Heating Inefficiency

Clarendon Hills, IL using ~7 kBTU/sf for 15 °F temperature change | Warren- 201 Liberty St. using ~3 kBTU/sf for 15 °F temperature change

	approx. heating until:	per 15 °F temp change:
Naperville South, IL	79 °F	~2 kBTU/sf
Warren -201 Liberty St., PA	72 °F	~3 kBTU/sf
Clarendon Hills, IL	68 °F	~7 kBTU/sf
Greensburg S Main St, PA	63 °F	~3 kBTU/sf
Towne Center Saginaw, MI	60 °F	~3 kBTU/sf

Energy Signature

all electric buildings:
- electric heating
- base load

buildings with gas consumption:
- cooling
- heating
- base gas load
- base electric load
- total consumption

Engaging Stakeholders in Building Energy and Water Reduction
Kai-Wei Hsu & Ting Wang

ID-F

Intelligent Dashboards for Facility Managers

With Real Time Building Automation and Electric, Gas and Water Consumption

Intelligent Dashboard for FM and the Public

Real-Time IEQ Status

Electrical Load Breakdowns

Hour by Hour Energy Consumption Maps (8760 hrs/1 yr)

Facility Manager Space and System Read-outs

Second Floor

W — Wall Sensor A — Aircuity
P — Pyranometer G — Glazing Sensor

Exterior Condition		
Outside Air Temp.	73.4	F
Outside RH	49.4	

206_ VAV_2-7		
Zone CO2	573	ppm
Zone RH	45	%
Zone Temp	74.9	F
Discharge Air Temp.	63.5	F
Air Flow Rate	1880	cfm

222_VAV_2-5		
Zone CO2	534	ppm
Zone RH	46	%
Zone Temp	73.0	F
Discharge Air Temp.	62.6	F
Air Flow Rate	1435	cfm

227_VAV_2-8		
Zone CO2	495	ppm
Zone RH	45	%
Zone Temp	72.7	F
Discharge Air Temp.	62.7	F
Air Flow Rate	1029	cfm

VAV A-6 CBRE
VAV 2-7
VAV 2-6
VAV 2-5
VAV 2-4 EEB-Hub
VAV 2-8
2-2 2-3 2-1

201_VAV_A-6		
Zone CO2	587	ppm
Zone RH	47	%
Zone Temp	73.9	F
Discharge Air Temp.	63.7	F
Air Flow Rate	3135	cfm

205_VAV_2-6		
Zone CO2	543	ppm
Zone RH	45	%
Zone Temp	74.8	F
Discharge Air Temp.	63.5	F
Air Flow Rate	2216	cfm

214_VAV_2-1		
Zone CO2	516	ppm
Zone RH	49	%
Zone Temp	72.5	F
Discharge Air Temp.	72.0	F
Air Flow Rate	586	cfm

223_VAV_2-4		
Zone CO2	530	ppm
Zone RH	43	%
Zone Temp	74.8	F
Discharge Air Temp.	62.4	F
Air Flow Rate	1483	cfm

212_VAV_2-6		
Zone CO2	544	ppm
Zone RH	46	%
Zone Temp	74.6	F
Discharge Air Temp.	72.8	F
Air Flow Rate	245	cfm

213_VAV_2-3		
Zone CO2	519	ppm
Zone RH	44	%
Zone Temp	75.3	F
Discharge Air Temp.	72.9	F
Air Flow Rate	90	cfm

Alarm Cold Comfortable Hot Alarm

AHU1
Building Automation System 9/30/2013 10:25:00 AM
Hub Scientific Database 9/29/2013 12:01:00 AM

Return Air		
Return Air Temp.	68.0	F
Damper Position	84	%
Return Air Temp.	74.2	F
Return St. Pressure	-0.07	in
Return Air Humidity	42.2	%
Return Air CO2	467	ppm

Mixed Air		
Mixed Air Temp.	67.0	F
Mixed Air Static Pres.	1.15	in
Mixed Air Temp.	74.2	F
After Filter St. Pres.	-0.07	in
Mixed Air Humidity	42.1	%

After Heating Coil		
	Systems Flow & Energy	
Temperature	67.6	F
Static Pressure	-0.07	in

Systems Flow & Energy		
Return Air Flow (calc)	-0.07	in
OA Air Flow	1.6	cfm
Supply Air Flow	0	cfm

Supply Air		
External Pressure	1.12	in
External Pressure Stpt.	1.13	in
Temperature	57.9	F
Temperature Stpt.	63.0	F
Avg. Supply Velocity	0	fpm
Avg. Supply Temp.	75.5	F
Supply Air Temp.	75.6	F
Supply Air St. Pressure	-0.07	in
Supply Air RH	40.4	%
Supply Air CO2	522	ppm

Outside Air		
OA Temp	73	F
OA Humidity	49	%
Damper Position	16	%
Avg. Fresh Air Temp.	64	F
Avg. Fresh Air Veloc.	0	fpm
OA		
Damper Position	13	%

Heating Coil / Boiler		
Status HW Heat. Valve	0	%
HW Temp. Supply	79	F
HW Temp. Return	77	F
HW Heating Energy	0	Btu/h
Status HW Heat. Valve	81	%

Evap. Coil & Cond. Unit		
Hot Gas Bypass Temp.	74	F
Liquidline Temp.	63	F

Fan		
Supply Fan Status	●	/
Fan Speed	76	rpm
Fan Speed	0	rpm

More than 20 Universities can access and share real time building information

ID-O

Intelligent Dashboards for Occupants

with individualized plug load meter/controllers

Office Equipment Plug Loads as a Percent of Total Office Electricity

Plug Load Best Practices Guide
NBI/Pier 2012

setting up
workstation
energy detection

(wow, abandoned technology
is still drawing power)

Intelligent Dashboard CBPD, Carnegie Mellon University
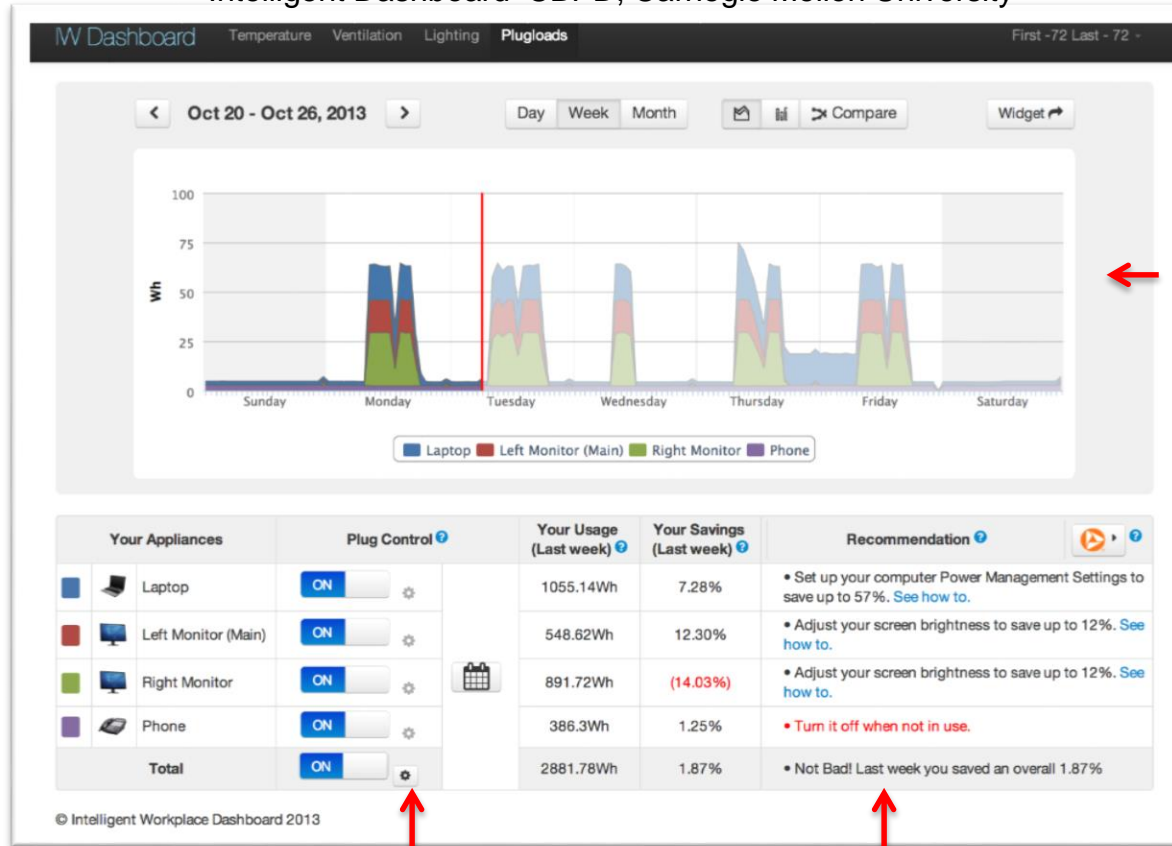
advancing C3 qualities

communication

control

expert consulting

Field Study – 3 interfaces

(n=20)

(n=20)
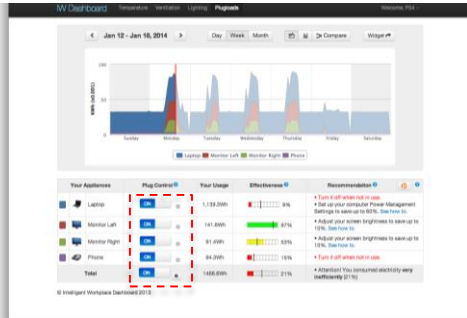
(n=20)
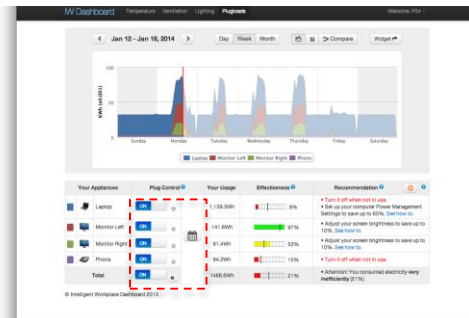
(n=20)

Large office building (n=80)

Energy Savings Per Group (Pre – During – Post)

Ray Yun, Intelligent Dashboard CBPD, Carnegie Mellon University
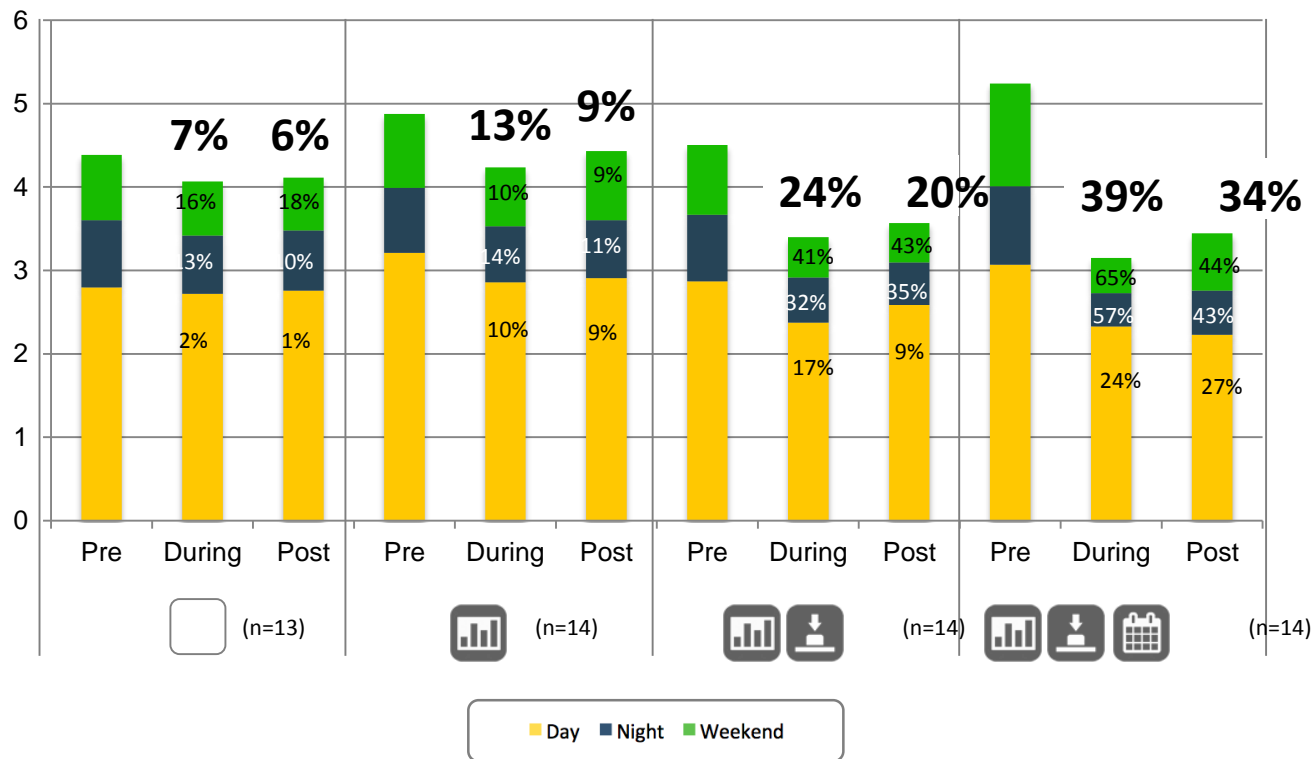
Data Available On Campus

About 6,500,000 sqft (65+ Buildings) = 80,000 data points

- Revenue Grade Electric Meters installed on 30+ buildings (query each second)
- Building Automation Systems for 15+ buildings
- Building Water consumption data, Building Steam meter data
- Environmental data
- Weather Data (on Campus and nationwide with 1300 weather stations starting 1/1/1970)

Challenges On Campus

6 Hardware and BAS dependent vendors

- Multiple BAS vendors: Siemens, Johnson Control, Automated Logic, American Automation, Delta, KMX
- Each with a proprietary portal for access and data visualization
- Limited trending capabilities
- Data gets overridden or lost over time
- "Expert" needed to access the data and identify potential errors

Figure flow labels:

City/Large Building Portfolio Data
- Building Attributes
- Energy Bill
- Real-Time Sub-Metering Data
- Real Time BAS/Sensor Data

Data quality control and labeling using **BEDES** taxonomy

SEED API

BPD API

PI System

SEED

BPD

Data filters with analytic tools

Business Tools (Microsoft, SAP, OSIsoft PI Clients)

Open Access Data

DOE Websites

Laptops/Desktop Tablets/Mobile

CMU: FM Interface

CMU: Occupant Interface

Portfolio Manager

Interfaces/Data Analytics Reporting
Policy Makers• Building Engineers• Building Occupants• Public• Researchers

Data Collection

Data Repository

Data Filters

Analytics Tools (transparent, ubiquitous, ++)

Academic projects

All students and researchers have access to all Campus data

- Through the OSIsoft PI WEB API
- Though PI Coresight
- Through Data Download Webpage

Several Classes using data real time data for projects

- Information System Students (Connect FMS)
- Architecture Students (Reactive Spaces, CBPD Masters)
- Heinz Engineering and Public Policy Students (Big Data)

Campus Open Data Access

Create and download custom report

Understand the Data

Gates Building
10,547 points

	A	B	C	D	E	F	G
1	Location	Control Program	Name	Value	Object ID	Device ID	Object Name
2	/Carnegie Mellon University/Oakland Campus/Gates-Hillman SCSC/SCSC Gates/Third Floor	Room 3000 Classroom VAV	Flow Control / Flow Input	682.0 cfm	AI:1	DEV:2401203	flow_input_1
3	/Carnegie Mellon University/Oakland Campus/Gates-Hillman SCSC/SCSC Gates/Third Floor	Room 3000 Classroom VAV	Zone Temp / Zone Temp	70.1 F	AI:2	DEV:2401203	zone_temp_1
4	/Carnegie Mellon University/Oakland Campus/Gates-Hillman SCSC/SCSC Gates/Third Floor	Room 3000 Classroom VAV	Zone Temp / Override Time Remaining	0.0 min	AV:1	DEV:2401203	override_time_remaining_1
5	/Carnegie Mellon University/Oakland Campus/Gates-Hillman SCSC/SCSC Gates/Third Floor	Room 3000 Classroom VAV	Discharge Temp	56.3 F	AI:3	DEV:2401203	da_temp_1
6	/Carnegie Mellon University/Oakland Campus/Gates-Hillman SCSC/SCSC Gates/Third Floor	Room 3000 Classroom VAV	Zone CO2	455.0 ppm	AI:4	DEV:2401203	zone_co2_1
7	/Carnegie Mellon University/Oakland Campus/Gates-Hillman SCSC/SCSC Gates/Third Floor	Room 3000 Classroom VAV	OCC Sensor	On	BI:1	DEV:2401203	occ_sensor_1
8	/Carnegie Mellon University/Oakland Campus/Gates-Hillman SCSC/SCSC Gates/Third Floor	Room 3000 Classroom VAV	HWV Command	8.3 V	AO:1	DEV:2401203	hwv_command_1
9	/Carnegie Mellon University/Oakland Campus/Gates-Hillman SCSC/SCSC Gates/Third Floor	Room 3000 Classroom VAV	Airflow	685.87 cfm	AV:2	DEV:2401203	flow_1
10	/Carnegie Mellon University/Oakland Campus/Gates-Hillman SCSC/SCSC Gates/Third Floor	Room 3000 Classroom VAV	Airflow Setpoint	1200.0 cfm	AV:3	DEV:2401203	flow_sp_1
11	/Carnegie Mellon University/Oakland Campus/Gates-Hillman SCSC/SCSC Gates/Third Floor	Room 3000 Classroom VAV	Cool Request	0	AV:4	DEV:2401203	cool_request_1

(Unigrams, K-MERS) from text data

Semantic information defining by Clustering

VAV# DISCHARGE TEMPERATURE

AHU# SUPPLY TEMPERATURE

Relationship defining by Data-driven method

Analysis of points name semantic with Clustering

	All the text features (563EA)
D_1	0 1 0 0 1 0 …
D_2	1 0 0 0 0 0 …
D_3	1 1 1 0 0 1 …
D_4	1 0 0 0 0 0 …
…	…
D_{10547}	1 0 0 0 0 0 …

10,547 X 563 matrix with binary variable
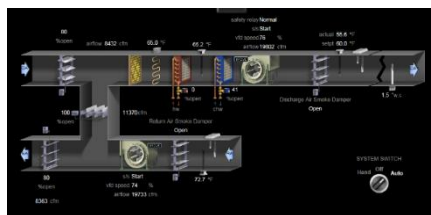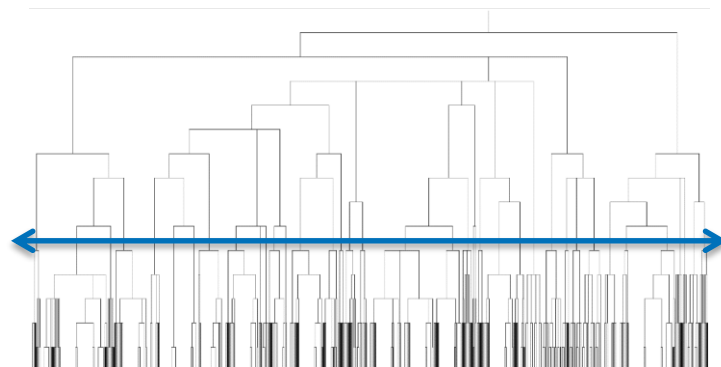
287 VAVs (sensor reading) ⟷ 6 AHUs (counting)

VAV1

VAV2

AHU1
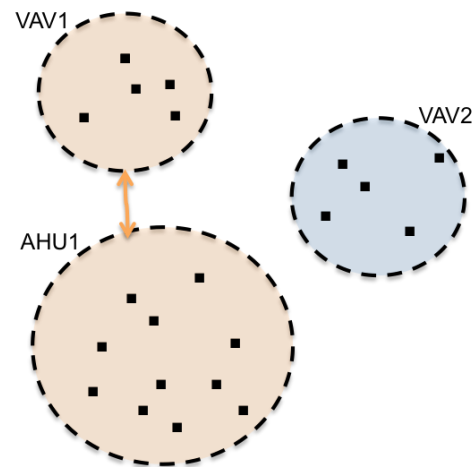
Fault Detection and Diagnostic (Predictive Maintenance)

1 Collect Data Real-Time

2 Train Model against baseline

3 Predict (project) baseline behavior

4 Measure variation between prediction and measured behavior

5 Trigger notification, corrective actions
Save Time, Money, and Energy
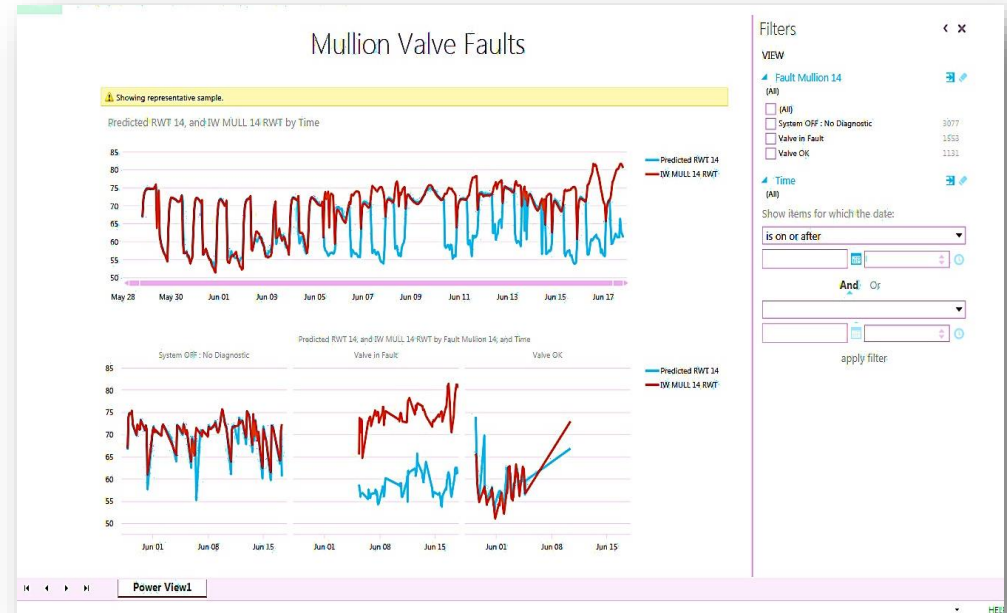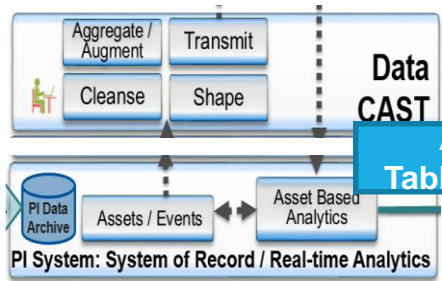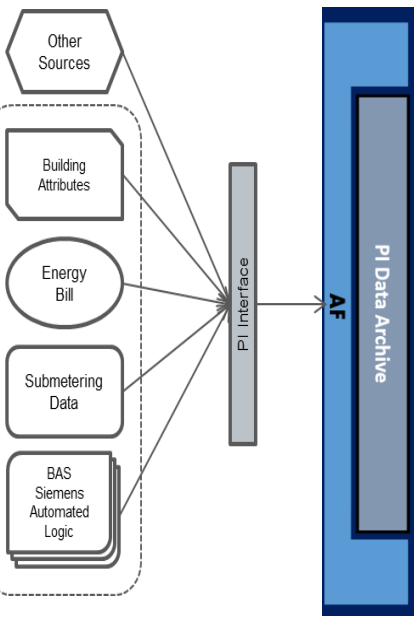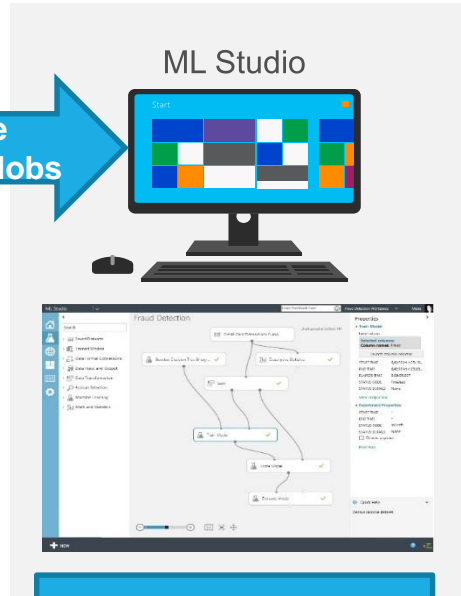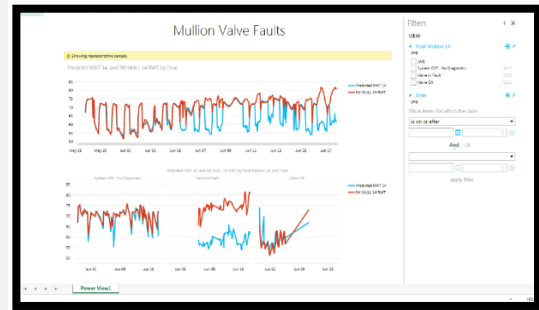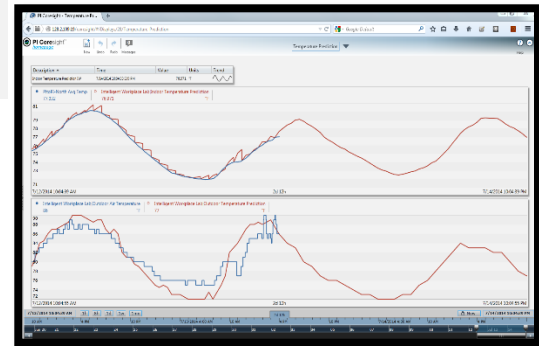
ConnectFMS : Crowd Sourcing App

report a problem

snap photos

make comments

vote on posts

Reactive Spaces
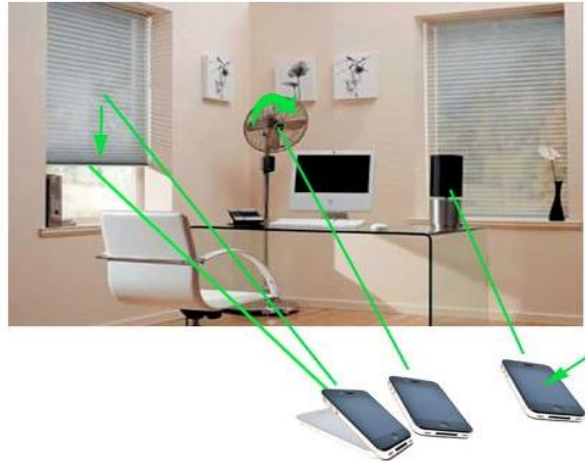
https://reactivespaces.wordpress.com/

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PROJECT HEARTBEAT

Innovative Solutions

„Human in the Loop" Smartphone:
an Occupancy Sensor, Environmental & Energy Feedback, a "Magic" Remote

CMU CBPD & Technical University of Munich Thesis Projects
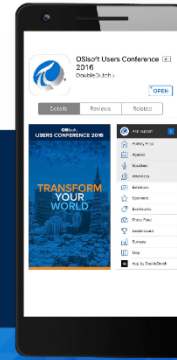
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Please wait for the **microphone** before asking your questions

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감사합니다

谢谢

Danke

Gracias

Merci

Thank You

ありがとう

Спасибо

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