Sustainability Research for Cutting Edge Practice

Vivian Loftness FAIA, University Professor and Paul Mellon Chair in Architecture

The Center for Building Performance & Diagnostics (CBPD)

40 years of B.Arch, MS & PhD graduates
MSSD, MSBPD, PhDBPD, DPP plus UG in classes each year

26 Years of University/ Industry/Government Consortia
ABSIC $300K – $1M of research each year

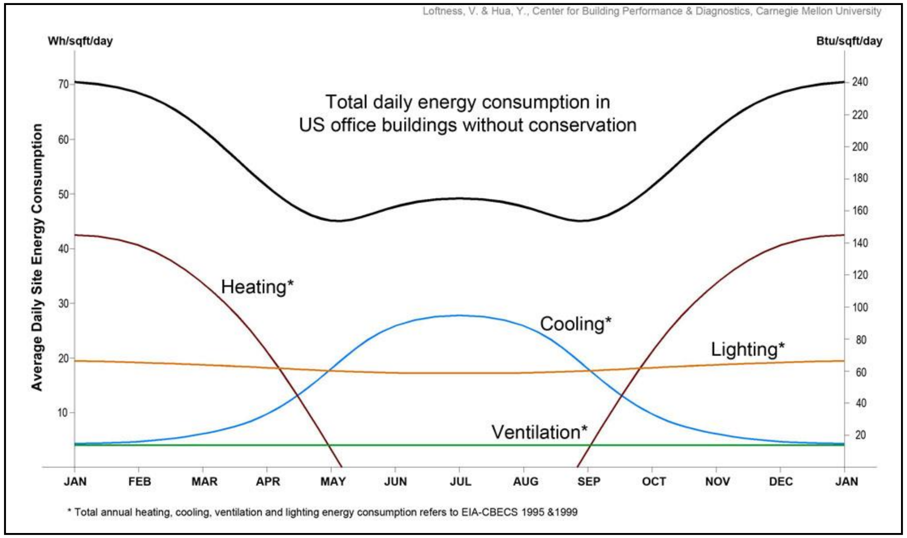
1999 Business Week Award, 2000 AIA Honor Award,
2013 NSF Alexander Schwarzkopf Prize
"for exemplary research contribution to technology innovation and its positive impact on industry and the society as a whole".

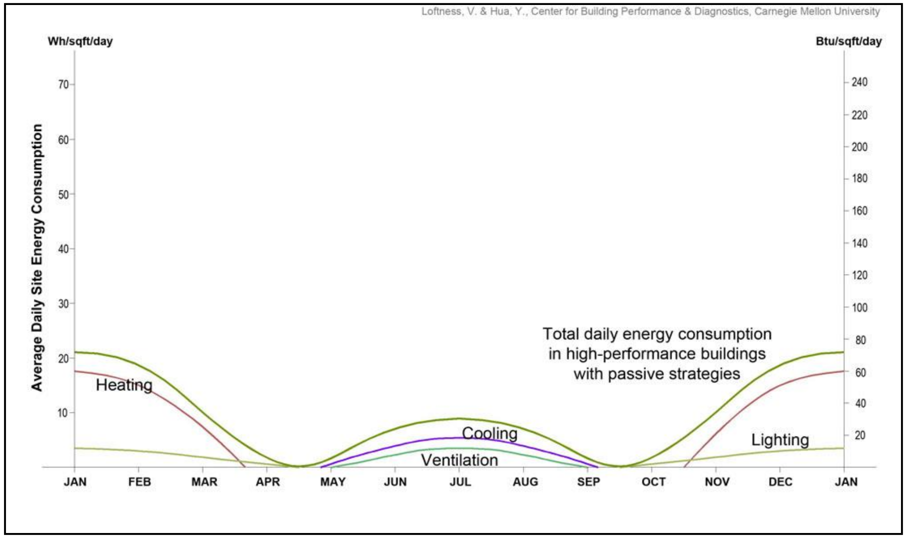
 

Research on Systems Integration for
Building Performance and Environmental Sustainability

The Intelligent Workplace -
a Living Laboratory for
Innovative Enclosures, Heating, Cooling, Lighting,
Networking, Controls, & Interior Systems

48-315 Environmental Systems: Climate, Energy in Buildings (9)
48-723 Performance of Advanced Building Systems (9)
12-748 Mechanical and Electrical System Design for Buildings (6)
48-752 Zero Energy Housing (9)
48-795 LEED, Green Design and Building Rating in Global Context (6)





Guidelines for High Performance Low Energy Buildings

Land-use, Site and Water
Enclosure
HVAC
Lighting
Networking
Interiors
Building Delivery Process

Example clients: State Department, Architect of the Capitol, Electricite de France, US Army CERL, BAC Singapore, Sichuan and Tainjin China, General Services Administration… & of course Educational Curriculum

ABSIC/CBPD Guidelines for
High Performance Enclosure Systems

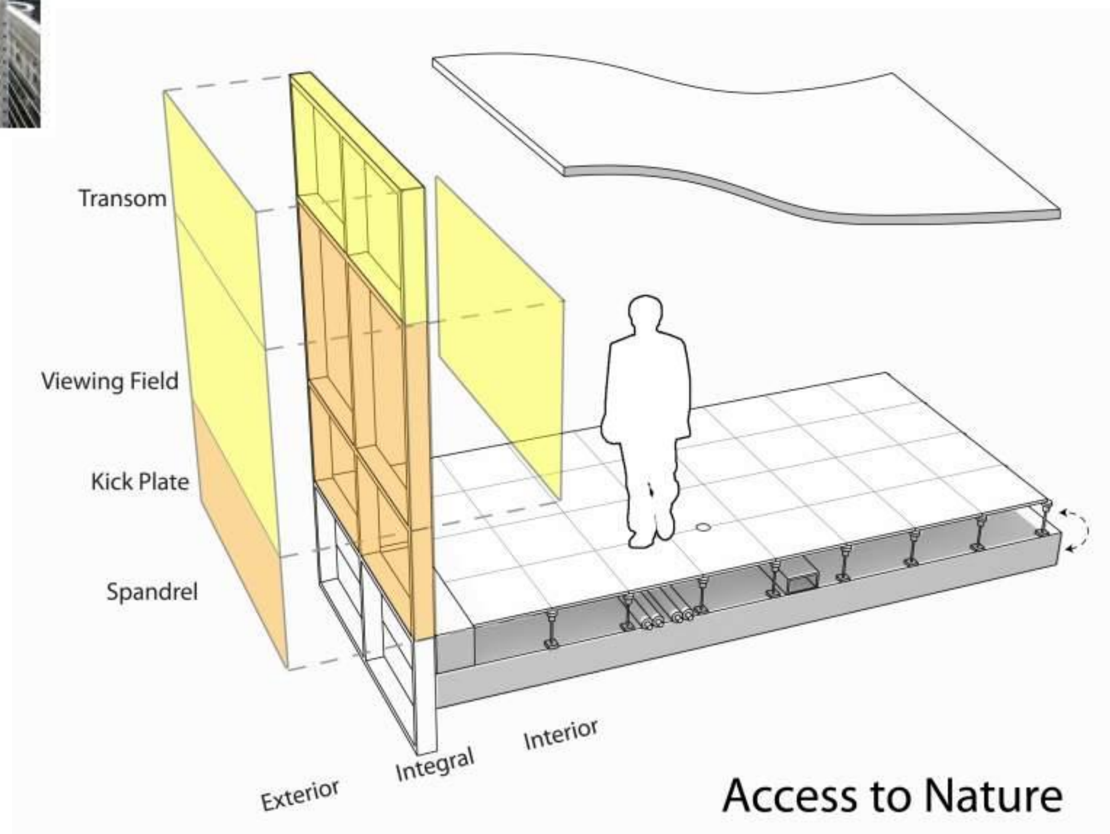


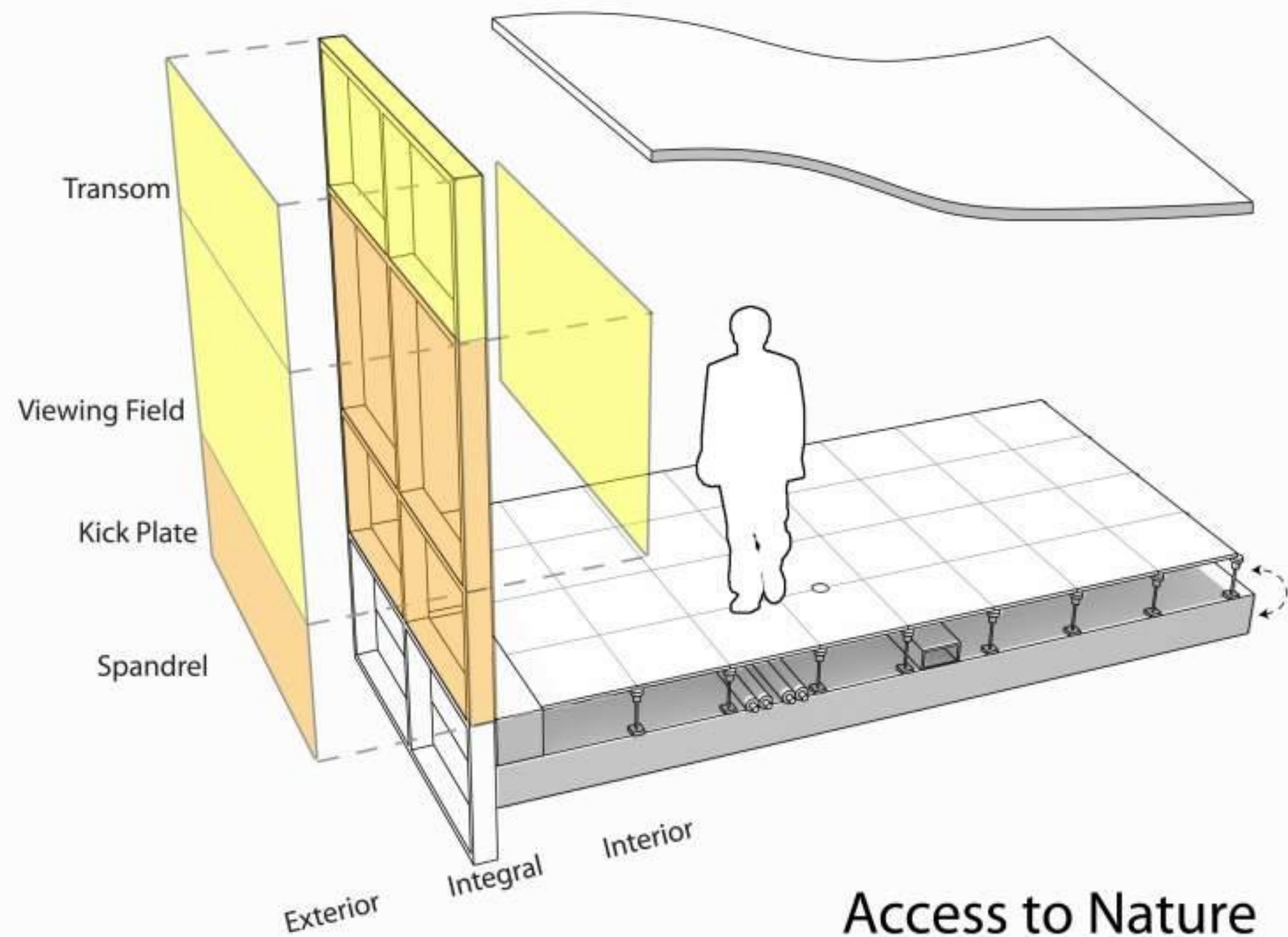
1. Maximize individual access to the natural environment
2. Maximize daylighting for task and ambient lighting
3. Maximize natural ventilation with mixed-mode conditioning
4. Minimize enclosure heat loss/heat gain
5. Design solar heat and glare control
6. Engineer load balancing and mean radiant temperature control
7. Engineer passive and active solar heating, cooling and power
8. Maximize enclosure integrity and material sustainability

	INTERIOR	INTEGRAL	EXTERIOR
TRANSOM	A1	A2	A3
VIEWING FIELD	B1	B2	B3
BRUESTUNG	C1	C2	C3
SPANDREL	D1	D2	D3

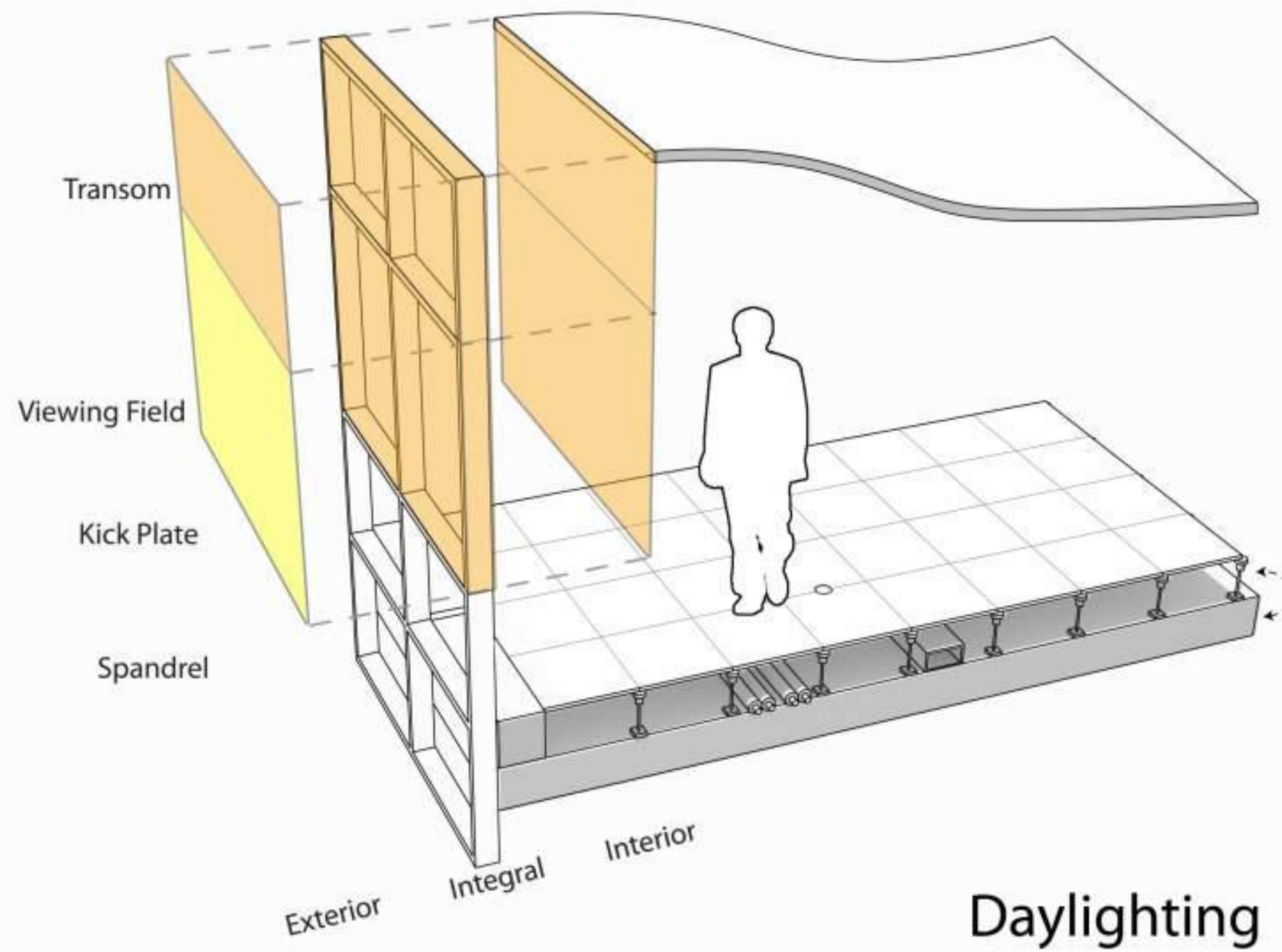
Sustainable Enclosures ensure:

access to nature
daylighting
natural ventilation
heat loss/ heat gain control
solar heat and glare control
load balancing
heat & power generation
water management
longevity & change
systems integration

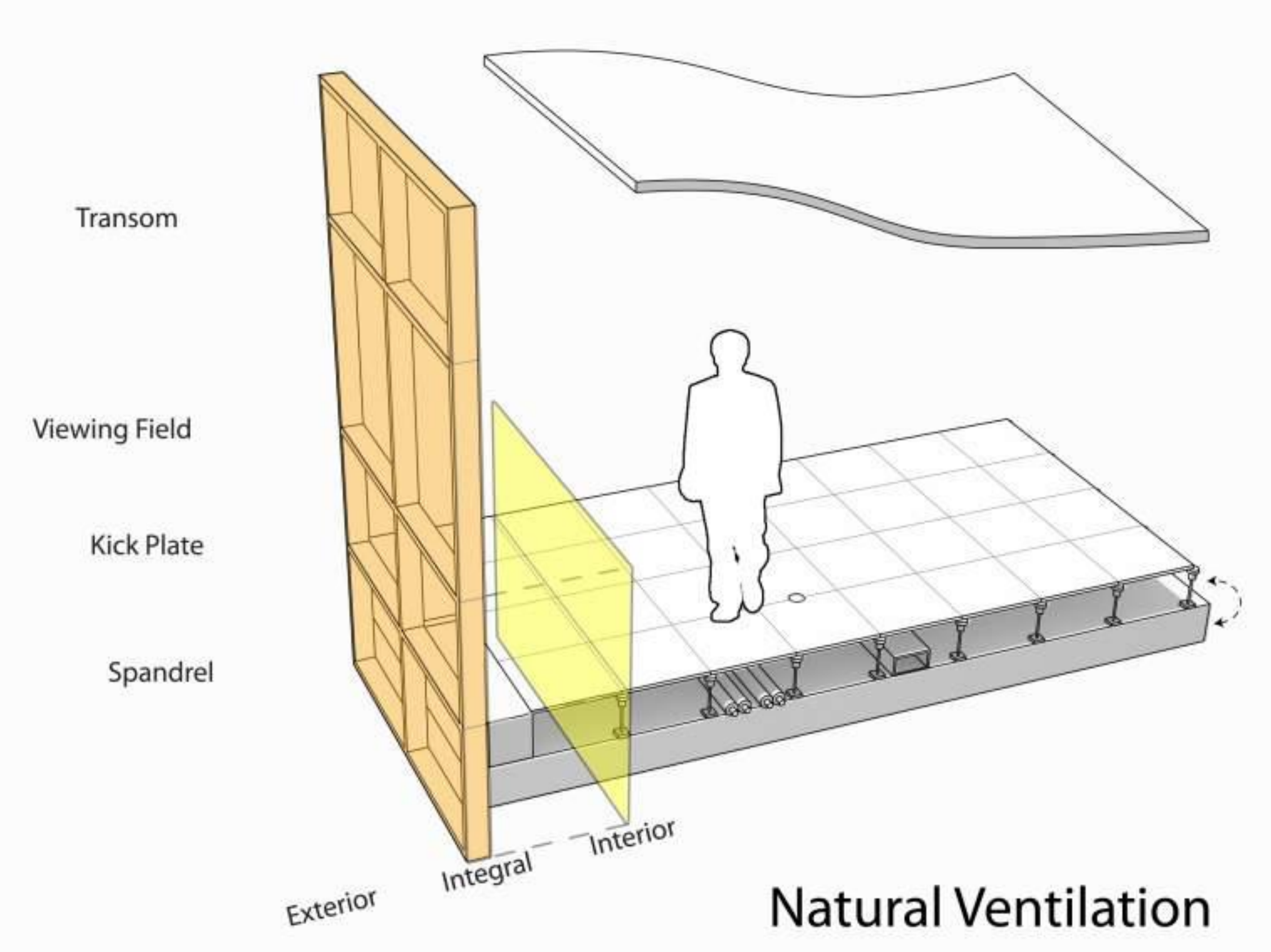


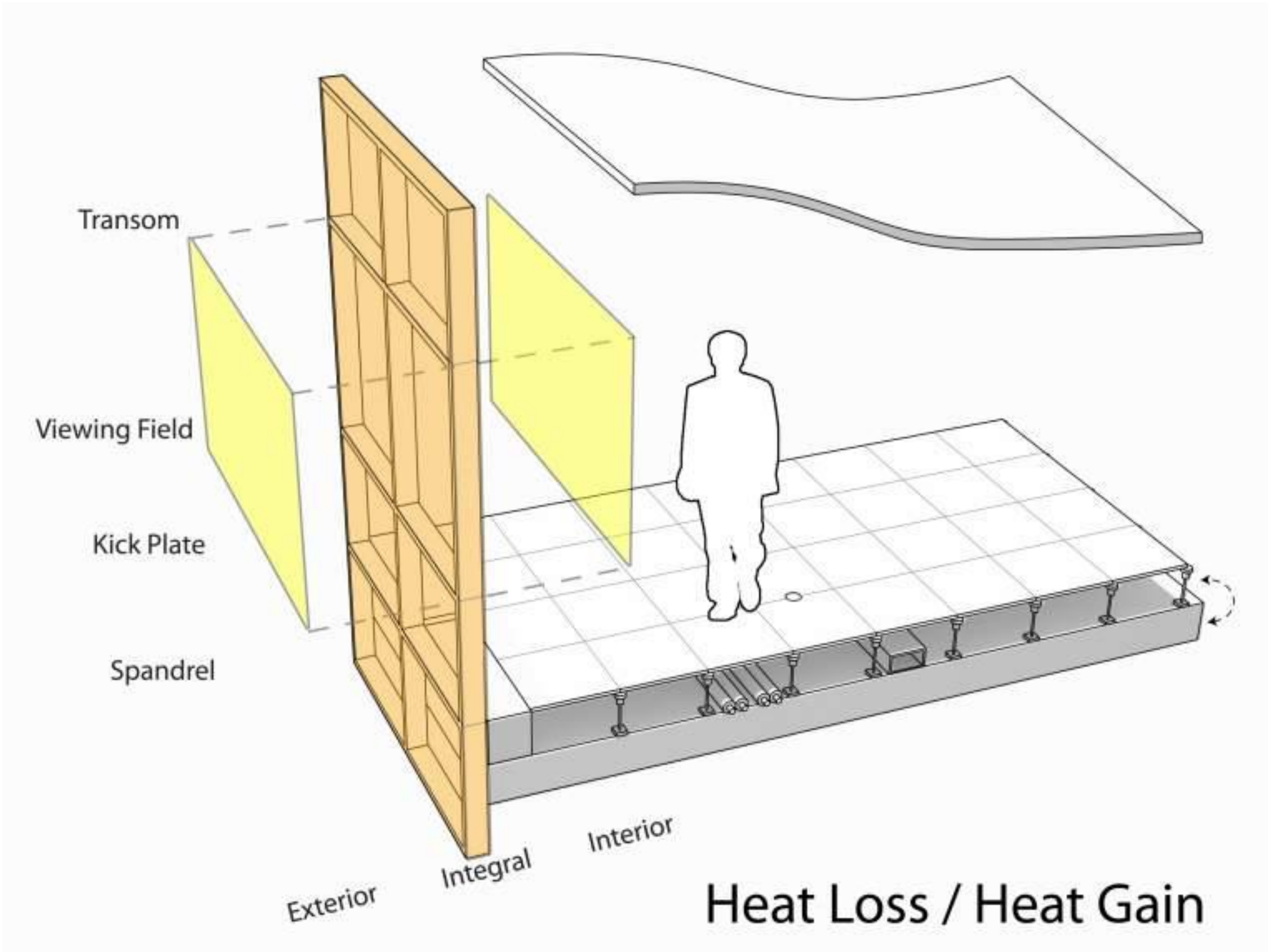


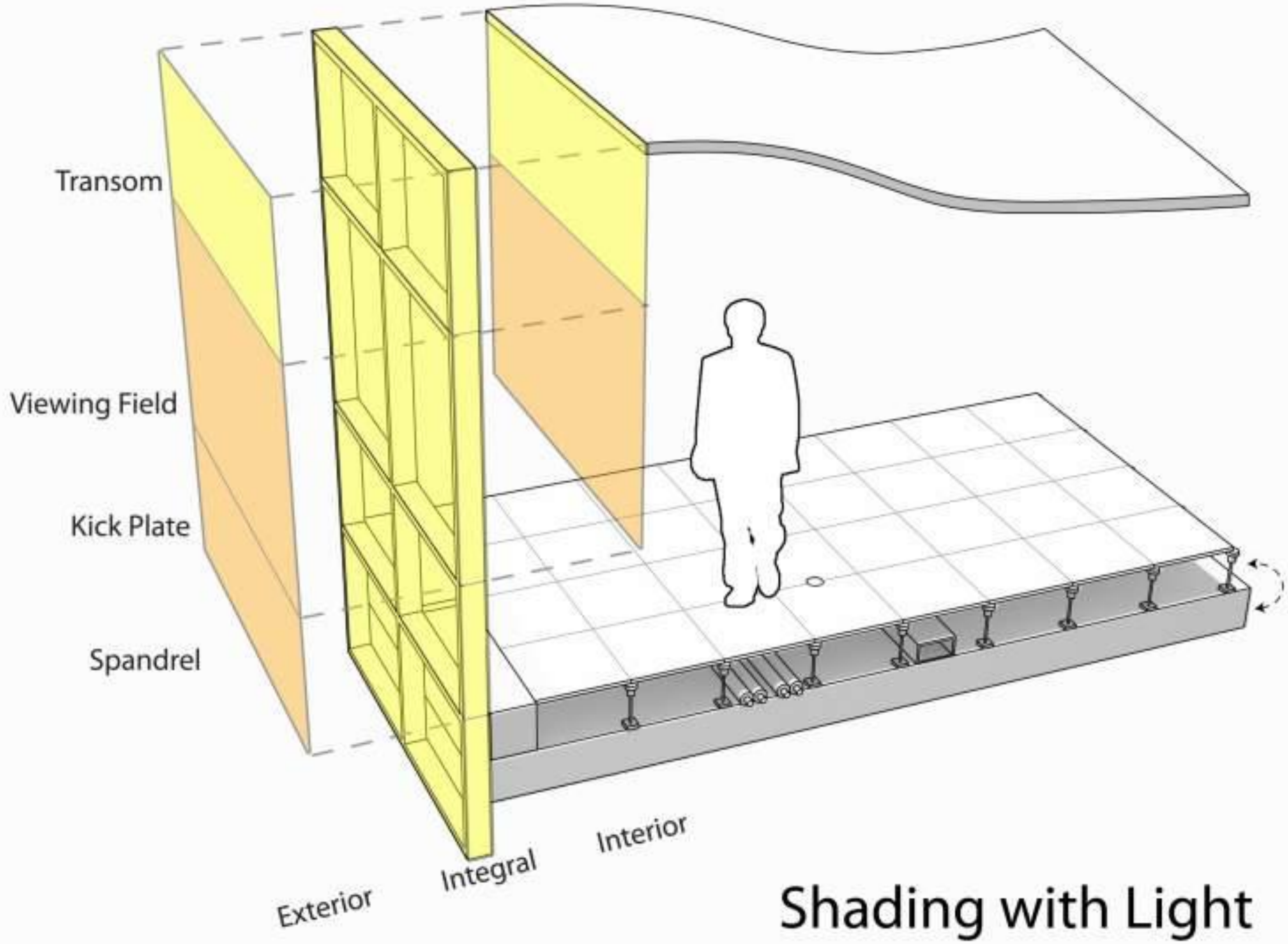
Access to Nature



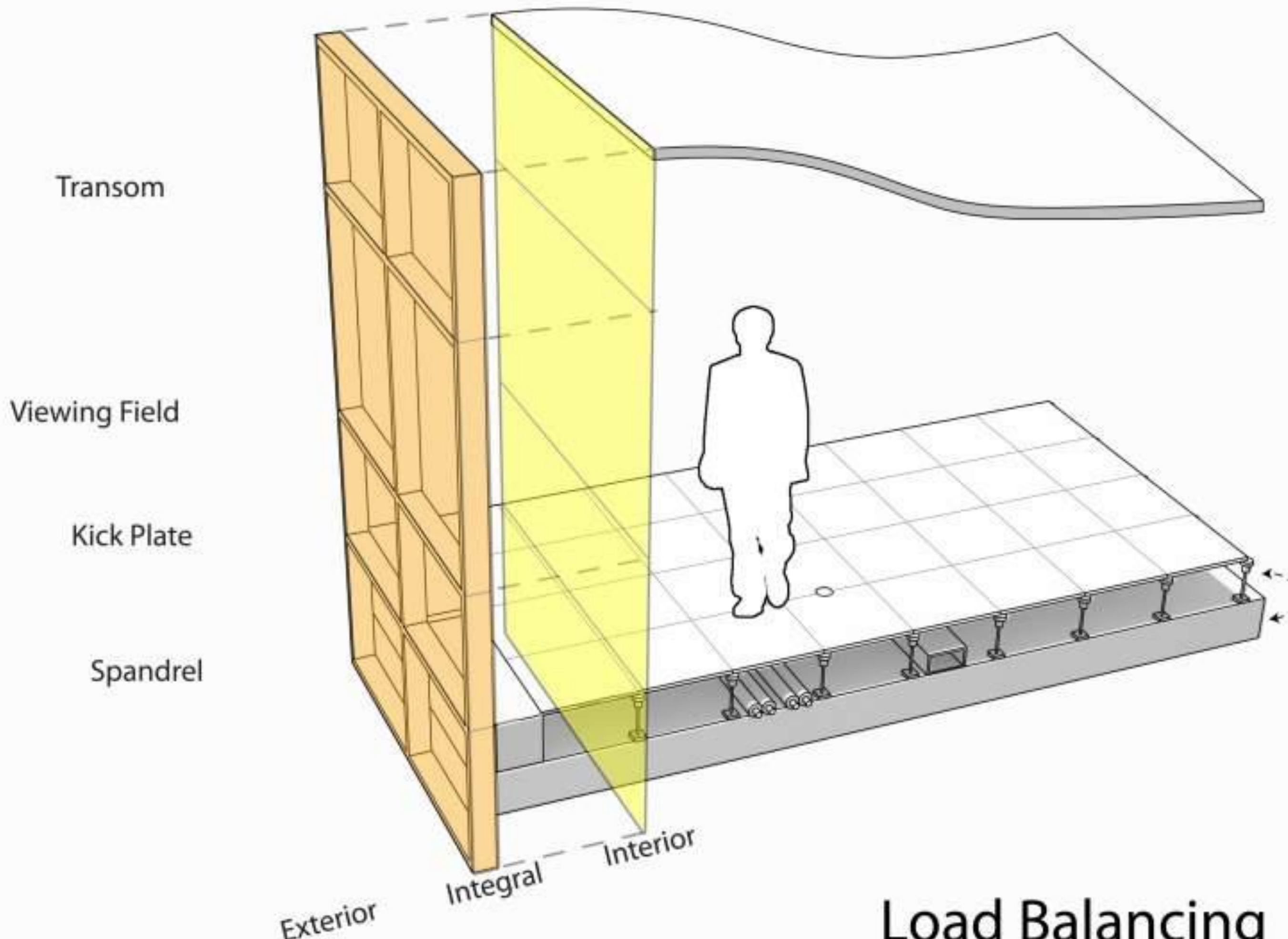
Transom
Viewing Field
Kick Plate
Spandrel
Exterior
Integral
Interior
Daylighting


Transom
Viewing Field
Kick Plate
Spandrel
Exterior
Integral
Interior
Natural Ventilation

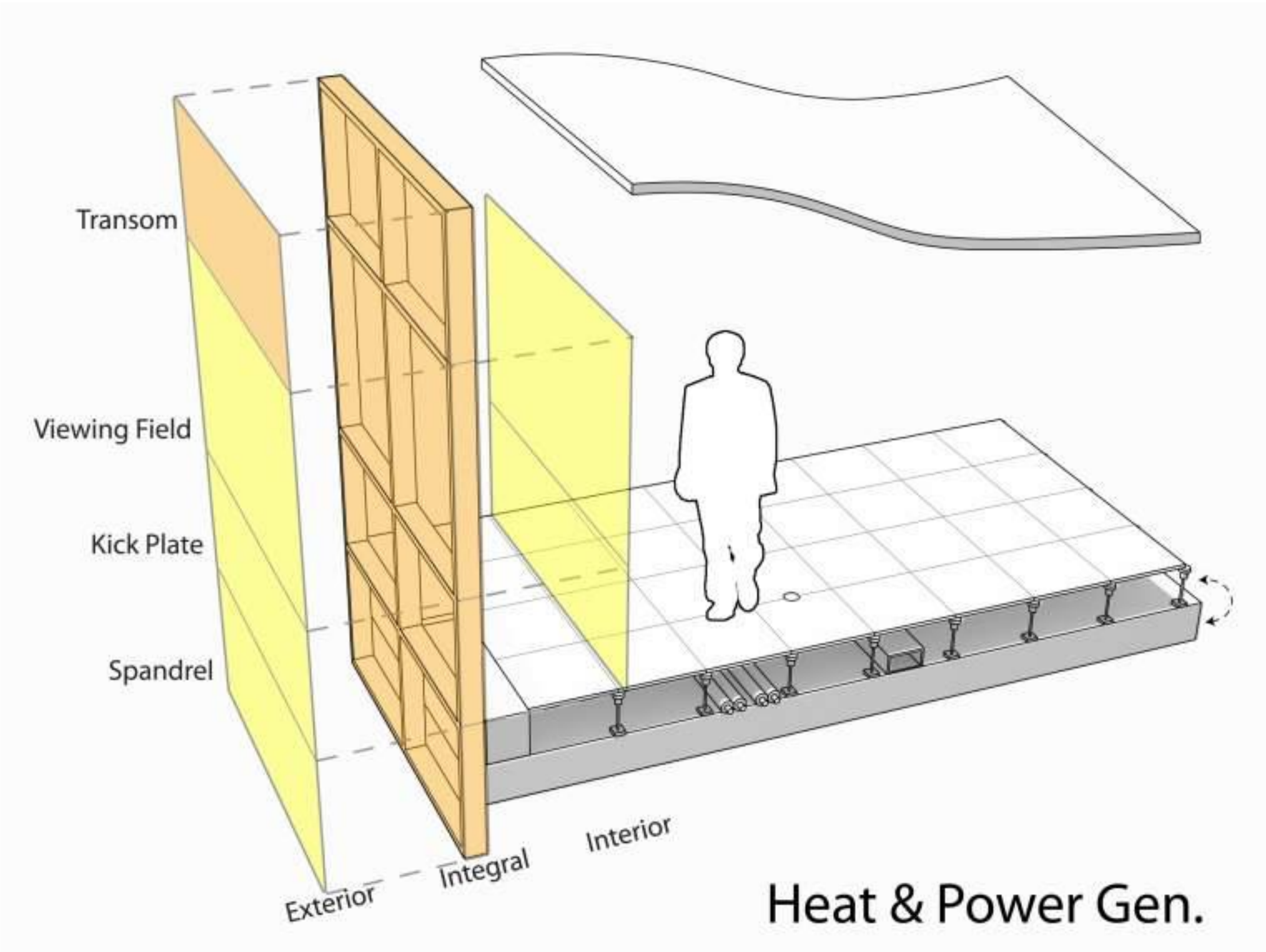

Transom
Viewing Field
Kick Plate
Spandrel
Exterior
Integral
Interior
Heat Loss / Heat Gain

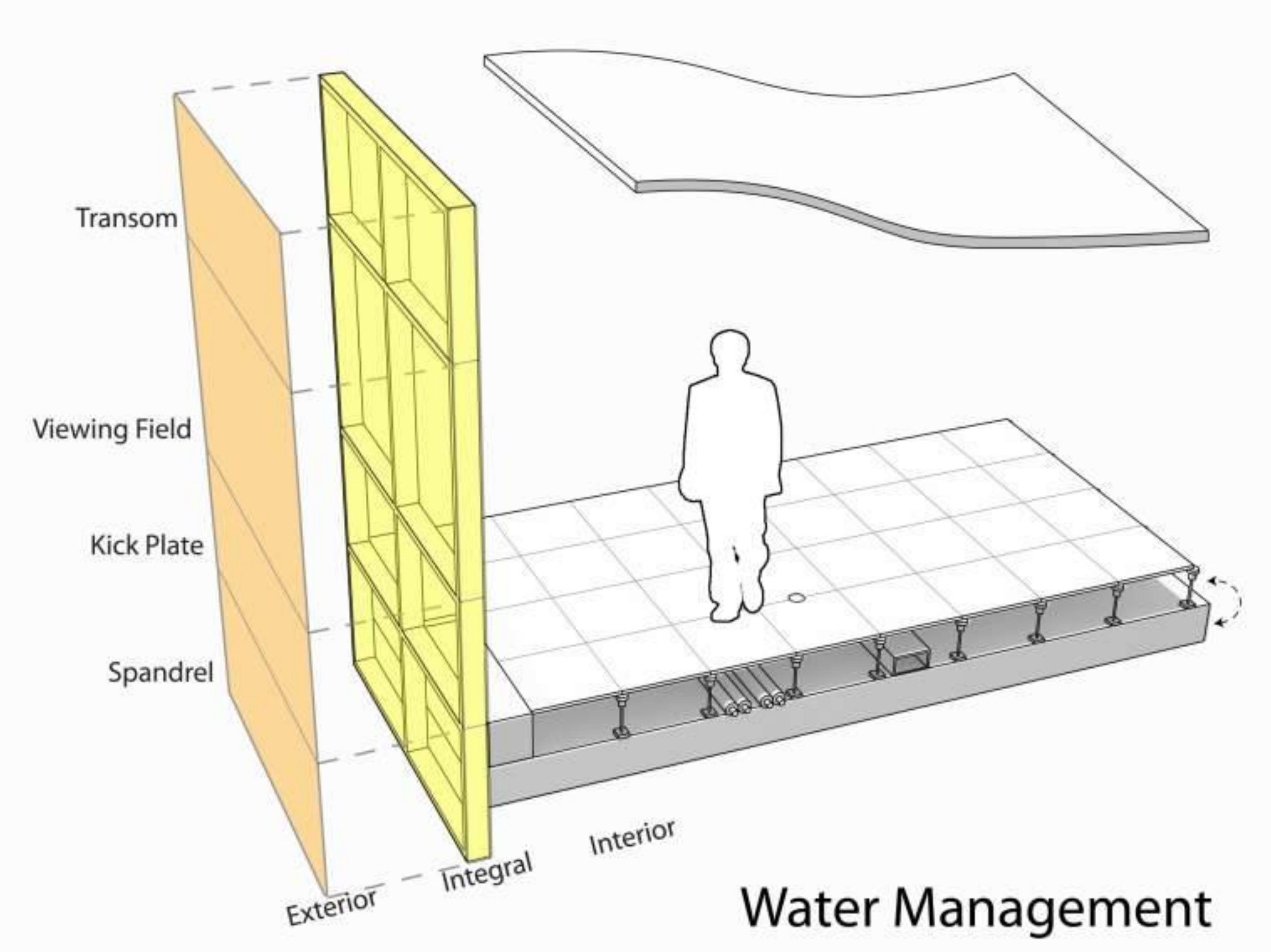


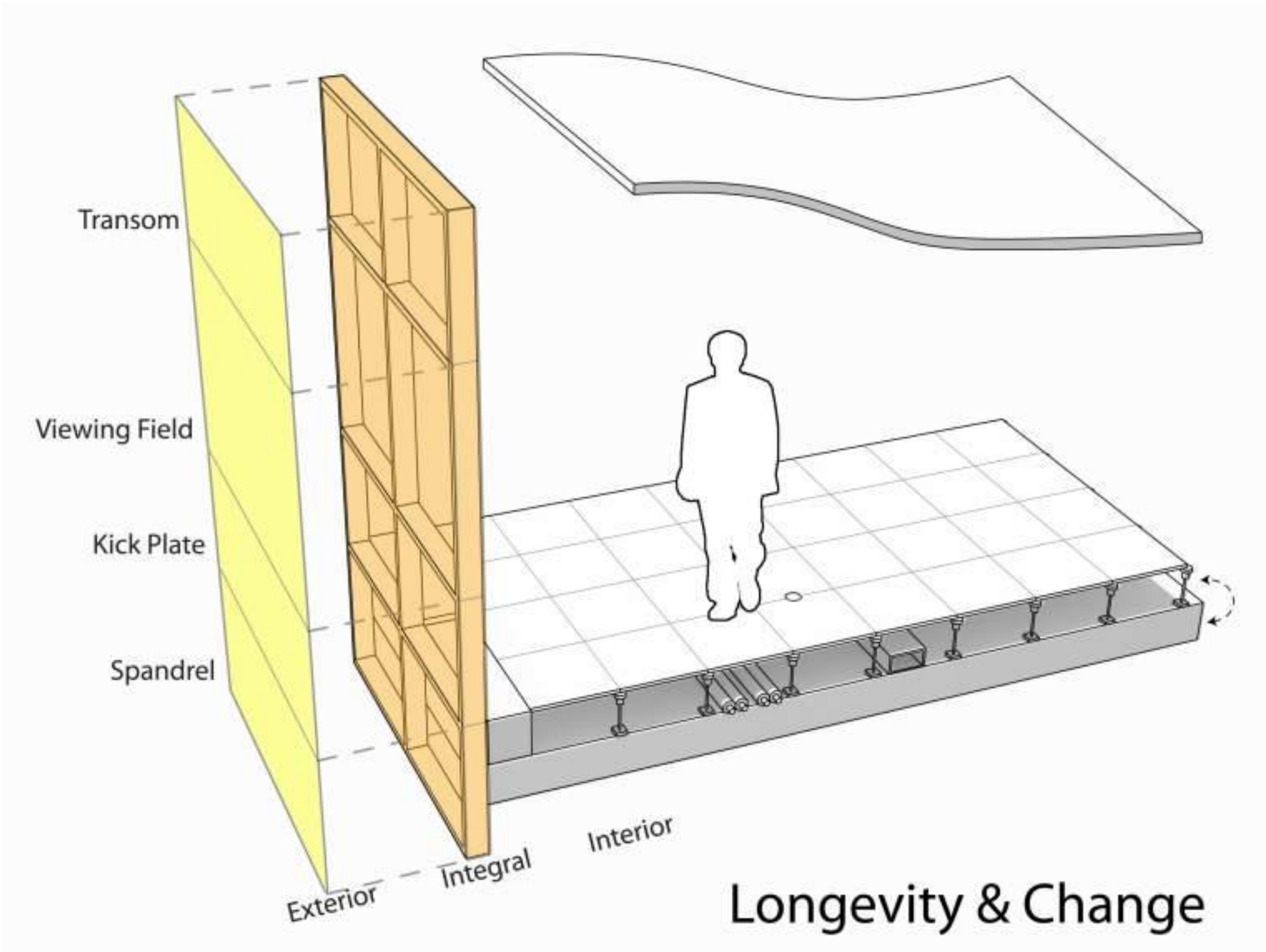
Shading with Light

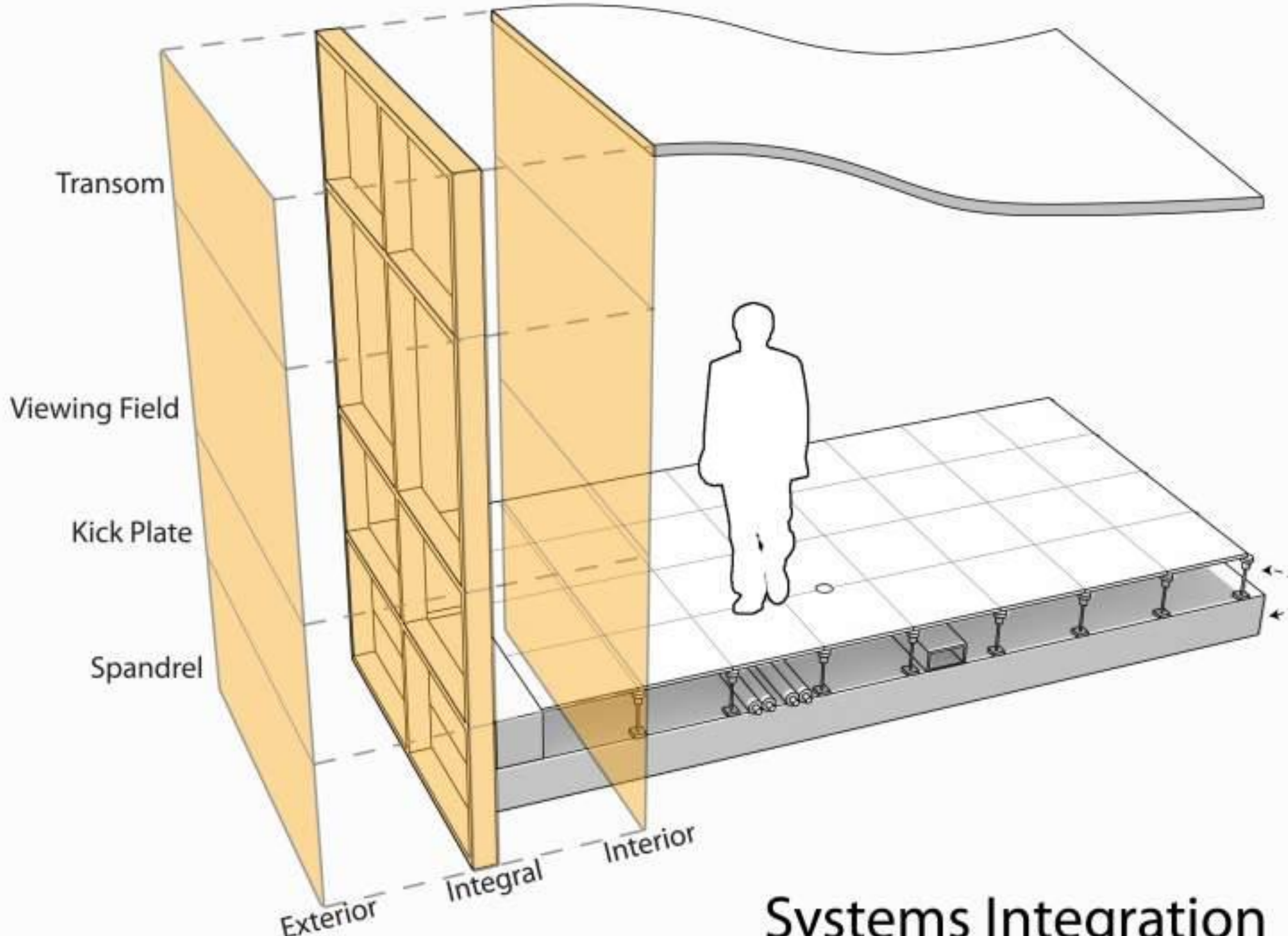


Load Balancing


Transom
Viewing Field
Kick Plate
Spandrel
Exterior
Integral
Interior
Heat & Power Gen.


Transom
Viewing Field
Kick Plate
Spandrel
Exterior
Integral
Interior
Water Management


Transom
Viewing Field
Kick Plate
Spandrel
Exterior
Integral
Interior
Longevity & Change



Systems Integration

ABSIC/CBPD Guidelines for

High Performance HVAC

1. Separate ventilation systems from thermal conditioning
2. Design for natural ventilation with mixed-mode conditioning
3. Provide task conditioning and individual control
4. Design for continuous change with plug and play HVAC & controls
5. Design architecture ‘unplugged” for maximum efficiency and passive
6. Engineer load balancing
7. Engineer ‘energy cascades’ power, cooling, heating with renewables
8. Create distributed, communicating, modifiable automation systems
9. Pursue Innovative HVAC system integration with enclosure systems.

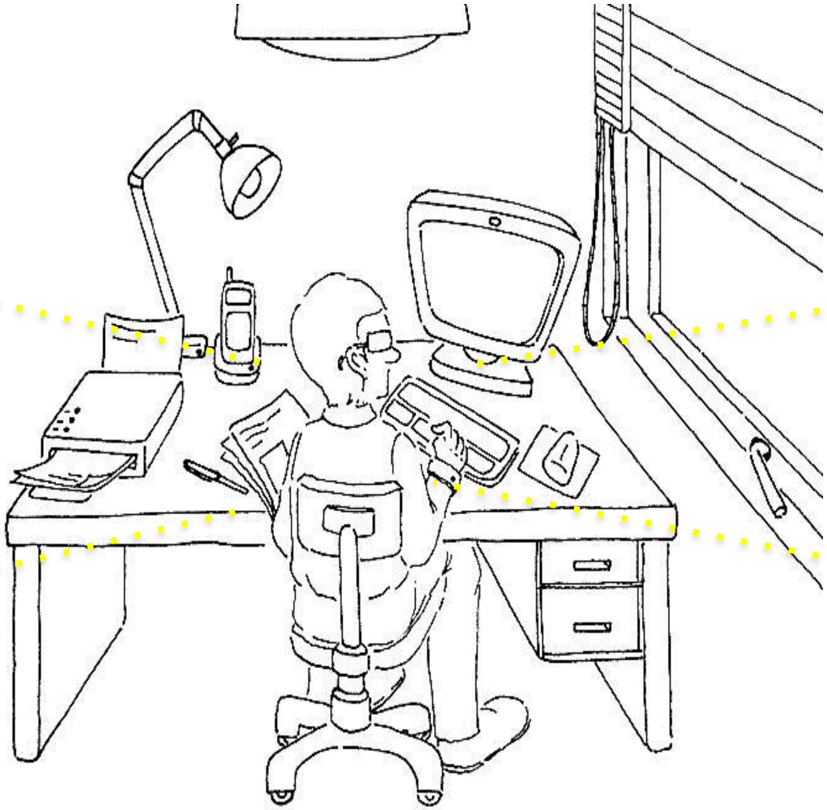
POE & the National Environmental Assessment Toolkit (NEAT)

Make that **POE+M**

workstation measurements of:

Air Quality
Carbon Dioxide
Carbon Monoxide
Total Volatile Organic Compounds
Particulates
Ozone
Radon

Acoustic Quality
Background sound levels
Room Criteria
Noise Criteria
Balanced Noise Criteria



Visual Quality
Light level desk
Light level screen
Light level keyboard
Brightness contrast
Uniform Glare Index

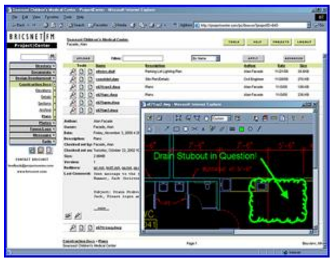
Thermal Quality
Air temperature at 1.1 m
Air temperature at 0.6 m
Air temperature 0.1 m
Relative Humidity
Air velocity
Vertical temp asymmetry
Horizontal temp asymmetry

+ Personal factors

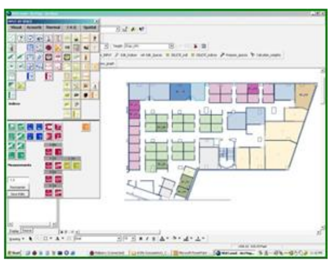
Clothing, Gender, Age, Activity/Metabolic Rate

Local signs of stress: heaters, fans, sweaters, blankets, deodorizers, taped over diffusers, blocked windows, computer shrouds, personal task lamps…

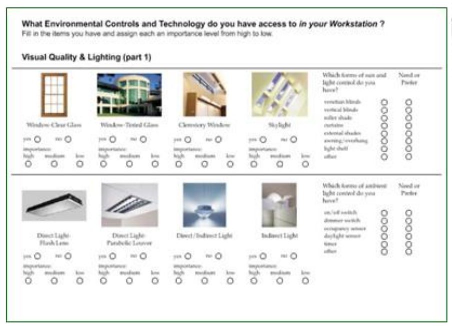
Clients: GSA all feds, DOE, DOD, Bank of Am, Lend Lease, EDF, Phipps, Convention Center records collection



sampling strategy

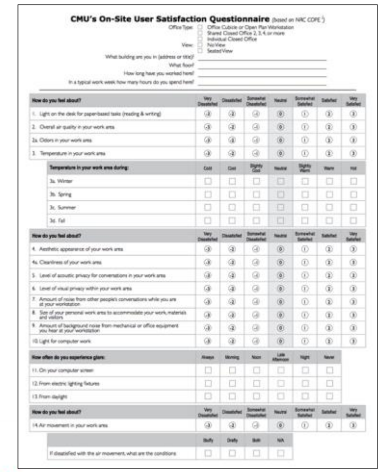


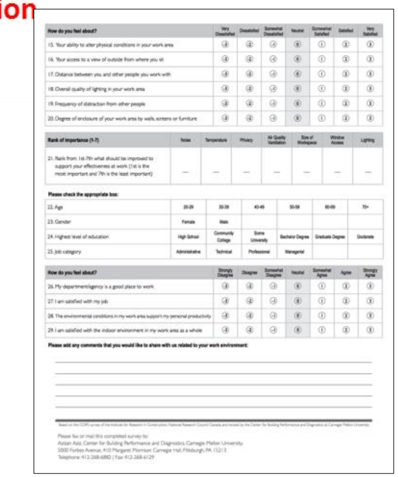
user satisfaction questionnaires (BOSS and COPE)



technical attributes of building systems (TABS)

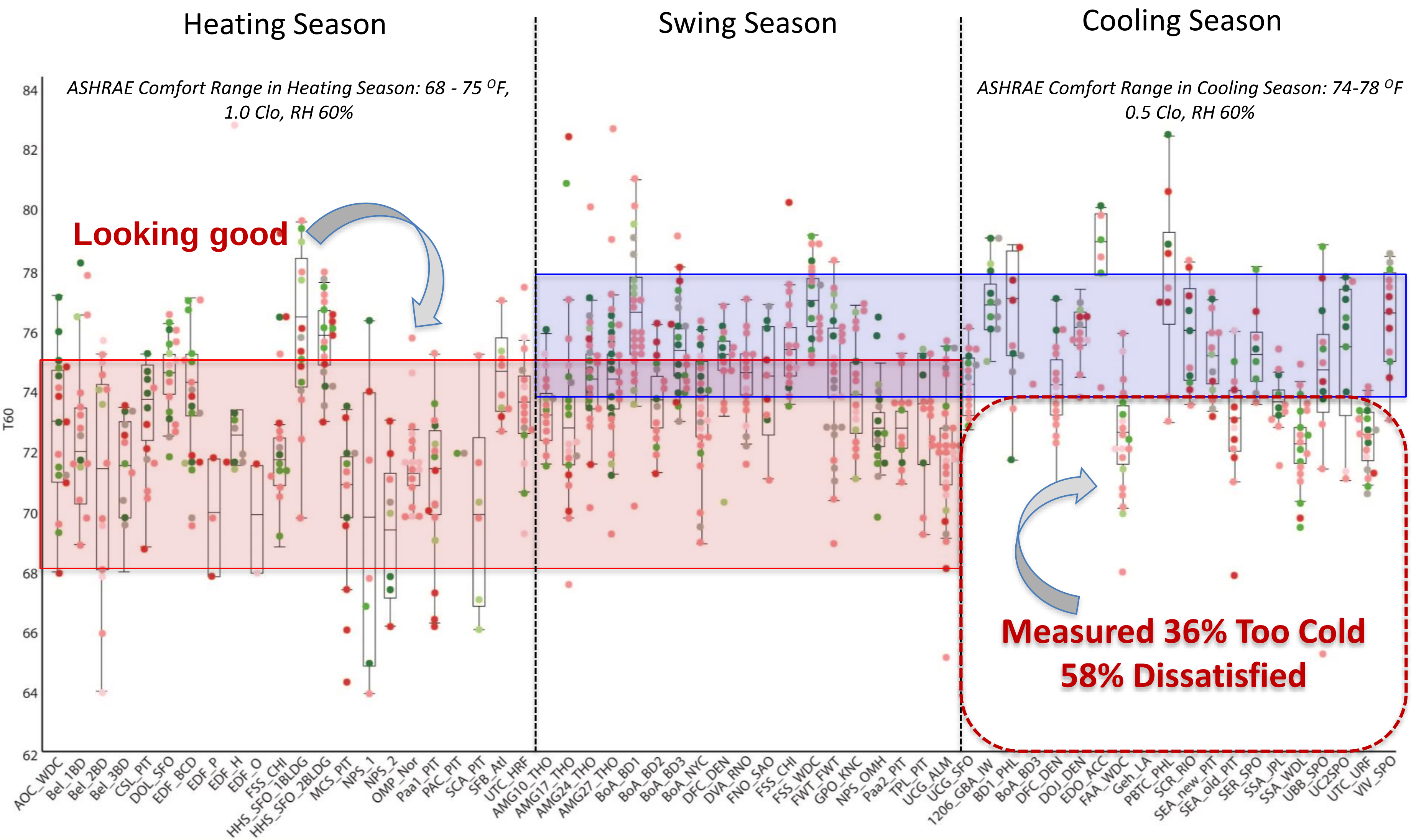
field instrumentation (NEAT)





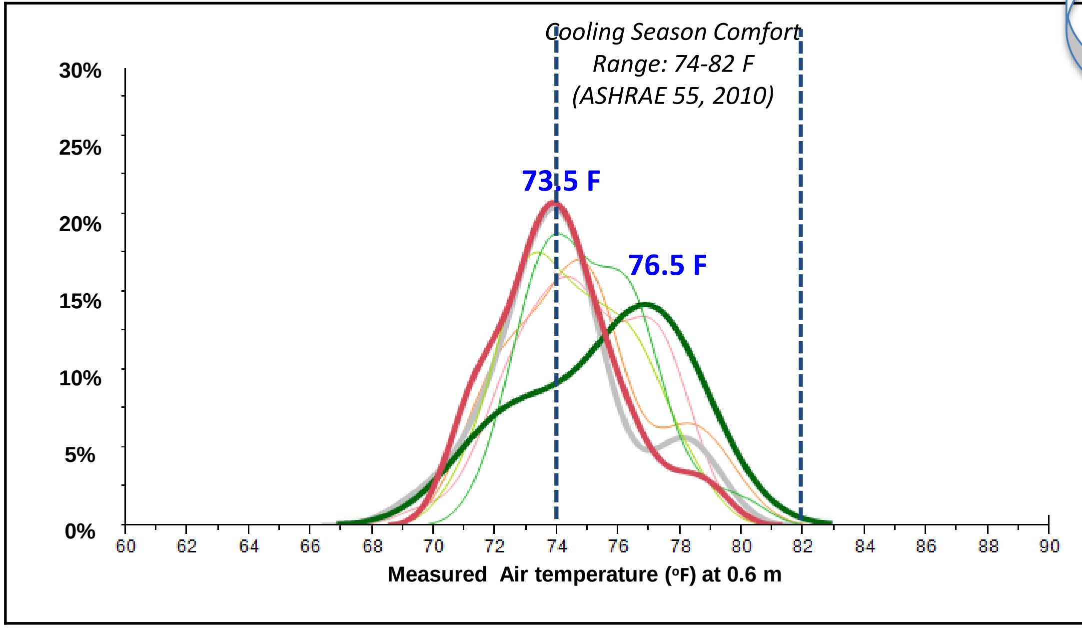
Air temperature measurements 0.6 m from the floor

CBPD, CMU (n = 1,282 workstations, 64 buildings)



Cooling season user satisfaction with air temperature at 0.6 m

CBPD, CMU, Cooling Season (n=446)



72.8 - 73.5°F

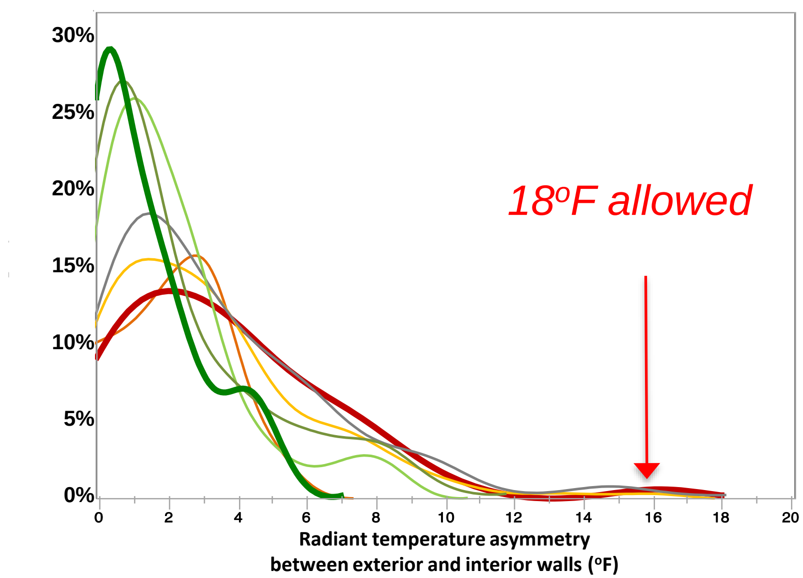
Occupant satisfaction Survey		Average Air Temperature (F)
	Very Unsatisfactory	72.9
	Unsatisfactory	72.8
	Somewhat Unsatisfactory	73.5
	Neutral	74.2
	Somewhat Satisfactory	74.6
	Satisfactory	76.1
	Very Satisfactory	76.7
Overall Average		**74. 6**

74.6 - 76.7 °F

$P < 0.05$
Mean of Response 74.58 F

Radiant temperature asymmetry & user satisfaction level

Perimeter Workstations (n=391)



3.5 - 4.0 °F

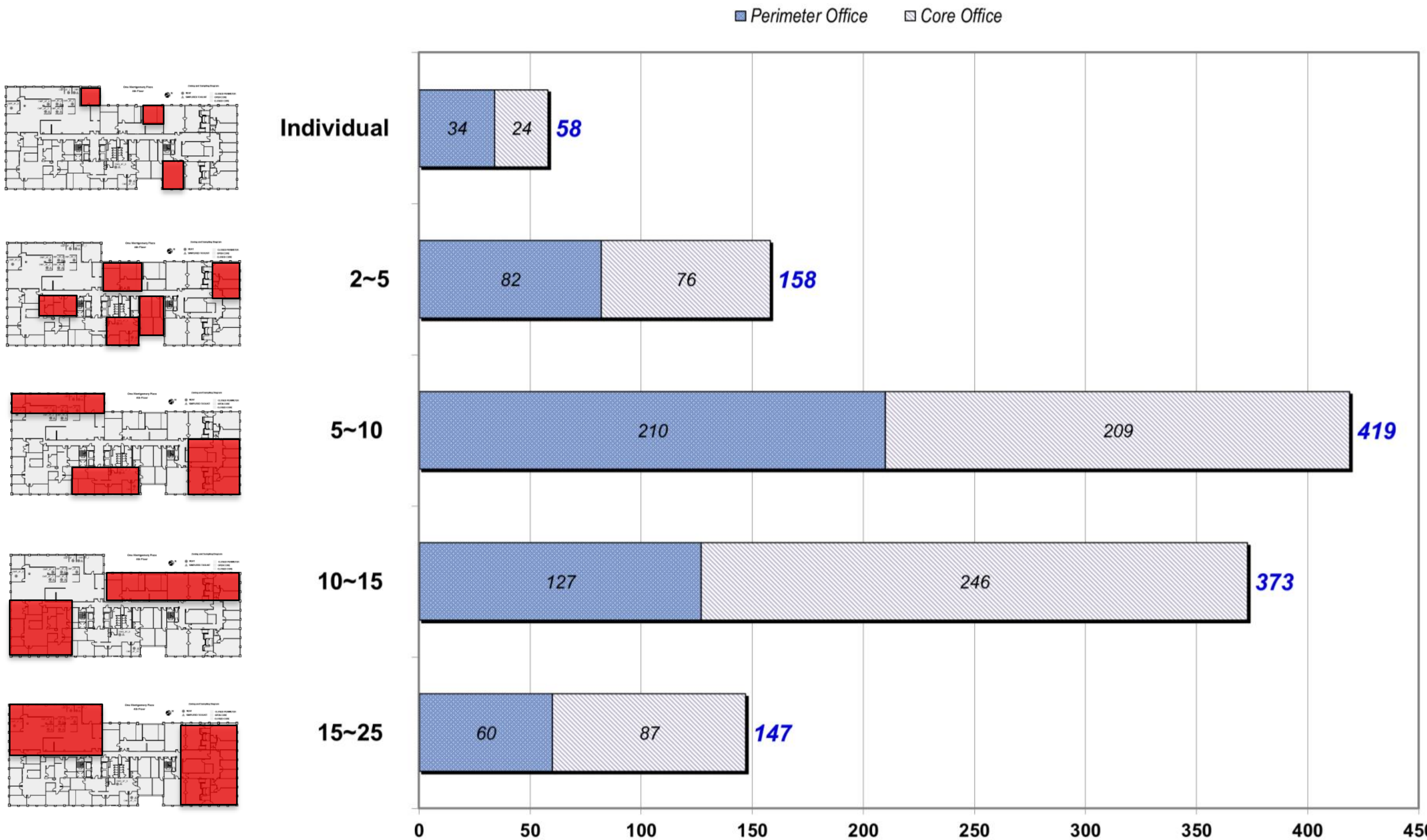
Occupant satisfaction Survey		Average Temp. Δ [Ex-In] (°F)
	Very Unsatisfactory	3.47
	Unsatisfactory	4.02
	Somewhat Unsatisfactory	3.65
	Neutral	3.35
	Somewhat Satisfactory	2.25
	Satisfactory	2.13
	Very Satisfactory	1.58
Overall Average		2.97

1.6 - 2.3 °F

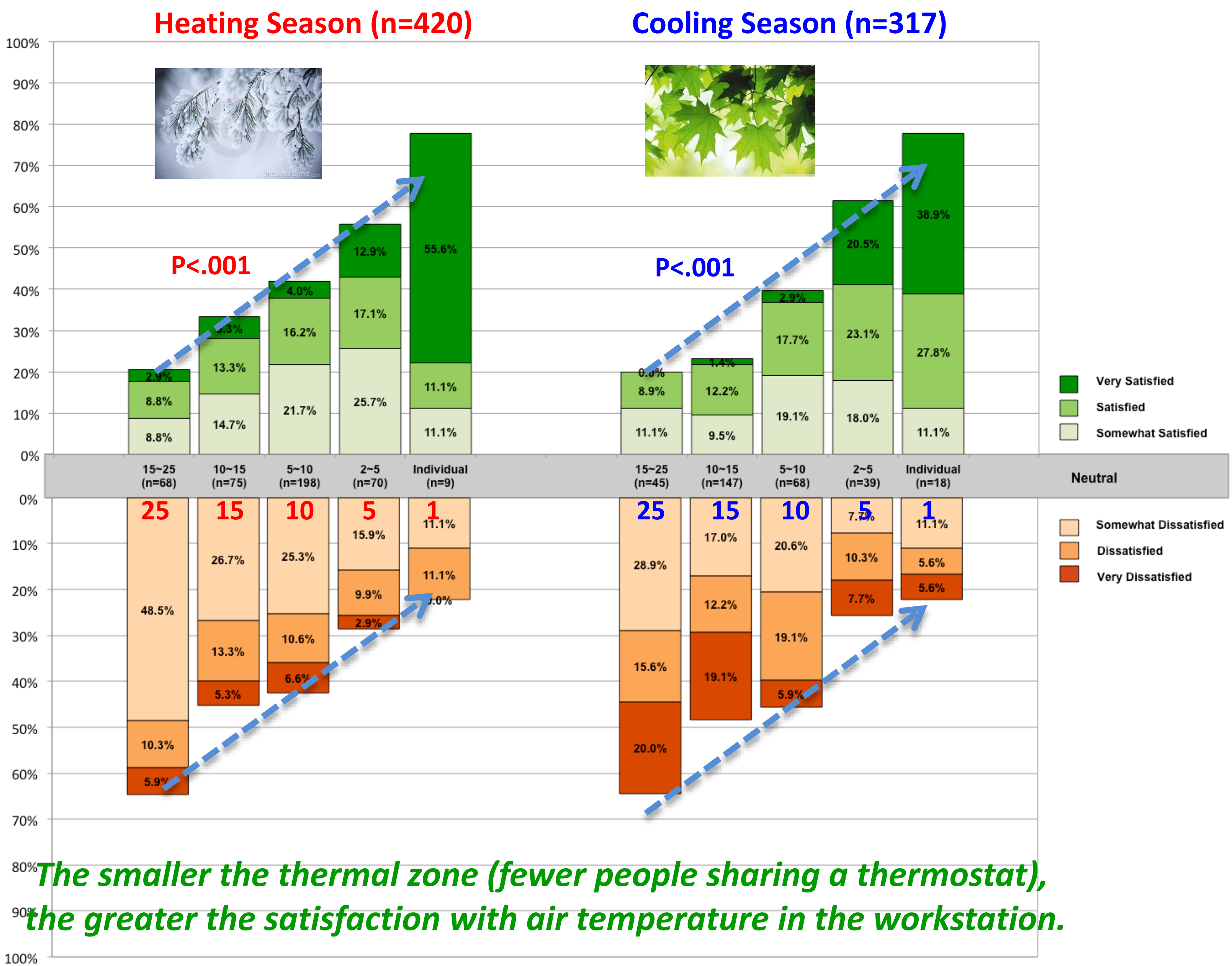
$P < 0.001$
Mean of Response 2.97 °F

Distribution in Size of Zone (TABS)

64 buildings, combination of Perimeter and Core workstations



Temperature Satisfaction by "Size of Zone"

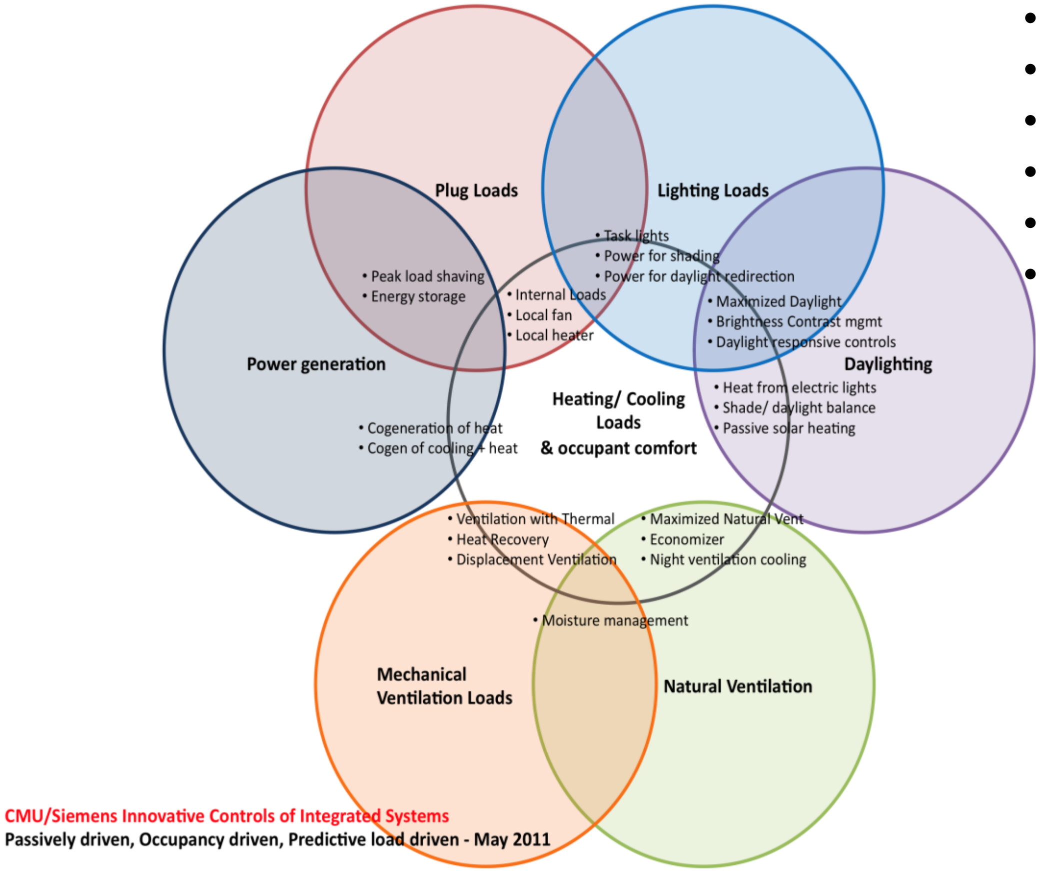


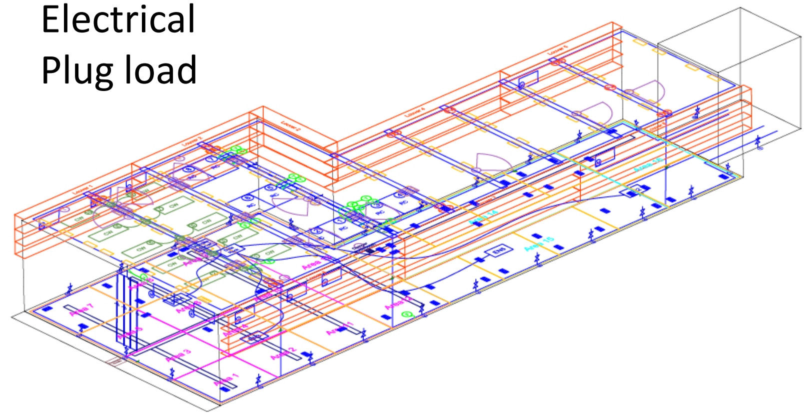
The smaller the thermal zone (fewer people sharing a thermostat), the greater the satisfaction with air temperature in the workstation.

The Intelligent Workplace

Networked Intelligence Integrating all systems

- Heating
- Cooling
- Ventilation (mechanical and natural)
- Lighting, and day-lighting
- Electrical
- Plug load





sensors, actuators, user interfaces, central intelligence & information feedback, integrated system and control innovations for IEQ and energy effectiveness.

Potential of using Bio-signals for Adaptive Individualized Controls

Factors Affecting Comfort

Humidity

Air temp.

MRT

Air velocity

Clo

MET

BMI

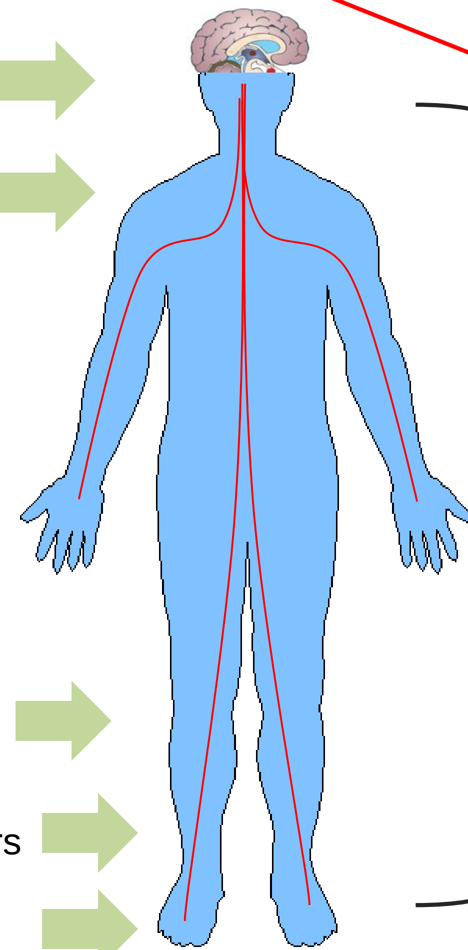
Gender

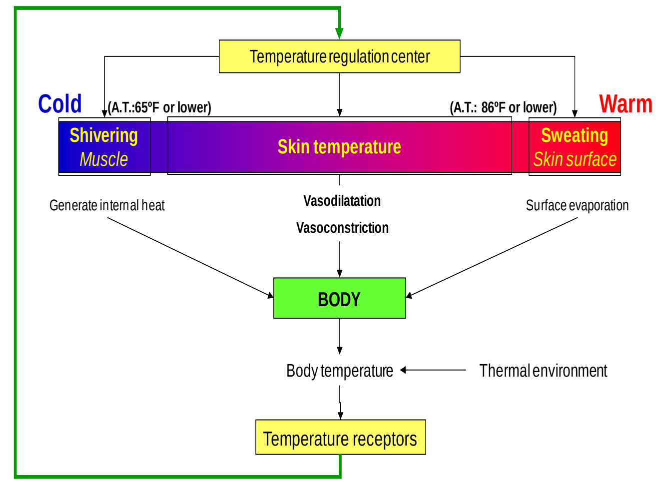
Age

Ethnic origin

Other environmental factors

Other individual factors



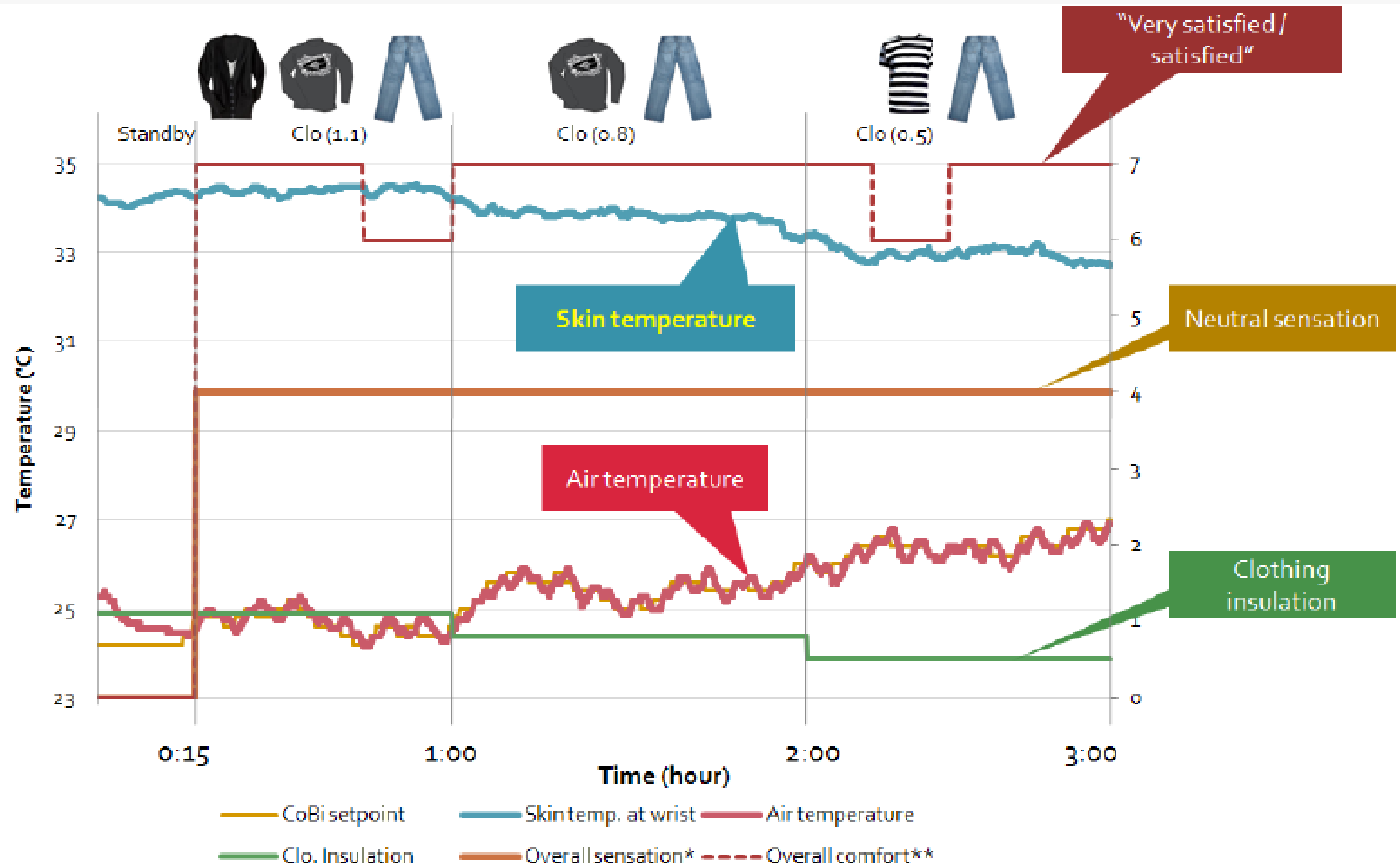


CoBi Bio-signals for thermal sensation prediction !!

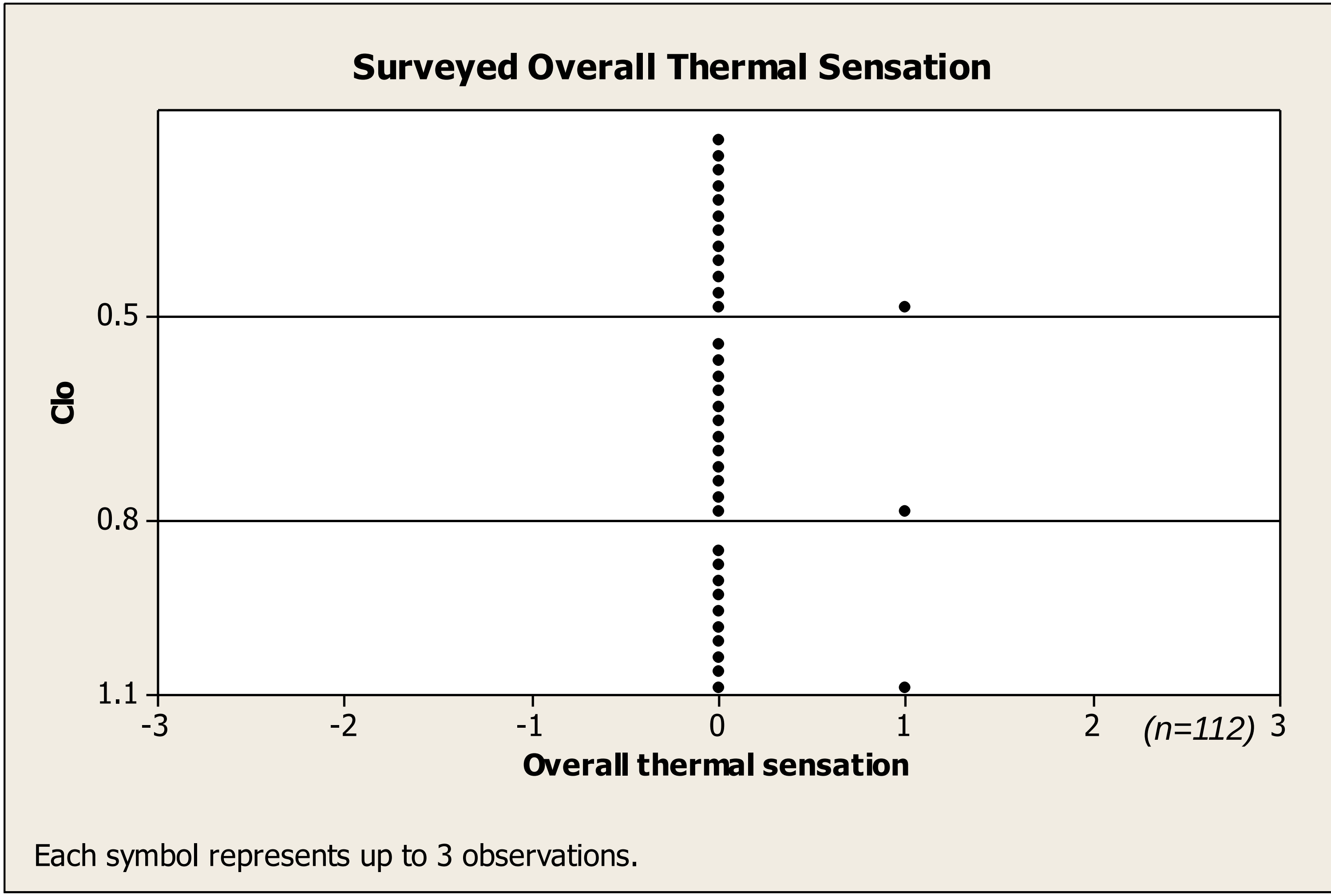
Applicable to ---

1. Individual control
2. Dynamic conditions
3. Real time control with non-intrusive sensing

Wrist temperature driven air temperature settings result in outstanding satisfaction across different clo-values

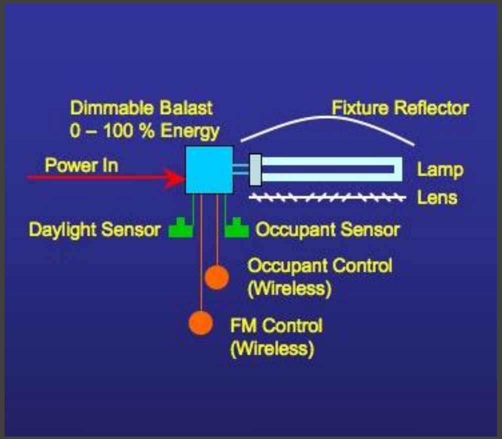


With the CoBi controller, 93% reported thermally neutral sensations while 7% reported slightly warm sensation, as compared to an average US satisfaction of <60%.



ABSIC/CBPD Guidelines for

High Performance Lighting

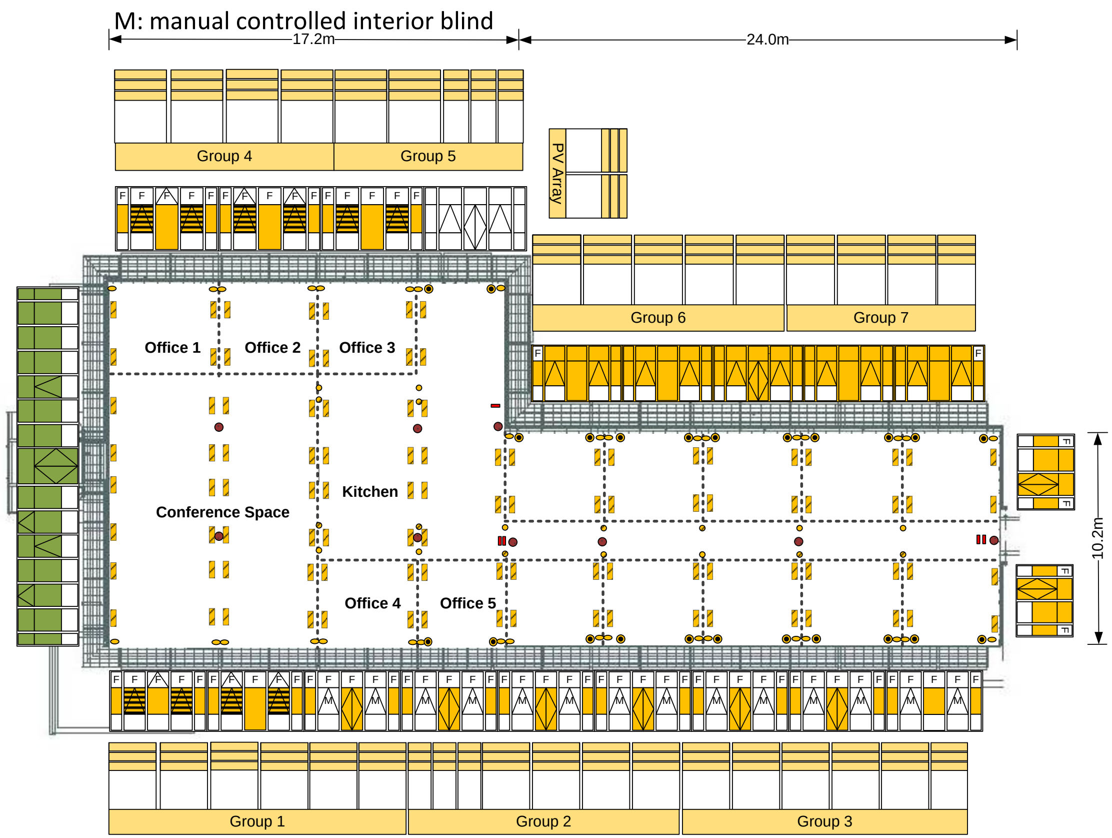


1. Provide Daylight as the dominant light source without glare or overheating
2. Separate task lighting from ambient lighting
   (or design relocatable task-ambient systems)
3. Introduce indirect-direct lighting for spatial dynamics without shadowing.
4. Maximize lighting quality with high performance luminaires.
5. Provide for reconfigurability with plug-and-play fixtures.
6. Design for continuous change in lighting zone size and advanced controls
7. Pursue innovative lighting systems integration

Building Controls Research: Intelligent Workplace & Field Testbeds

Lighting/ Daylighting/Shading Systems

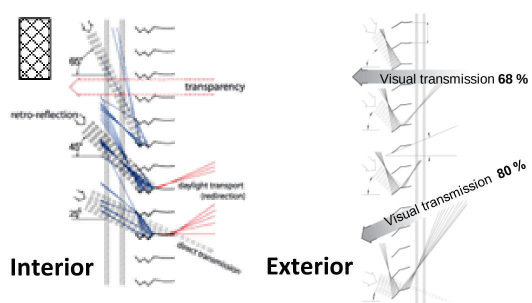
- 100 Zumtotel LaTrave Fixtures
- 36 Pico Fixtures
- 12 Zumtobel Dancer Fixtures
- 23 Floor Light Fixtures
- 8 Fire Alarm Light Fixtures
- 5 Fire Exit signs
- 10 motorized blinds
  10 24VDC switches
- 65 motorized blinds
  130 110 VAC relays



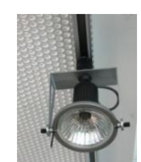
100 Zumtobel LaTrave relocatable luminaires
20% up, 80% down light
1-100% dimming ballast
2 x 55W U-shape lamps
LPD 1.63w/sf.

1 WaldmannTycoon
direct / indirect luminaires
Occupancy sensor
Daylight sensor

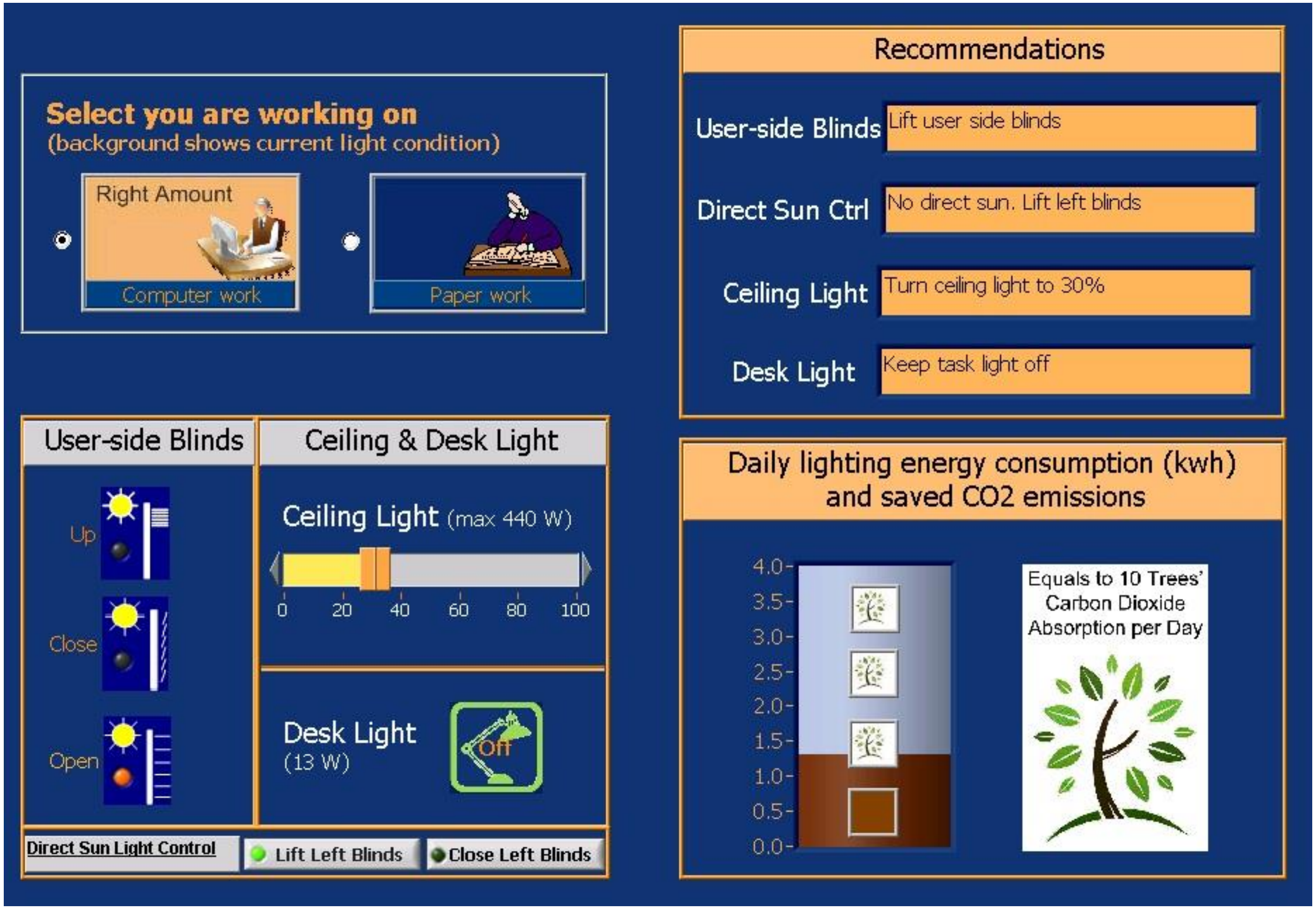
7 Daylight Redirection Louver sets
3 tiers
0˚ (closed) - 105˚ (fully open)
208 V, single phase



74 RetroSolar motorized blinds
0 – 100% up and down
0˚ – 90˚ tilt
65 110VAC
10 24VDC



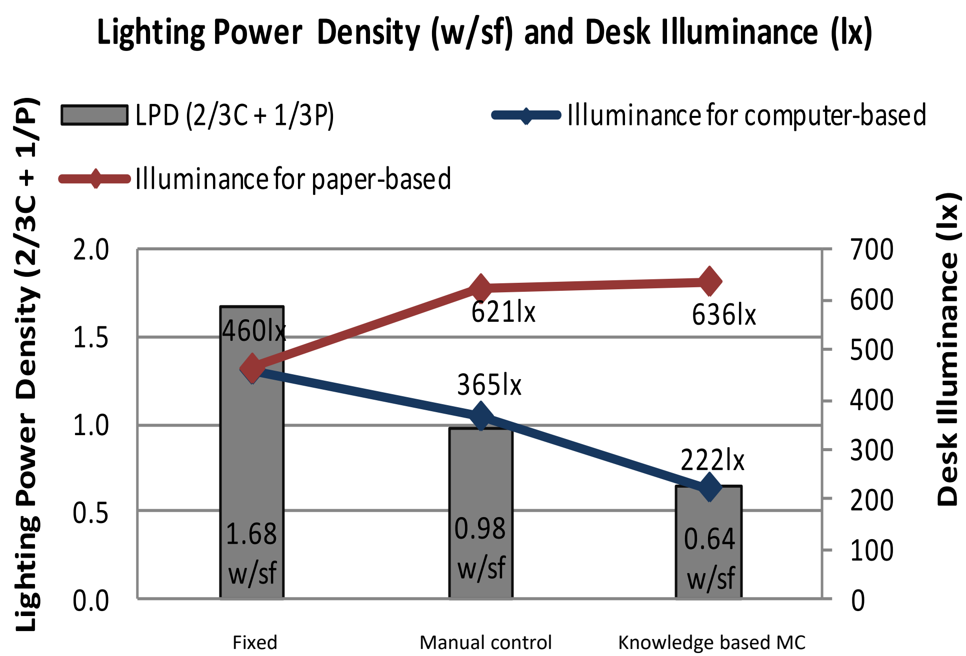
12 track light :
15W LED
3000 K
770 Lumen



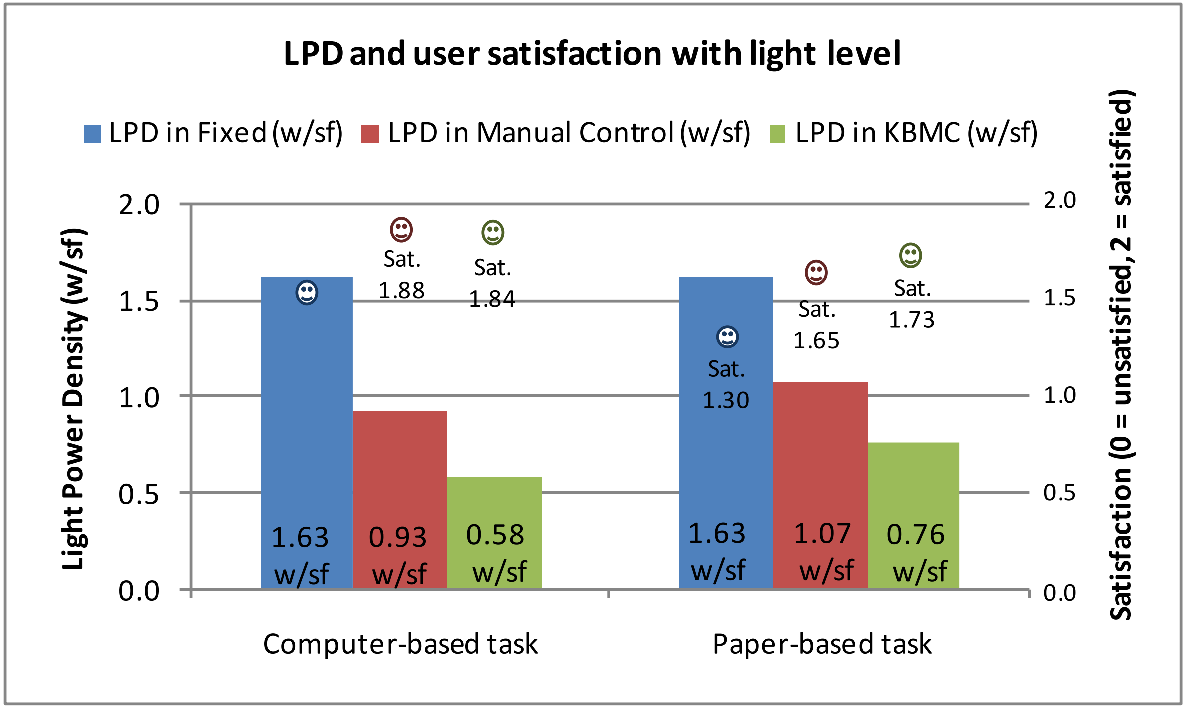
The Impacts of Real-time Knowledge Based Personal Lighting Control on Energy Consumption, User Satisfaction and Task Performance in Offices

Yung Gu, 2011 PhD dissertation

lighting power demand drops with user controls



- Lighting power demand was reduced 43% with manual settings (MC) compared to fixed (F) and was reduced 64% with KBMC regardless of task type.
- Desk top light levels for paper-based tasks was increased to over 620 lux with MC and KBMC compared to the 500 lux standard - at measurably lower energy.

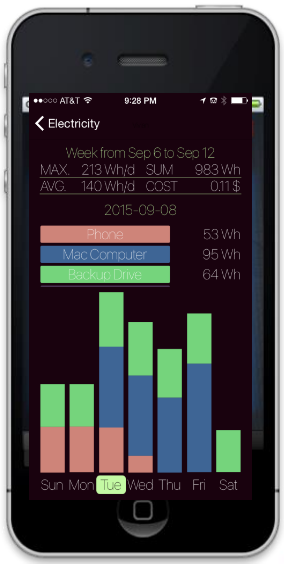


- ✓ **<u>Manual controls</u>** of blinds and task lights and <u>online control</u> of overhead lights offer **43%** **<u>energy saving</u>** + **<u>higher user satisfaction</u>** + no decrement in task performance.
- ✓ **<u>Knowledge-based manual control</u>** of blinds, task lights and online control of overhead lights offer **64%** <u>energy saving</u> + no decrement in user satisfaction and task performance.

The Impacts of Real-time Knowledge Based Personal Lighting Control on Energy, Dr. Yun Gu 2011

Innovative User integrated Control Solutions

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

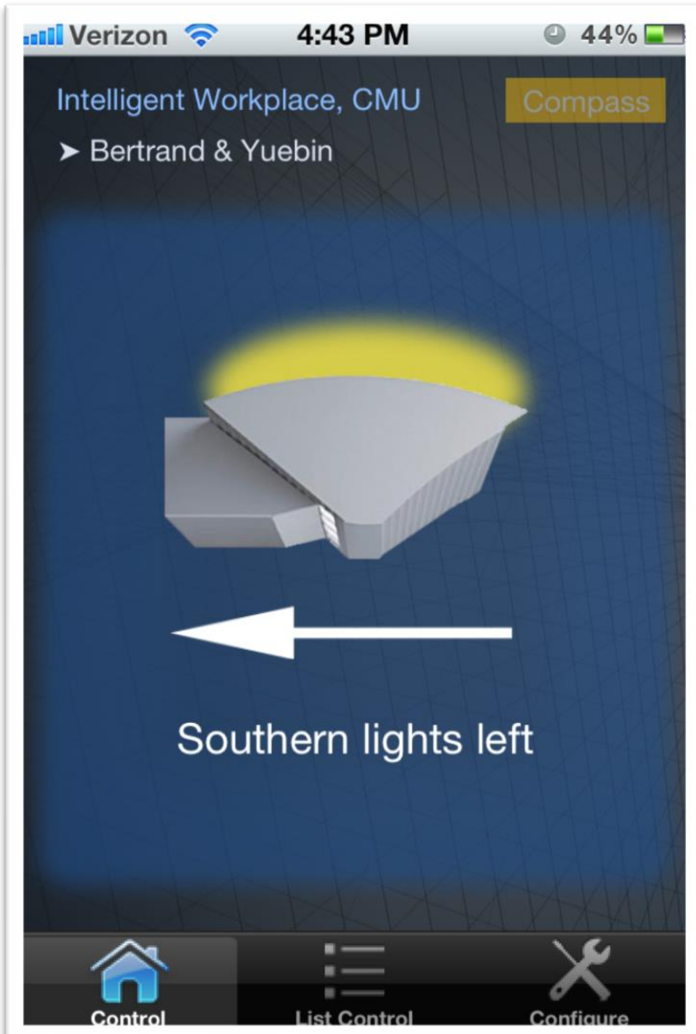


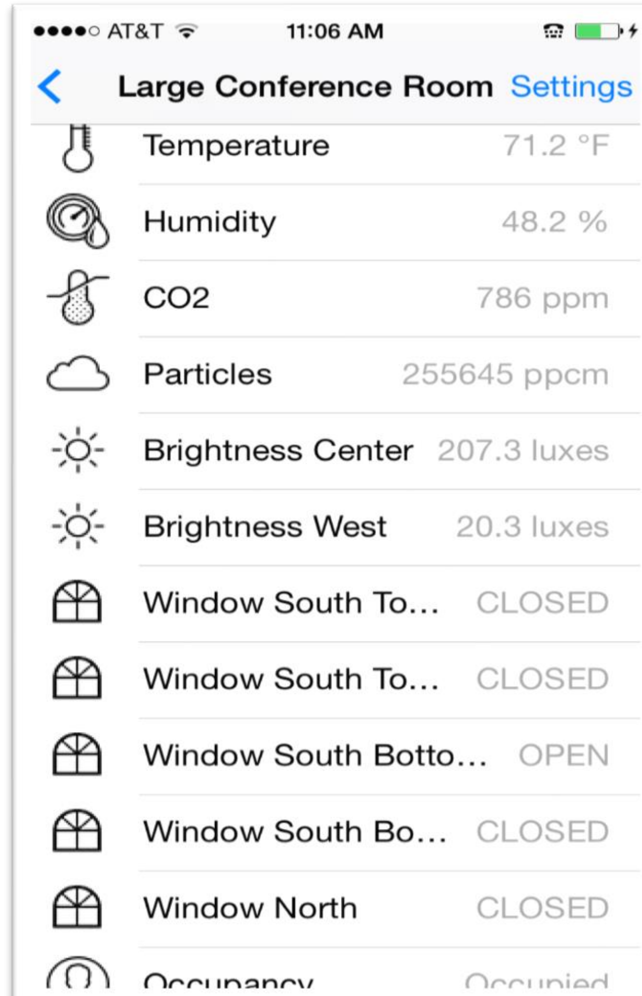
CMU CBPD & Technical University of Munich Master and PhD Thesis Projects

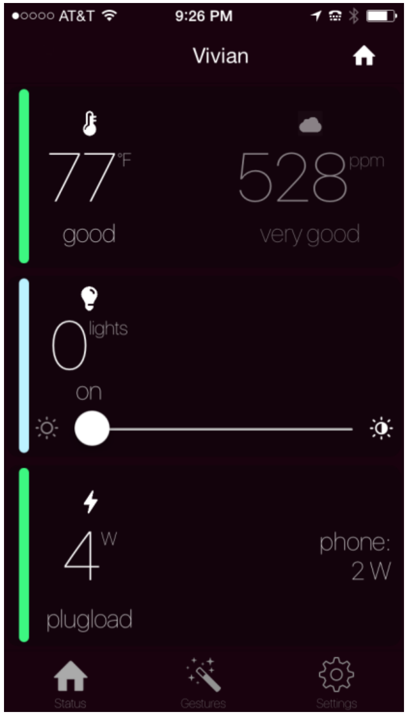
I-Phone User Interface – Sensors, Controllers, Energy

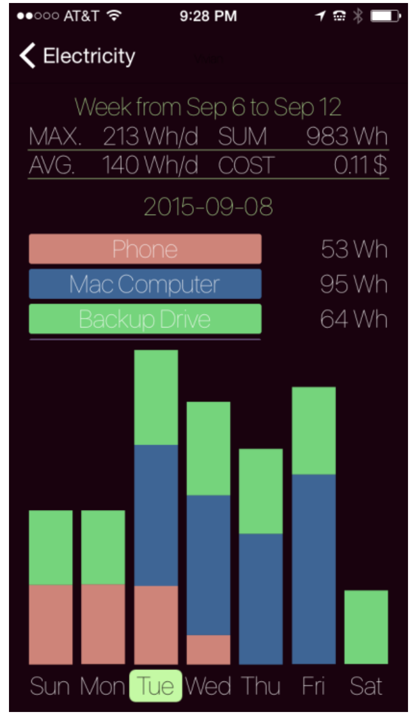
Lights, Blinds, Task Lights, External Louvers & more

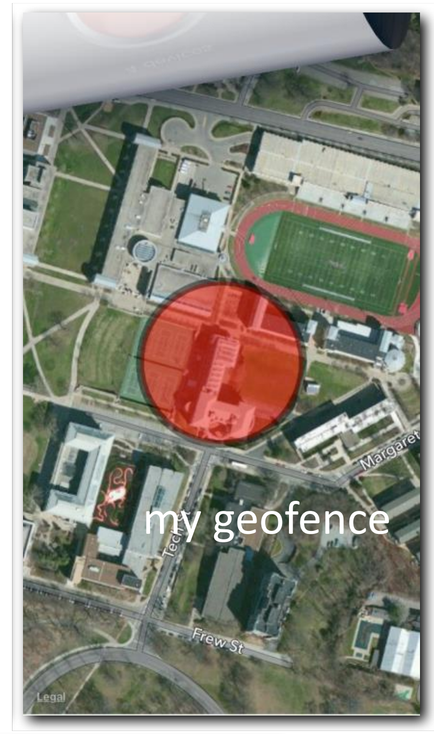
openHAB empowering the smart home

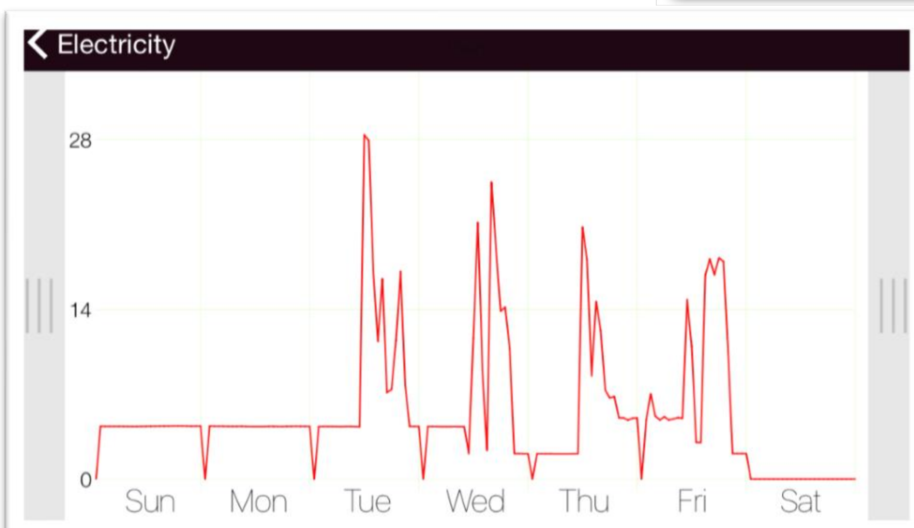





●○○○○ AT&T
9:26 PM
Vivian
77 °F
good
528 ppm
very good
0 lights
on
4 W
plugload
phone:
2 W
Status
Gestures
Settings


●●○○○ AT&T
9:28 PM
Electricity
Week from Sep 6 to Sep 12
MAX. 213 Wh/d SUM 983 Wh
AVG. 140 Wh/d COST 0.11 $
2015-09-08
Phone 53 Wh
Mac Computer 95 Wh
Backup Drive 64 Wh
Sun Mon Tue Wed Thu Fri Sat


my geofence
Margaret
Frew St
Legal


Electricity
28
14
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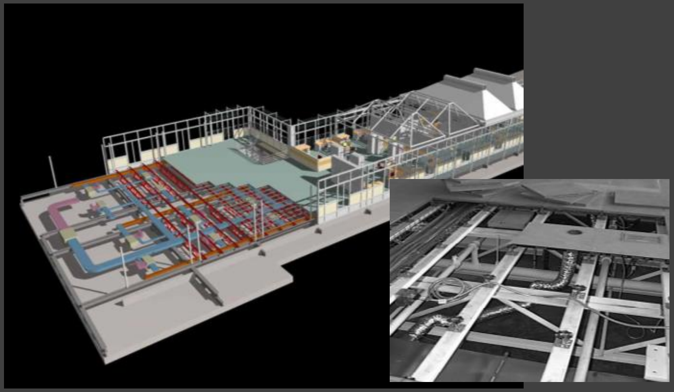
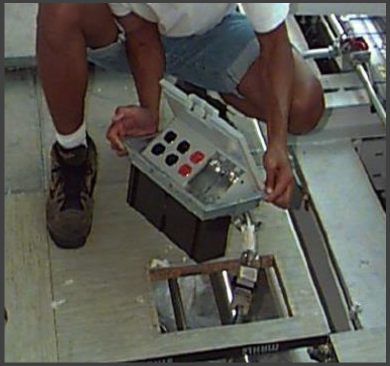
Sun Mon Tue Wed Thu Fri Sat

ABSIC/CBPD Guidelines for

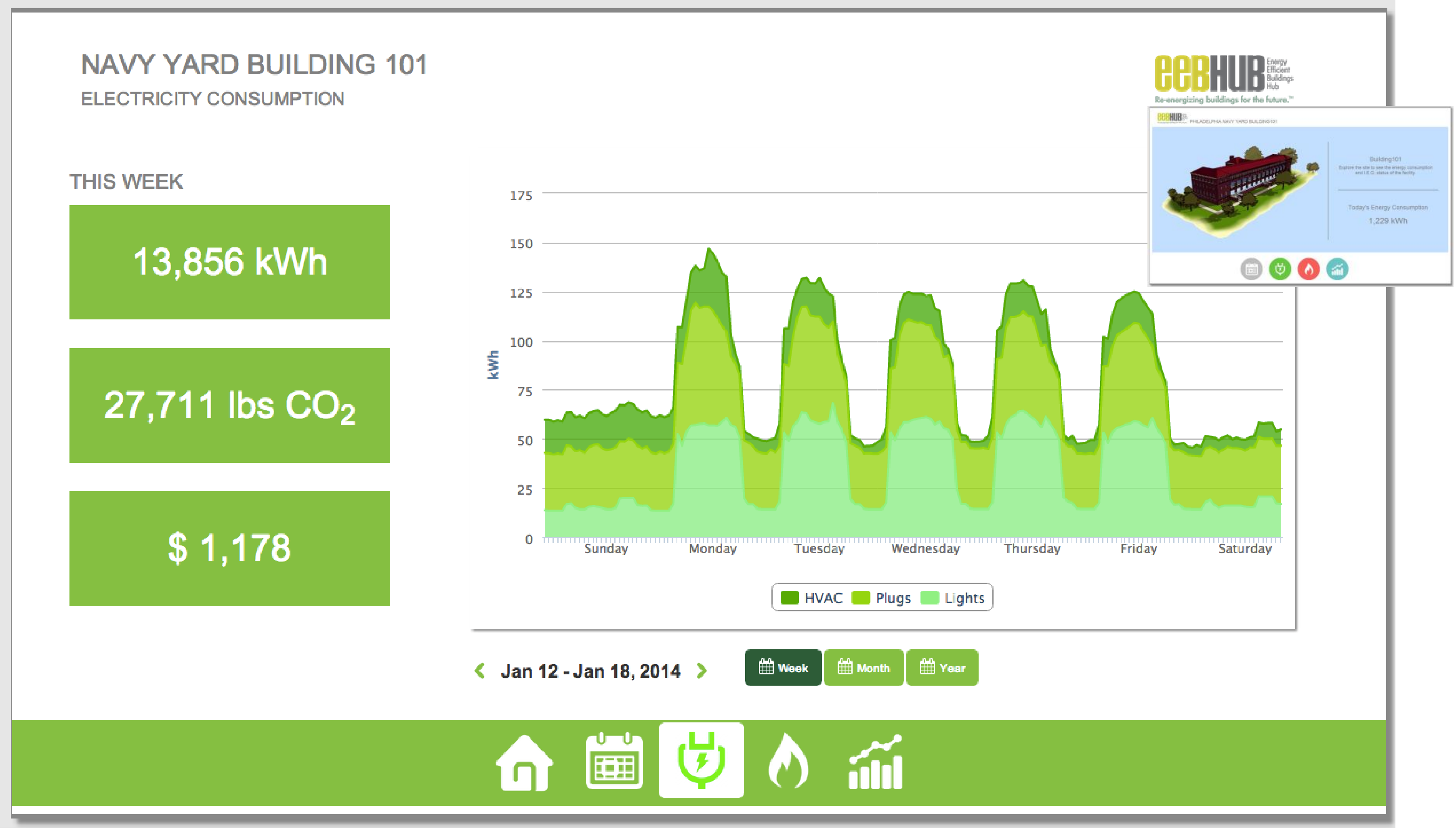
High Performance Connectivity





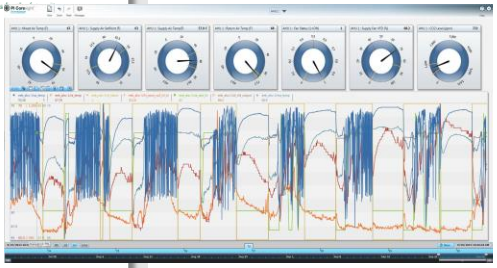
1. Design for the Internet of Things with distributed sensors and controls
2. Engineer independent plug-and-play networks – data/voice, power, security, and environmental services – with central communication
3. Design distributed cores for accessible, modifiable vertical distribution
4. Resolve integrated, reconfigurable plenum systems – ceiling or floor
5. Ensure user accessible, modifiable grid and nodes for connectivity
6. Create wiring harnesses for data/voice, power, security, environment
7. Select terminal units that provide all services in reconfigurable boxes
8. Create robust monitoring and individualized controls

Building Data Analytics
Intelligent Dashboards for Corporate and Campus Leaders [ID-C]



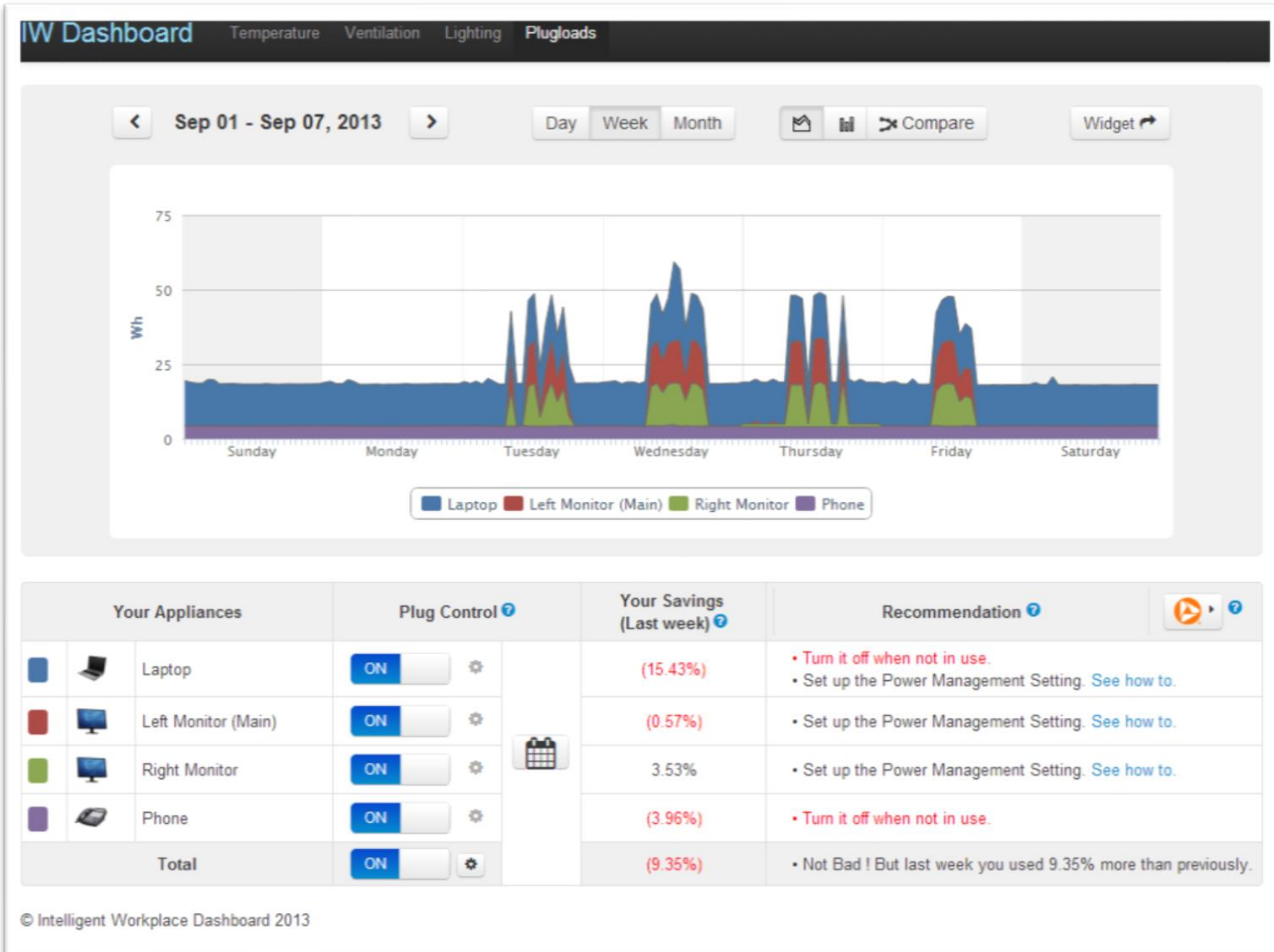
Building Data Analytics
Intelligent Dashboards for Facility Executives [ID-F]

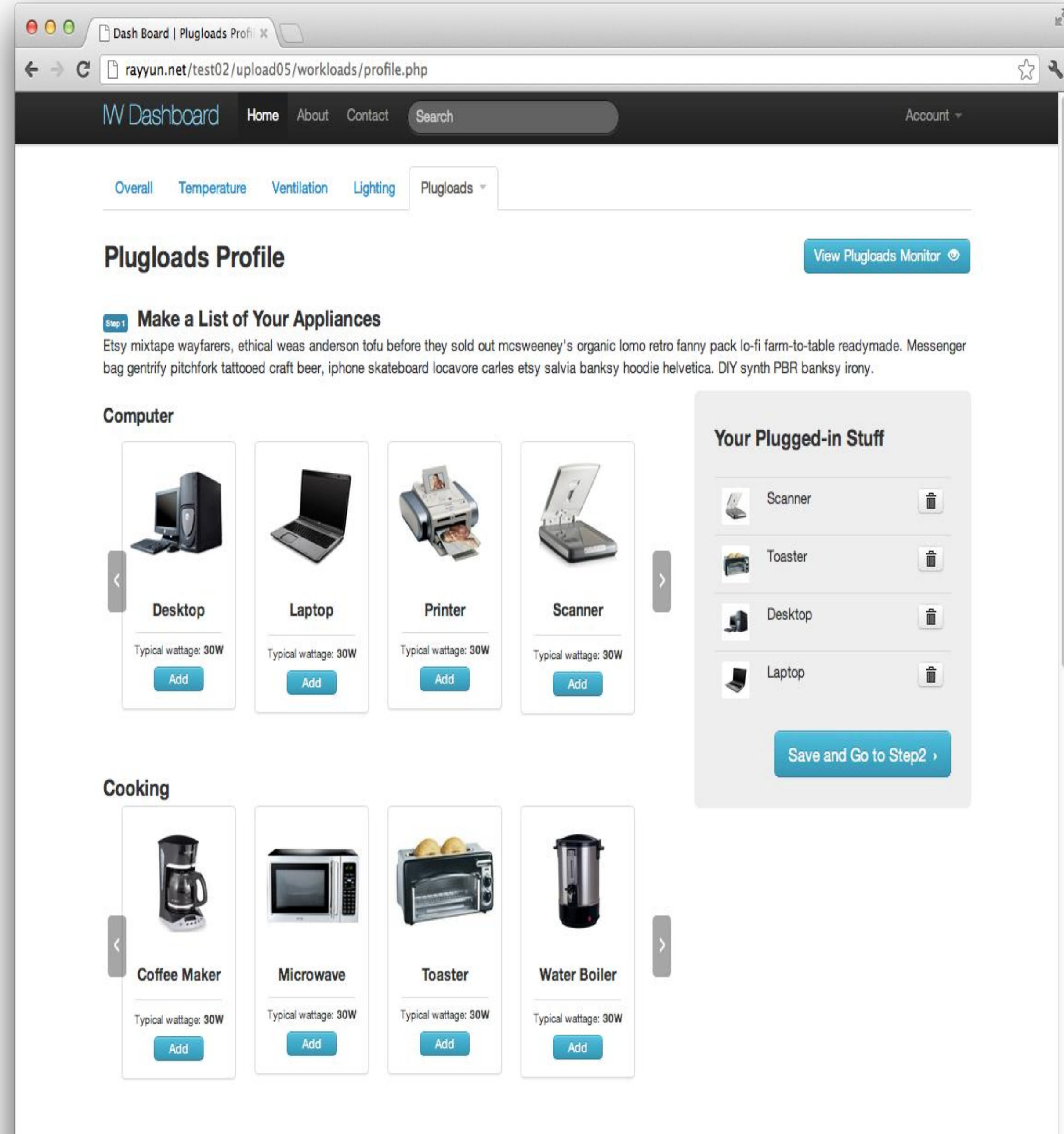
In alliance with OSIsoft, the CBPD has developed rapid, broadly applicable building analytics and communication output from multiple sources of real-time data to support energy efficiency recommendations, actions and verification.



DOE CBEI and DOD ESTCP

Building Data Analytics
Intelligent Dashboard for Occupants (ID-O)

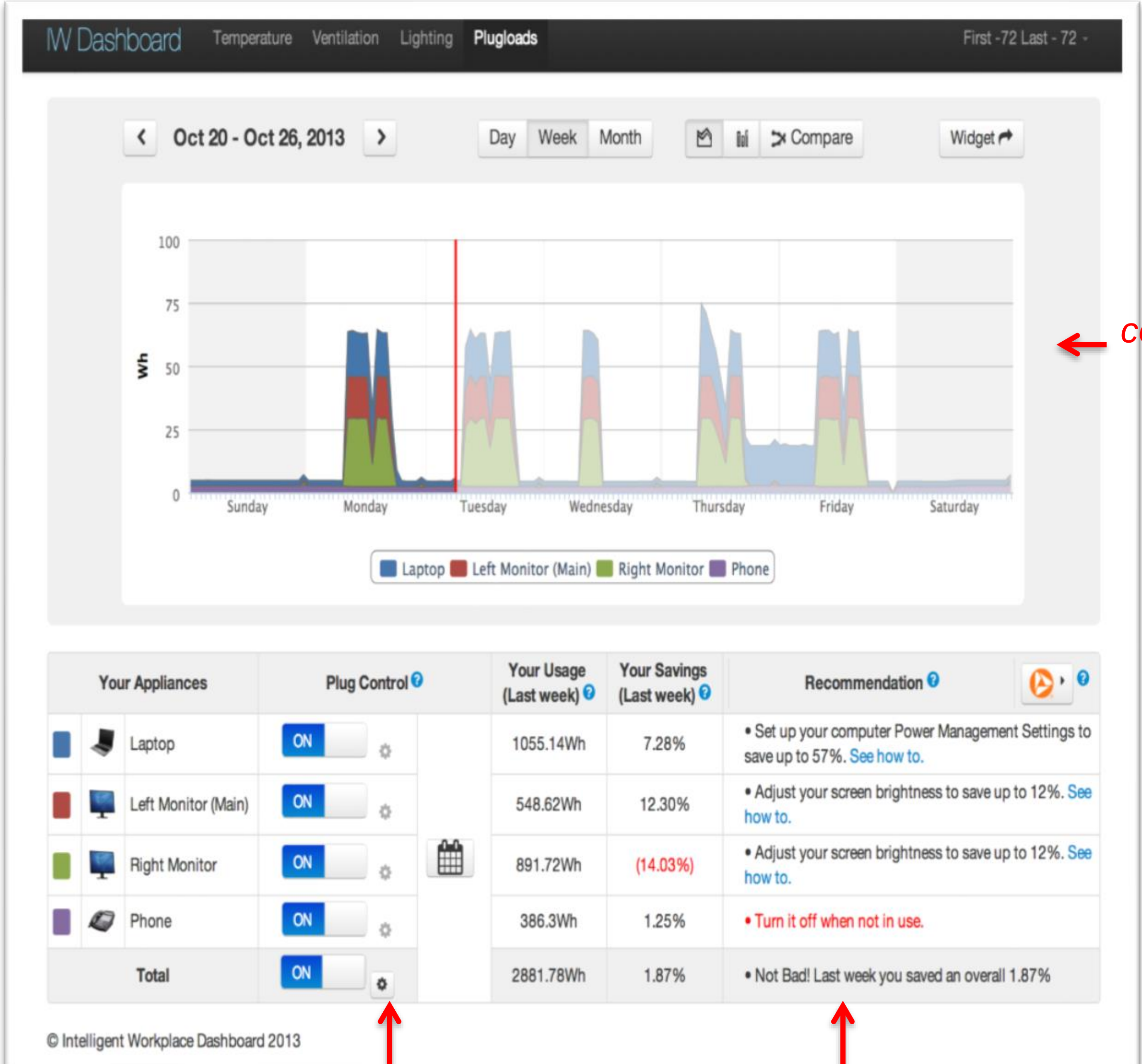




setting up workstation energy detection

(wow, abandoned technology is still drawing power)

advancing
C3 qualities



communication

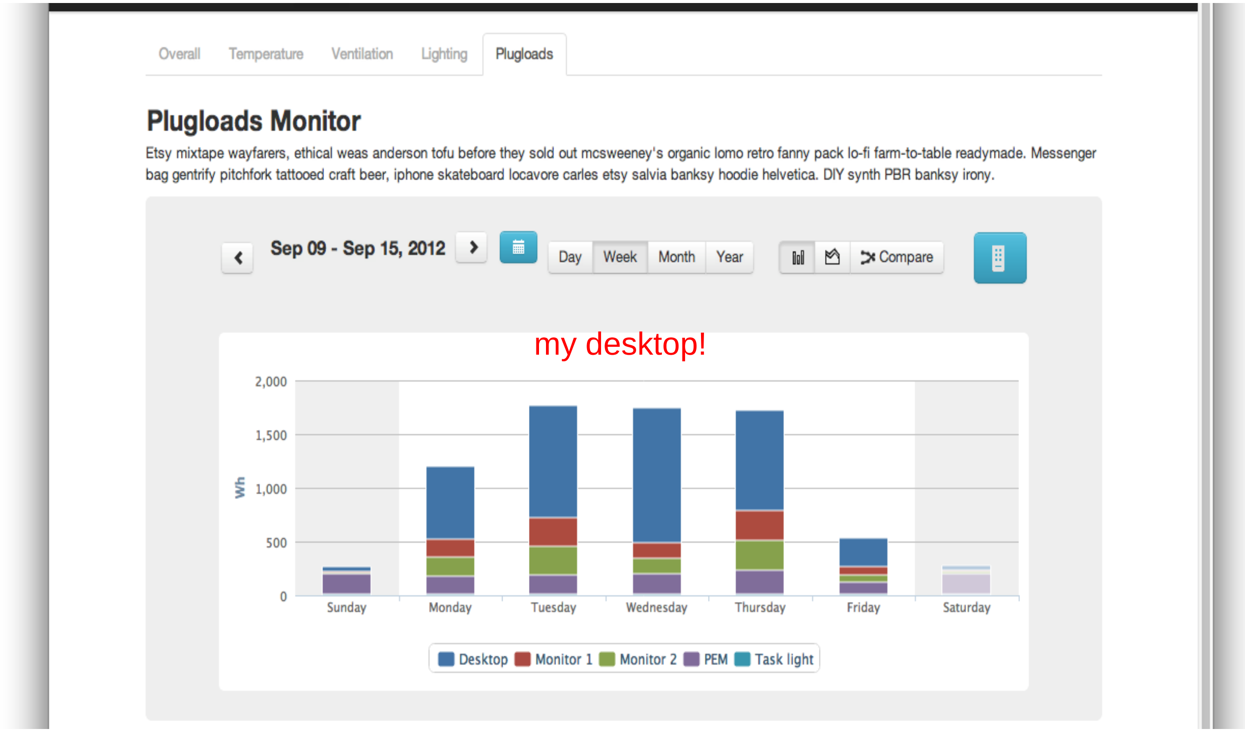
control

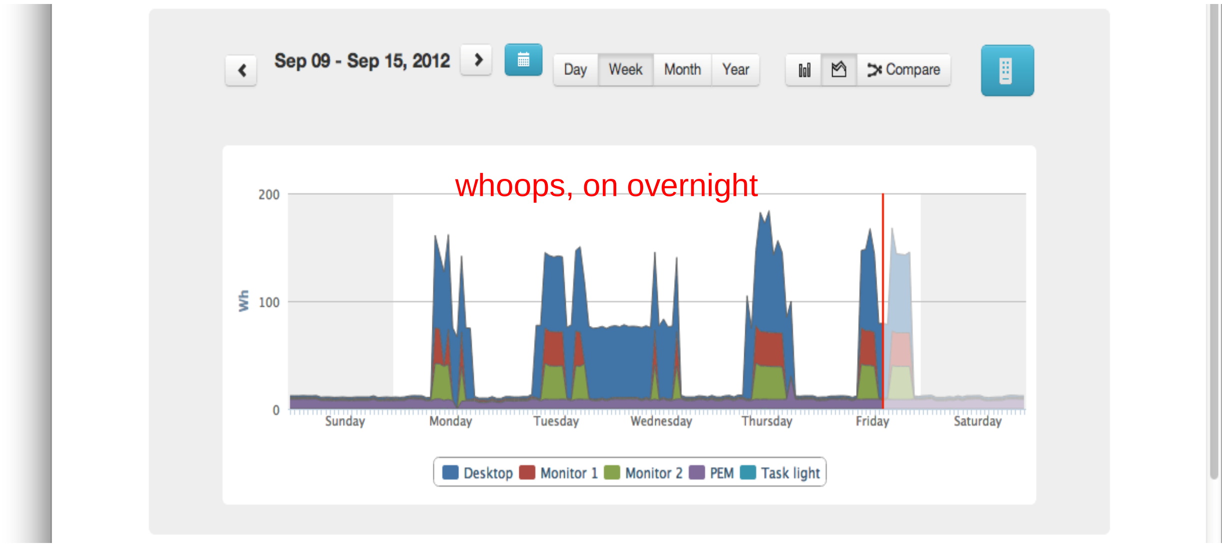
expert consulting

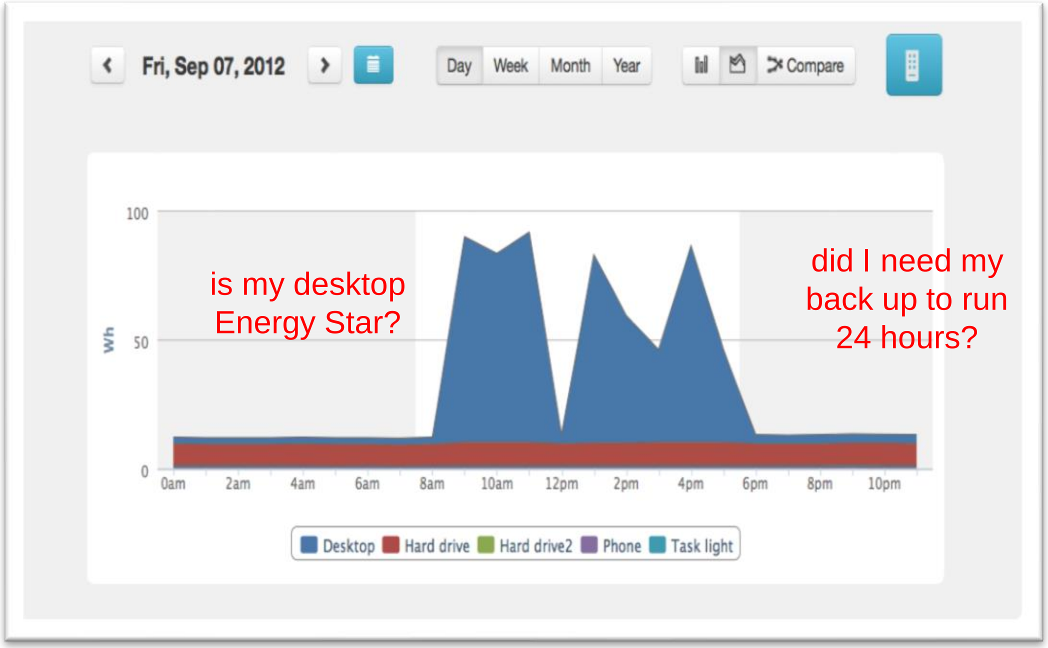
selecting the format that communicates to you:

Bar chart or linear graph

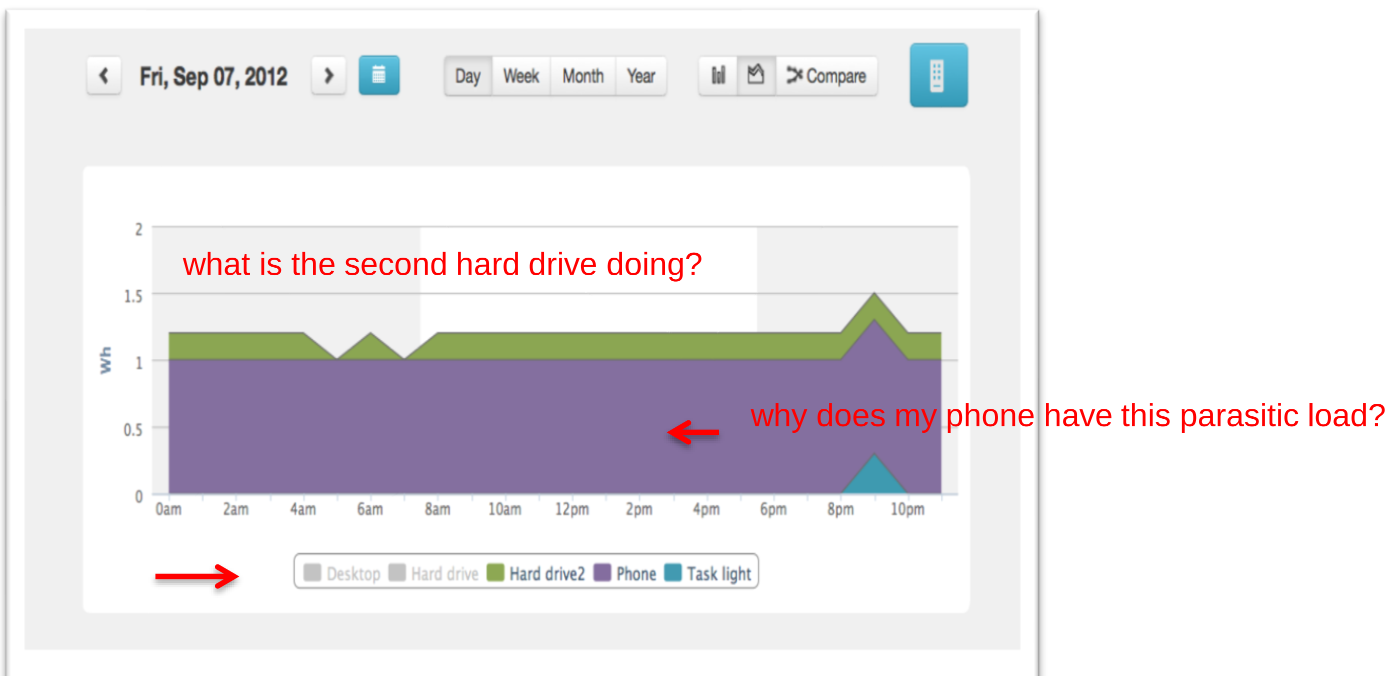
day, week, month, year

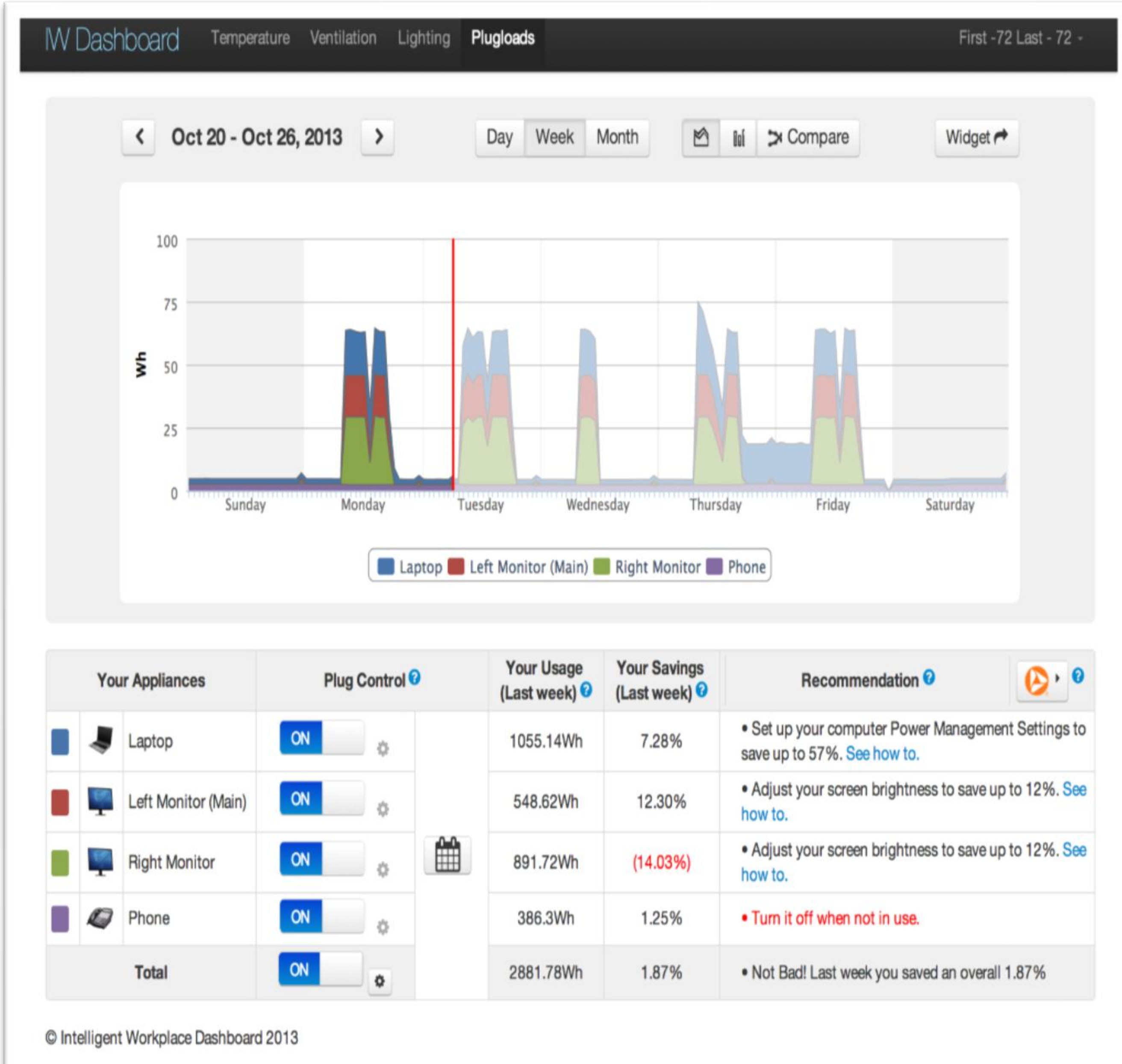






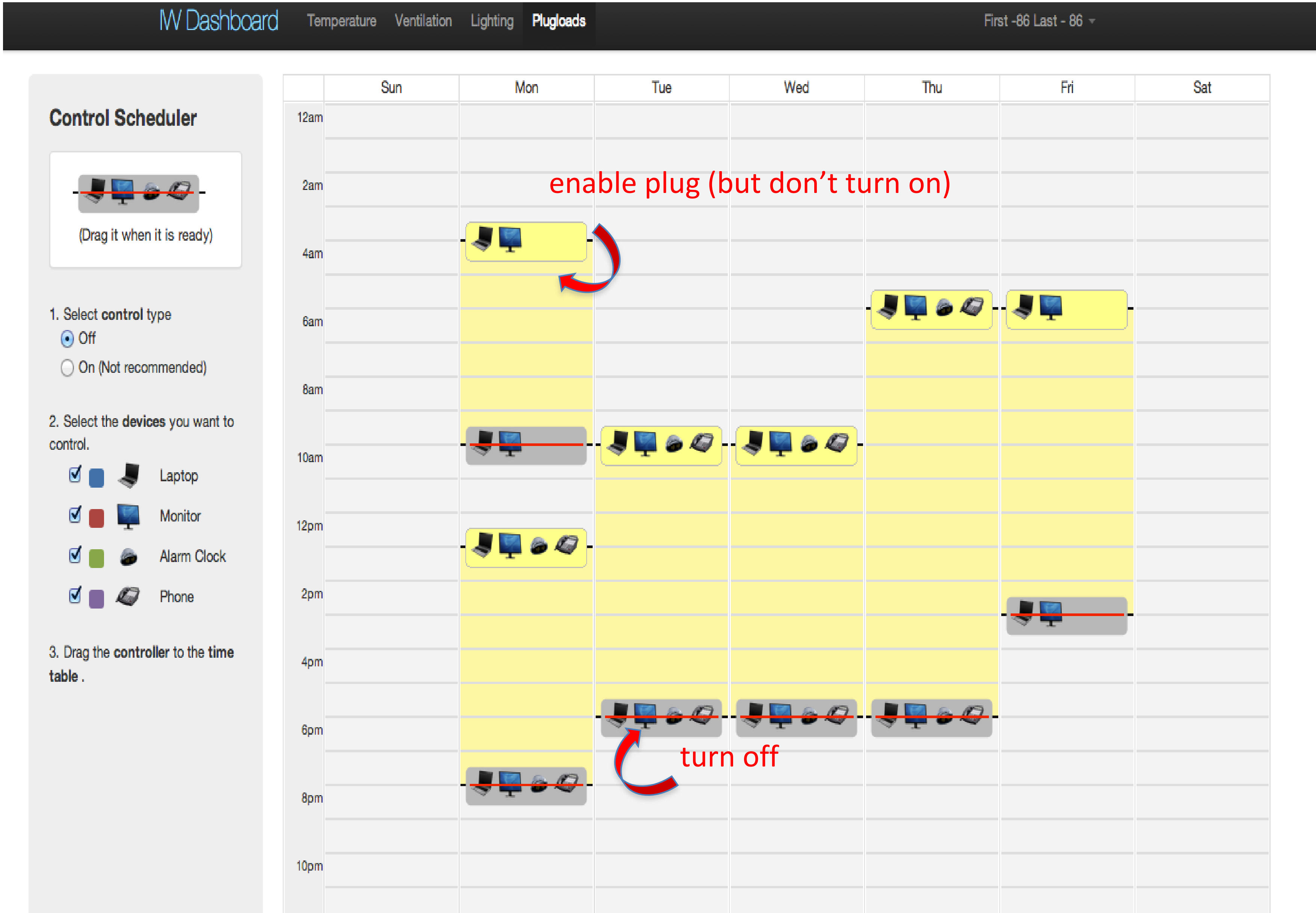
and if I unclick the big energy users...





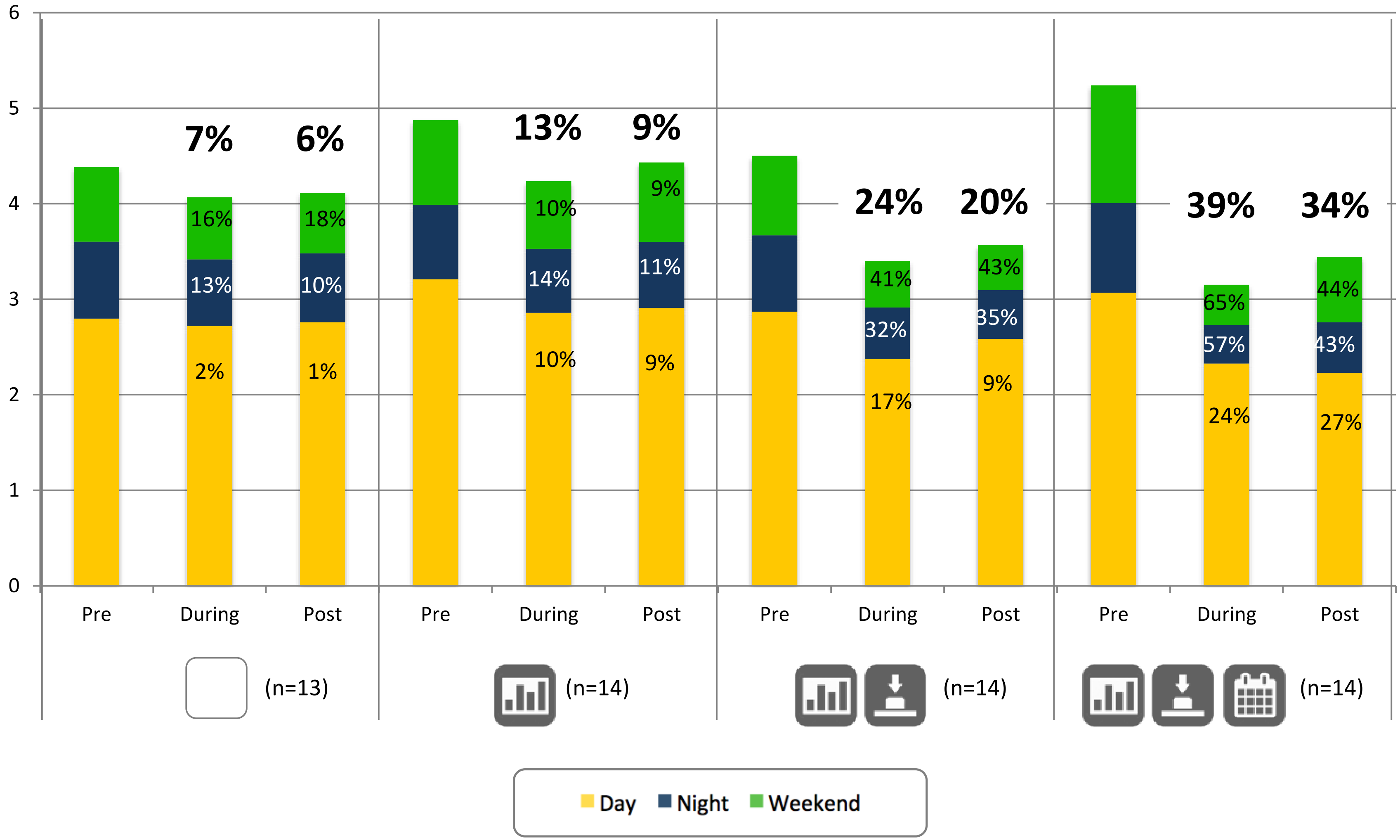
following the recommendations

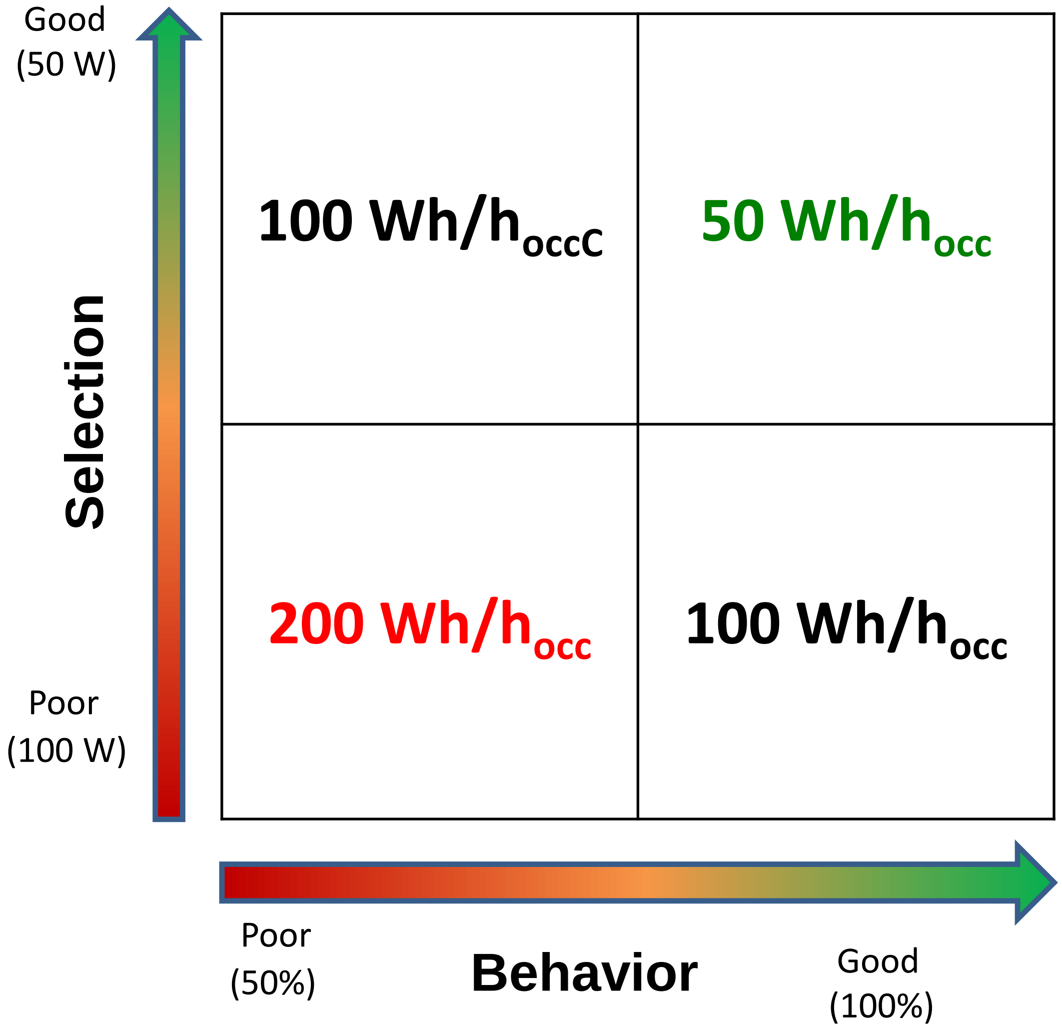
(generated by expert analysis of use)



IW Dashboard
Temperature
Ventilation
Lighting
Plugloads
First -86 Last - 86
Control Scheduler
(Drag it when it is ready)
1. Select control type
Off
On (Not recommended)
2. Select the devices you want to control.
Laptop
Monitor
Alarm Clock
Phone
3. Drag the controller to the time table .
Sun
Mon
Tue
Wed
Thu
Fri
Sat
12am
2am
4am
6am
8am
10am
12pm
2pm
4pm
6pm
8pm
10pm
enable plug (but don't turn on)
turn off

Energy Savings Per Group (Pre – During – Post)



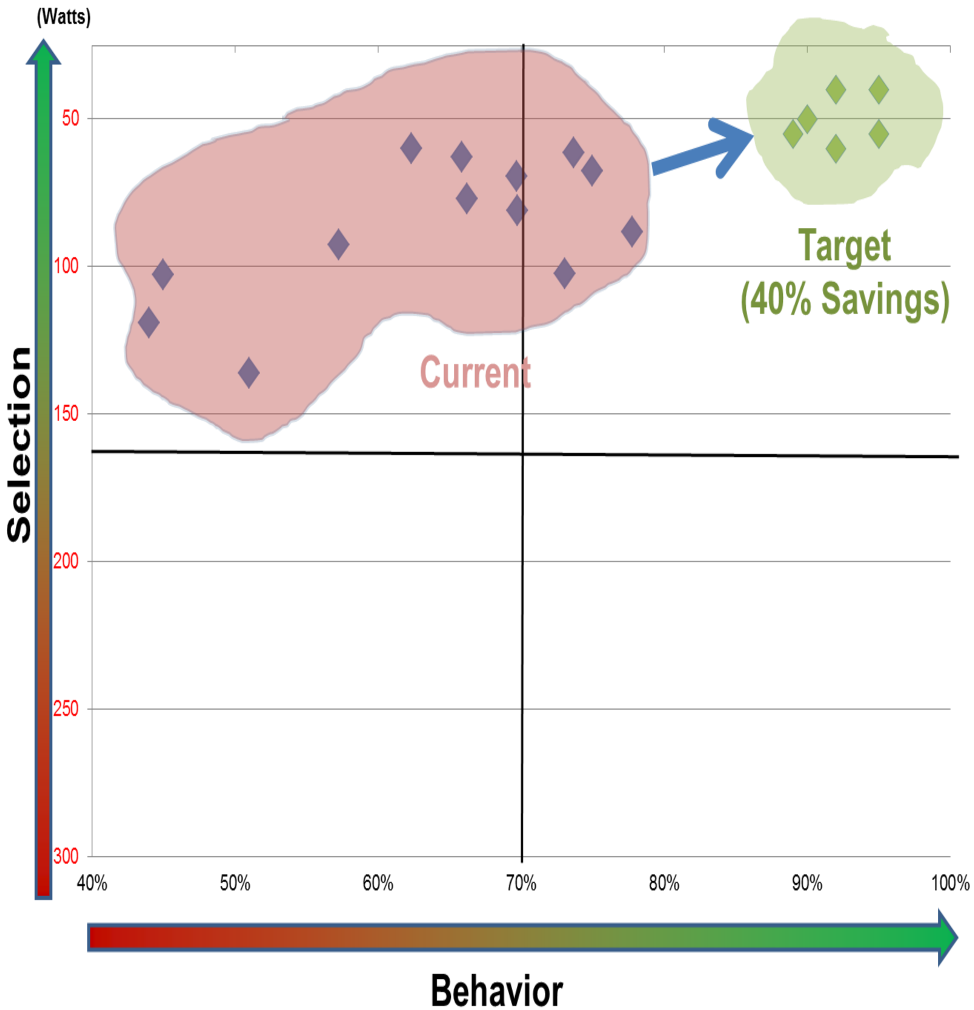


plug load sustainability matrix

Selection driven by policy, office protocol, feedback

+

Behavior driven by feedback, incentives, competition, ease of control



a corporate green leader: field data on 75 workstations

ABSIC/CBPD Guidelines for

High Performance Interior Systems

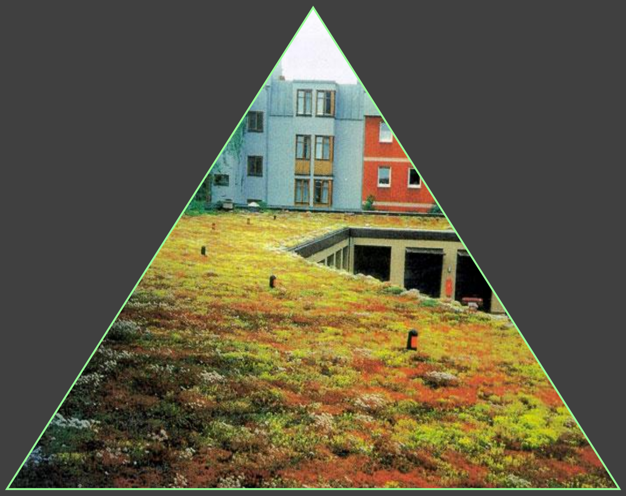
1. Design neighborhood clarity & shared spaces with flexibility
2. Design layers of ownership, multiple work environments
3. Ensure ergonomics/ functional support for shared work processes
4. Ensure ergonomics/functional support for individual work processes
5. Design “layers of closure”, privacy and acoustic control
6. Design “layers of mobility” for workstations and workgroups
7. Provide levels of personalization
8. Ensure environmental infrastructure for changing densities/ closure
9. Ensure technical infrastructure to support changing densities/ closure
10. Select interior system/components for material & energy conservation
11. Select healthy, maintainable interior components
12. Design for access to the natural environment

Triple Bottom Line

Profit

Economy

Financial Capital



People

Equity

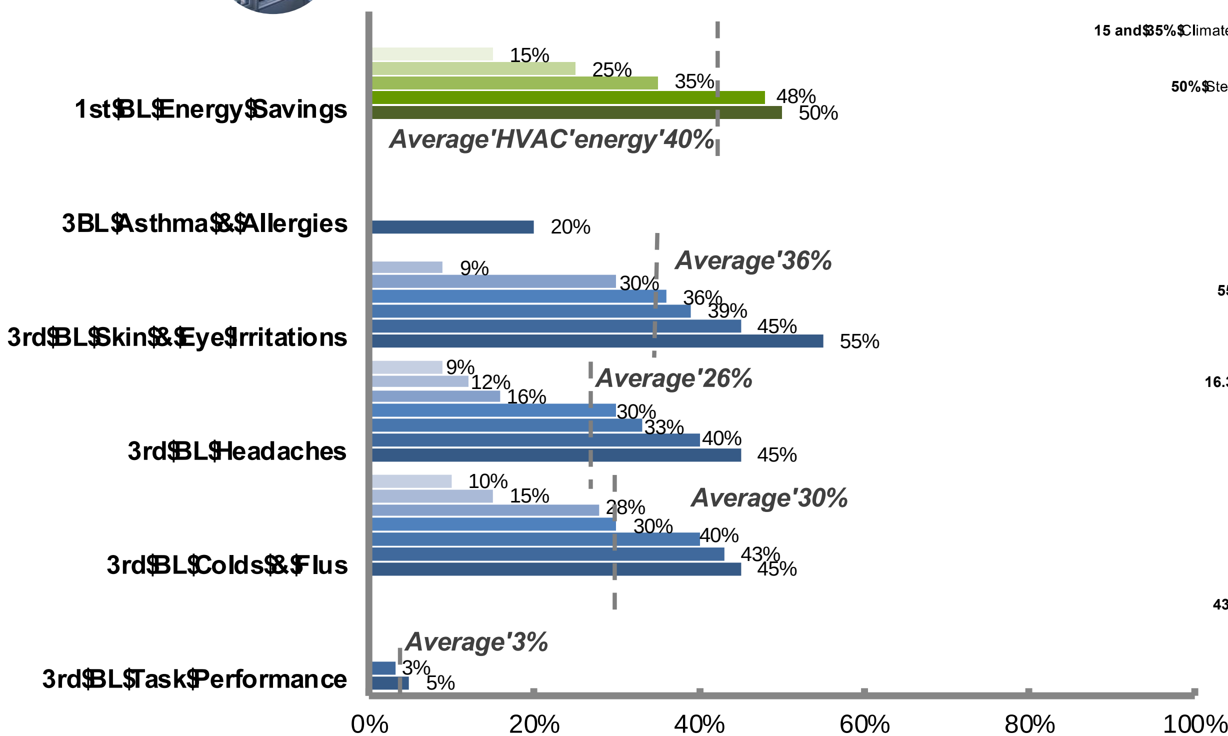
Human Capital

Planet

Environment

Natural Capital

Ensure Windows are Operable for Natural Ventilation



Energy$Savings$
15 and$35%$Climate Sustainability Tool (2007)
25%$Guzowski (2002)
17$48%$Wang et al(2015)
50%$Steemer & Manchanda (2009)

Asthma$&$Allergies
20%$Zweers et al. (1989)

Skin$&$Eye$Irritations
9%$Toftum (2010)
30%$Teeuw et al (1994)
36%$Burge et al. (1987)
39%$Zweers et al. (1989)
45%Olli & Fisk (2002)
55%$Zhounghua et al (2012)

Headaches
9%$Burge et al. (1987)
12%$Harrison et al. (1992)
16.3%$Zhounghua et al (2012)
30%$Teeuw et al (1994)
33%$Kroeling (1998)
40%$Gao et al (2003)
45%$Olli & Fisk (2002)

Colds$&$Flus$
10%$Burge et al. (1987
15%$Harrison et al. (1992)
28%$Kroeling (1998)
30%$Teeuw et al (1994)
40%$Burge et al. (1987)
43%$Zhounghua et al. (2012)
45%$Olli & Fisk (2002)

Task$Performance
3%$Wargocki et al. (2000)
5%$Seppanen (2003)

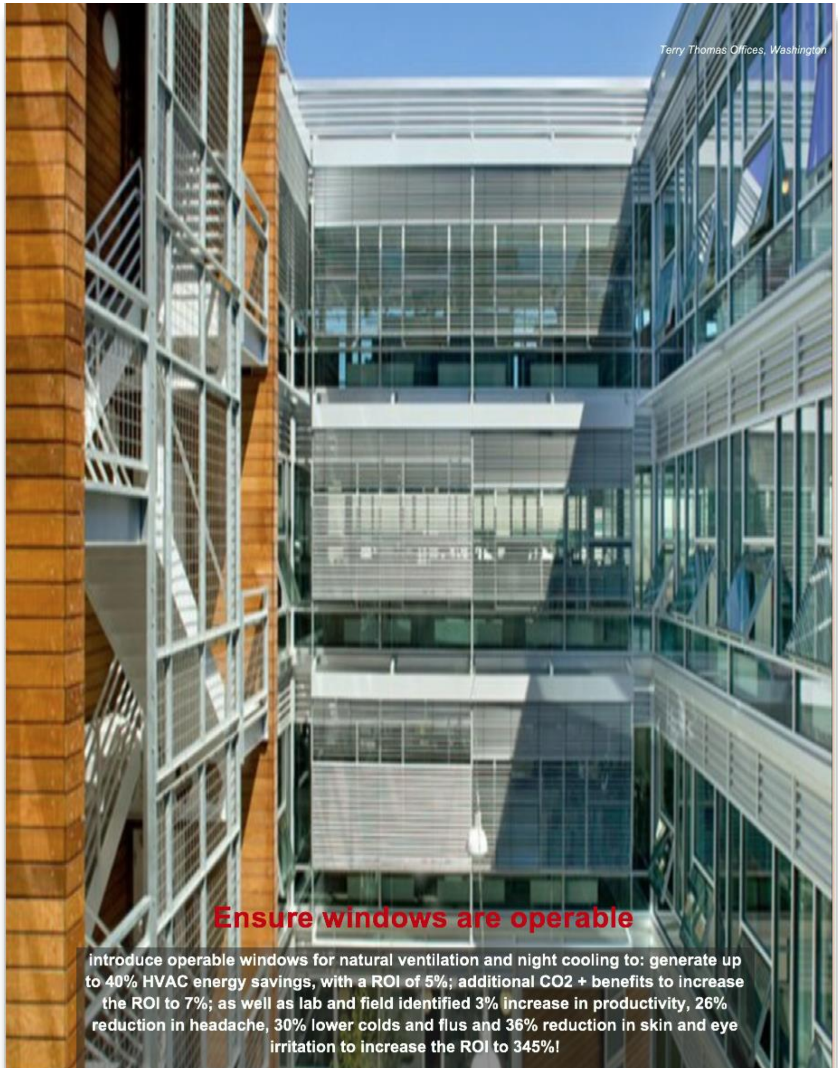


Table 19: Triple bottom line calculations for introducing operable windows for natural ventilation and night cooling

Costs of buying operable windows for natural ventilation and night cooling

	Per sq. ft.	Per employee
First cost for the investment	$15	$360
Initial Investment costs for a 100,000 sq. ft. building *(for 1/3 baseline building perimeter area)*	**$120,000**	

1st Financial Capital savings

	Per sq. ft.	Per employee
HVAC Energy Savings (40%)	$0.09	$19
Annual 1st bottom line savings	**+$0.09**	**+$19**
ROI (Financial)	**5%**	
Payback Period	**19 years**	
Cumulative 15-year Net Present Value	**$ 73,000**	

2. Financial + Environmental Capital savings

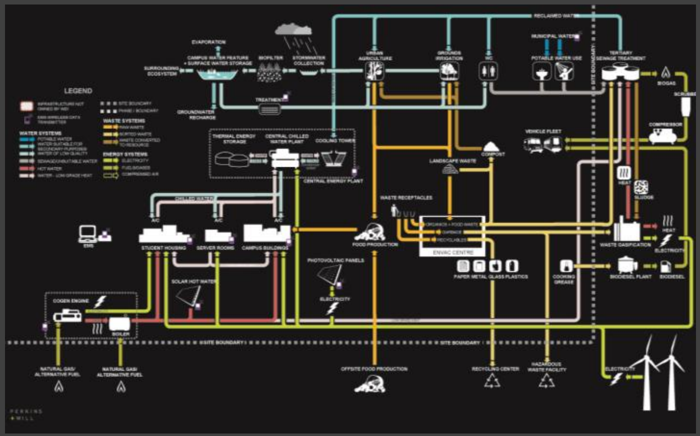
	Per sq. ft.	Per employee
Environmental benefits from energy savings of:	0.96 kWh	192 kWh
Air pollution emissions (SO_x, NO_x, PM, CH4)	$0.02	$3
CO_2 reductions	$0.01	$2
Water savings	$0.004	$0.8
Annual 2nd bottom line savings	**+$0.03**	**+$5.8**
Cumulative ROI (Financial + Environmental)	**7%**	
Payback Period	**14 years**	
Cumulative 15-year Net Present Value	**$94,950**	

3. Financial + Environmental + Human Capital savings

	Per sq. ft.	Per employee
Headache reduction (26% * $73)	$0.10	$19
Cold & flu reduction (30% * $68)	$0.10	$20
Skin & eye irritation reduction (41% * $86)	$0.15	$31
Asthma & allergies reduction (20% * $105)	$0.10	$20
Productivity increase (3%)	$5.62	$1,125
Annual 3rd bottom line savings	**+$6.21**	**+$1241**
ROI (Financial + Environment+ Human)	**345%**	
Payback Period	**2 months**	
Cumulative 15-year Net Present Value	**$ 805,700**	

ABSIC/CBPD Guidelines for

High Performance Urban Systems



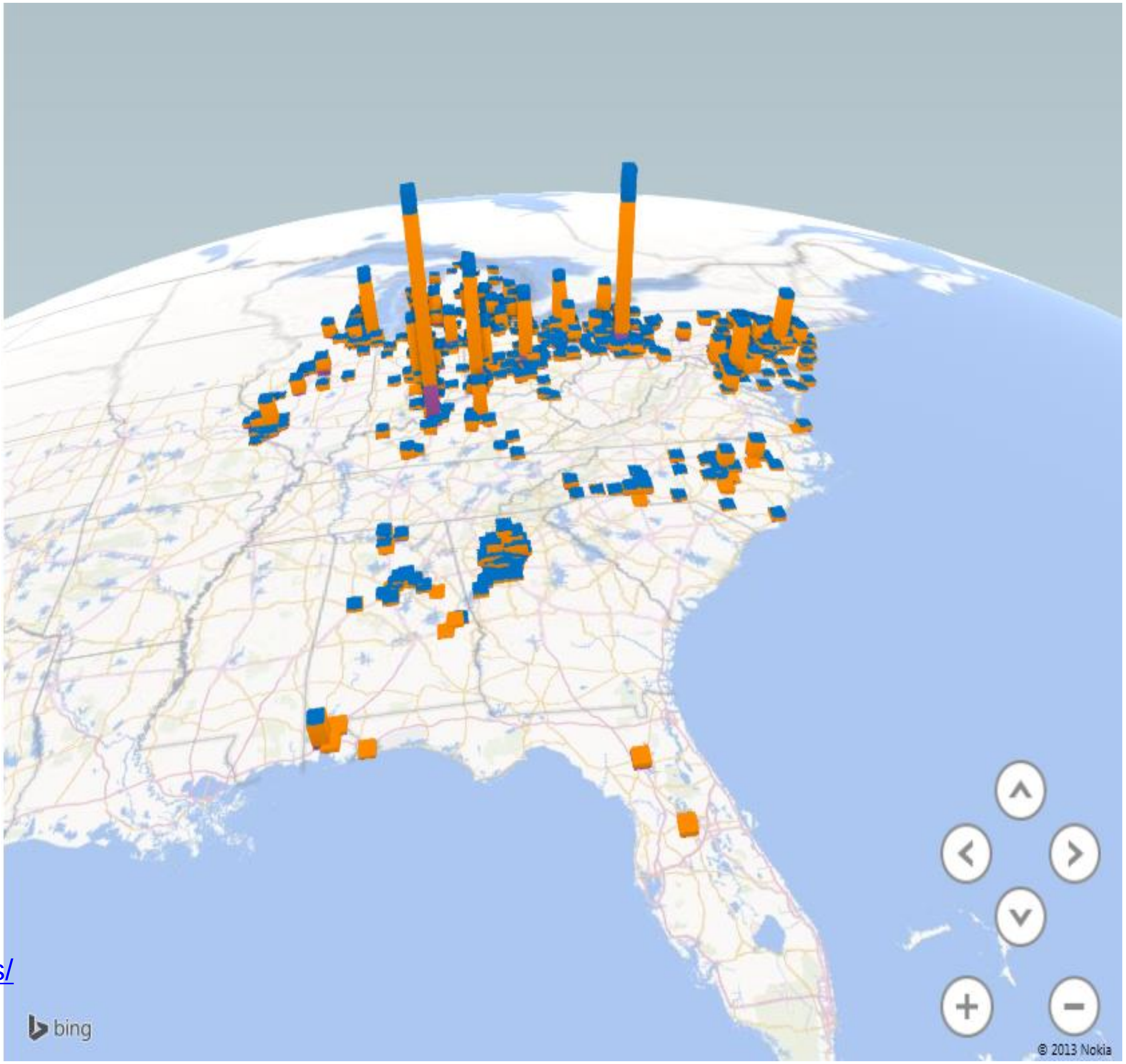
1. Design for mixed use live-work-learn-play
2. Design for mobility with a transportation portfolio
3. Design the ‘watershed’ with highest and best use for fresh water
4. Design the ‘air shed’ for outdoor air quality
5. Design the ‘waste shed’ including waste to energy
6. Design local food infrastructures
7. Merge data, power, voice with smart infrastructures
8. Design the energy shed with highest and best use for electric and thermal energies and buildings as power plants

GIS & Portfolio Data Analytics
Benchmarking Laws and 2030 Urgency

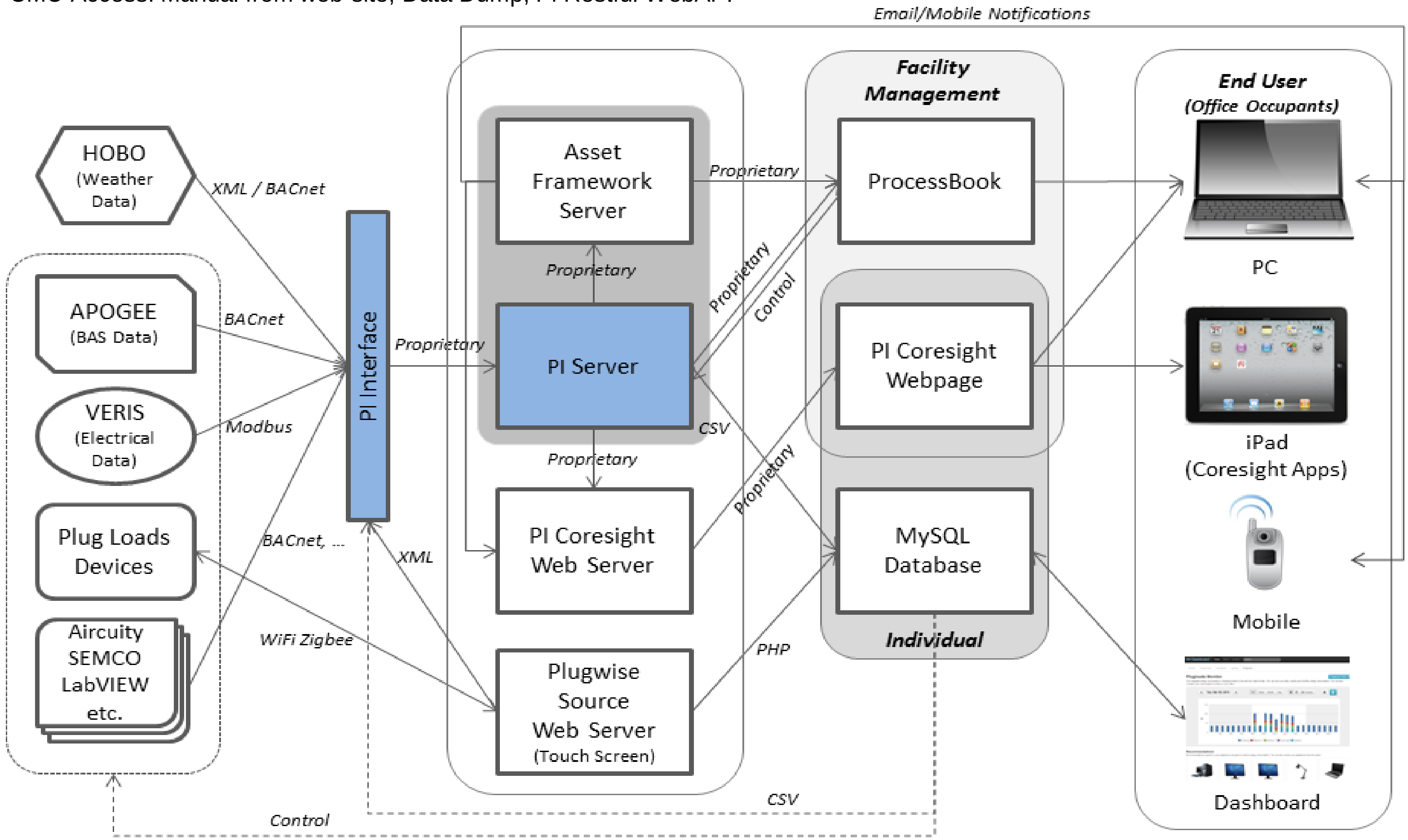
ID-C Challenge PNC:
To monitor and analyze a portfolio of 4000 Assets (Headquarter, datacenters, branches, ATMs) for strategic improvements

City of DC 300
City of Pittsburgh 140
CMU 85
GSA 1500

http://www.cmu.edu/cbpdanalytics/



CBPD building a CMU Campus Wide database
Electric Meters 30+ buildings (queried each second)
Building Automation Systems for 15+ buildings
Environment & Weather Data
CMU Access: Manual from web-site, Data Dump, Pi Restful WebAPI



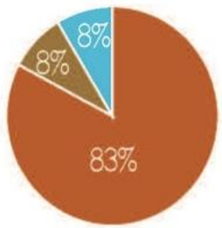
Integrated Intelligent Data Platform

CMU PiSystem (open data) & DOE SEED (non-proprietary)

2013 Utility Consumption Executive Summary

1 In 2013, spent a total of:

$59 million on utilities



total utility spending by resource consumption

$5 million on water

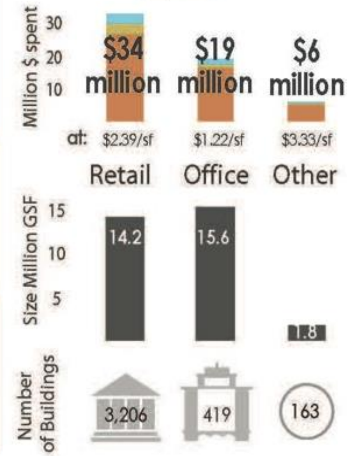
$5 million on gas

$49 million on electricity

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:



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

C2

2013 PNC RETAIL Energy (Electricity + Gas) 25 Highest Expenditures

1 Retail Energy Profile:

2,533 buildings data out of 3,206 total

13 million out of 14 million square feet total

$31 million total energy cost

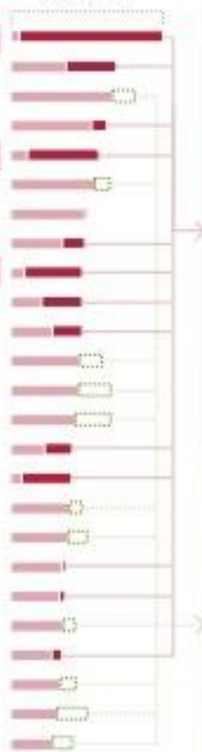
2 Among all Retail buildings:

74% perform worse than the ENERGY STAR median for bank branch

ENERGY STAR median energy performance bank branch: **87.0 kBTU/sf**

3 Top 25 Energy Expenditures

	total cost
1. Kalamazoo Main, MI	$129,360
2. Naperville South Office, IL	$89,752
3. Fall Hill - Fredericksburg, VA	$85,671
4. Decatur Johnston St, AL	$81,559
5. Civic Center, NJ	$74,835
6. Dover, DE	$73,217
7. Tucker, GA	$64,921
8. Glenview Pointe, KY	$62,729
9. Beverly IL - 10701 S Western Ave, IL	$60,658
10. Plainfield - Park Avenue, NJ	$60,592
11. Somerset, NJ	$60,586
12. Miracle Mile - Monroeville, PA	$58,628
13. Vineland - Landis Avenue, NJ	$57,986
14. St Charles-Fox Field Commons Office, IL	$55,121
15. Chatham Road Office, IL	$52,217
16. Manassas Crossroads, VA	$51,791
17. Opelika - 2nd Avenue, AL	$50,354
18. Telegraph Office, MO	$48,759
19. Pell City - North Martin Street, AL	$46,392
20. Farmers & Mechanics, MD	$46,081
21. Mobile - Crichton, AL	$44,645
22. Morrow, GA	$43,694
23. New Cumberland, PA	$42,328
24. Ashland Building, KY	$39,696
25. Asheboro - 115 S Fayetteville, NC	$39,404



4 Top Opportunities for Savings in Energy

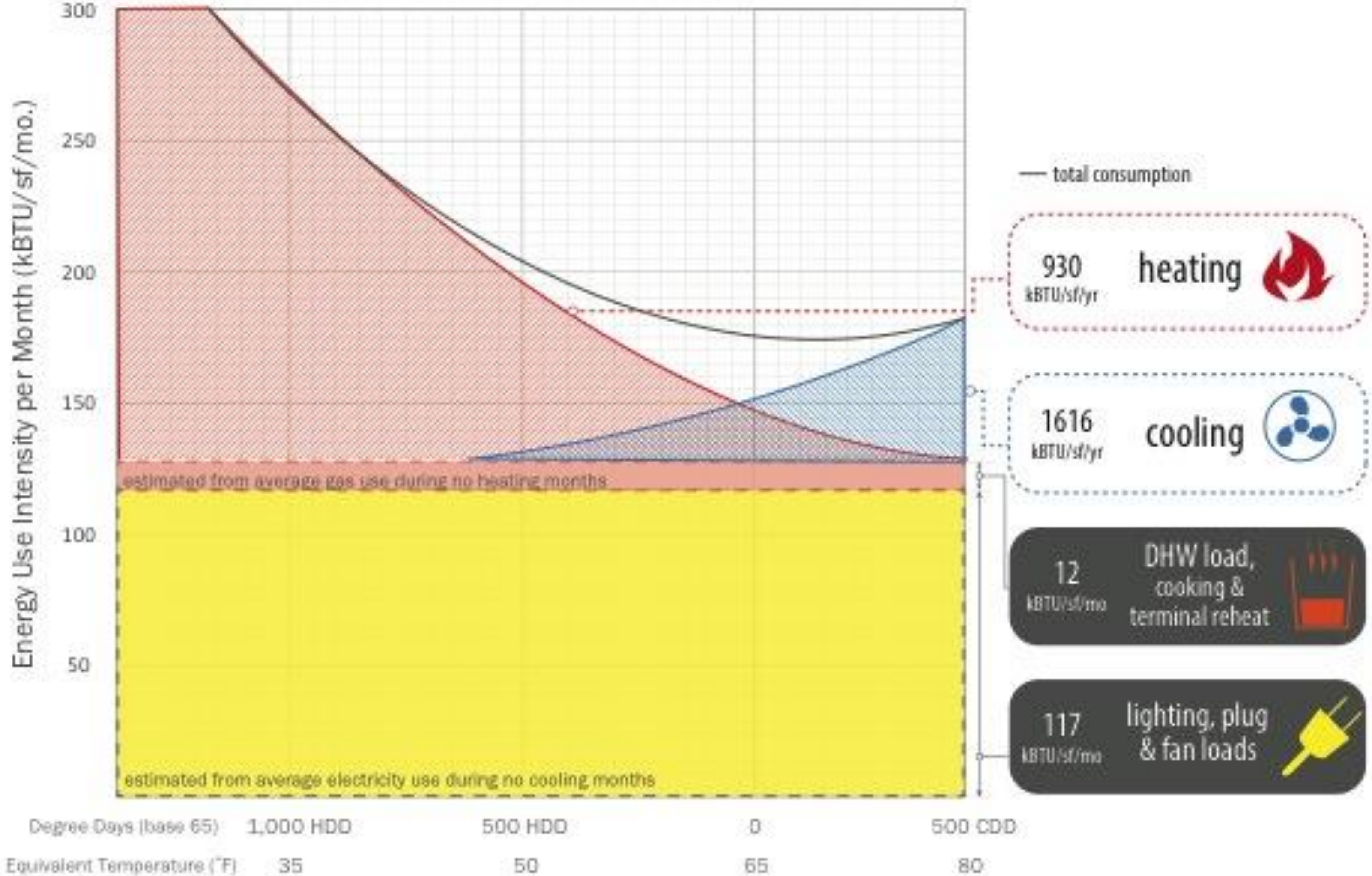
$451,886 in potential savings if buildings operated at median energy use intensity

		comments:
1. Kalamazoo Main, MI	$122,053	
2. Civic Center, NJ	$60,502	
3. Beverly IL - 10701 S Western Ave, IL	$49,102	
4. Naperville South Office, IL	$42,808	
5. Manassas Crossroads, VA	$42,565	
6. Plainfield - Park Avenue, NJ	$34,478	
7. Somerset, NJ	$25,372	
8. Chatham Road Office, IL	$23,643	
9. Glenview Pointe, KY	$18,797	
10. Decatur Johnston St, AL	$13,014	
11. Morrow, GA	$9,056	
12. Farmers & Mechanics, MD	$4,938	
13. Pell City - North Martin Street, AL	$3,346	
14. Tucker, GA	$2,205	

$193,374 in current savings by performing better than median

		comments:
15. Mobile - Crichton, AL	-$9,886	
16. Opelika - 2nd Avenue, AL	-$10,022	
17. Dover, DE	-$11,317	
18. Asheboro - 115 S Fayetteville, NC	-$13,074	
19. New Cumberland, PA	-$13,306	
20. Telegraph Office, MO	-$16,093	
21. Fall Hill - Fredericksburg, VA	-$18,763	
22. Miracle Mile - Monroeville, PA	-$18,899	
23. Ashland Building, KY	-$25,292	
24. Vineland - Landis Avenue, NJ	-$26,884	
25. St Charles-Fox Field Commons Office, IL	-$29,833	

2011-2013 Monthly Gas and Electricity Source Consumption by Degree Days for Bank Branch Kalamazoo Main, MI



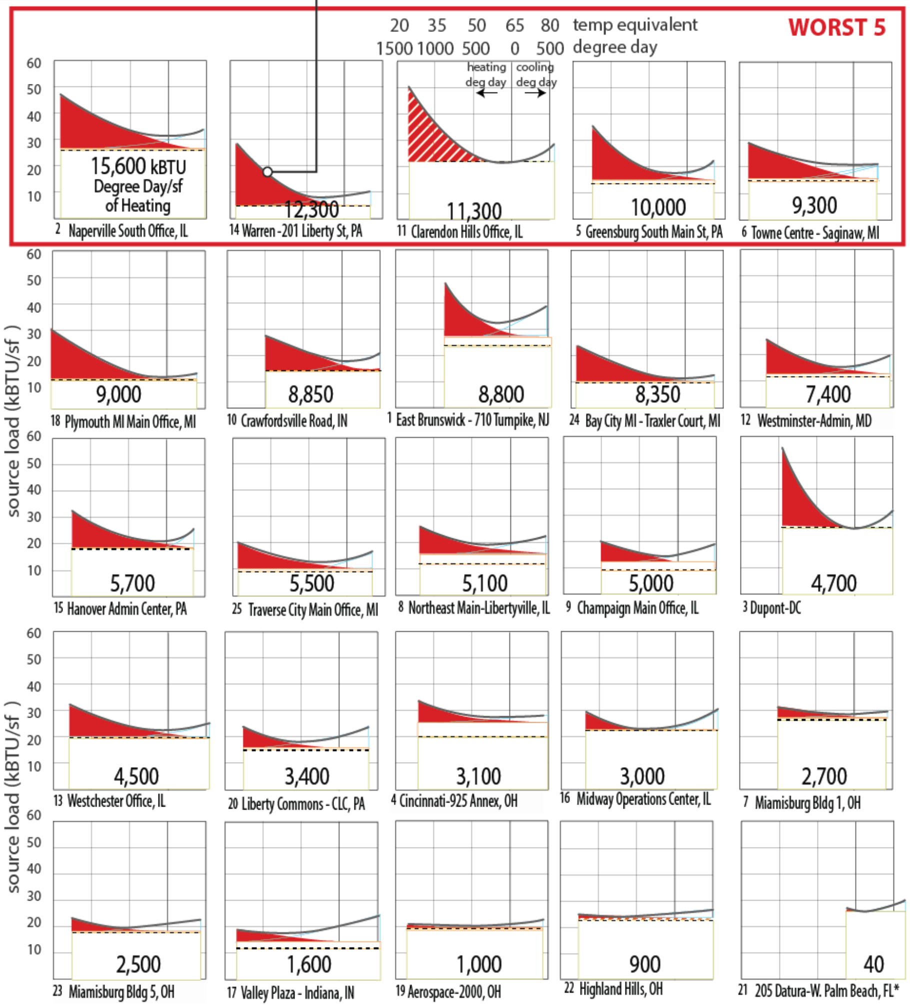
2011-13 OFFICE HEATING

of PNC's 25 Highest Energy Use Intensities Bank Branches Source Electricity & Gas

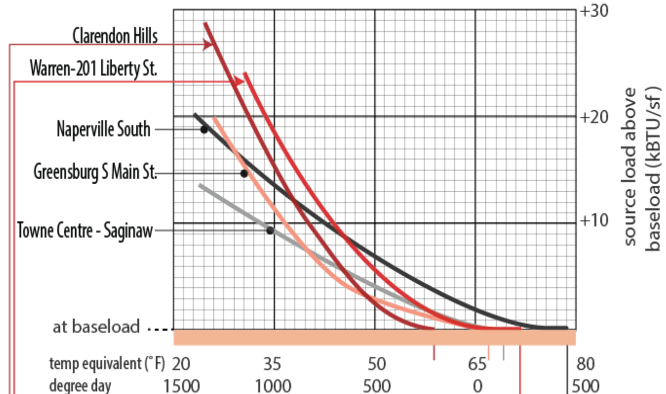
1 High heating load MAY be due to a building's:

- Poor Envelope
- Heating System Inefficiency
- Poor Seasonal Operation

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



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



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

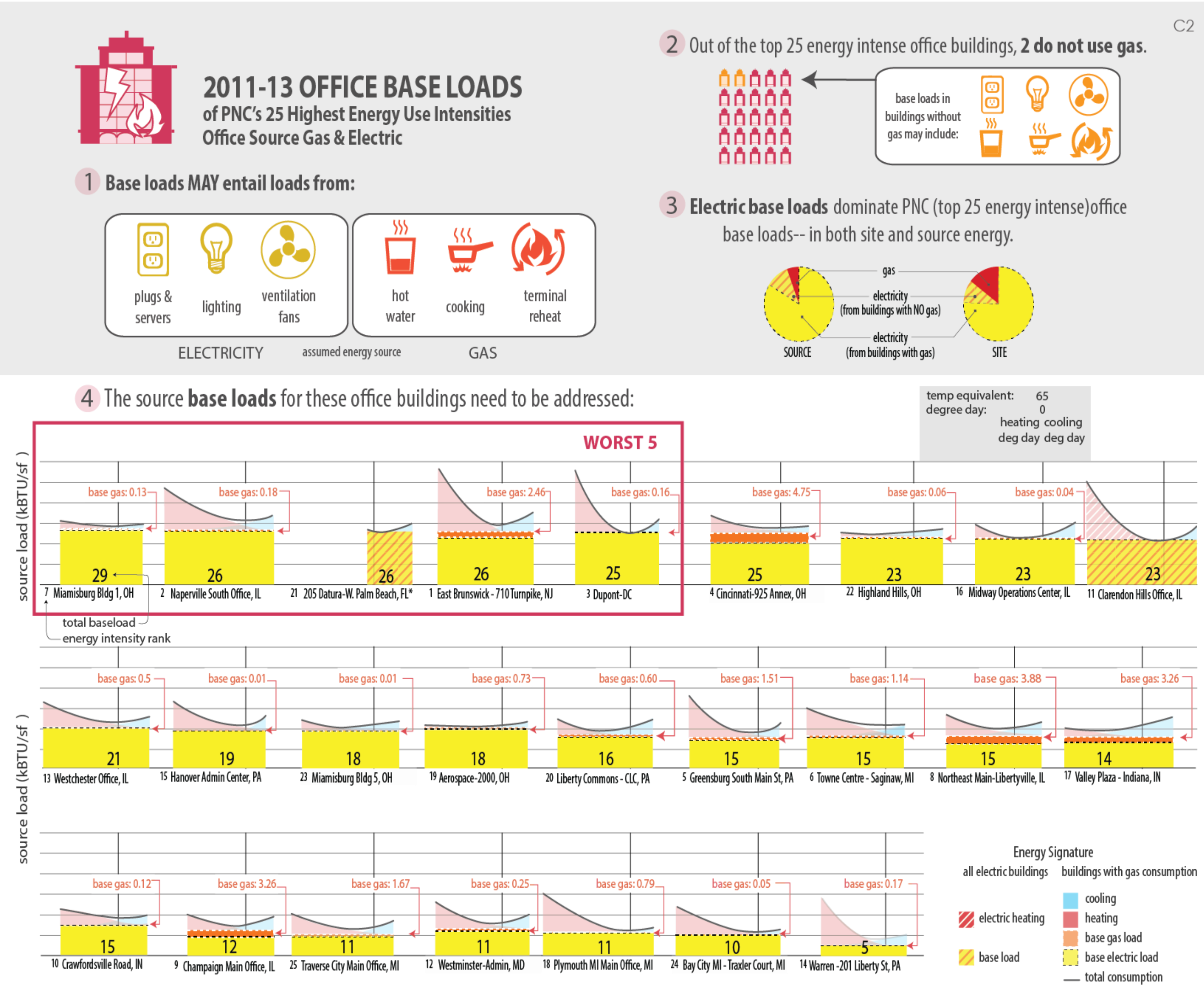
- **Clarendon Hills, IL using ~7 kBTU/sf for 15 °F temperature change**
- **Warren- 201 Liberty St. using ~3 kBTU/sf for 15 °F temperature change**

	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



C2
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
hot water
cooking
terminal reheat
ELECTRICITY
assumed energy source
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
4 The source base loads for these office buildings need to be addressed:
temp equivalent: 65
degree day: 0
heating deg day
cooling deg day
WORST 5
source load (kBTU/sf)
base gas: 0.13
29
7 Miamisburg Bldg 1, OH
base gas: 0.18
26
2 Naperville South Office, IL
26
21 205 Datura-W. Palm Beach, FL*
base gas: 2.46
26
1 East Brunswick - 710 Turnpike, NJ
base gas: 0.16
25
3 Dupont-DC
base gas: 4.75
25
4 Cincinnati-925 Annex, OH
base gas: 0.06
23
22 Highland Hills, OH
base gas: 0.04
23
16 Midway Operations Center, IL
23
11 Clarendon Hills Office, IL
total baseload
energy intensity rank
source load (kBTU/sf)
base gas: 0.5
21
13 Westchester Office, IL
base gas: 0.01
19
15 Hanover Admin Center, PA
base gas: 0.01
18
23 Miamisburg Bldg 5, OH
base gas: 0.73
18
19 Aerospace-2000, OH
base gas: 0.60
16
20 Liberty Commons - CLC, PA
base gas: 1.51
15
5 Greensburg South Main St, PA
base gas: 1.14
15
6 Towne Centre - Saginaw, MI
base gas: 3.88
15
8 Northeast Main-Libertyville, IL
base gas: 3.26
14
17 Valley Plaza - Indiana, IN
source load (kBTU/sf)
base gas: 0.12
15
10 Crawfordsville Road, IN
base gas: 3.26
12
9 Champaign Main Office, IL
base gas: 1.67
11
25 Traverse City Main Office, MI
base gas: 0.25
11
12 Westminster-Admin, MD
base gas: 0.79
11
18 Plymouth MI Main Office, MI
base gas: 0.05
10
24 Bay City MI - Traxler Court, MI
base gas: 0.17
5
14 Warren -201 Liberty St, PA
Energy Signature
all electric buildings
buildings with gas consumption
electric heating
base load
cooling
heating
base gas load
base electric load
total consumption

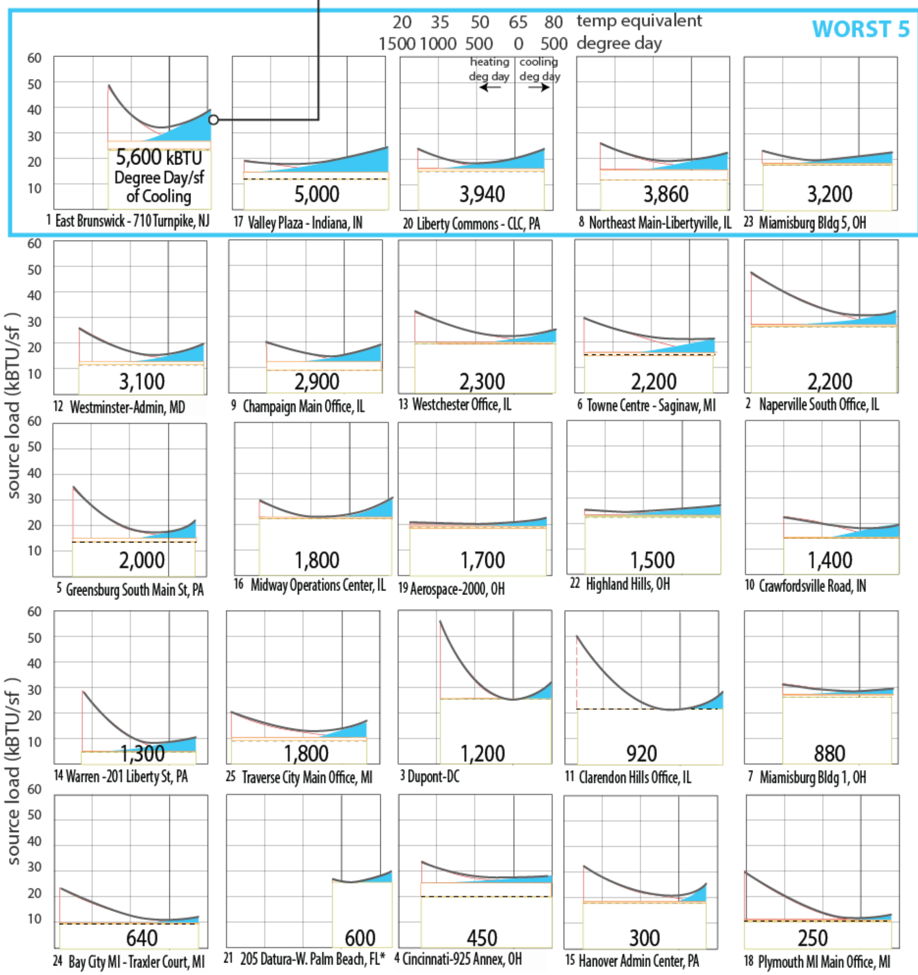
2011-13 OFFICE COOLING

of PNC's 25 Highest Energy Use Intensities Office Source Electricity

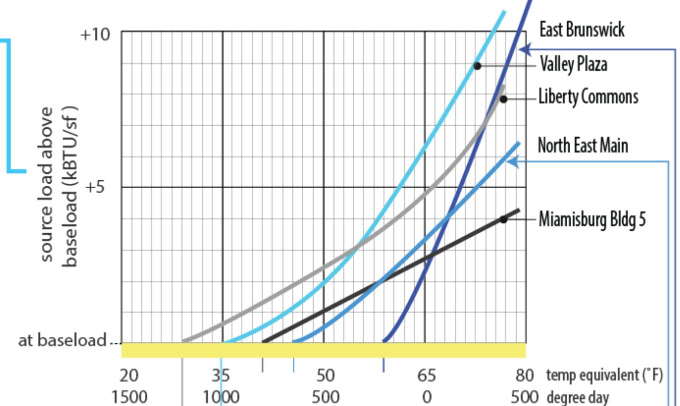
1 High cooling MAY be due to a building's:

Poor Envelope | Insufficient Shading | Air Conditioning Inefficiency | Poor Seasonal Operation

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



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



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

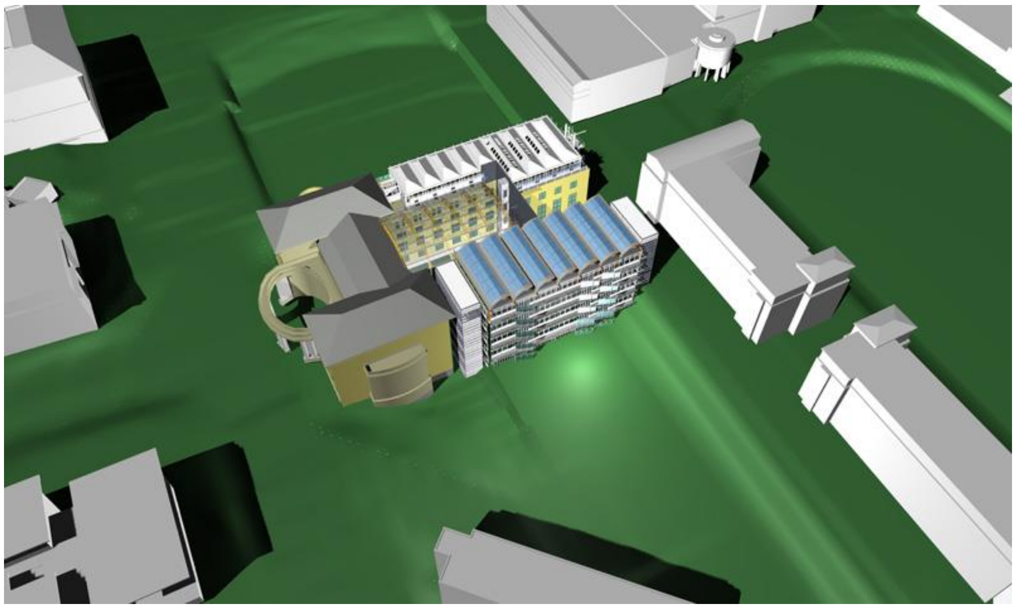
East Brunswick, NJ using ~7 kBTU/sf for 15˚F of temperature change

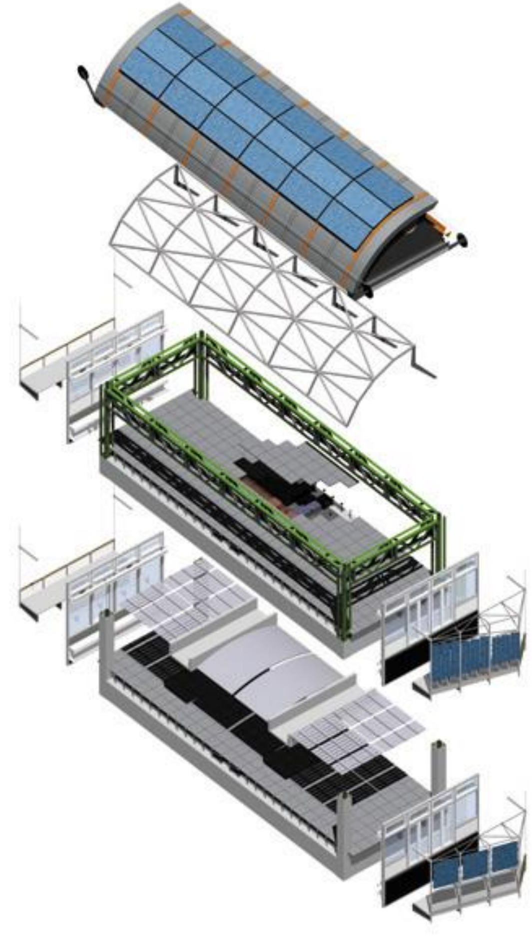
North East Main, IL using ~3 kBTU/sf for 15˚F of temperature change

	approx. cooling until:	per 15˚F temp change:
Liberty Commons, PA	29˚F	~2 kBTU/sf
Valley Plaza, IN	35˚F	~2 kBTU/sf
Miamisburg Bldg 5, OH	41˚F	~2 kBTU/sf
Nort East Main, IL	46˚F	~3 kBTU/sf
East Brunswick, NJ	59˚F	~7 kBTU/sf

Energy Signature

all electric buildings	buildings with gas consumption
	cooling
electric heating	heating
	base gas load
base load	base electric load
	total consumption





a MMX extension as a ‘platform’ for CMU Invention Works

Curricular and Technological Flexibility
Human Health and Productivity
Environmental Sustainability
Natural Conditioning towards Net Zero
Energy Cascades towards Energy Plus


RECYCLE