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BUILDINGS OF THE FUTURE SCOPING STUDY

Seeing beyond this century

NYC Workshop
9:00 AM – 4:30 PM (ET)
May 04, 2015

NORA WANG (PNNL)
PAT PHELAN (DOE)

Buildings of the Future Scoping Study

U.S. DEPARTMENT OF ENERGY Funded by the Department of Energy Building Technologies Office

INTRODUCTION VIDEO

Buildings of the Future Scoping Study

There are many encouraging visions and goals for buildings in 30 or 50 years. For example:

Architecture 2030 Challenge:
Design new buildings to meet fossil fuel reduction goals.

International Energy Agency:
Reduce global CO_2 emissions in the building sector to just one-quarter of current levels.

What will buildings be like in 100 years?

What roles can or should buildings play in our lives?

Scope

The Buildings of the Future Scoping Study will develop a vision for what U.S. mainstream commercial and residential buildings could become in 100 years.

Buildings of the Future Scoping Study

U.S. DEPARTMENT OF ENERGY

Activities

A series of research and outreach activities from October 2014 to September 2015, including thought leader interviews, webinars, panel discussions, and a national workshop.

We will gather input from the international community, but the focus is on the U.S.

Vision = **Knowledge** + **Wisdom** + **Imagination**
Understand the history and current technologies
Investigate the trends and projections
Reveal the unknown areas

Buildings of the Future
Scoping Study

Past Events

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Environment & Natural Resource	Utility Services & Other Supply	Occupants	Connected Built Environment

Date	Event	Panelists (or Leads)	Focus
March 18	Webinar	Mary Ann Lazarus/HOK Chris Garvin/Terrapin Bright Green Thomas Knittel/HOK Nora Wang/PNNL (Moderator)	Resilience Biomimicry Biophilia
March 30	IEA EBC Annex 66 Expert Meeting (Berkeley, CA)	Clint Andrews/Rutgers Steve Selkowitz/LBNL Cary Chan/Swire Properties Hui Zhang/UC Berkeley CBE Led by: Jared Langevin/DOE	Occupants Behavior and Enabling Technologies
April 2	Living Future unConference (Seattle, WA)	Panel Discussion (Morning) Nora Wang/PNNL Pat Phelan/DOE Steve Shankle/PNNL Workshop (Afternoon) PNNL partnered with ZGF Architects, New Building Institute, EcoDistricts	Building-Grid Integration Connected Building Districts Information Technologies Real Estate Market Dynamics
April 14	DOE BTO Peer Review Meeting (D.C.)	Dave Rouse/APA Jason Christopher/DOE Jon Francis/Bosch Nora Wang/PNNL (Moderator)	Urban Planning Security Internet of Things

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Upcoming Events

Pacific Northwest NATIONAL LABORATORY

Environment & Natural Resource	Utility Services & Other Supply	Occupants	Connected Built Environment

Date	Event	Panelists (or Leads)	Focus
June (TBD)	Webinar	Led by: Roderick Jackson/ORNL	Advanced Manufacturing and Construction
June (TBD)	Webinar	Led by: PNNL	Codes and Regulations
June 28 – July 2 (TBD)	ASME ES2015 (San Diego, CA)	Moncef Krarti/CU-Boulder Yunho Hwang/UMD Agami Reddy/ASU Led by: Jorge Gonzalez/CUNY Pat Phelan/DOE	Building Technologies
June/July (TBD)	Atlanta	Led by: Centers for Disease Control and Prevention	Health, Well-being
July 31	National Workshop (D.C.)	Led by: Nora Wang/PNNL (Partnered with AIA)	Final Release

Buildings of the Future Scoping Study

Outcome

A synthesis of this work will be targeted for a leading peer-reviewed journal.

This published document will detail visions for a well-planned future for buildings where advances stem not only from the reduced use of resources, but also from social and environmental benefits and increased building values as resource assets instead of resource consumers.

Buildings of the Future Scoping Study

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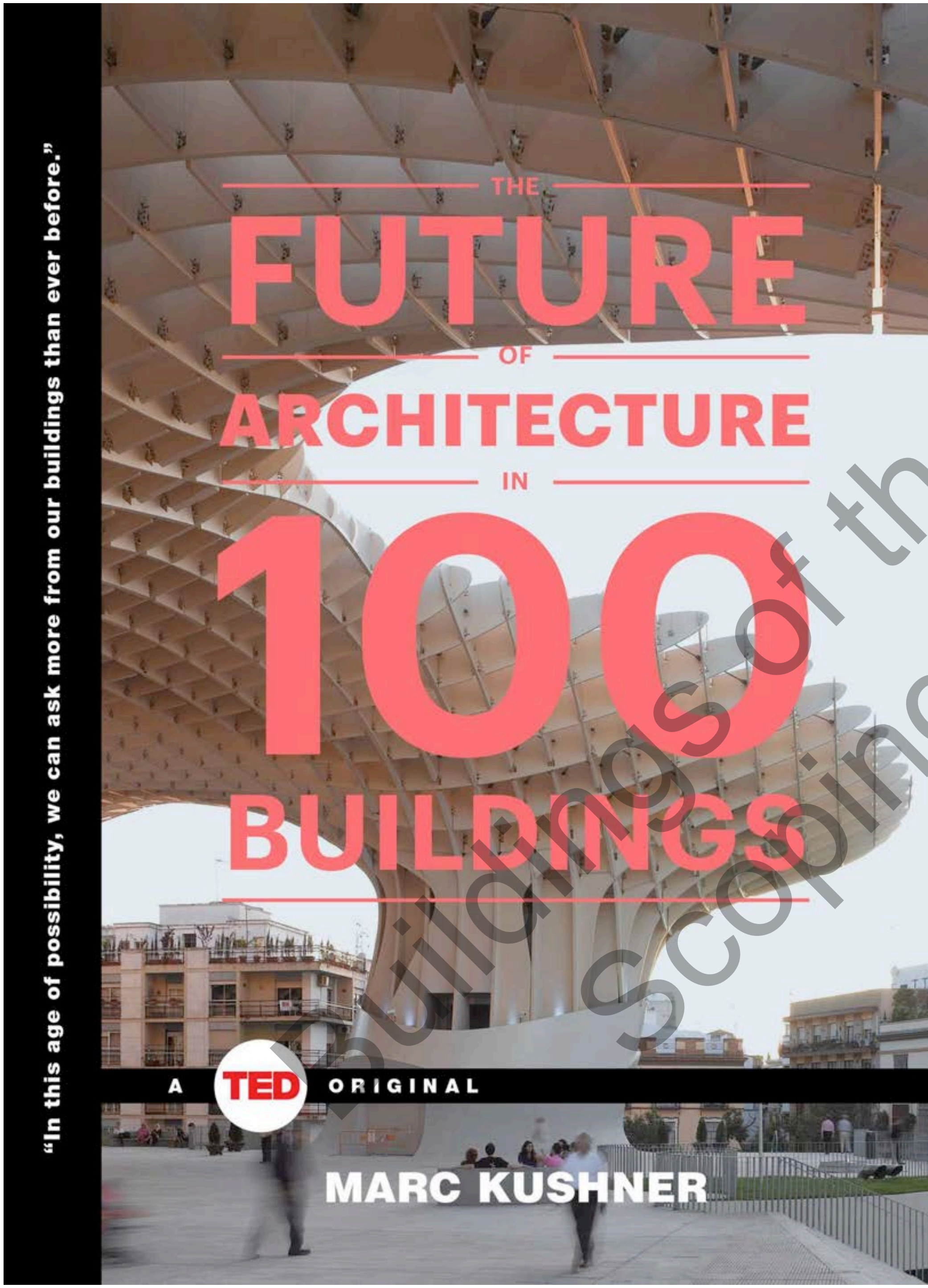

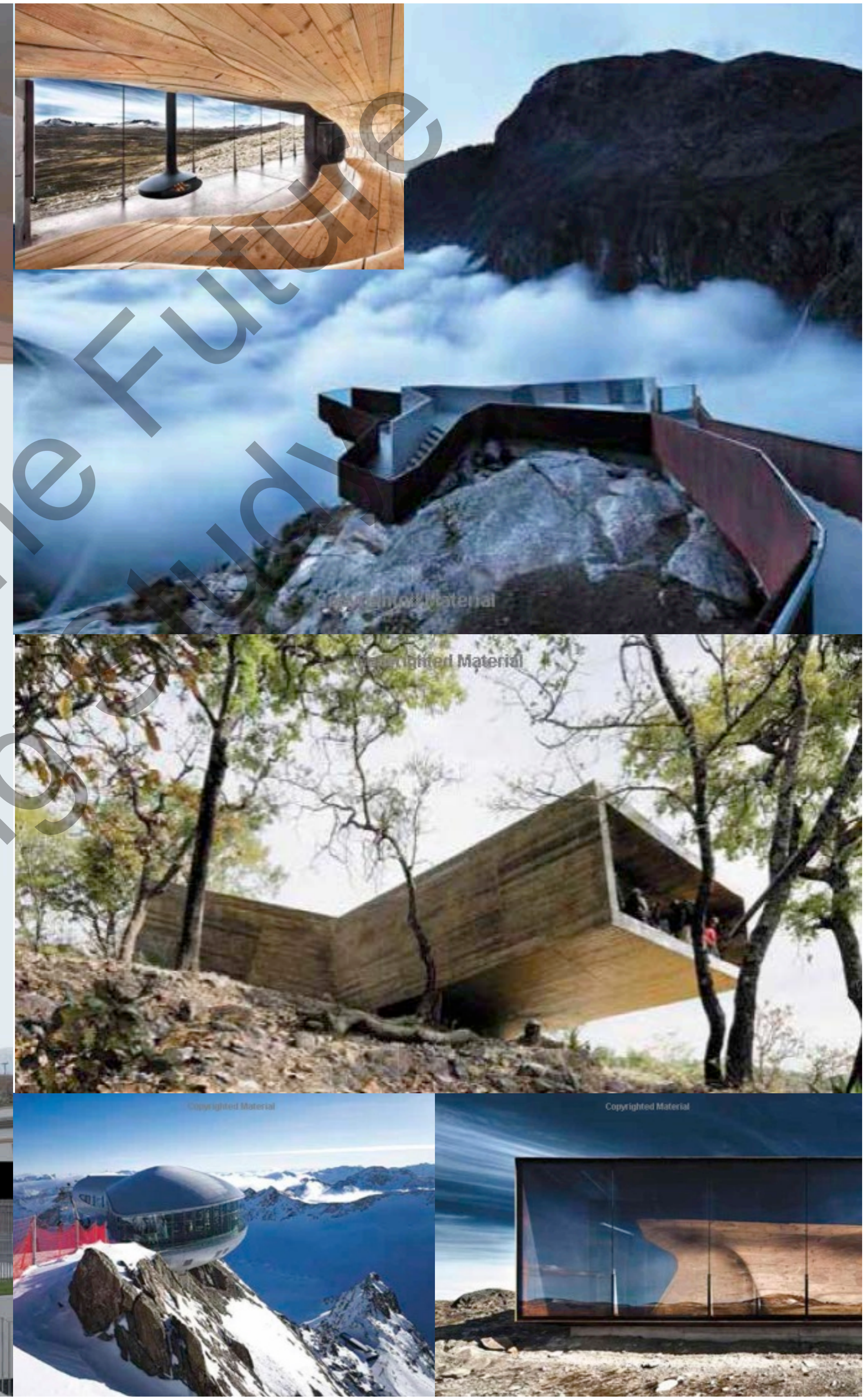

Buildings of the Future
Scoping Study

Scope

The Buildings of the Future Scoping Study will develop a vision for what U.S. **mainstream** commercial and residential buildings ^ could become in 100 years.

(and any new building use types)

Buildings of the Future Scoping Study

Scope

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Essential factors that should be measured or tracked to ascertain building quality:

- *Energy and water consumption*
- *Greenhouse gas emissions and other waste*
- *Material use*
- *Resilient design*
- *Occupants' health and productivity*
- *Cyber and physical security*

Topics that indirectly impact the long-term trajectory of buildings:

- *Modes of urban transportation*
- *Grid modernization*
- *Information technology development*

Actors and infrastructure that influence the way buildings are designed, built, and operated:

- *Utility infrastructure*
- *Real estate market dynamics*
- *Occupant needs*
- *Building control and communication*
- *Regulations*
- *Construction and procurement*
- *Environmental concerns*

Buildings of the Future Scoping Study

Building Stock Turnaround

- Today's average building
- High efficiency building (<10 years old)
- Zero net energy building
- Zero emission building
- "Future building" 1.0
- "Future building" 2.0

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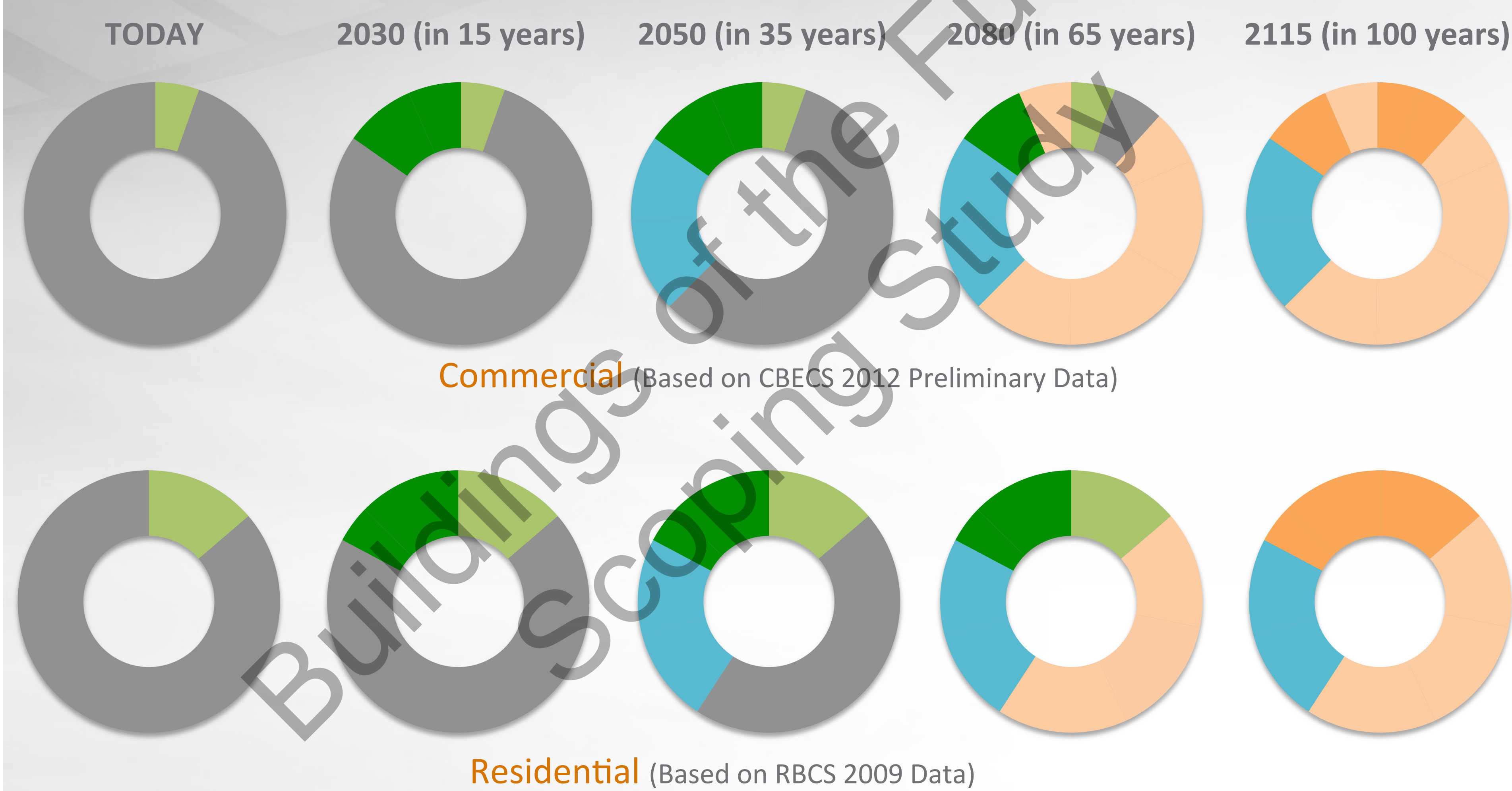

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Assuming 80 years of average service life; NOT including added building volume.

Aircraft

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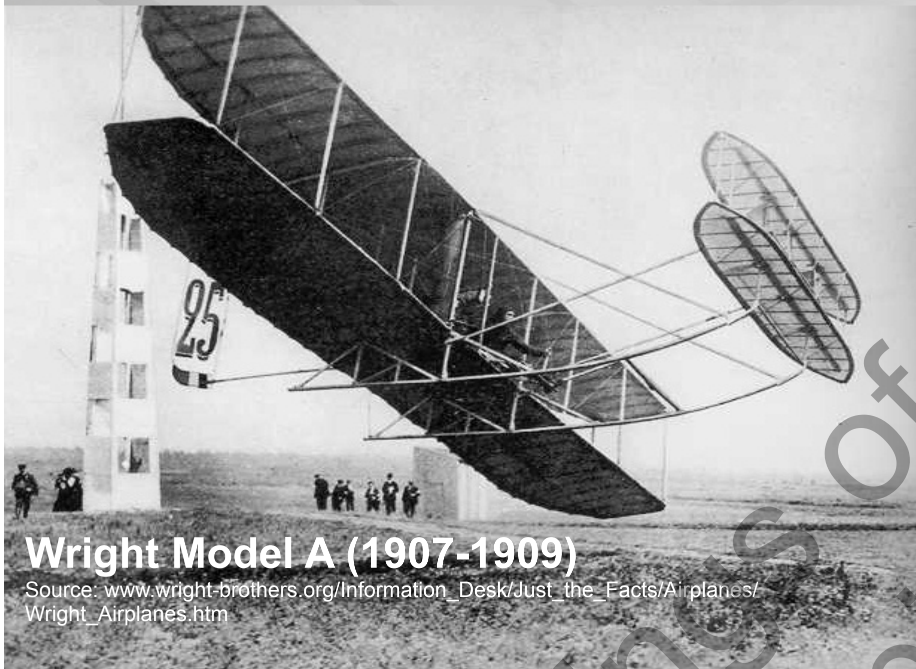

Wright Model A (1907-1909)
Source: www.wright-brothers.org/Information_Desk/Just_the_Facts/Airplanes/Wright_Airplanes.htm

F35 – the most advanced fighter aircraft today
Source: www.airforce-technology.com/features/feature-world-most-advanced-fighter-aircraft-f35/

Boeing 787 Dreamliner – commercial aircraft today
Source: www.newairplane.com/787/flythedream/

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Automobile

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Ford Model A (1903) $850
Source: corporate.ford.com/our-company/heritage/vehicle-history-news-detail/670-model-a-1903

Google Self-Driving Car
Source: mashable.com/2012/08/07/google-driverless-cars-safer-than-you/

Tesla Model S – 60kW Battery, 208 mile range (EPA), autopilot
Source: www.teslamotors.com

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Building Services

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Appliances

1911: Whirlpool's first electric wringer

Space Conditioning

1902: Carrier's first air-conditioning system

Telecommunication

1887-1913: A telephone tower connected 5000 telephone lines
(Stockholm, Sweden)

First TV invented in 1924, sold in 1947
First computer 1947
First computer-to-computer link (ARPANET) 1969; first email sent 1971

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Source: assets.whirlpoolcorp.com/wp-content/uploads/history_100years_factsheet.pdf
www.wired.com/2009/07/dayintech_0717/
twistedsifter.com/2014/08/stockholm-telephone-tower-connects-5000-lines/

Buildings

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Home Insurance Building
Chicago, 1885
First steel framed skyscraper
138 feet

Woolworth Building
New York, 1913
Tallest building 100 years ago
792 feet

Burj Khalifa
Dubai, 2010
Tallest building in the world
2700 feet

1 World Trade Center
New York, 2014
Tallest building in the U.S.
1776 feet

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100 years ago in the U.S.

Only **14%** of homes had a bathtub. Only **8%** of homes had a telephone. A three minute call from Denver to New York City cost **11 dollars**. There were only **8,000 cars** in the US and only **144 miles** of paved roads. The maximum speed limit in most cities was **10 mph**. Average life expectancy was **47. One in ten** U.S. adults couldn't read or write. Only **6%** of all Americans had graduated from high school.

Source: www.chicagoarchitecture.info/Building/3168/The-Home-Insurance-Building.php
commons.wikimedia.org/wiki/File:View_of_Woolworth_Building_fixed_crop.jpg
foundtheworld.com/burj-khalifa/
www.newyorkarchitecture.info/Building/439/One-World-Trade-Center.php
www.rense.com/general70/100yrs.htm

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History of Energy Consumption (Source)

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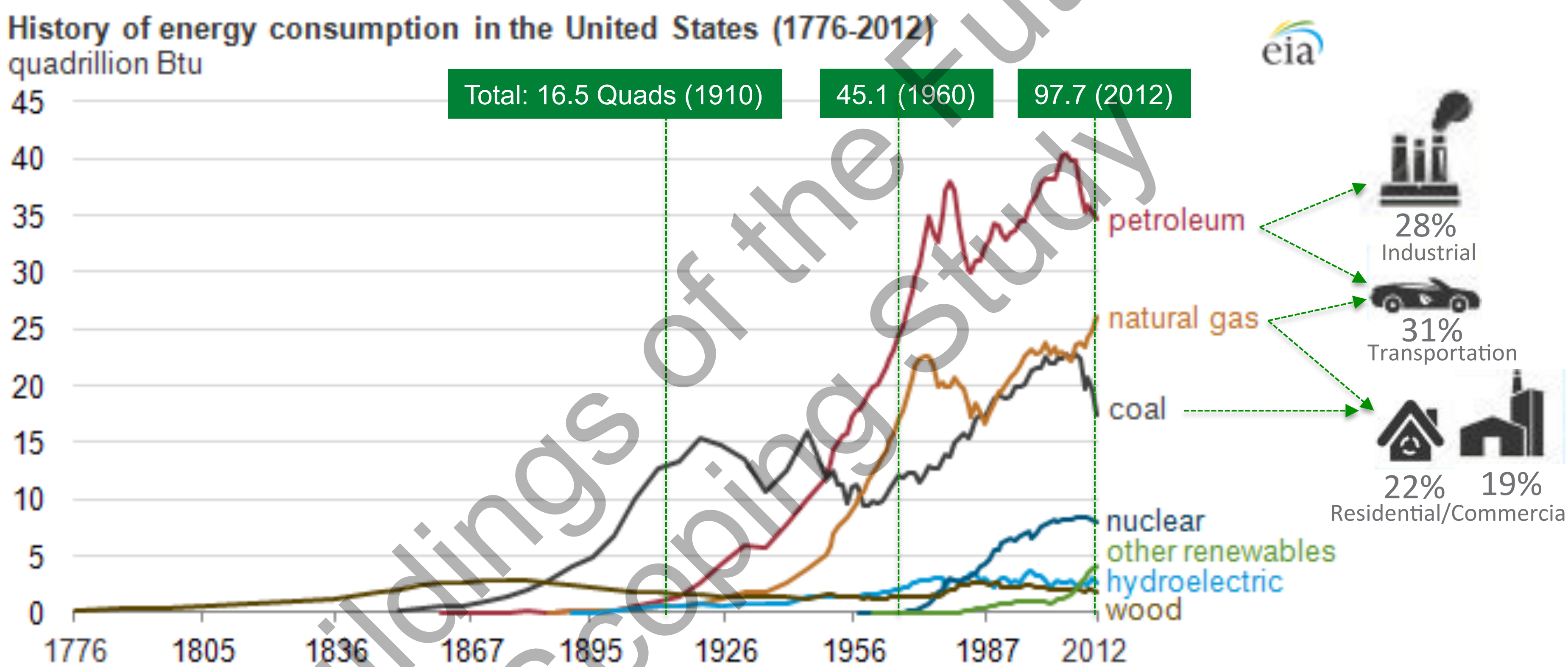

Wood as primary energy source until mid- to late- 19th century.

Coal became dominant in the late-19th century.

Petroleum products and natural gas rose in the mid-20th century.

Source: Annual Energy Review 2011 (Energy Information Administration)
www.eia.gov/totalenergy/data/annual/pdf/aer.pdf
www.eia.gov/todayinenergy/detail.cfm?id=11951
www.eia.gov/todayinenergy/detail.cfm?id=10
www.eia.gov/totalenergy/data/annual/showtext.cfm?t=ptb1601

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History of Energy Consumption (Growth)

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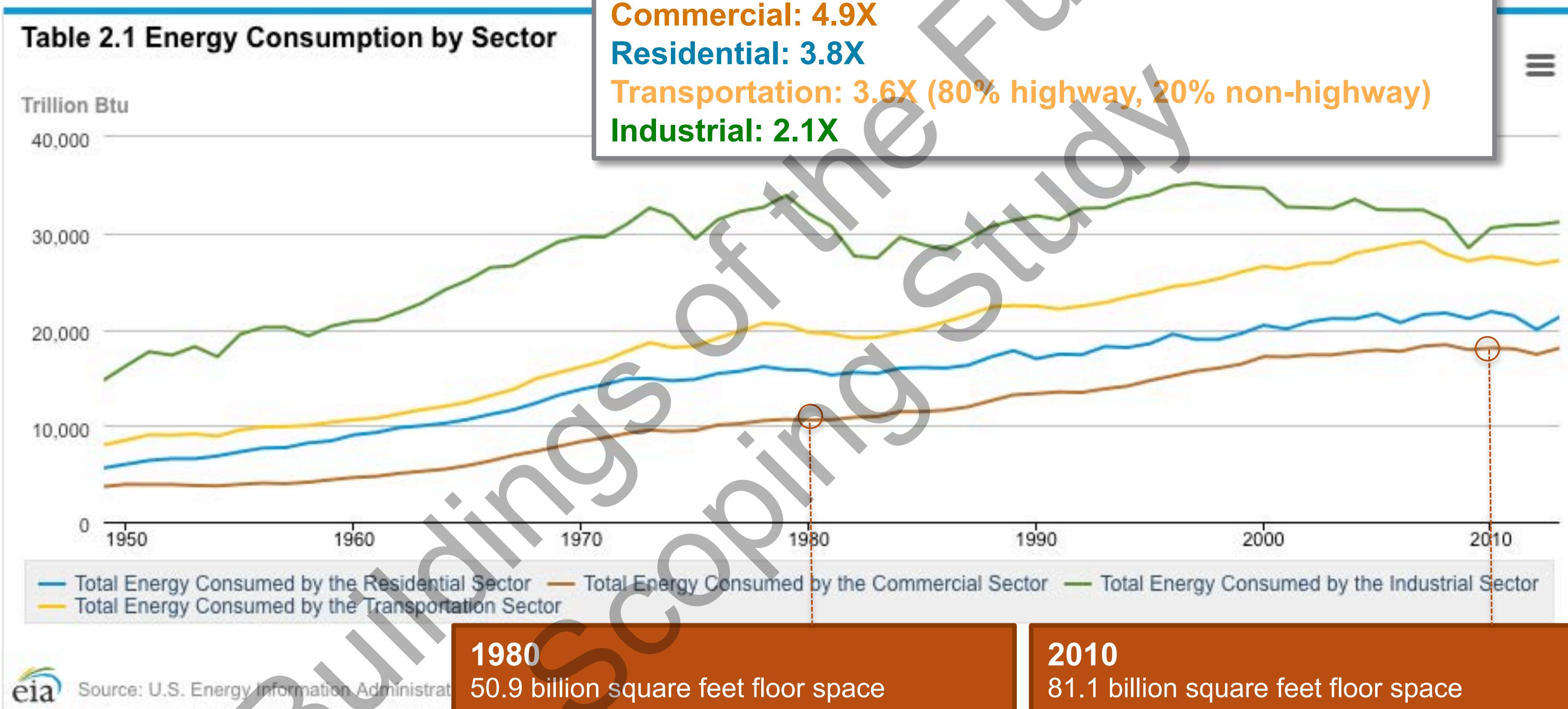
Energy Use Growth in 60 Years:
Commercial: 4.9X
Residential: 3.8X
Transportation: 3.6X (80% highway, 20% non-highway)
Industrial: 2.1X



1980
50.9 billion square feet floor space
10.57 Quads
118 kBtu/sq.ft. site energy use intensity
208 kBtu/sq.ft. source energy use intensity

2010
81.1 billion square feet floor space
18.22 Quads
108 kBtu/sq.ft. site energy use intensity
225 kBtu/sq.ft. source energy use intensity

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Source: www.eia.gov/beta/MER/index.cfm?tbl=T02.01#/?f=A
cta.ornl.gov/data/tedb33/Edition33_Chapter02.pdf
buildingsdatabook.eren.doe.gov/TableView.aspx?table=3.1.3

History of Energy Consumption (Commercial)

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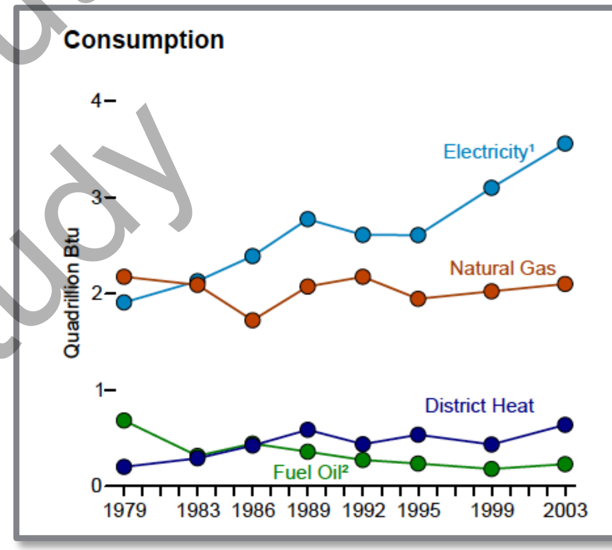
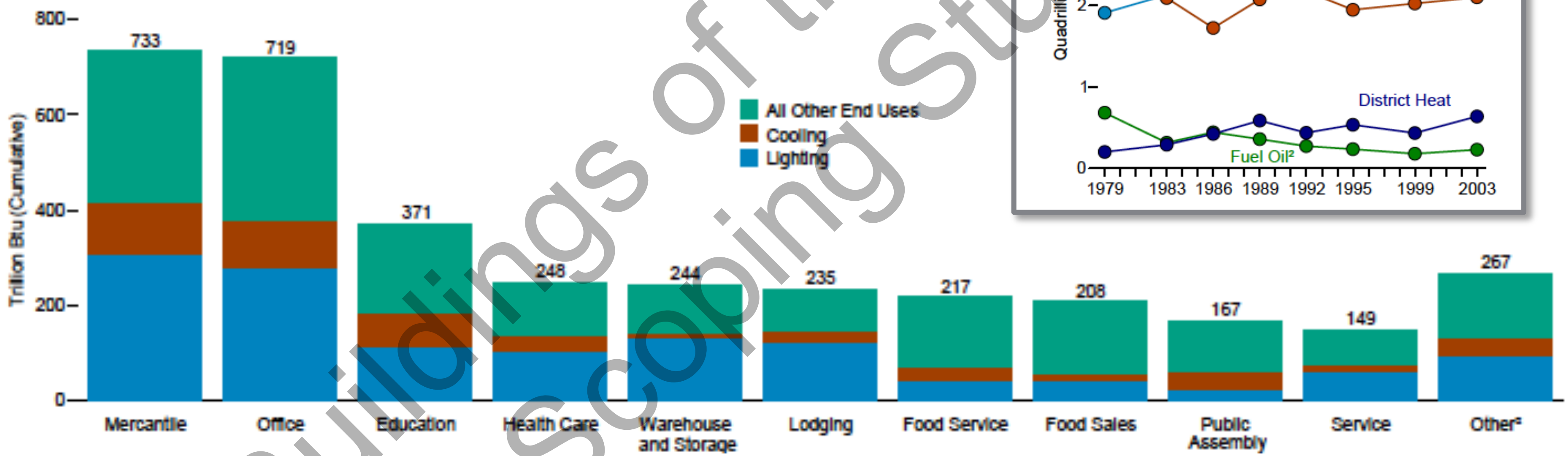


Electricity Energy Use by Principal Building Activity (2012)



Buildings of the Future Scoping Study

Source: Source: Annual Energy Review 2011 (Energy Information Administration) www.eia.gov/totalenergy/data/annual/pdf/aer.pdf

History of Energy Consumption (Residential)

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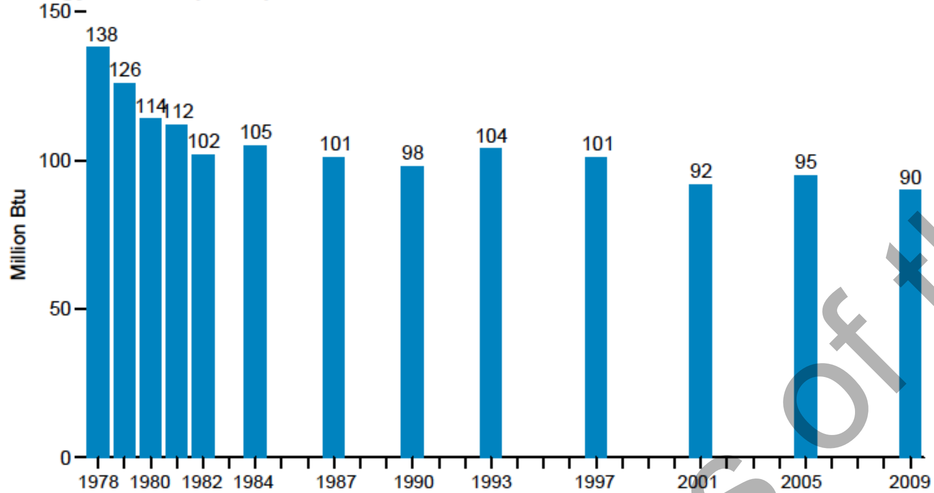
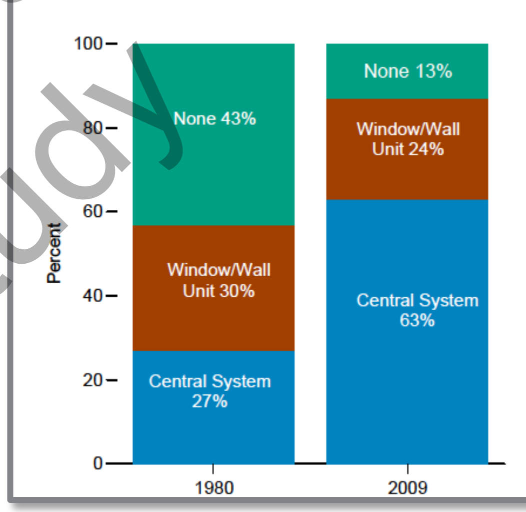
Energy Consumption per Household, Selected Years, 1978-2009[1]

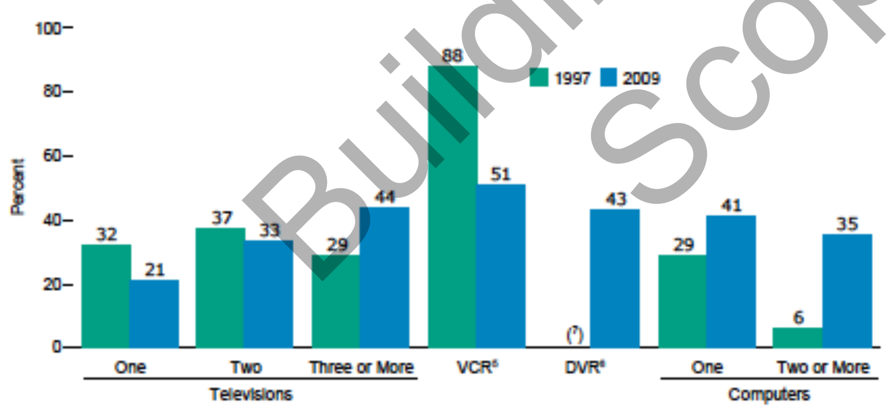


Air-Conditioning Equipment, 1980 and 2009

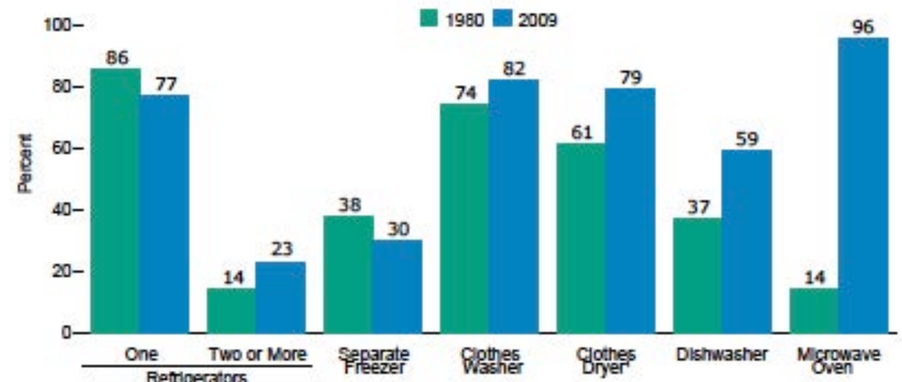


Energy use per household has been decreasing.
More AC, electronics, appliances in our houses.

Share of Households With Selected Electronics, 1997 and 2009



Share of Households With Selected Appliances, 1980 and 2009



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Source: Source: Annual Energy Review 2011 (Energy Information Administration) www.eia.gov/totalenergy/data/annual/pdf/aer.pdf

Energy Use Intensity for Residential Buildings

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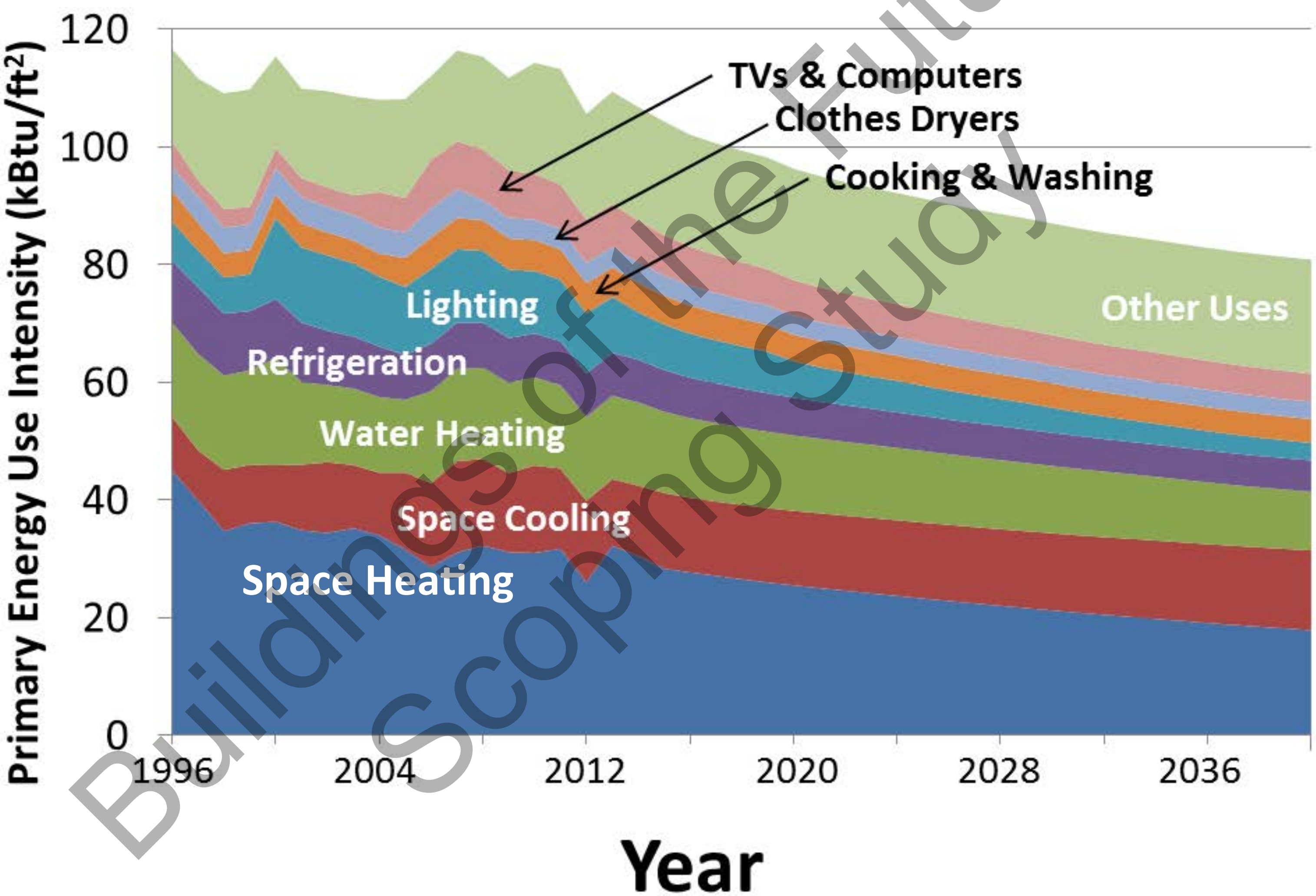

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Source 2014 Annual Energy Outlook

Economy Growth vs. Energy Use

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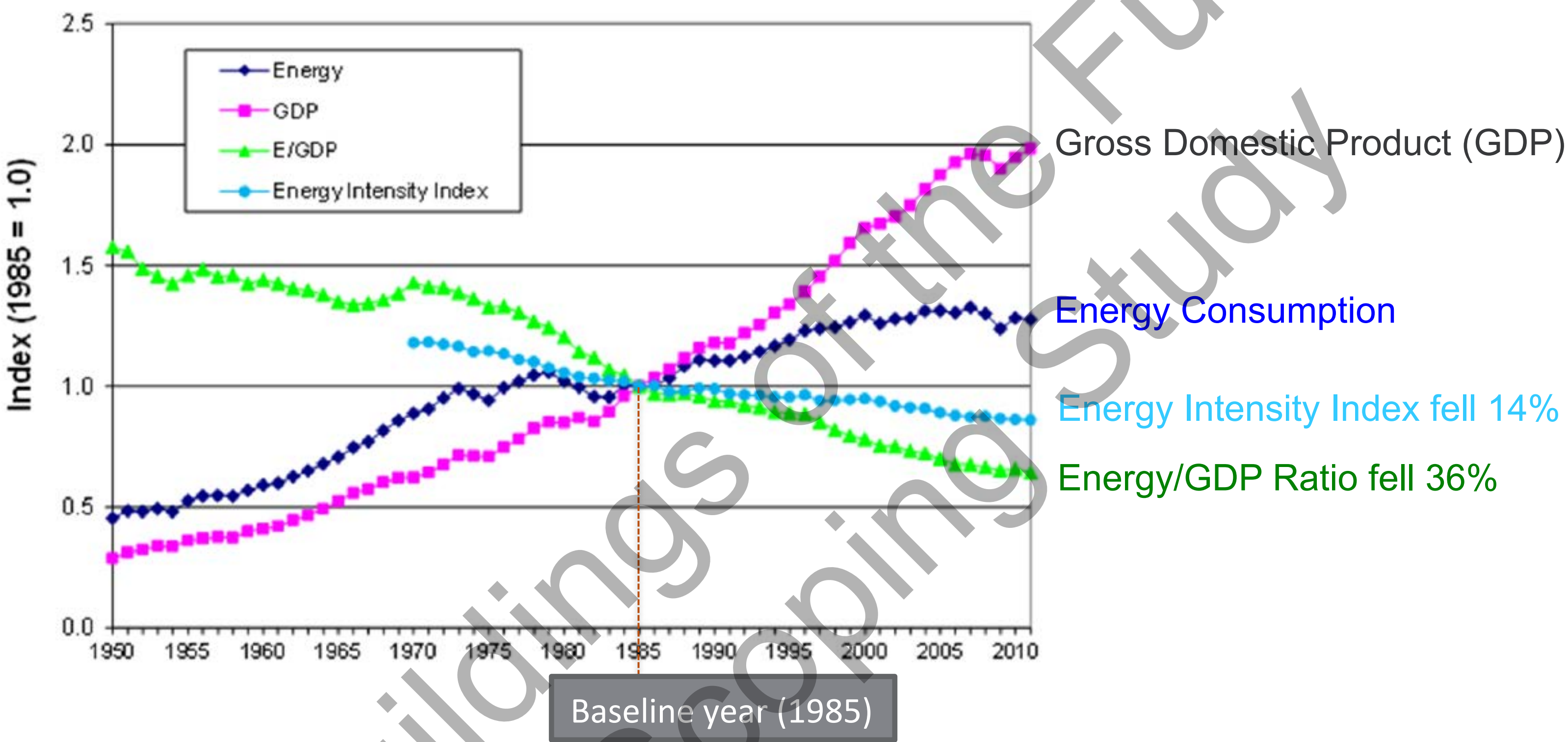

The economy-wide Energy Intensity Index excludes structural factors (e.g. decline of energy-intensive industries) and reflects changes in energy intensity associated with energy efficiency.

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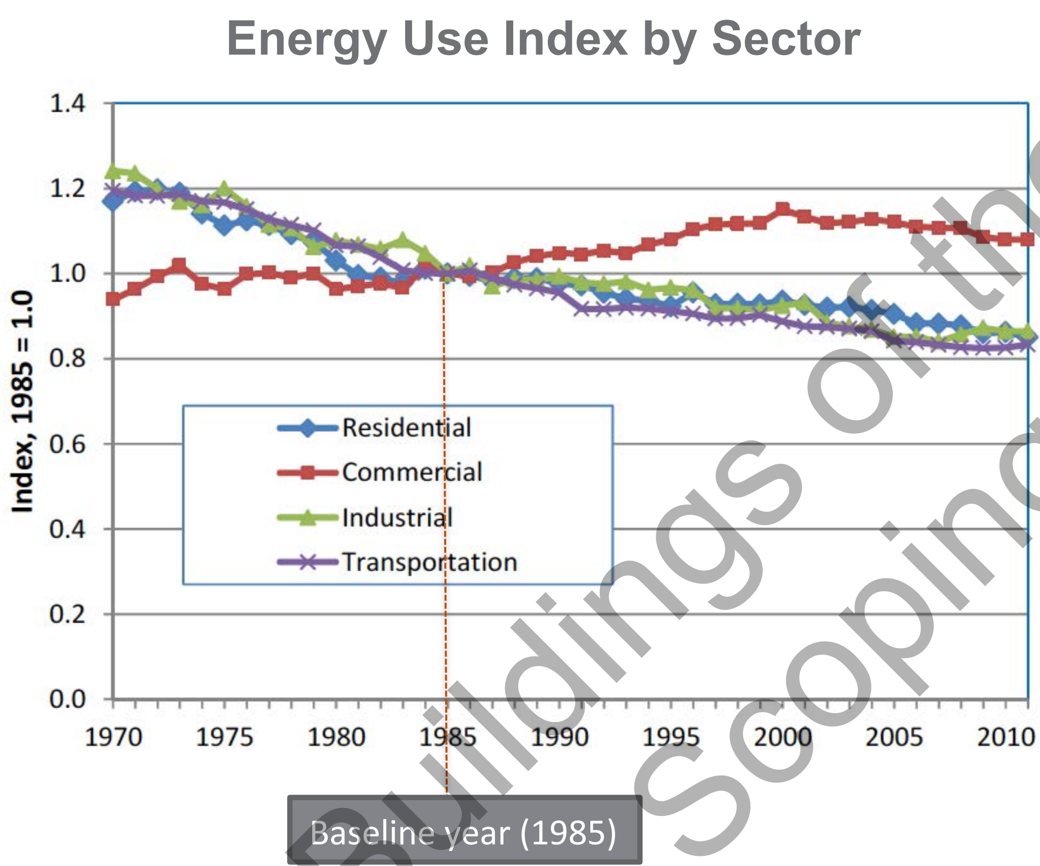
Source: A Comprehensive System of Energy Intensity Indicator for the U.S.: Methods, Data, and Key Trends. (Pacific Northwest National Laboratory) www.pnnl.gov/main/publications/external/technical_reports/PNNL-22267.pdf

Economy Growth vs. Energy Use



Commercial

From 1985 to 2011:

Floor space increased by 46%

Energy use increased by 62%

Energy Intensity Index (2011) = 1.08

Residential

From 1985 to 2011:

Average housing unit size increased by 25%

Number of housing units increased by 30%

Energy use increased 40%

Energy Intensity Index (2011) = 0.85

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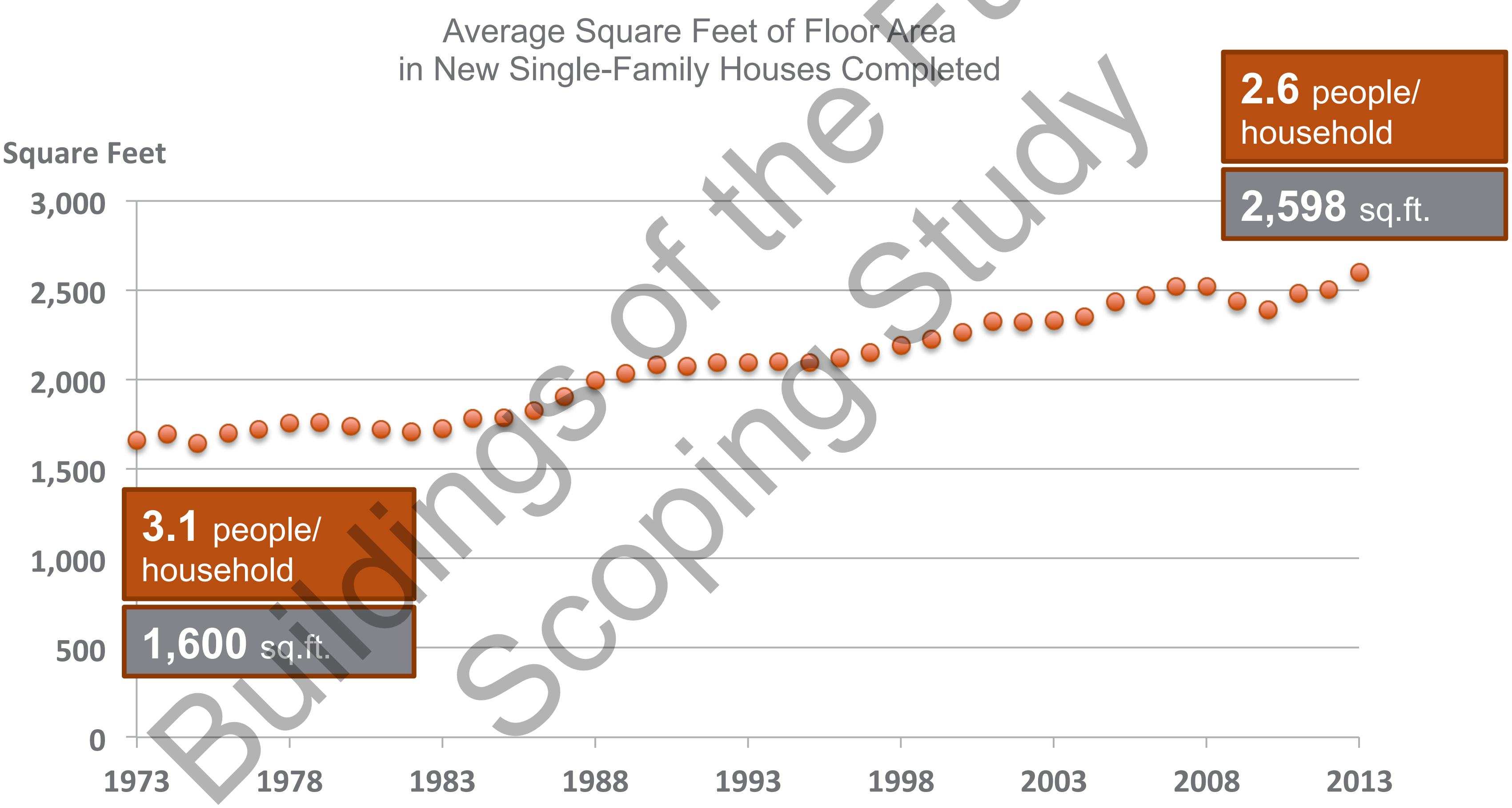
Source: A Comprehensive System of Energy Intensity Indicator for the U.S.: Methods, Data, and Key Trends. (Pacific Northwest National Laboratory) www.pnnl.gov/main/publications/external/technical_reports/PNNL-22267.pdf

American Housing Trend



Source: Data from www.census.gov/construction/chars/historical_data/
www.census.gov/prod/2013pubs/p20-570.pdf

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U.S. Housing Scenario (2050)

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Image Source:
exhibits.museum.state.il.us/exhibits/athome/1920/sideby/u-housing.jpg
www.npr.org/2012/05/29/153513153/american-dream-faces-harsh-new-reality
www.houstontomorrow.org/livability/story/future-of-housing-demand-is-
walkingreen.files.wordpress.com/2010/02/500x_forwarding-dallas.jpg

Automobile-dependent **suburban homes will lose value** compared to those in central locations.

Young adults have a strong **preference for urban living** (more compact development, smaller units).

Source: U.S. Housing Trends Generational Changes and the Outlook to 2050. http://onlinepubs.trb.org/Onlinepubs/sr/sr298pitkin-myers.pdf

How will green space fit into the changing demographics in the living environment?

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Congestion and Future City Transportation

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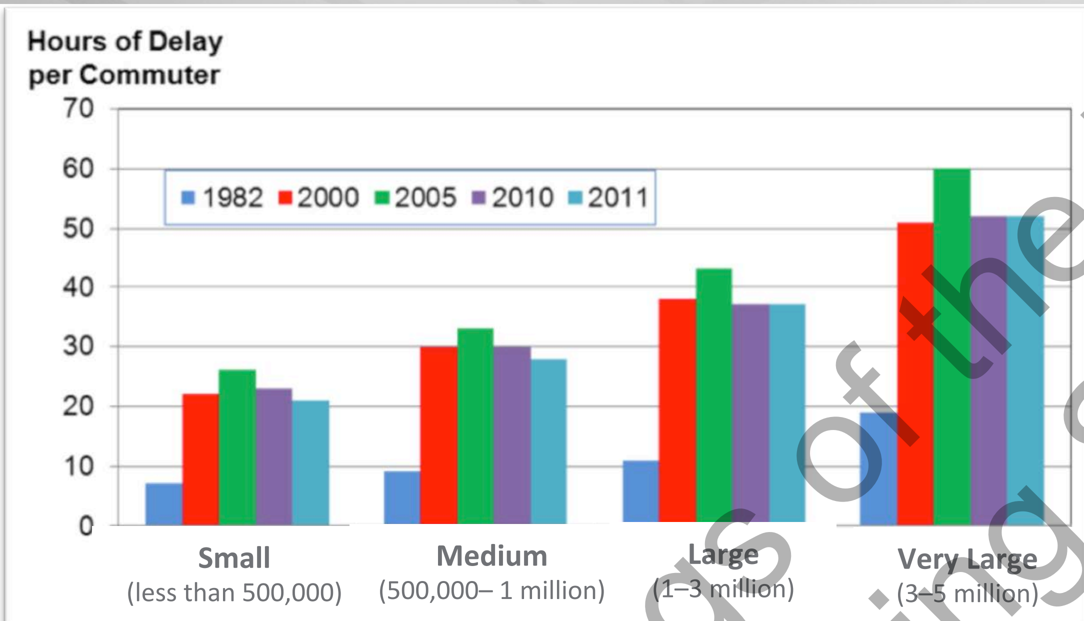

Congestion is worse in areas of every size.

Congestion costs are increasing.

Cost of extra time and fuel in 498 urban areas (in 2011 dollars):

In 2011 – $121 billion

In 2000 – $94 billion

In 1982 – $24 billion

"Cisco's Chief Technology Officer Padmasree Warrior has predicted a future of urban transport where driverless cars will be available on demand and congestion will be a thing of the past."

Source: 2012 Urban Mobility Report (Texas A&M Transportation Institute)
d2dtl5nnlpfr0r.cloudfront.net/tti.tamu.edu/documents/mobility-report-2012.pdf
www.irishtimes.com/news/technology/web-summit-cisco-predicts-future-of-driverless-cars-1.1987343
www.meetup.com/London-Futurists/events/120553342/

Le Corbusier's Radiant City (1935)

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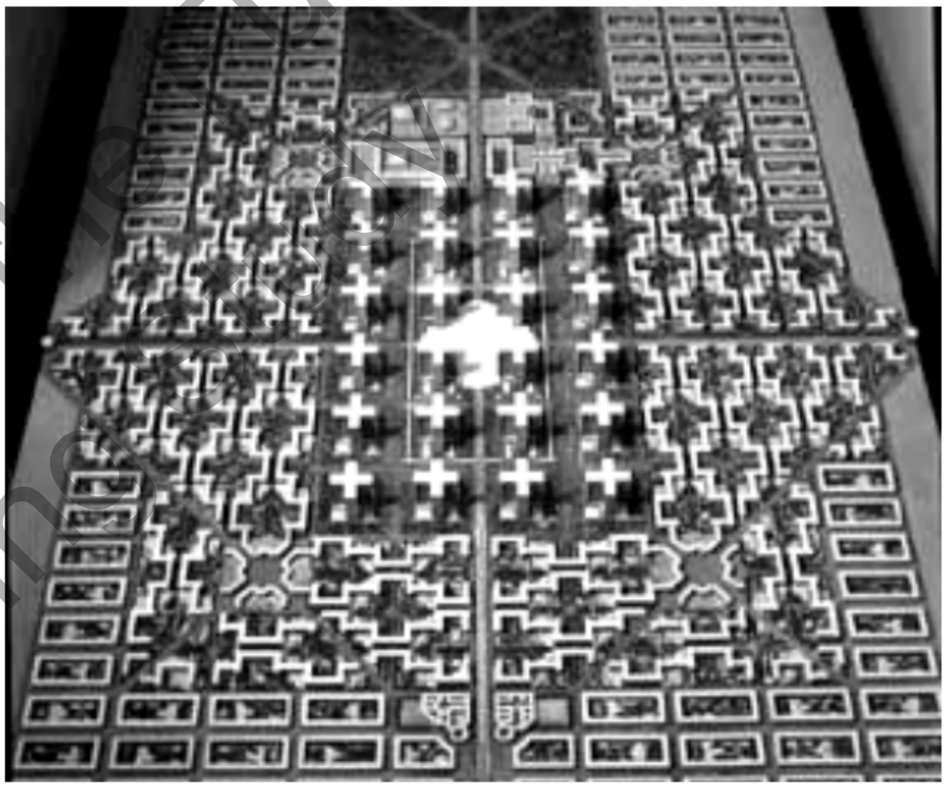

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Source: portalarquitetonico.com.br/masterplans-a-decada-de-60/

Peter Cook's Plug-In City (1964)

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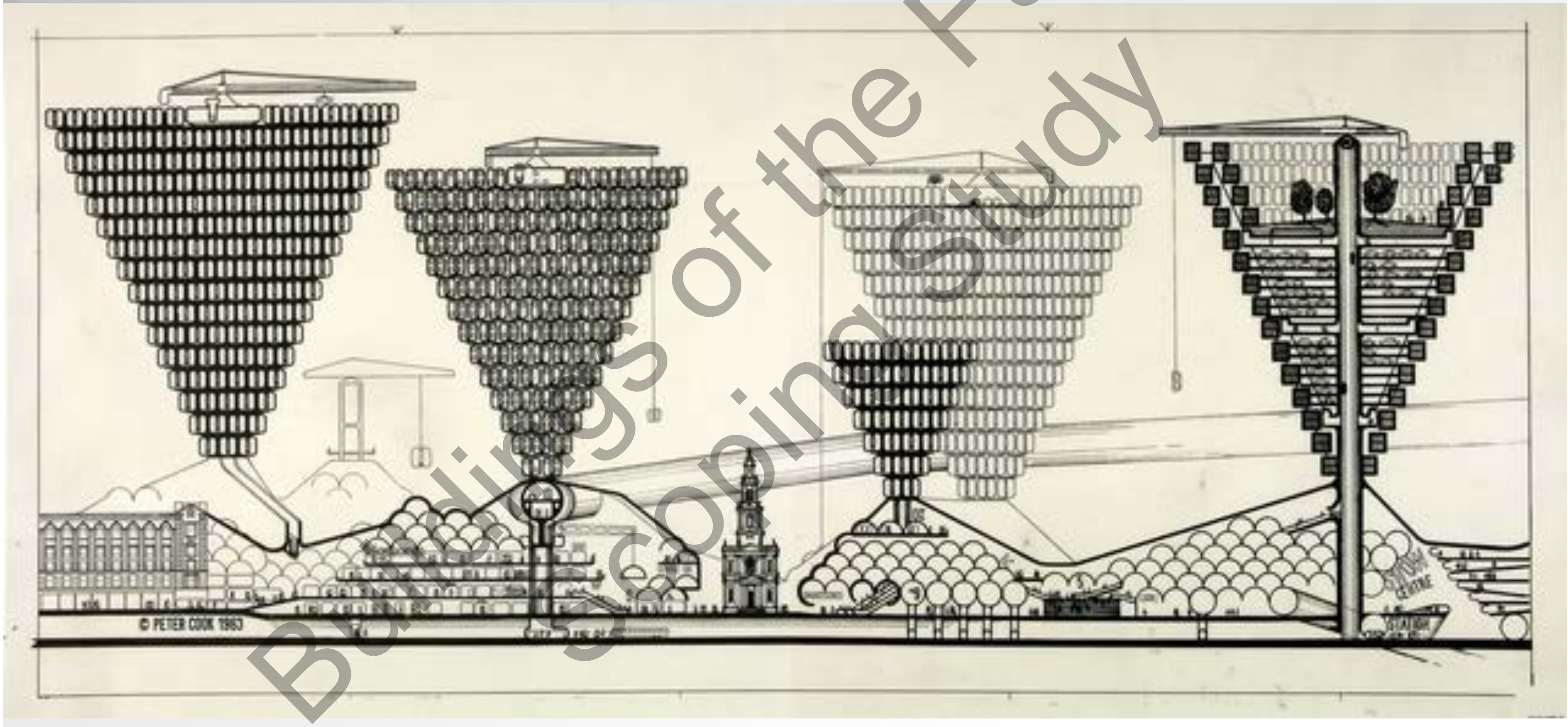

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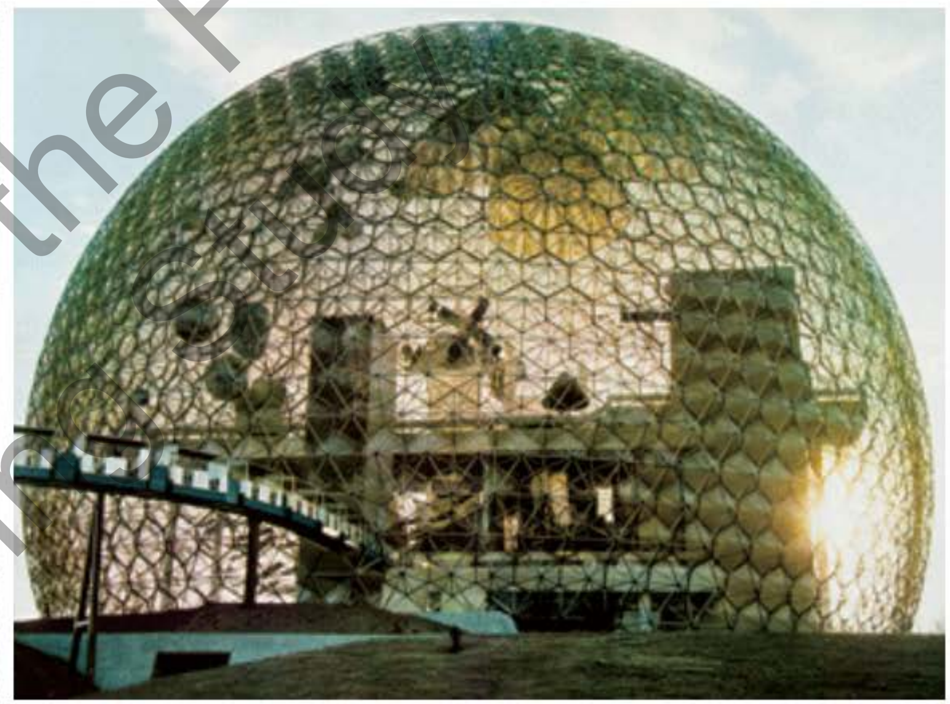
Source: http://www.archdaily.com/399329/ad-classics-the-plug-in-city-peter-cook-archigram/

Bucky Fuller’s Dome (1960)

Building the Future



Source: portalarquitetonico.com.br/masterplans-a-decada-de-60/

An Integrated Vision

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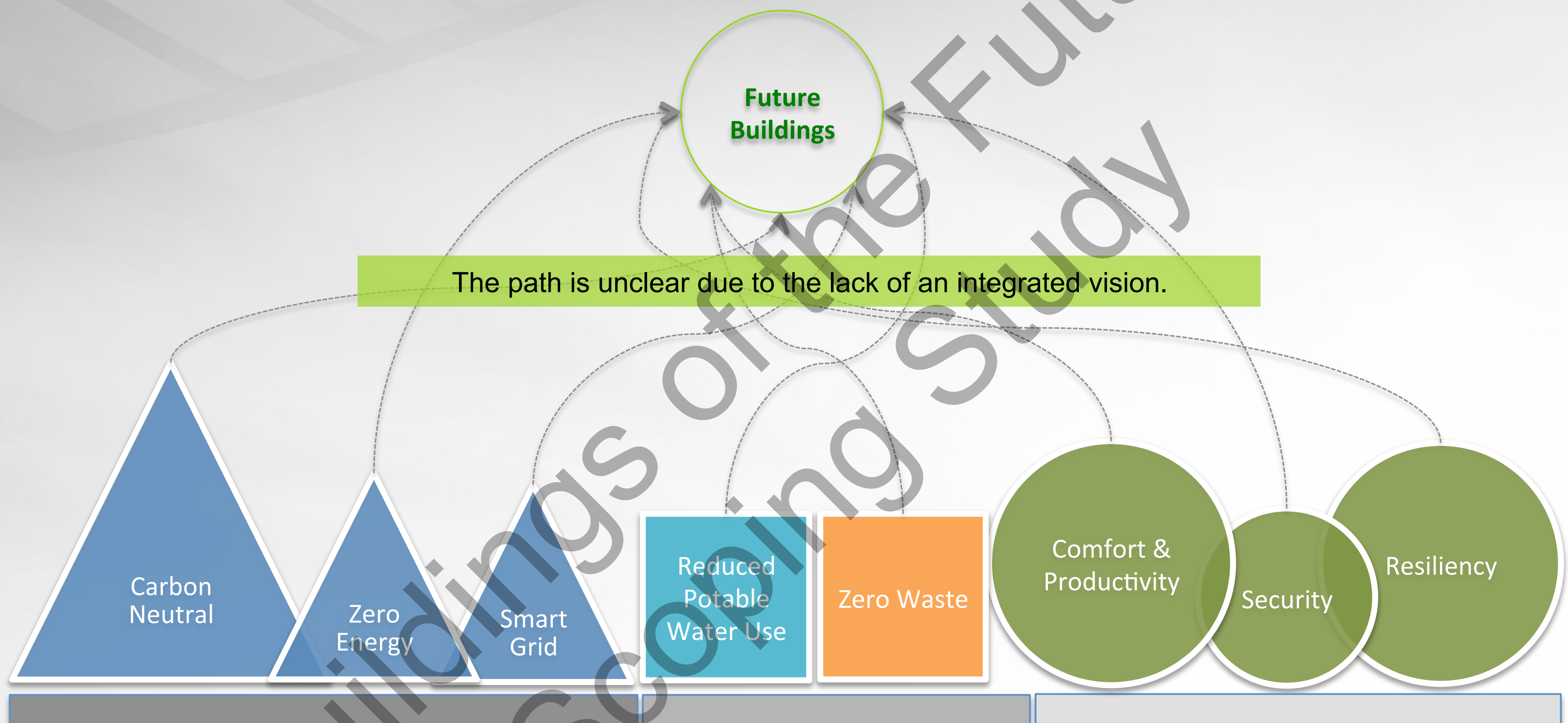

Group 1
- -Identified metrics (how to measure)
- -Quantitative targets (what to achieve)
- -Mostly known processes (how to achieve)
- -Some overlaps

Group 2
- -Identified metrics
- -Quantitative targets
- -Partially known processes
- -Little overlap

Group 3
- -Unclear metrics
- -Qualitative targets
- -Learning process
- -Some overlaps

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A Proactive, Coherent Paradigm

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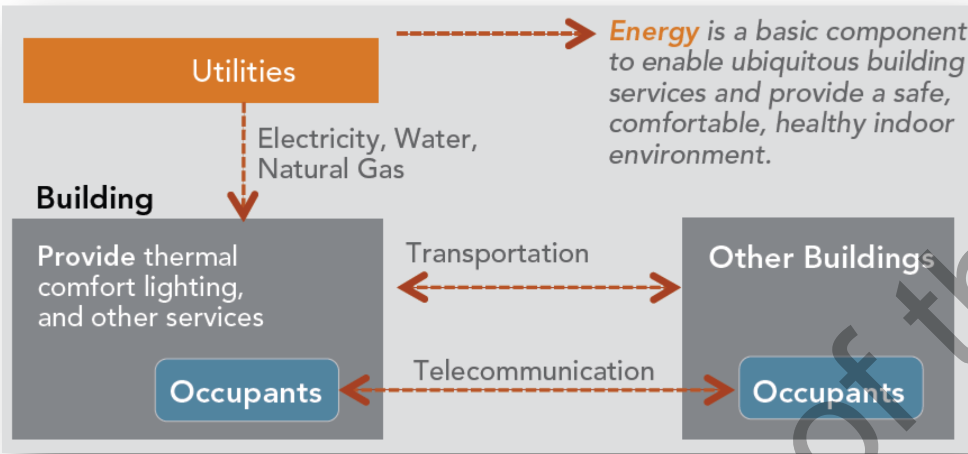
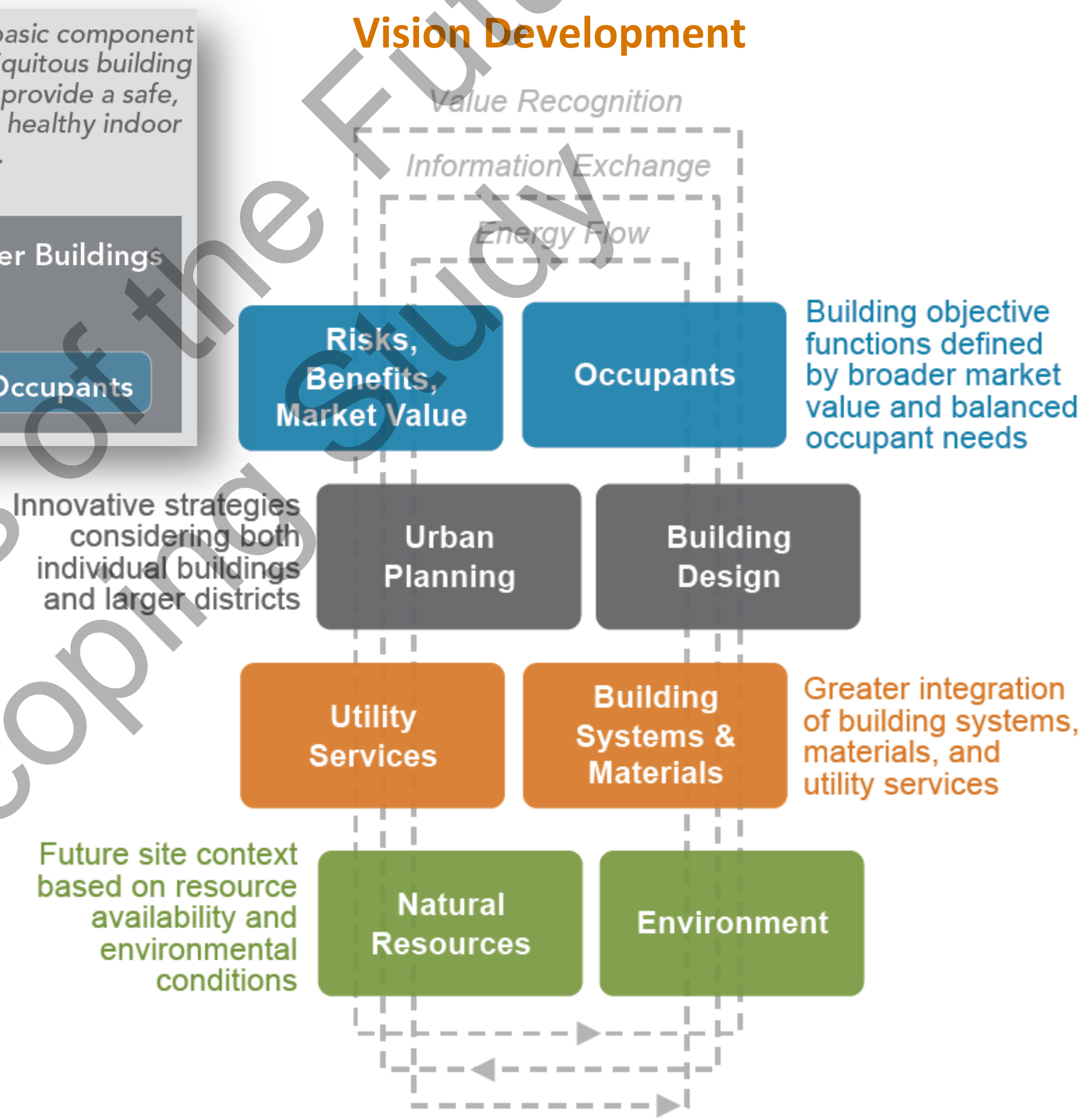


Energy and Building Services (Today's model)



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Future Context

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▶ Environment and Climate Change

According to the Intergovernmental Panel on Climate Change's Fifth Assessment Report (IPCC 2014), many aspects of climate change and associated impacts will continue for centuries, even if anthropogenic emissions of greenhouse gas are stopped. It is very likely that:

- *heat waves will occur with a higher frequency and longer duration;*
- *occasional cold winter extremes will continue to occur;*
- *mean precipitation will decrease in dry regions*
- *sea level will rise in more than about 95% of the ocean area;*
- *climate change will undermine food security and reduce renewable surface water and ground water resources in most dry sub-tropical regions.*

▶ Population Growth

Population in the U.S. is projected to increase from 321 million in 2015 to 420 million in 2060 (U.S. Census Bureau, 2014) and 462 million in 2100 (United Nations, 2012). In 2014, 81% of the population lived in urban areas; in 2050, 87% will live in urban areas (United Nations, 2014)

Population Projection (2100)

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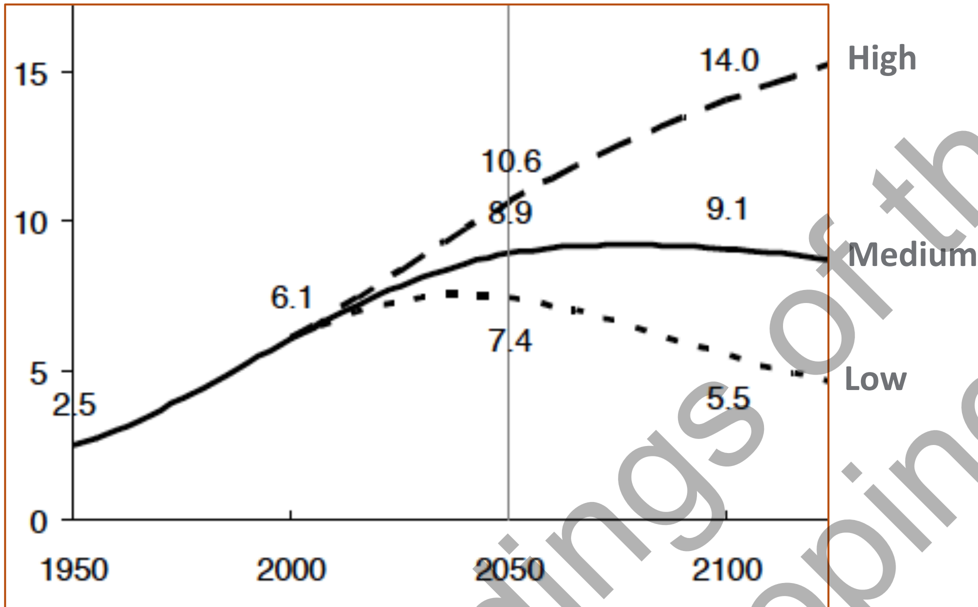
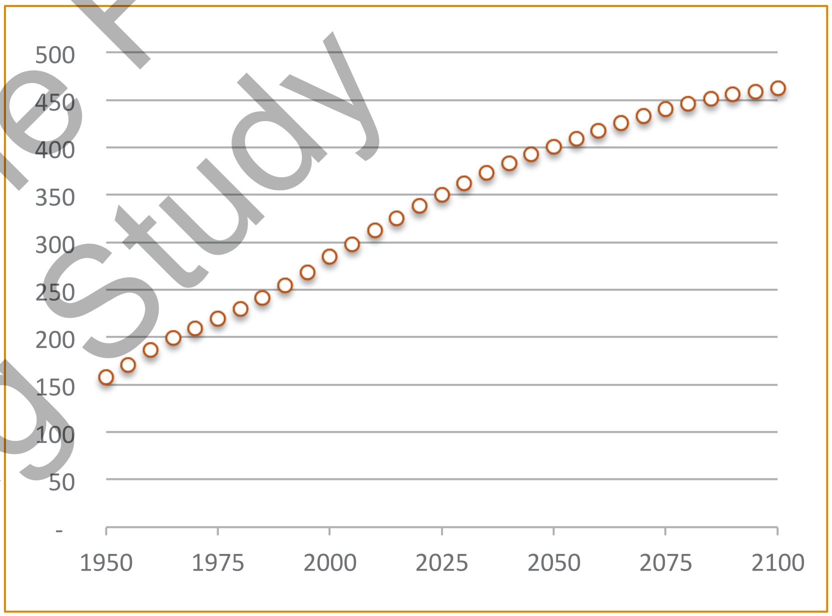
Estimated World Population (1950-2000) & Projections (2000-2100) (Billions)



U.S. Population & Projections (Millions)



Increased demand for food, water, energy sources.

People live in **unsafe areas** (e.g. floodplains, tsunami-prone coast).

Sprawl in the U.S. repurposes **2.2 million** acres of farmland, ranchland and forest every year.

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Source: World Population To 2300. (United Nations)
www.un.org/esa/population/publications/longrange2/WorldPop2300final.pdf
www.howmany.org/big_picture.php

Domestic Water Use (2030)

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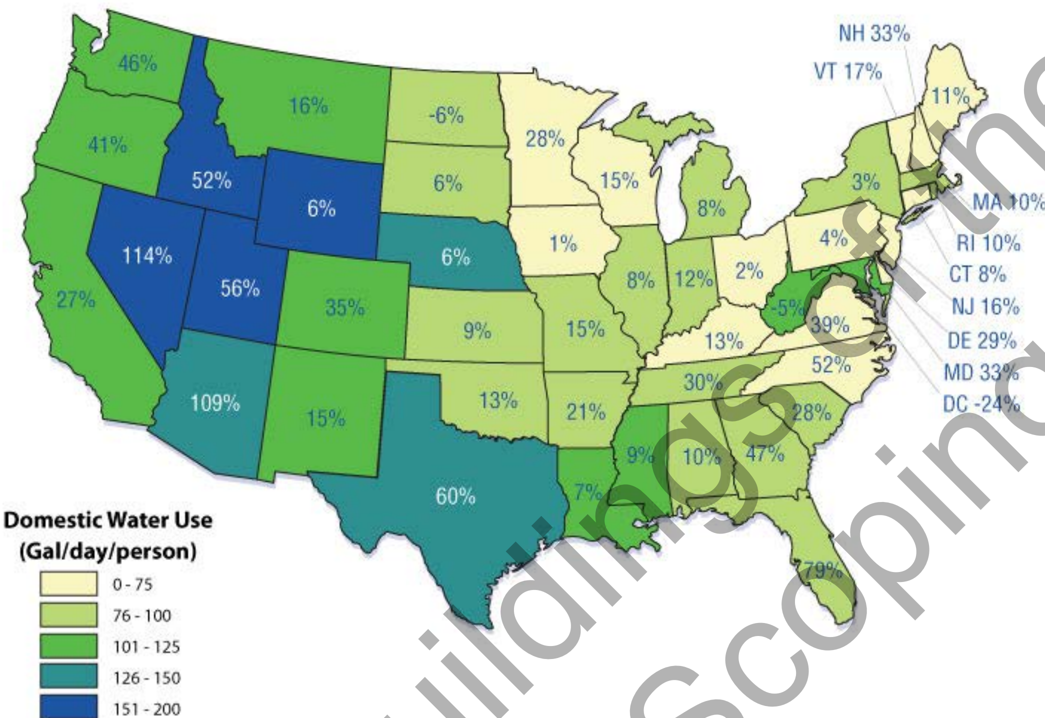
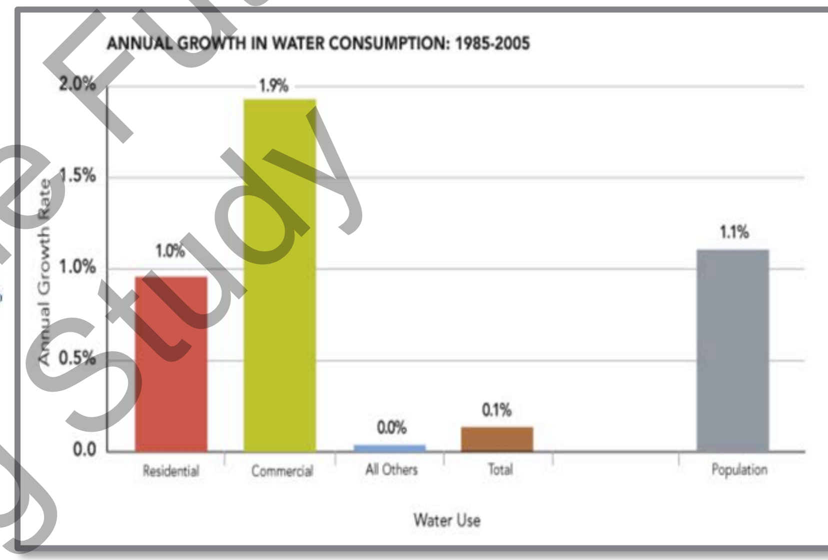
Domestic Water Use in Gallons per Day per Person and Projected Percent population Change by 2030





From 1985 to 2005, water use in the residential sector closely tracked population growth, while **water use in the commercial sector grew almost twice as fast**.

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Source: www.epa.gov/watersense/our_water/tomorrow_beyond.html

Water Supply Sustainability Index (2050)

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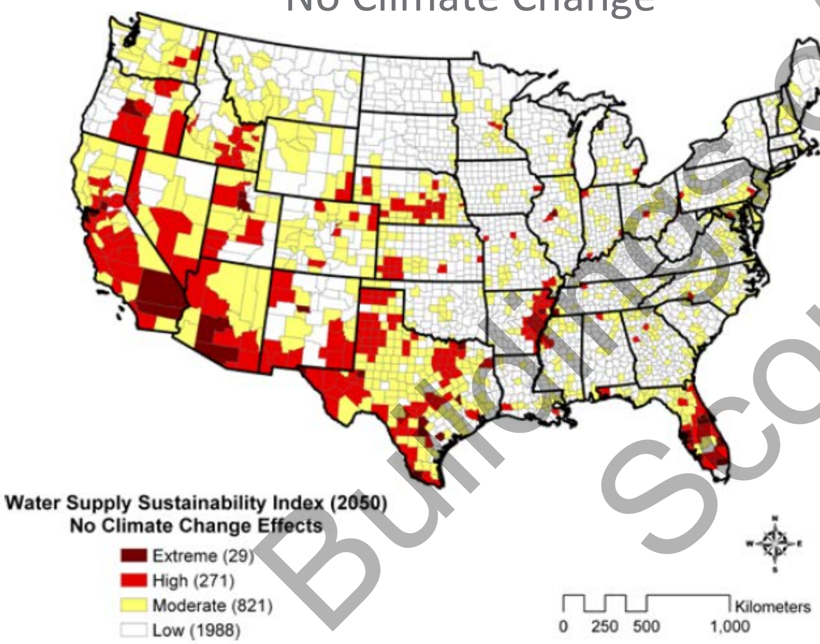
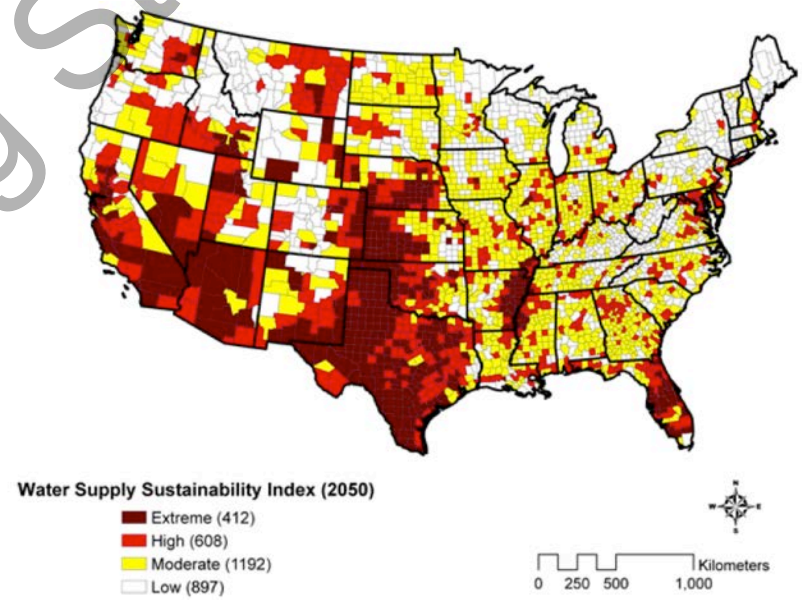
Buildings not only directly consume water, but also affect the water source by contributing to climate change. **Water supplies in 70% of counties in the U.S. may be at some risk** to climate change, and approximately one-third of counties may be at high or extreme risk.

No Climate Change



Business-As-Usual



Source: Evaluating Sustainability of Projected Water Demands Under Future Climate Change Scenarios. (Natural Resource Defense Council)
rd.tetratech.com/climatechange/projects/doc/Tetra_Tech_Climate_Report_2010_lowres.pdf

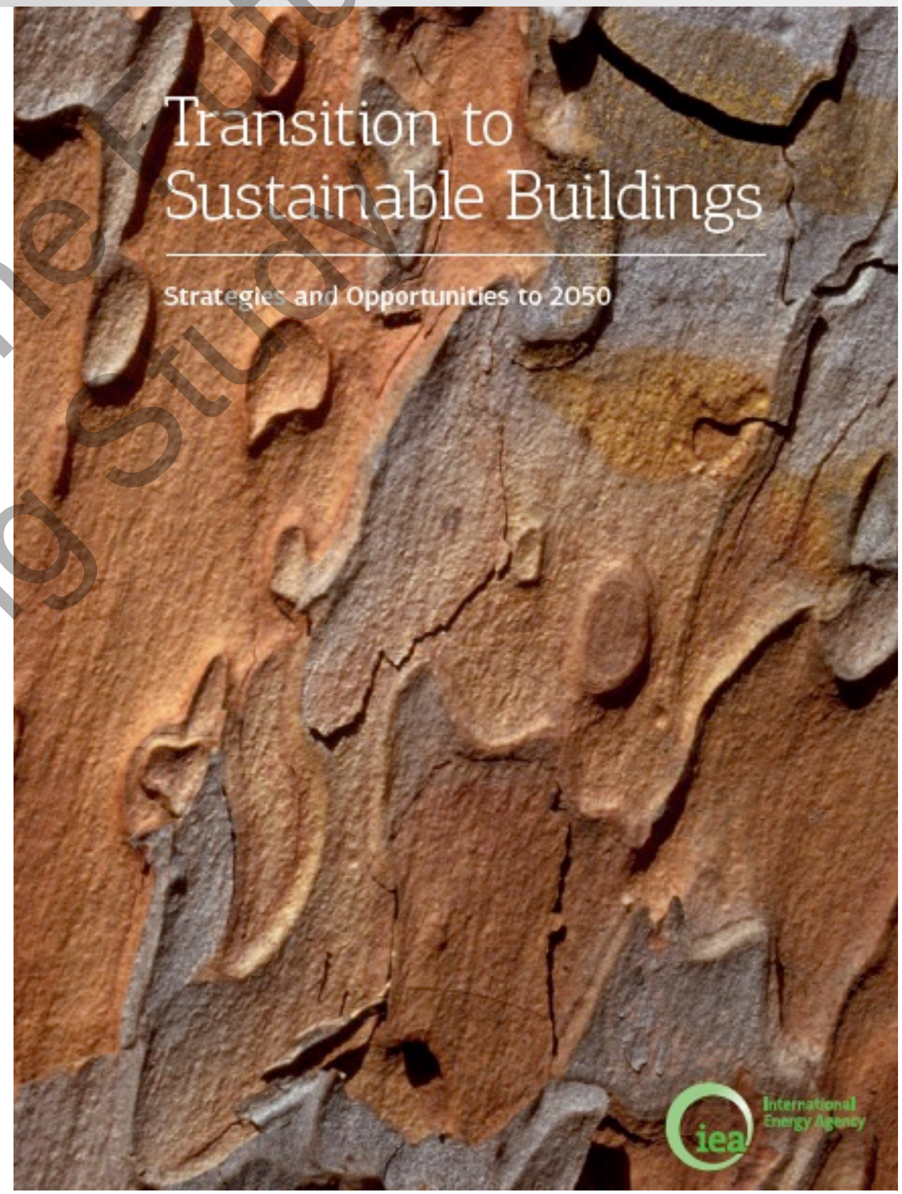
Transition to Sustainable Buildings by 2050 (International Energy Agency)

Buildings consume nearly **one-third** of global primary energy consumption.

Buildings are responsible for about **one-third** of total direct and indirect energy-related CO_2 emissions.

"In addition to technologies and architecture, behaviour, lifestyle, and culture have a major effect on buildings' energy use, presently causing 3–5 times differences in energy use for similar levels of energy services."

--Intergovernmental Panel on Climate Change's (IPCC) 5th Assessment Report (www.ipcc.ch)



Buildings of the Future
Scoping Study

Source: Transition to Sustainable Buildings: Strategies and Opportunities to 2050. (International Energy Agency)

Transition to Sustainable Buildings by 2050 (International Energy Agency)

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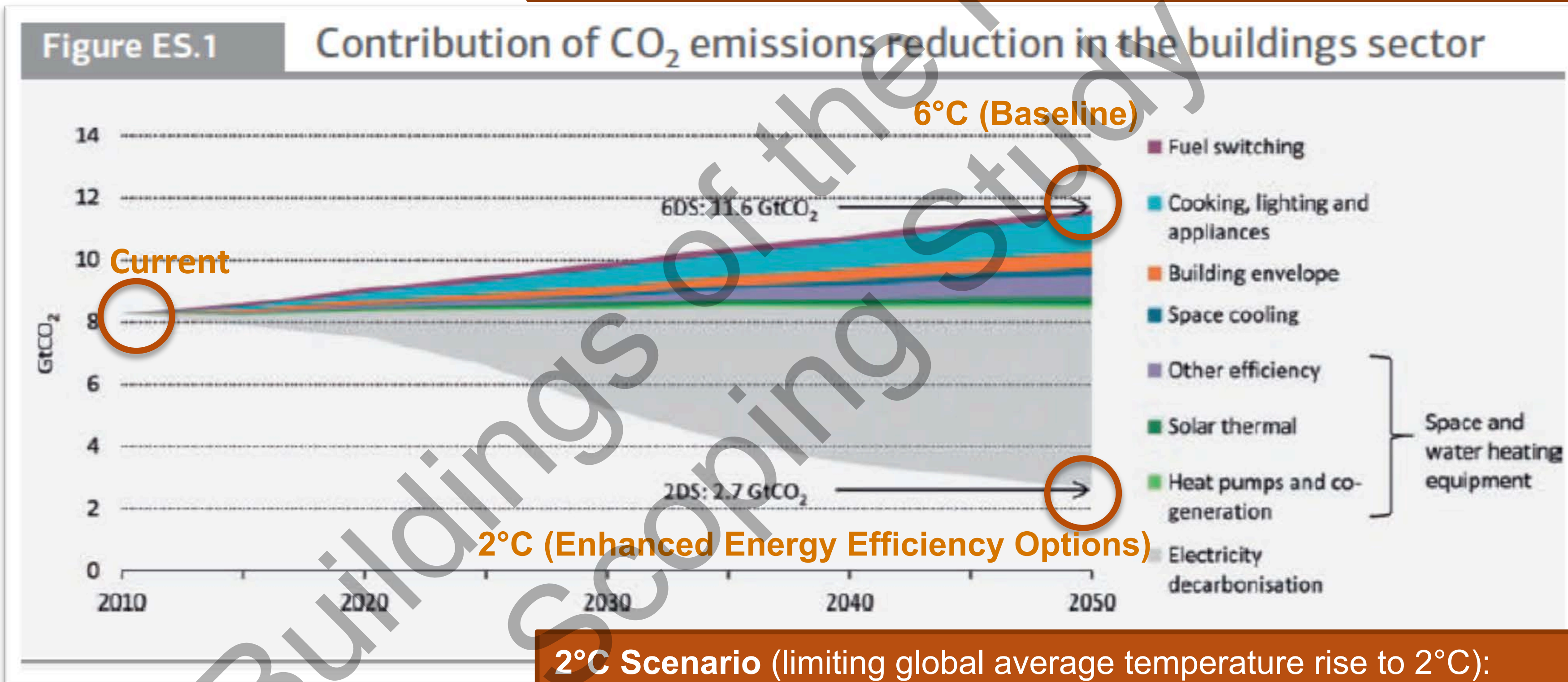
6°C Scenario (no action to improve building energy efficiency): Energy demand in buildings is projected to rise by 50% by 2050.

Global



2°C Scenario (limiting global average temperature rise to 2°C): CO_2 emissions in the building sector can be reduced to one-quarter of current levels.

Source: Transition to Sustainable Buildings: Strategies and Opportunities to 2050. (International Energy Agency)

Buildings of the Future Scoping Study

Carbon Neutral by 2030, 2050 (Architectural Society)

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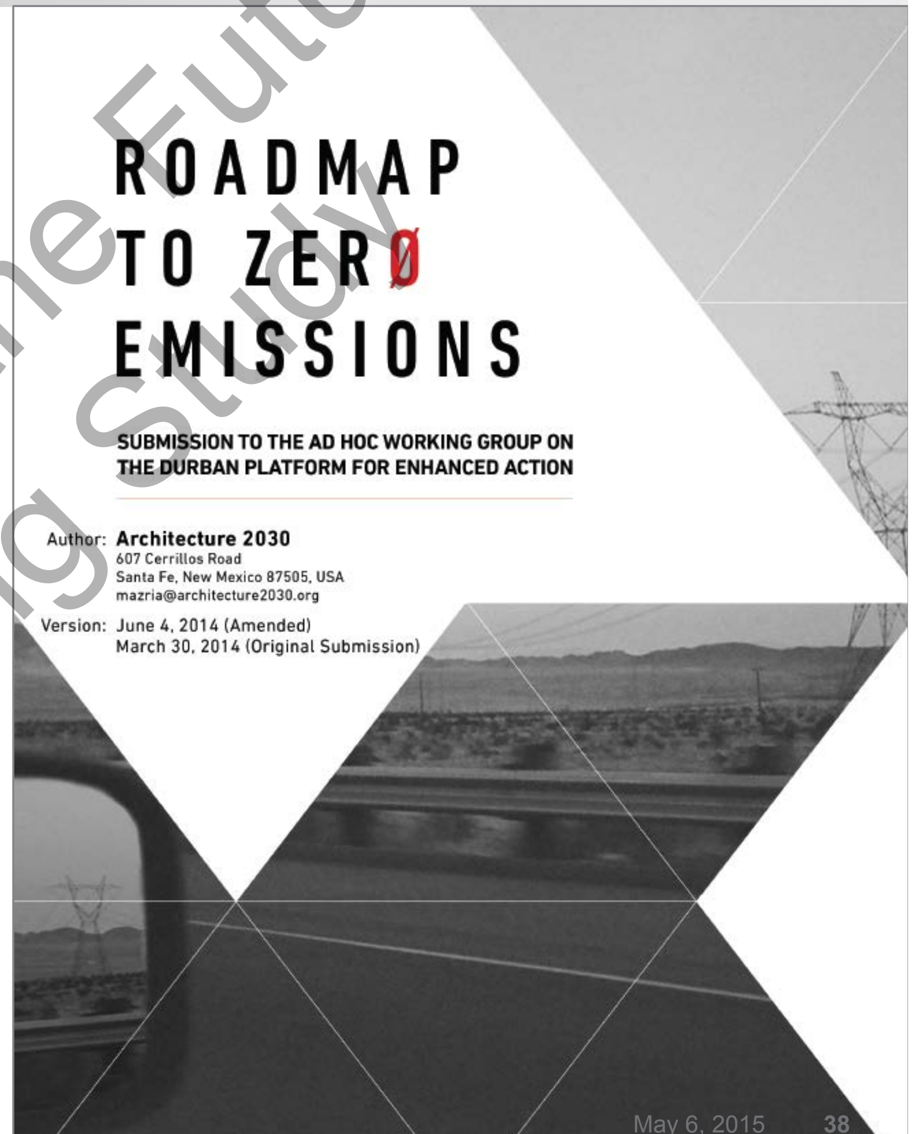
International Union of Architects (UIA) adopted the 2050 Imperative drafted by Architecture 2030.

Achieve total annual building sector CO_2 emissions reduction, relative to sector CO_2 emissions in 2015, within the following range:

	Existing Buildings	New Construction
2020	0% to 15%	80%
2025	15% to 30%	90%
2030	30% to 45%	Carbon Neutral
2035	45% to 60%	
2040	60% to 75%	
2045	75% to 90%	
2050	90% to 100%	
2055	Carbon Neutral	


ROADMAP TO ZERØ EMISSIONS

SUBMISSION TO THE AD HOC WORKING GROUP ON THE DURBAN PLATFORM FOR ENHANCED ACTION

Author: Architecture 2030
607 Cerrillos Road
Santa Fe, New Mexico 87505, USA
mazria@architecture2030.org

Version: June 4, 2014 (Amended)
March 30, 2014 (Original Submission)

Source: architecture2030.org/files/roadmap_web.pdf

Buildings of the Future Scoping Study

Expected Outcomes

Buildings of the Future
Scoping Study

This vision development will explore:

- the dynamic, multi-dimensional resource and information exchange within and between buildings, utility infrastructure, environment, and occupants;
- the 'value-added' opportunities that come from understanding the human/building interface;
- a full suite of comprehensive, transparent building performance metrics and targets to describe the value proposition of future buildings.

AGENDA

Cities of the Future: Intelligence and Resilience

Lead: Jorge Gonzalez, The City College of New York

Panelists:
Alex Washburn, Stevens Institute of Technology
Mark Arend, City University of New York
Stuart Gaffin, Columbia University

Urban Data for Future Cities

Lead: Masoud Ghandehari, New York University

Panelists:
Tom Butcher, Brookhaven National Labs
David Gifford, New York City Economic Development Corporation
Constantine Kontakosta, NYU
Mark De Yoanna, National Grid
Jin Jin Huang, Consolidated Edison,
Robert Cavey, Praxis Inc,

Occupants of the Future: Wellness and Performance

Leads: Edward Bogucz and Chetna Chianese, Syracuse University

Panelists:
Jianshun “Jensen” Zhang, Syracuse University
Vivian Loftness, Carnegie Mellon University
Joseph Allen, Harvard University

Smart Buildings and Smart Controls

Lead: Bill Worek, Stony Brook University

Panelists:
Mike Schell, AirTest
Marc Thuillard, Belimo-US
Larry Weber, Honeywell

Image: DLANDSTUDIO and Architecture Research Office
Source: http://www.komonews.com/news/national/Will-New-York-City-act-to-block-future-surges-180789791.html

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U.S. DEPARTMENT OF **ENERGY**

Buildings of the Future Scoping Study

DISCUSSIONS

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► Future Challenges and Changes

- In the distant future, what (different) challenges will cities in the U.S. face?
- How will changes in resource availability (land, water, energy, raw materials) affect building design and operations?
- How will changes in energy and material flow (e.g., different forms of energy, water supply, waste water treatment, etc.) influence buildings and districts?
- Will building use types, functions, and ownership be the same or different? Why?
- How will societal needs (e.g. owner and occupant interests and activities) shape future buildings?

► Drivers and Approaches

- How can buildings in the future adapt to the fast-changing technologies?
- Compared to today's practice, will there be more efficient ways of developing buildings to meet needs? What should we do differently to address the abovementioned challenges?
- What aspects of the built environment need to be developed, enhanced, or changed in the future? What could drive these changes?

Keep these **KEY WORDS** in mind:

Future
Vision
Integration
Connectivity
Interoperability
Changes
Values
Attributes
Metrics

► Visions

- How to integrate different goals and visions? For example, how can heath and resilience be integrated into other goals, such as reducing greenhouse gas emissions and energy use?
- What are the most important future building attributes?
- What performance metrics do we need to develop for future buildings?

EXPECTED WORKSHOP OUTCOMES

Buildings of the Future Scoping Study

U.S. DEPARTMENT OF ENERGY

THANK YOU!

Visit us at futurebuildings.pnnl.gov

Contact us at futurebuildings@pnnl.gov

Buildings of the Future Scoping Study

Cities of the Future: Intelligence and Resilience

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Panelists:
Mike Schell, AirTest
Marc Thuillard, Belimo-US
Larry Weber, Honeywell

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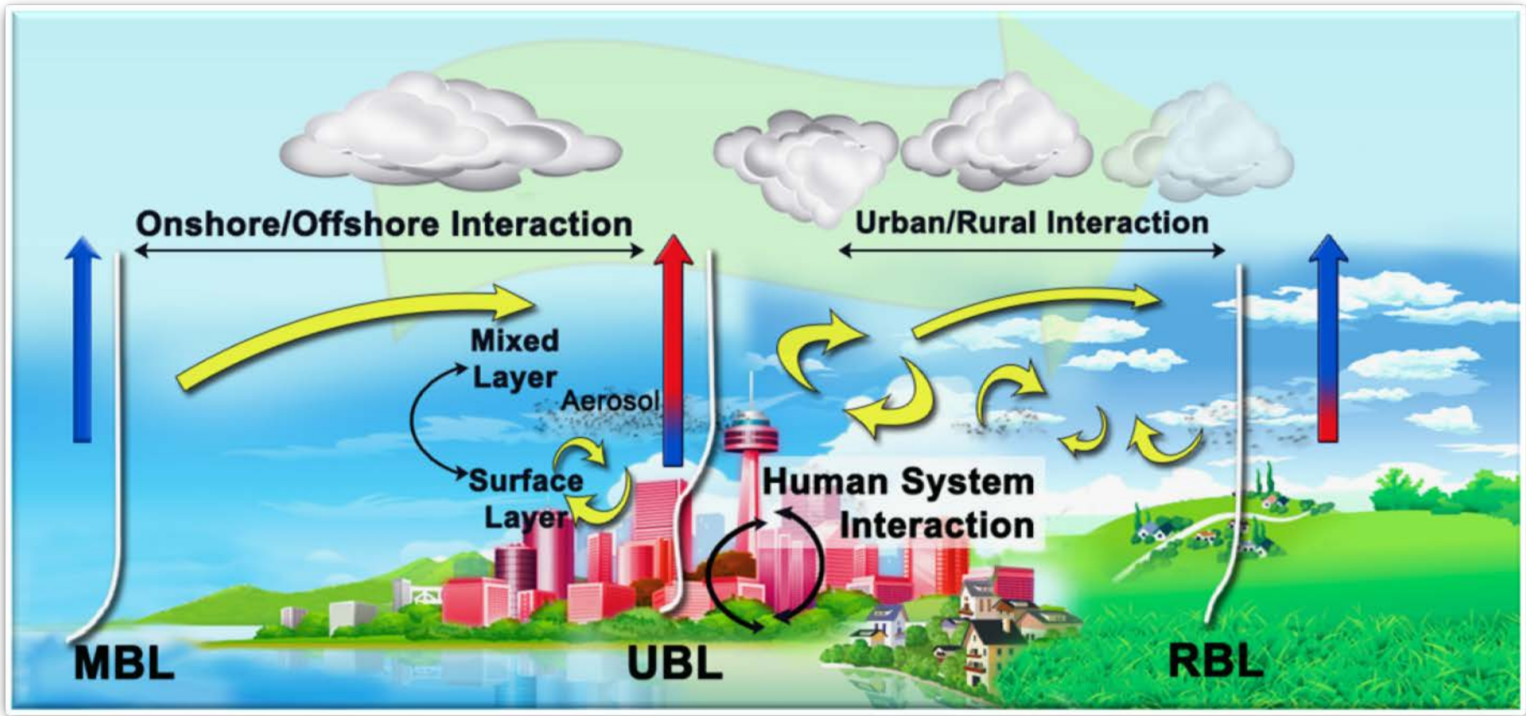
The very challenging coastal/urban environment.

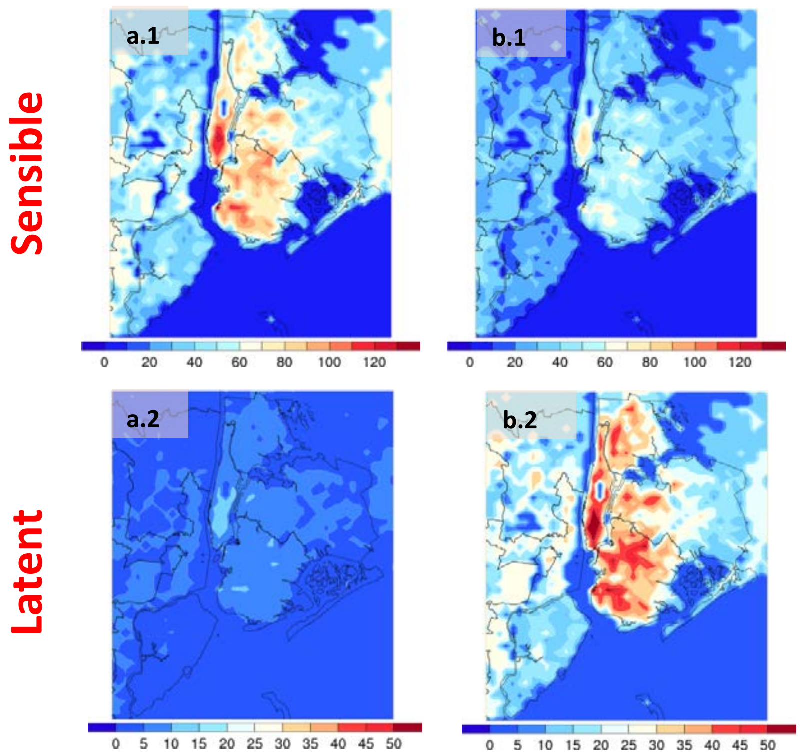


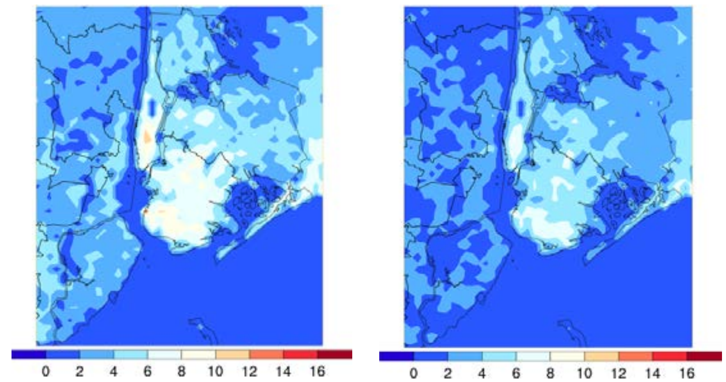
*The **fundamental challenge** is to understand and more accurately model coastal urban environments.*

the City College of New York

Understanding our coastal/built environment: The Heat Flux Challenge

Heat-Partition (Sensible/Latent) Spatial Distribution (W/m^2)





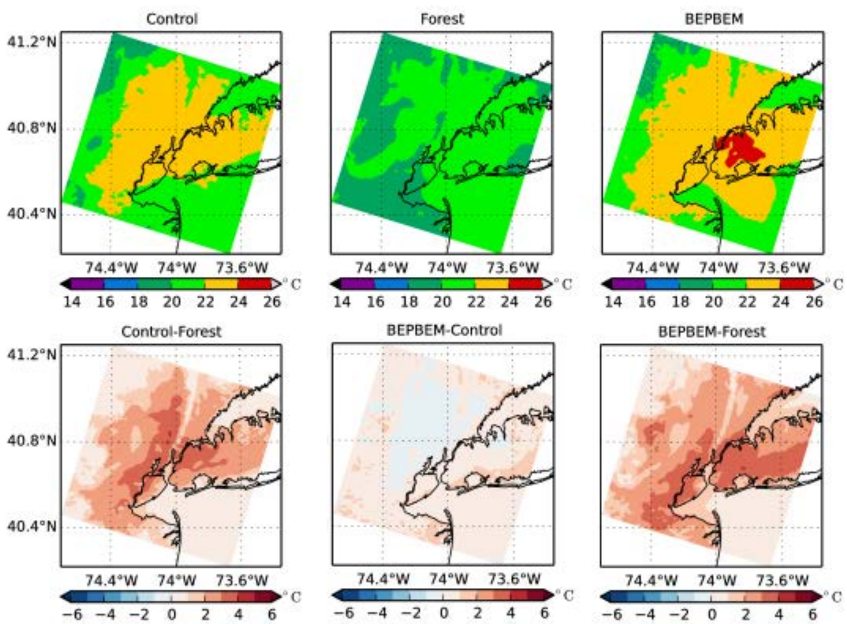
Average Daytime White Roof Sensible Heat Flux During Dry (Left) and Wet (Right) Days

Average Daytime Roof Sensible (1) and Latent (2) Heat Flux for Current (a) and Green Roof Options (b).

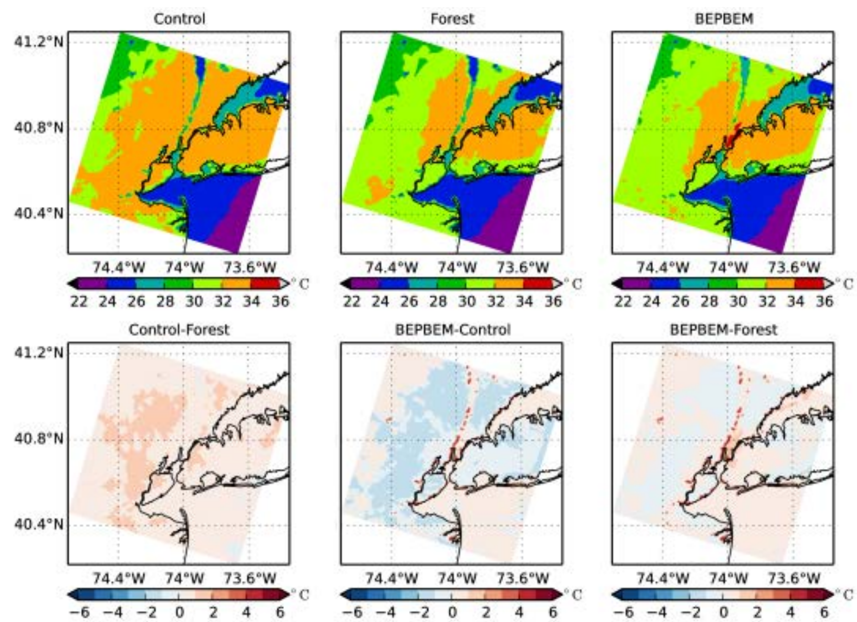
U.S. DEPARTMENT OF ENERGY

What may be the impacts of our coastal cities in the regional environments (July 2010 Heat Wave)

TMIN

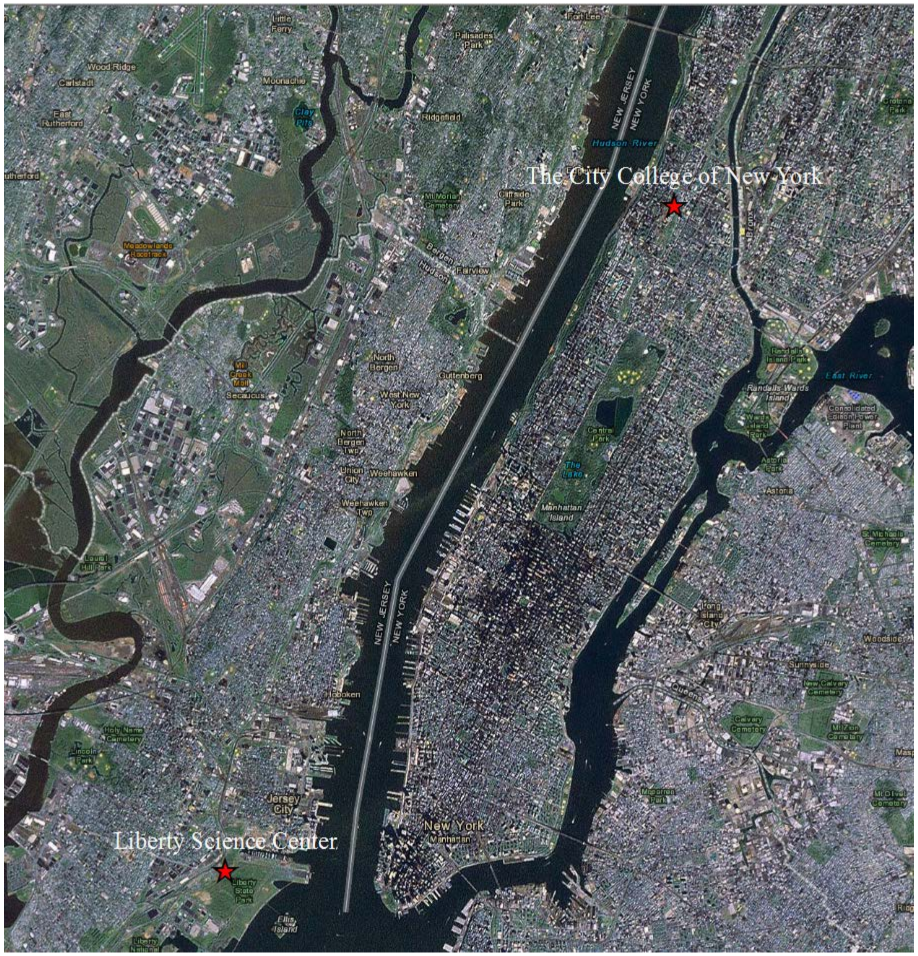


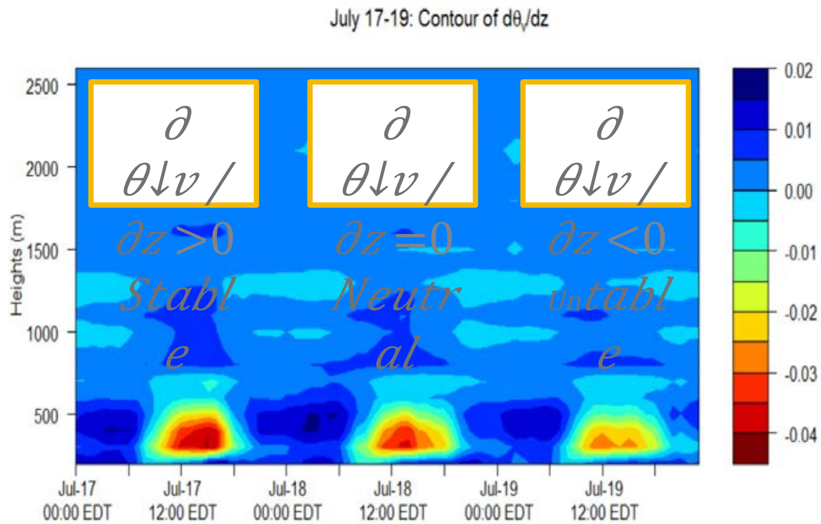
TMAX

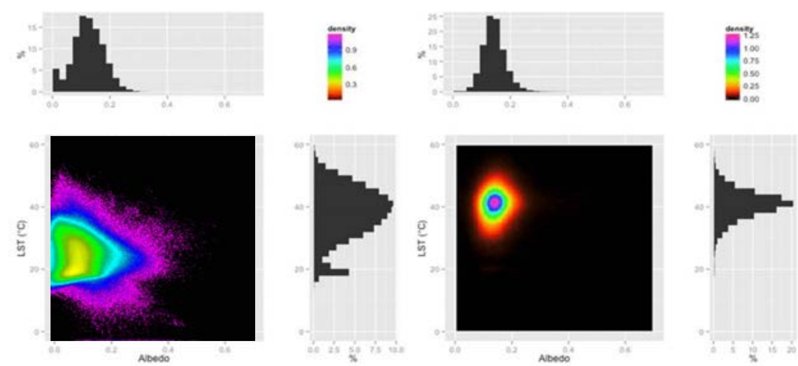


How sensitive or resilient is (will be) our coastal/urban environment to more frequent and intense extreme natural hazards?

How do we sense our future coastal/built environment?







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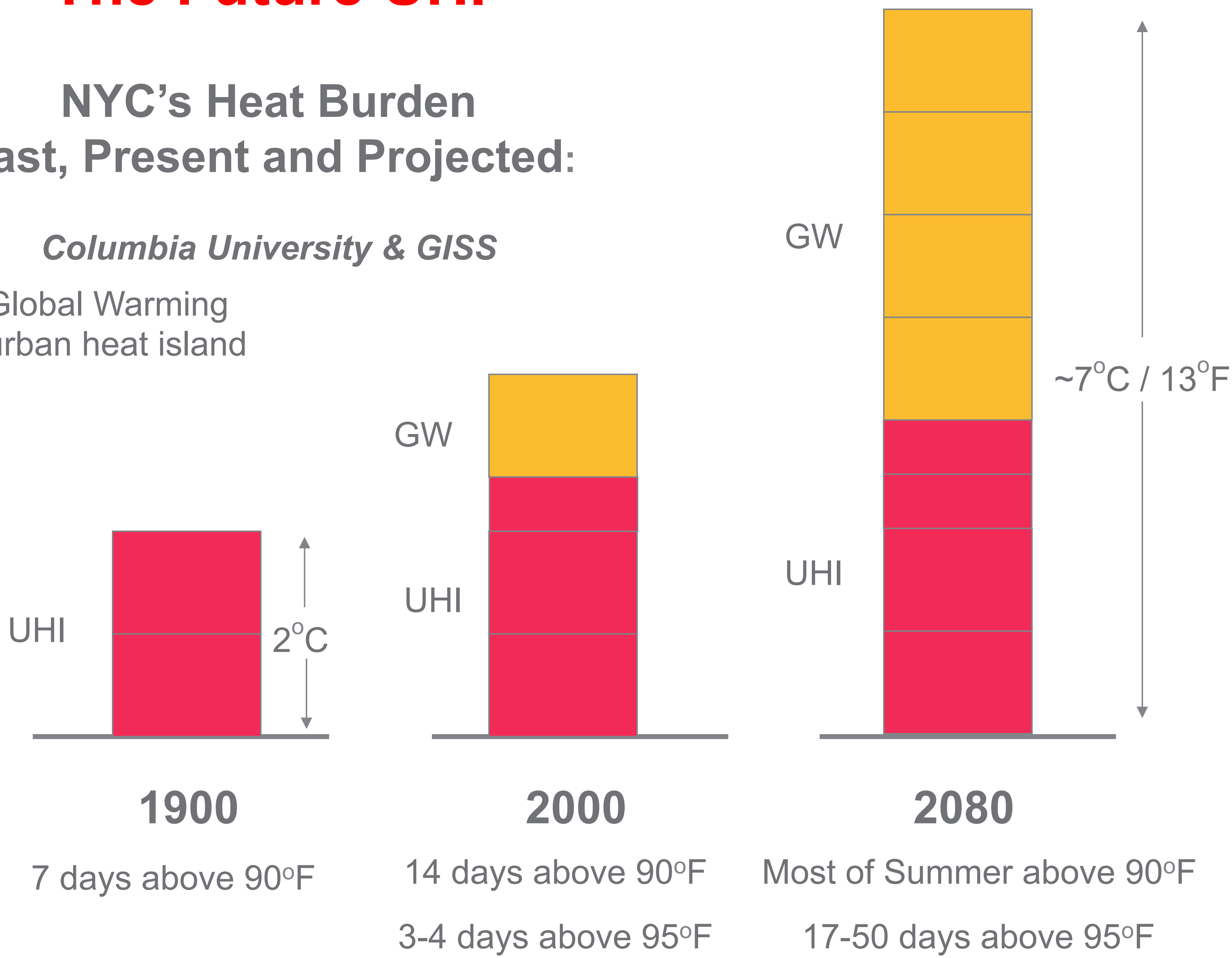
The Future UHI

NYC's Heat Burden Past, Present and Projected:

Columbia University & GISS

GW = Global Warming
UHI = urban heat island



Panelists: Cities of the Future: Intelligence and Resilience

Alexandros Washburn is Industry Professor and founding Director of the Coastal Resilience and Urban eXcellence (CRUX) Lab at the Stevens Institute of Technology.

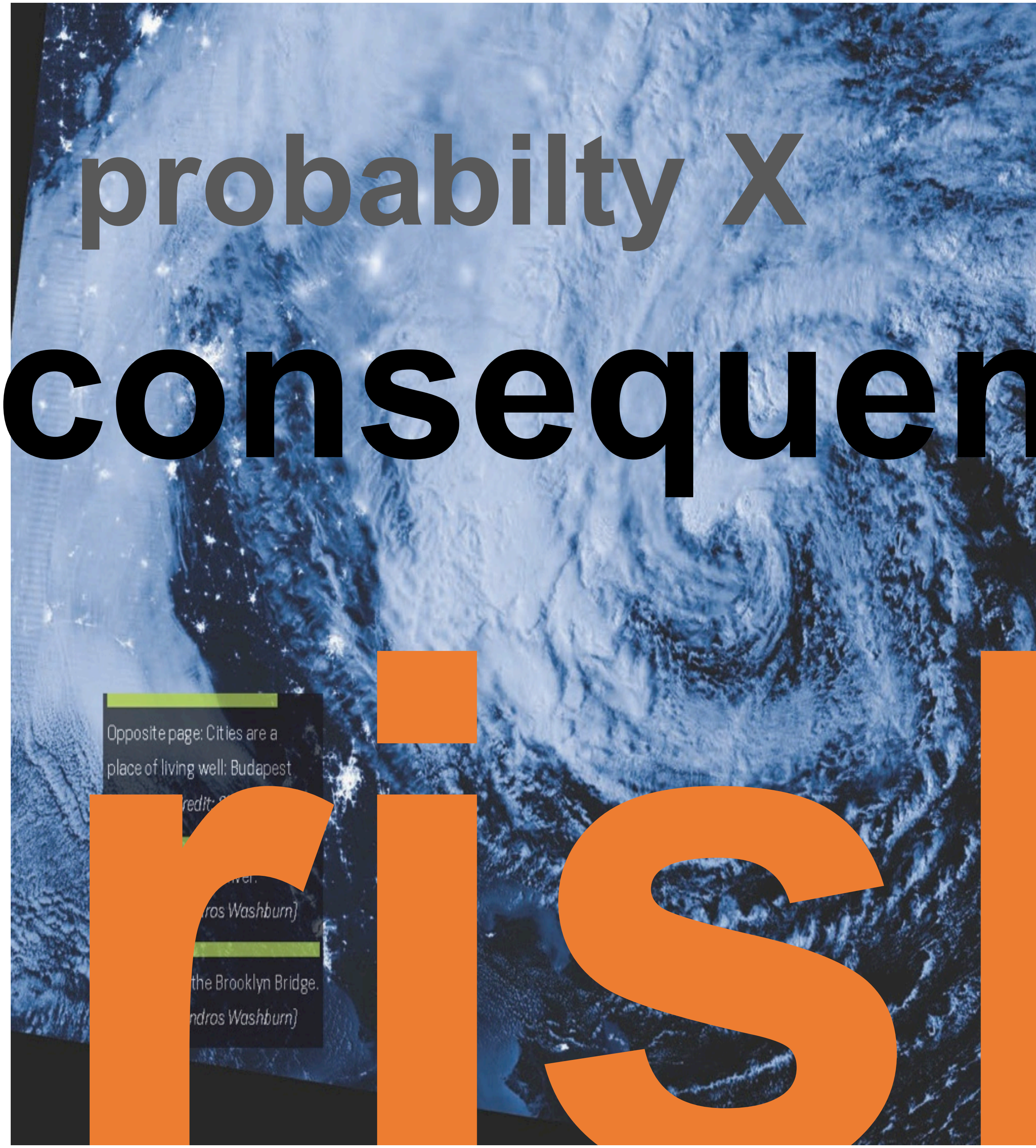
Dr. Mark Arend Research Professor at City College of New York, and Director of the NY City Meteorological Network.

Dr. Stuart Gaffin
Research Scientist at the Center for Climate Systems Research, *Columbia* University

probabilty X

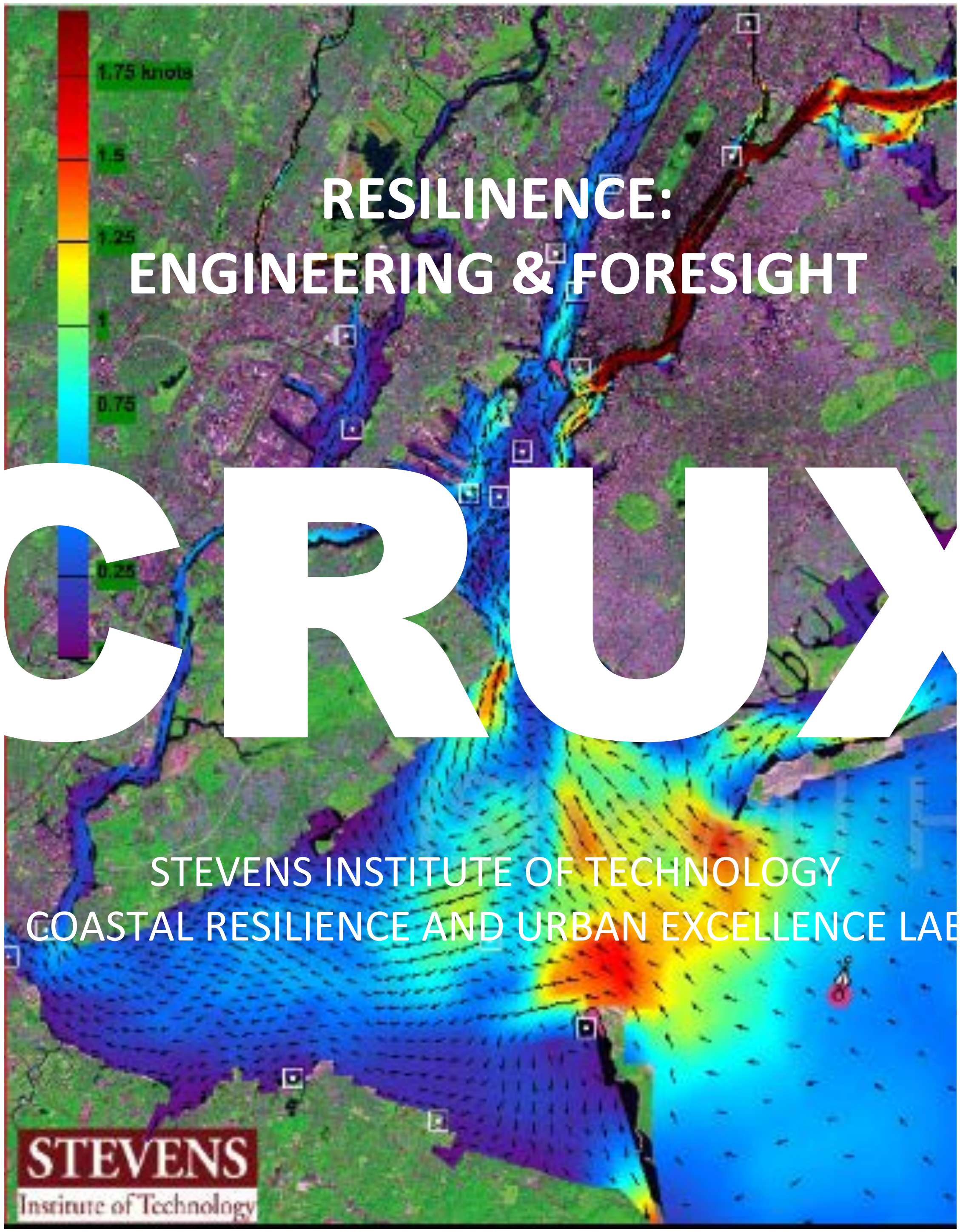
consequences

risk



RESILINENCE: ENGINEERING & FORESIGHT

CRUX

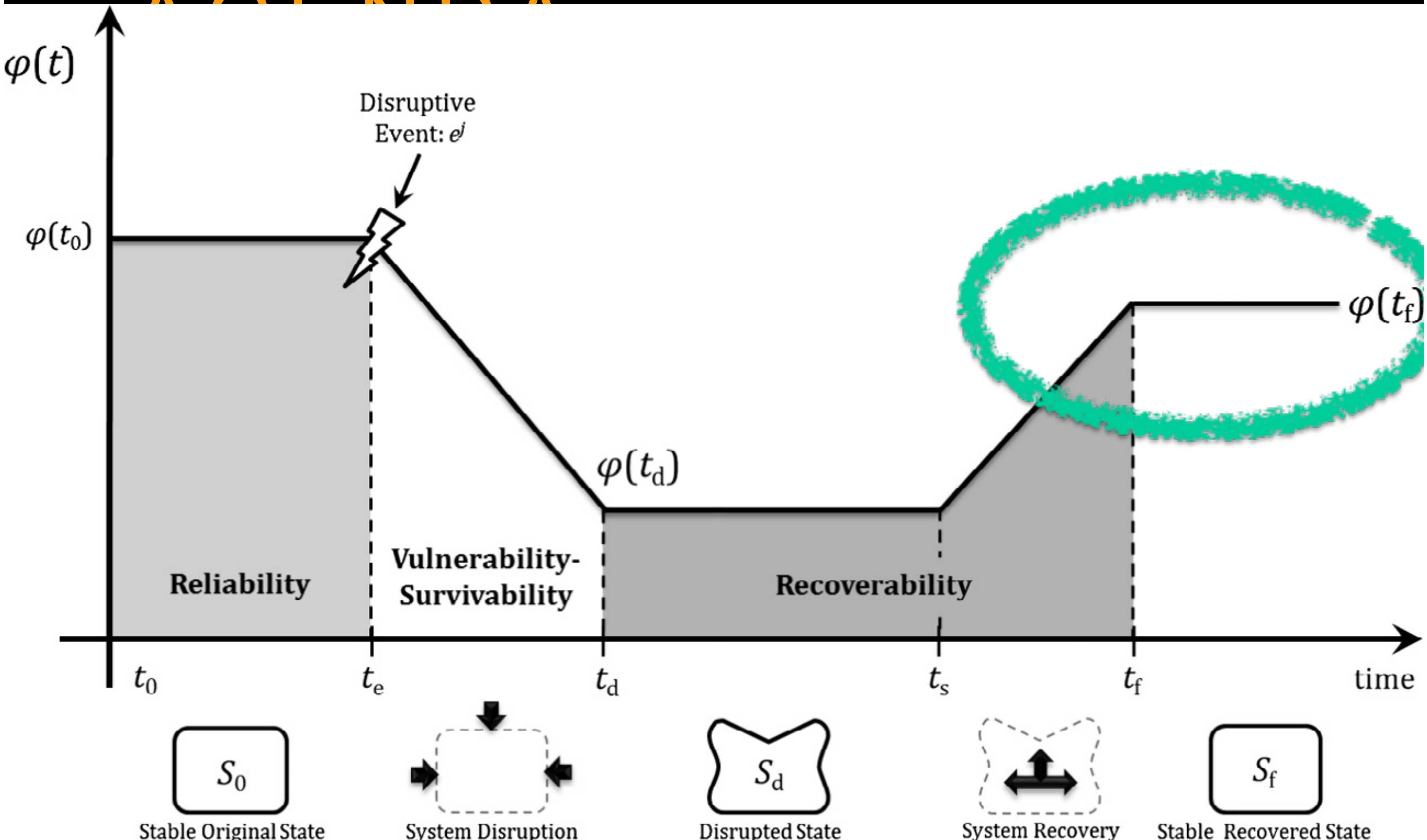


STEVENS INSTITUTE OF TECHNOLOGY

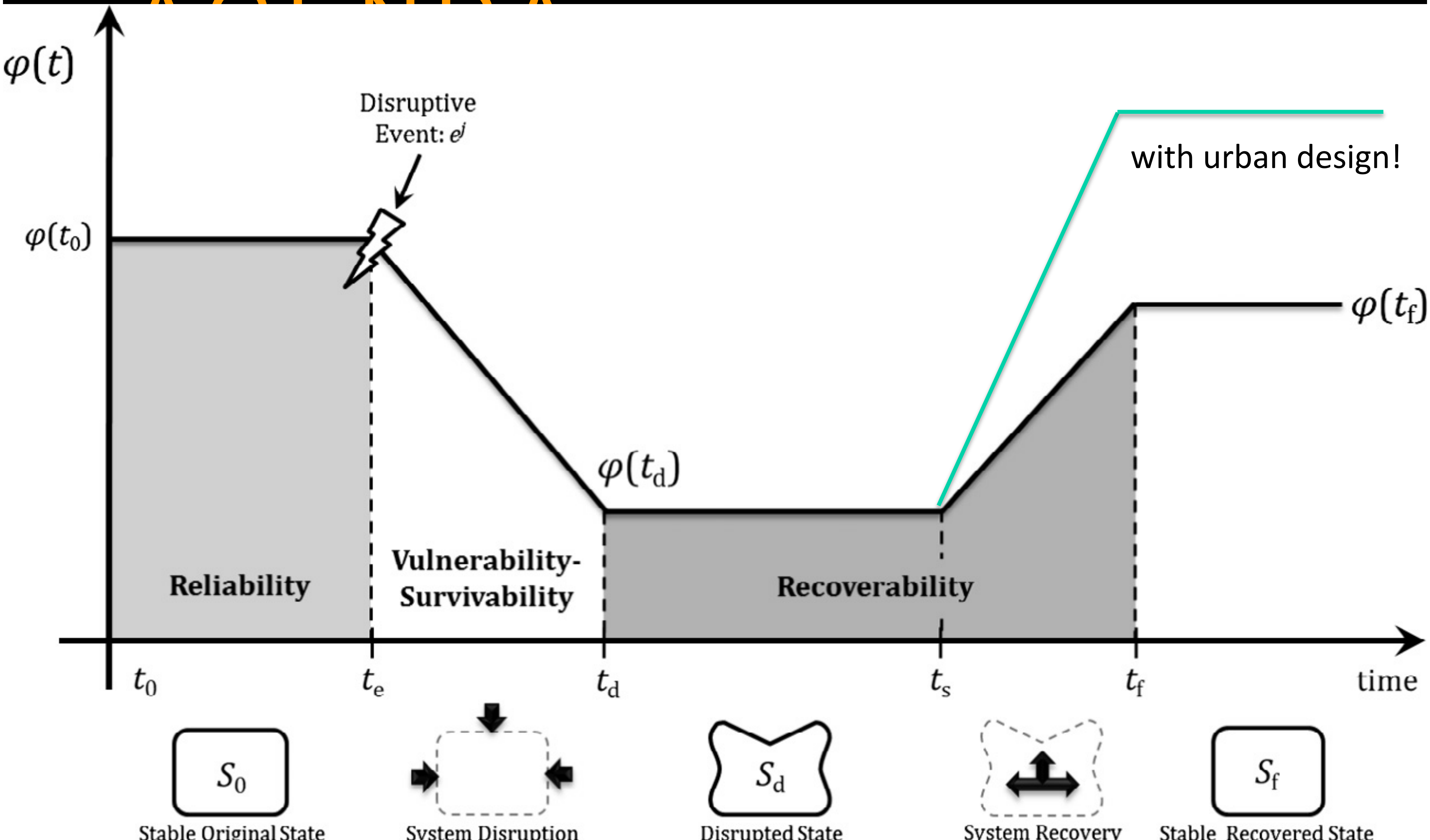
COASTAL RESILIENCE AND URBAN EXCELLENCE LAB

STEVENS Institute of Technology

AGENDA



$\varphi(t)$
Disruptive
Event: e^j
$\varphi(t_0)$
$\varphi(t_d)$
$\varphi(t_f)$
Reliability
Vulnerability-
Survivability
Recoverability
t_0
t_e
t_d
t_s
t_f
time
S_0
Stable Original State
System Disruption
S_d
Disrupted State
System Recovery
S_f
Stable Recovered State



φ(t)
Disruptive Event: e^j
φ(t0)
with urban design!
φ(tf)
φ(td)
Reliability
Vulnerability-Survivability
Recoverability
t0
te
td
ts
tf
time
S0
Stable Original State
System Disruption
Sd
Disrupted State
System Recovery
Sf
Stable Recovered State

to lower risk

to improve system performance

which includes quality of life because resilient systems are complex systems, and complex systems involve **people**

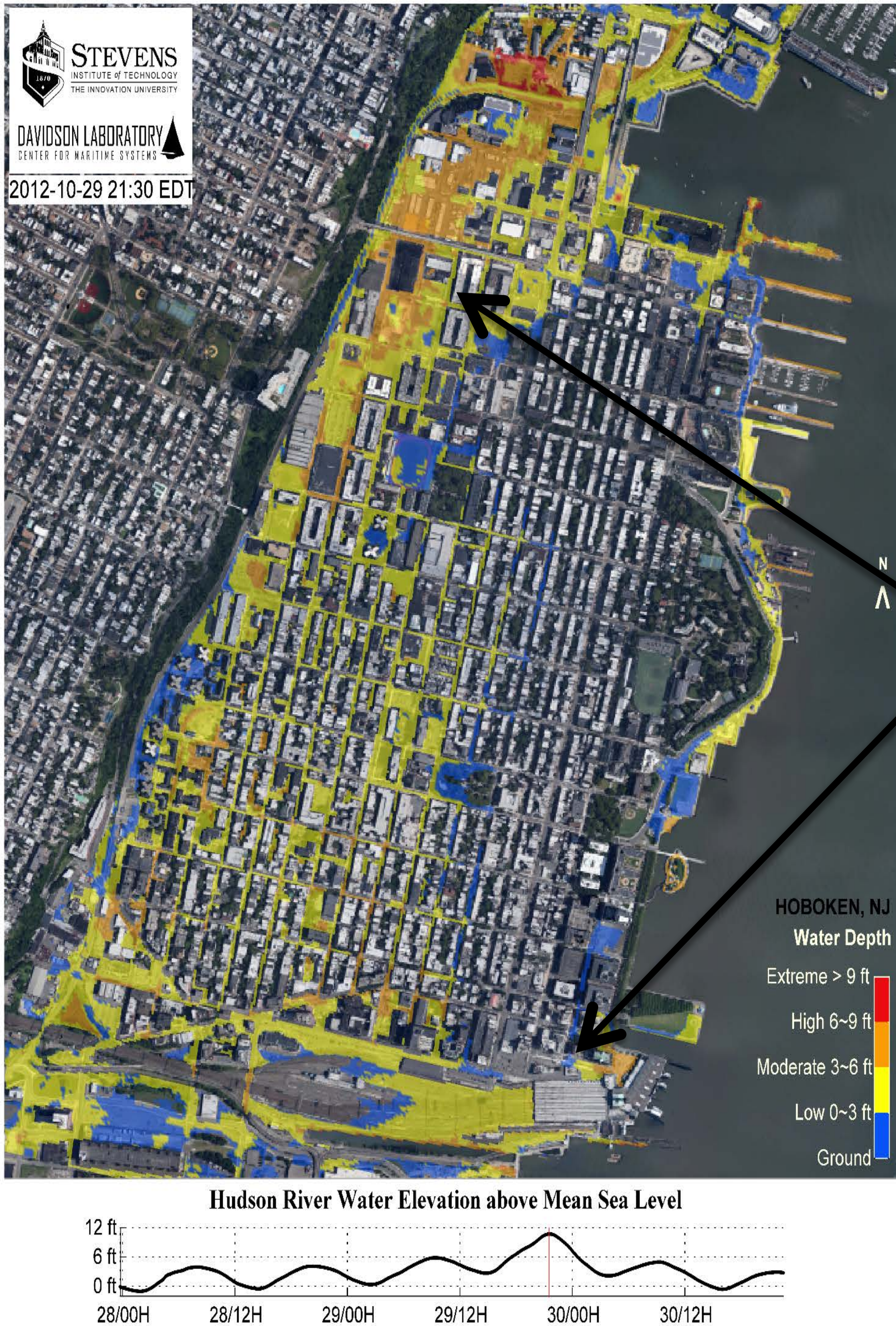
opportunity


resilience

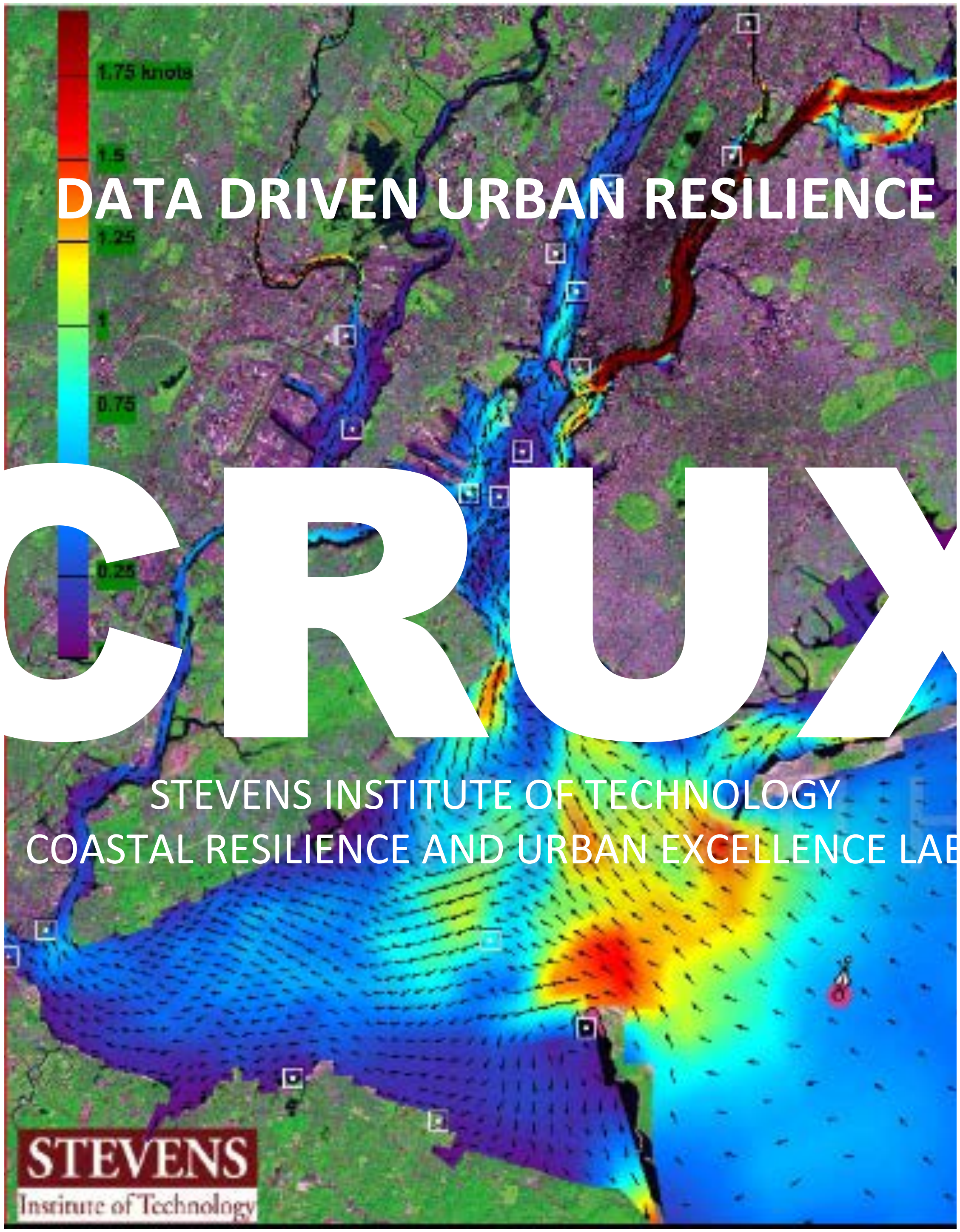
engineer resilience by using digital technology to overcome the limits of legacy infrastructure

example

opportunity


STEVENS
INSTITUTE of TECHNOLOGY
THE INNOVATION UNIVERSITY
DAVIDSON LABORATORY
CENTER FOR MARITIME SYSTEMS
2012-10-29 21:30 EDT
N
HOBOKEN, NJ
Water Depth
Extreme > 9 ft
High 6~9 ft
Moderate 3~6 ft
Low 0~3 ft
Ground
Hudson River Water Elevation above Mean Sea Level
12 ft
6 ft
0 ft
28/00H
28/12H
29/00H
29/12H
30/00H
30/12H

DATA DRIVEN URBAN RESILIENCE



CRUX

STEVENS INSTITUTE OF TECHNOLOGY

COASTAL RESILIENCE AND URBAN EXCELLENCE LAB

STEVENS
Institute of Technology

FLUID MODELING examples

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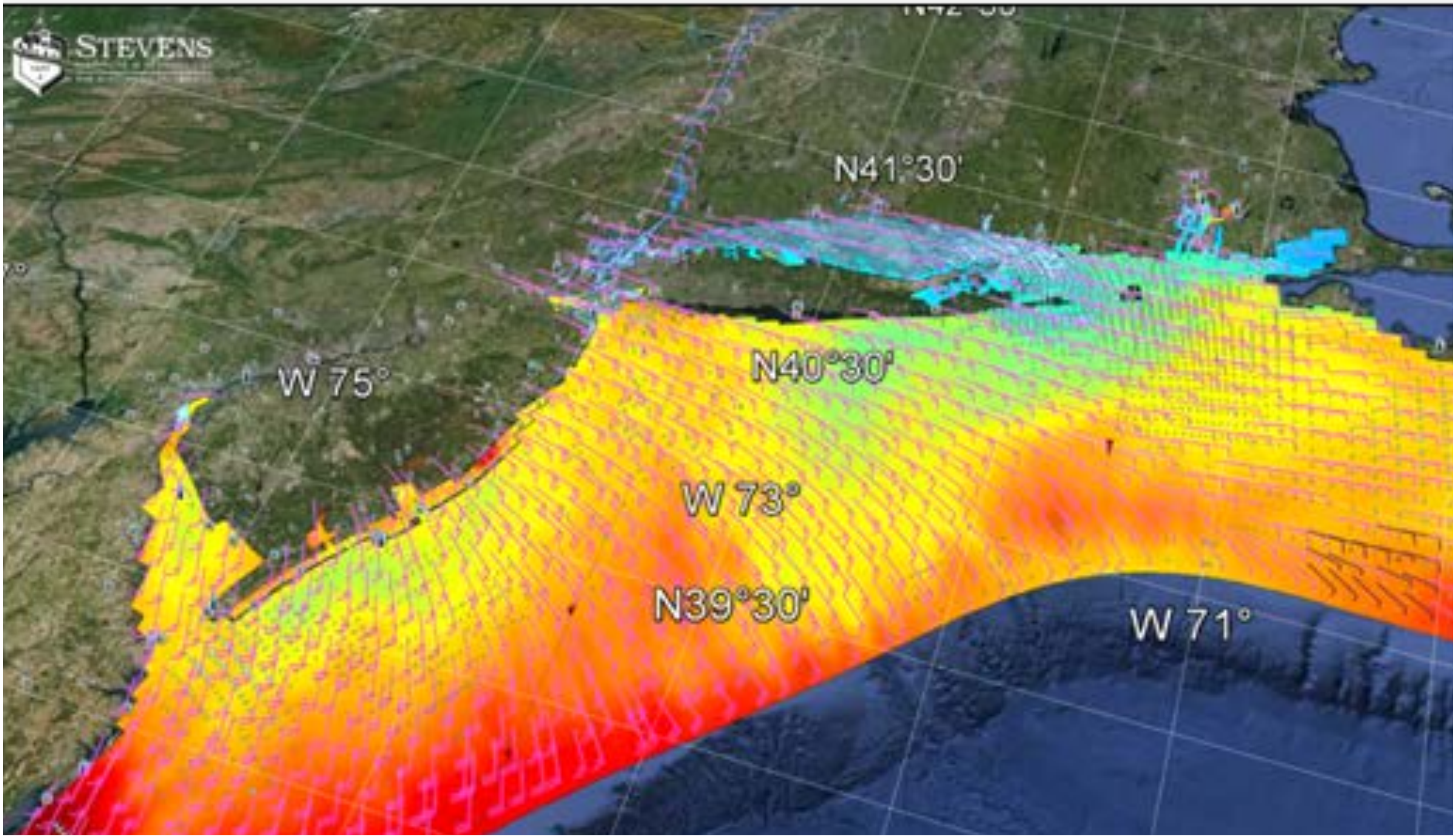
max_x = max(max(x));
max_y = max(max(y));

% the image data you want to show as a plane.
planeimg = abs(z);
```

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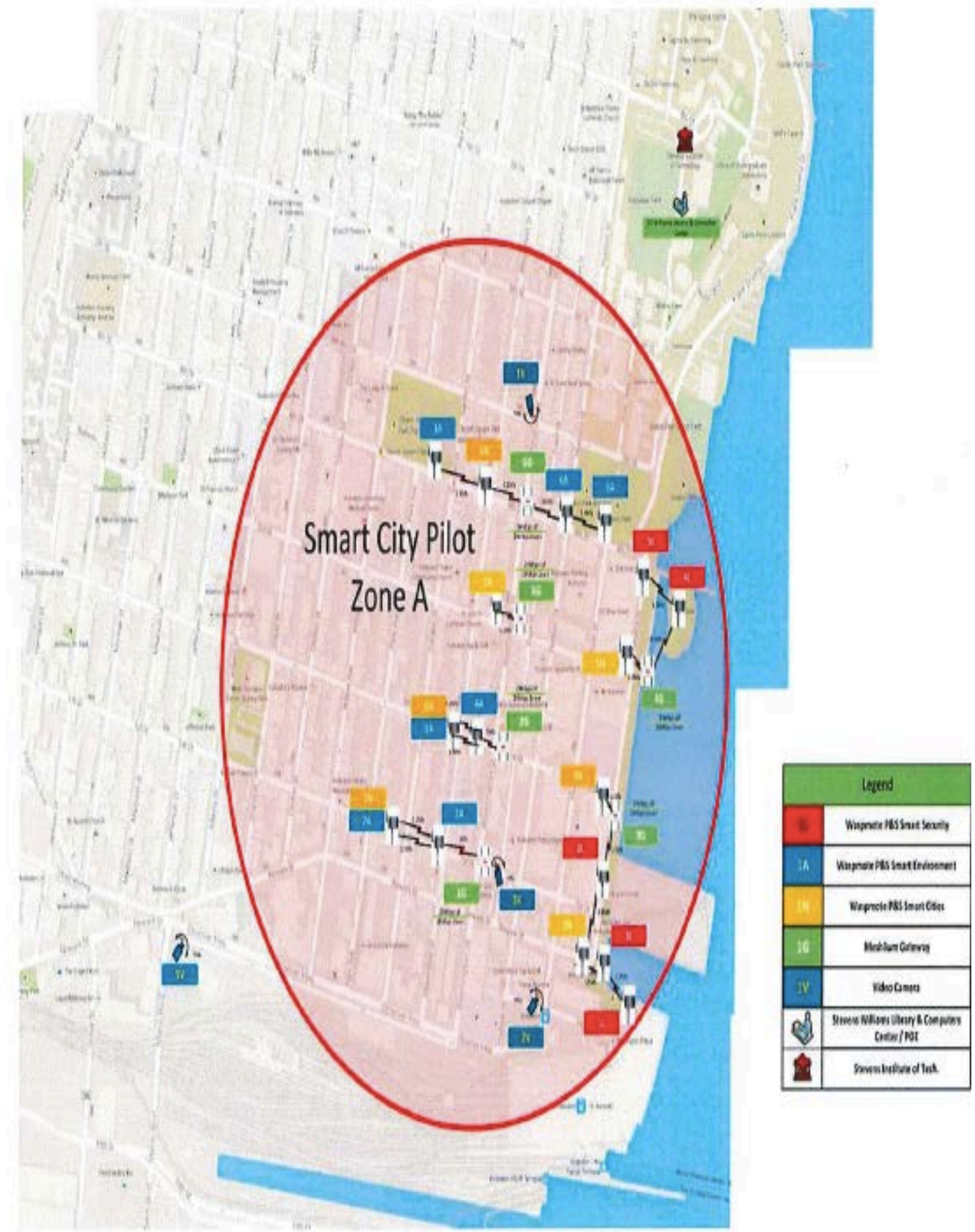
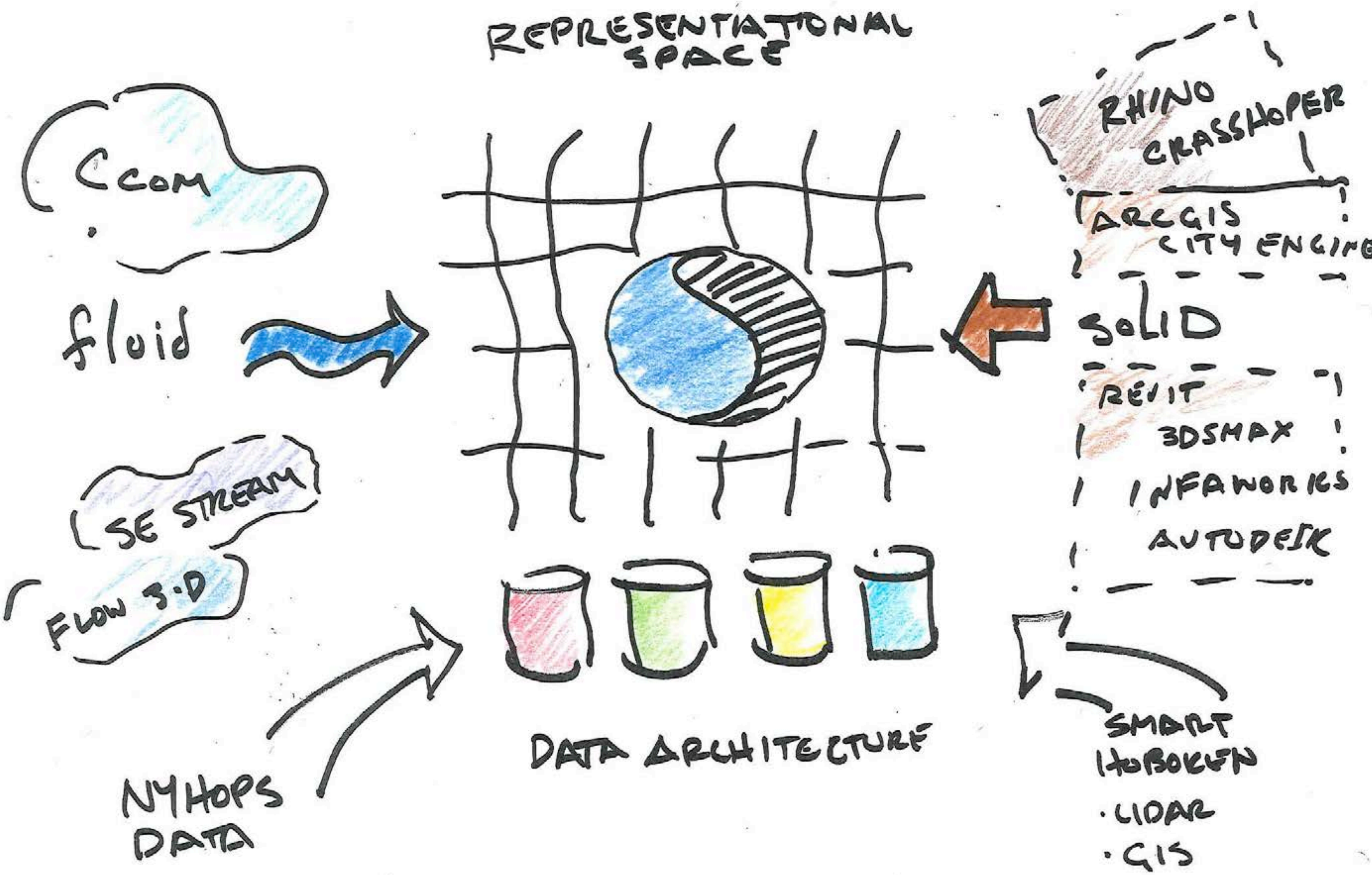
Mesh Topology

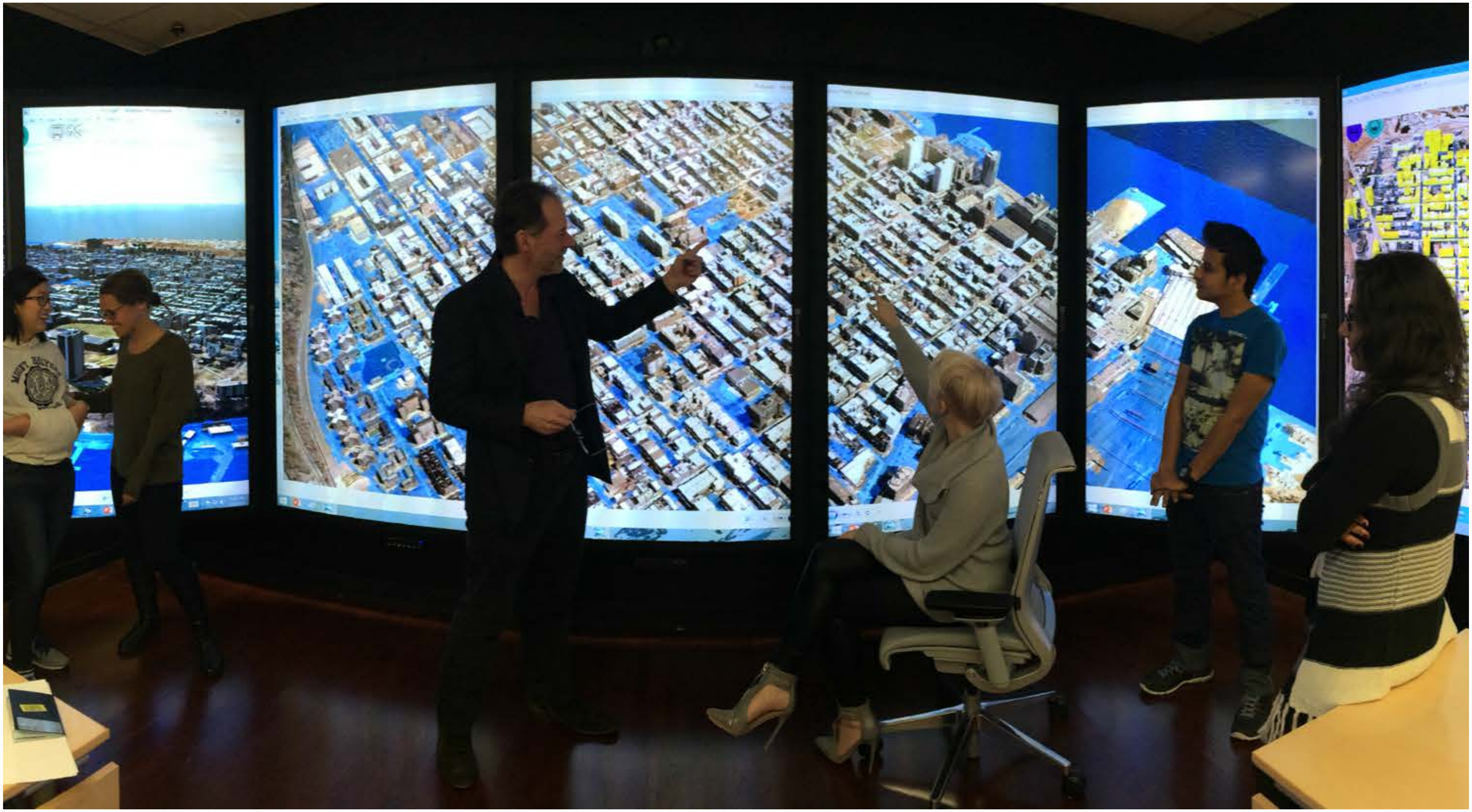


SURF & TURF



REPRESENTATIONAL SPACE
CCOM
fluid
SE STREAM
FLOW 3-D
NYHOPS DATA
DATA ARCHITECTURE
RHINO
GRASSHOPER
ARCGIS
CITY ENGINE
SOLID
REVIT
3DSMAX
INFAWORKS
AUTODESK
SMART HOBOKEN
· LIDAR
· GIS

THE WAY FORWARD: FLUID MODELING MEETS SOLID MODELING



Matrix Measures

nbbj

FEMA Objectives

IFPS Barrier Study Segment							
FEMA Objectives		100 Year Chance Flood Protection					
		500 Year Chance Flood Protection					
Required Barrier Height		XX Barrier Height					
		Levee	Wall			Gate	No-action
IFPS Typologies		Multi-purpose Levee	Concrete Wall	Deployable Wall	Dry FP Wall	Gate	Wet FP
Design Components	Structure Components	Levee	Wall	Polar	Façade Wall	Structure	
		Foundation	Foundation	Foundation	Foundation	Foundation	
				Deployable Panel		Gate	
	Public Benefit Components	Bike Path	Terrain Wall	Trees	Vegetation	Add-ons	
		Retail Space	Vegetated Knoll	Bench	Outdoor Gallery	Add-ons	
		Amphitheater	"Up and Over"	Bike Path	Social Space	Add-ons	
		Trees	Pavilion	Retail Space	Wetland	Add-ons	
		Add-ons	Add-ons	Add-ons	Add-ons	Add-ons	
Cost Parameters		$ per/unit of each design component	$ per/unit of each design component	$ per/unit of each design component	$ per/unit of each design component	$ per/unit of each design component	$ per/unit of each design component
Total Cost		$	$	$	$	$	N/A
Community Benefit Evaluation	Social	0-20	0-20	0-20	0-20	0-20	0-20
	Environmental	0-20	0-20	0-20	0-20	0-20	0-20
	Economic	0-20	0-20	0-20	0-20	0-20	0-20
Total Score		0-60	0-60	0-60	0-60	0-60	0-60

Testing IFPS Typologies

IFPS Barrier Study Segment							
FEMA Objectives		100 Year Chance Flood Protection					
		500 Year Chance Flood Protection					
Required Barrier Height		XX Barrier Height					
		Levee	Wall			Gate	No-action
IFPS Typologies		Multi-purpose Levee	Concrete Wall	Deployable Wall	Dry FP Wall	Gate	Wet FP
Design Components	Structure Components	Levee	Wall	Polar	Façade Wall	Structure	
		Foundation	Foundation	Foundation	Foundation	Foundation	
				Deployable Panel		Gate	
	Public Benefit Components	Bike Path	Terrain Wall	Trees	Vegetation	Add-ons	
		Retail Space	Vegetated Knoll	Bench	Outdoor Gallery	Add-ons	
		Amphitheater	"Up and Over"	Bike Path	Social Space	Add-ons	
		Trees	Pavilion	Retail Space	Wetland	Add-ons	
		Add-ons	Add-ons	Add-ons	Add-ons	Add-ons	
Cost Parameters		$ per/unit of each design component	$ per/unit of each design component	$ per/unit of each design component	$ per/unit of each design component	$ per/unit of each design component	$ per/unit of each design component
Total Cost		$	$	$	$	$	N/A
Community Benefit Evaluation	Social	0-20	0-20	0-20	0-20	0-20	0-20
	Environmental	0-20	0-20	0-20	0-20	0-20	0-20
	Economic	0-20	0-20	0-20	0-20	0-20	0-20
Total Score		0-60	0-60	0-60	0-60	0-60	0-60

Compare Cost & Public Benefits

IFPS Barrier Study Segment							
FEMA Objectives		100 Year Chance Flood Protection					
		500 Year Chance Flood Protection					
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		Levee	Wall			Gate	No-action
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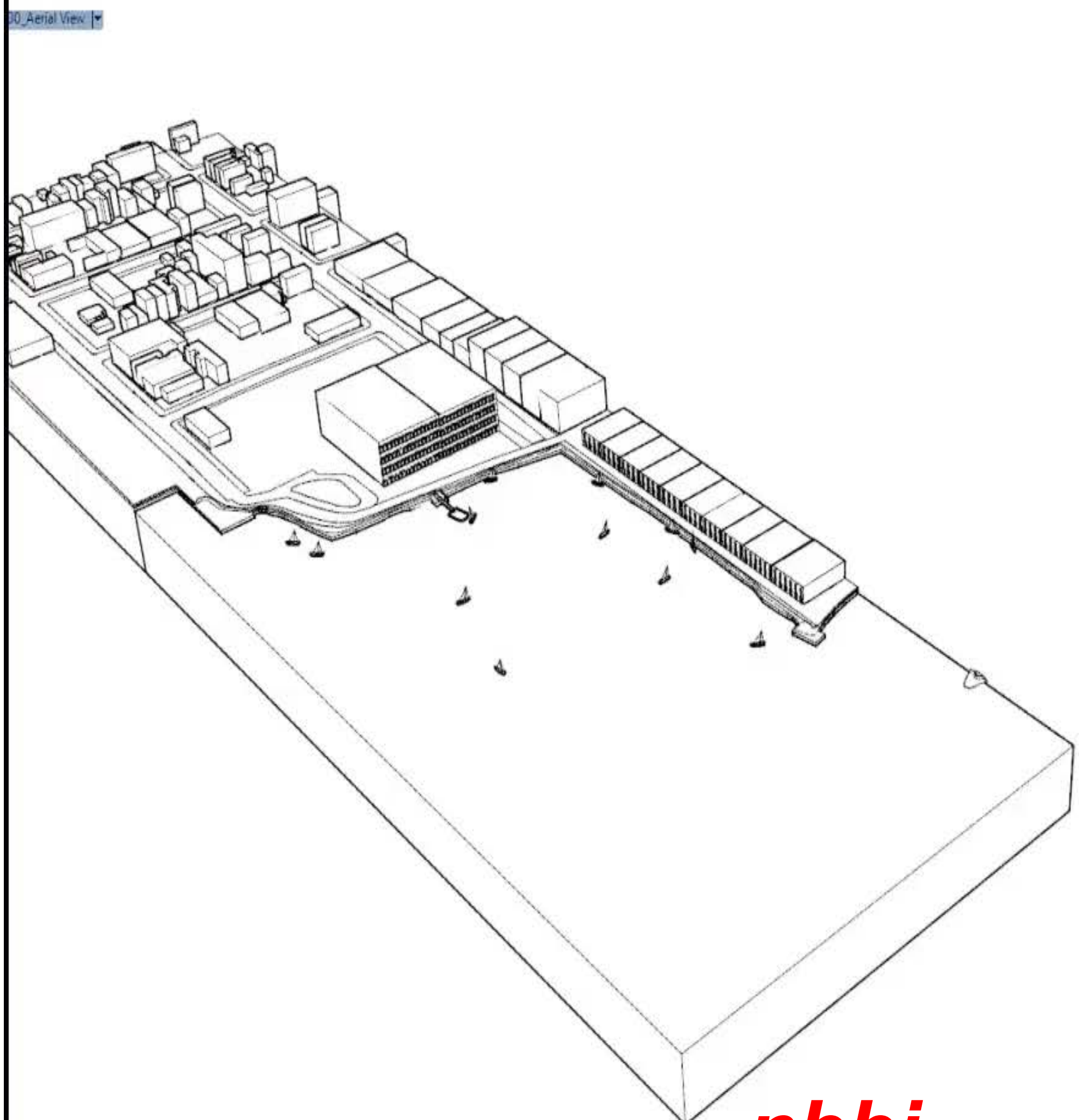
		Add-ons	Add-ons	Add-ons	Add-ons	Add-ons	
Cost Parameters		$ per/unit of each design component	$ per/unit of each design component	$ per/unit of each design component	$ per/unit of each design component	$ per/unit of each design component	$ per/unit of each design component
Total Cost		$	$	$	$	$	N/A
Community Benefit Evaluation	Social	0-20	0-20	0-20	0-20	0-20	0-20
	Environmental	0-20	0-20	0-20	0-20	0-20	0-20
	Economic	0-20	0-20	0-20	0-20	0-20	0-20
Total Score		0-60	0-60	0-60	0-60	0-60	0-60

Visualize Flood Mitigation Scenarios

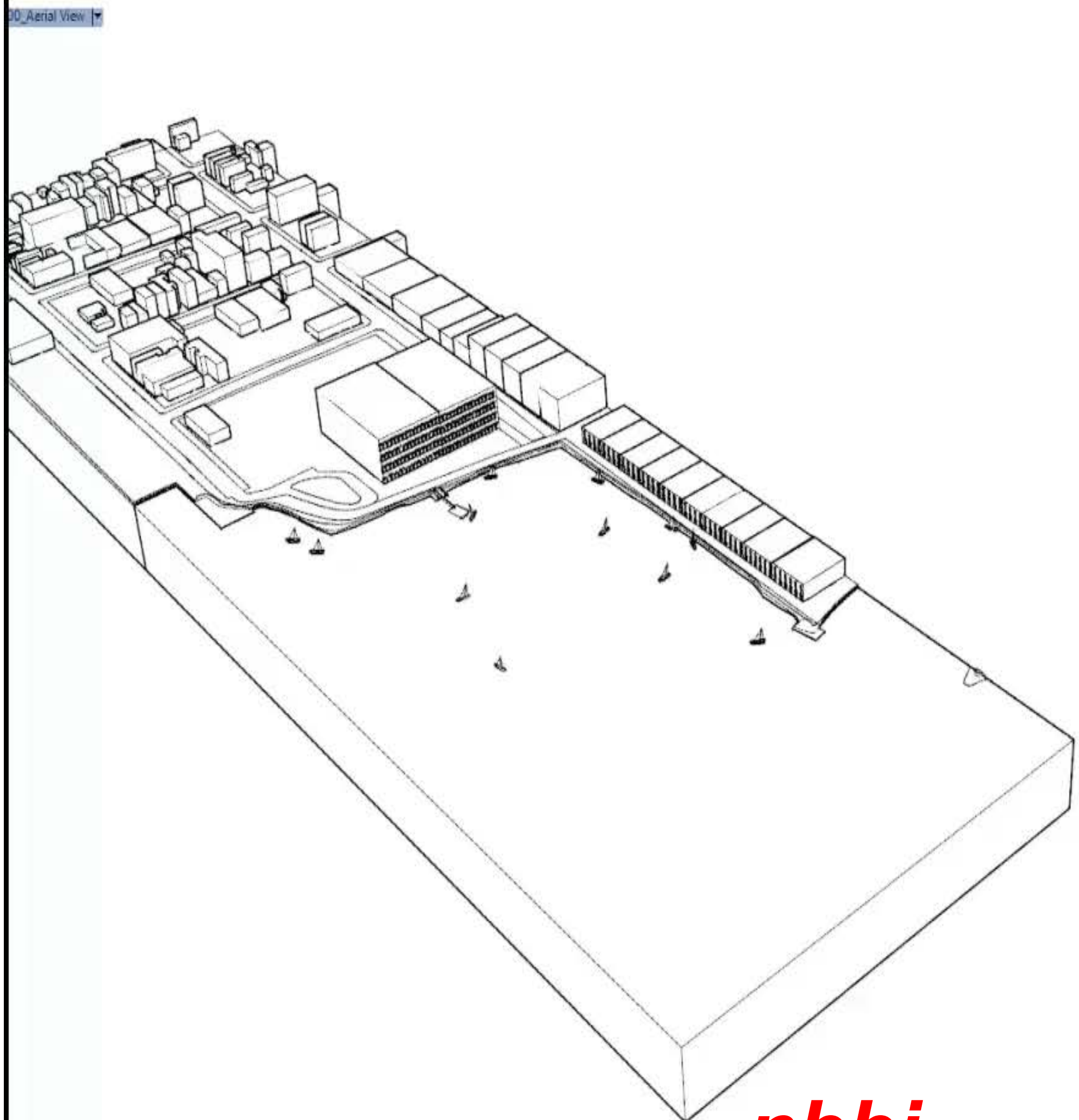
Perimeter Scenario

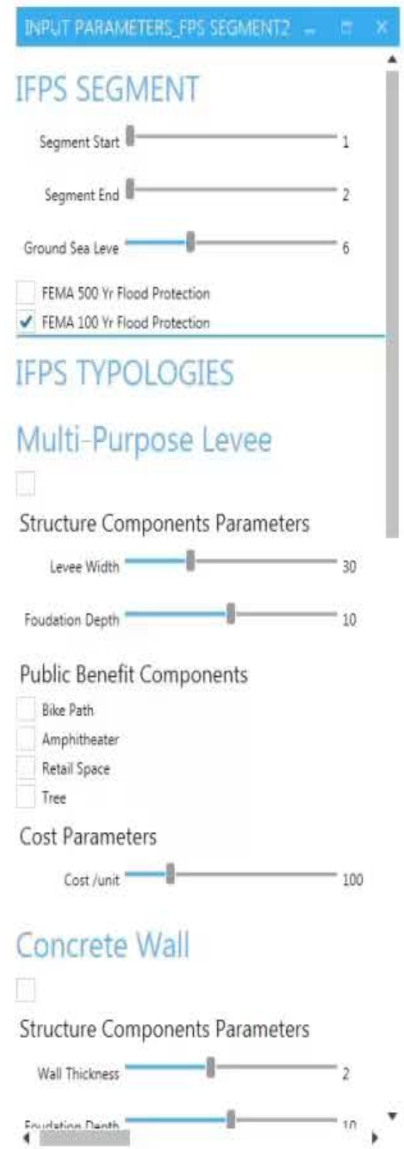


nbbj

DAT Allows for Focused Study

One Tool Used for Multiple Scales



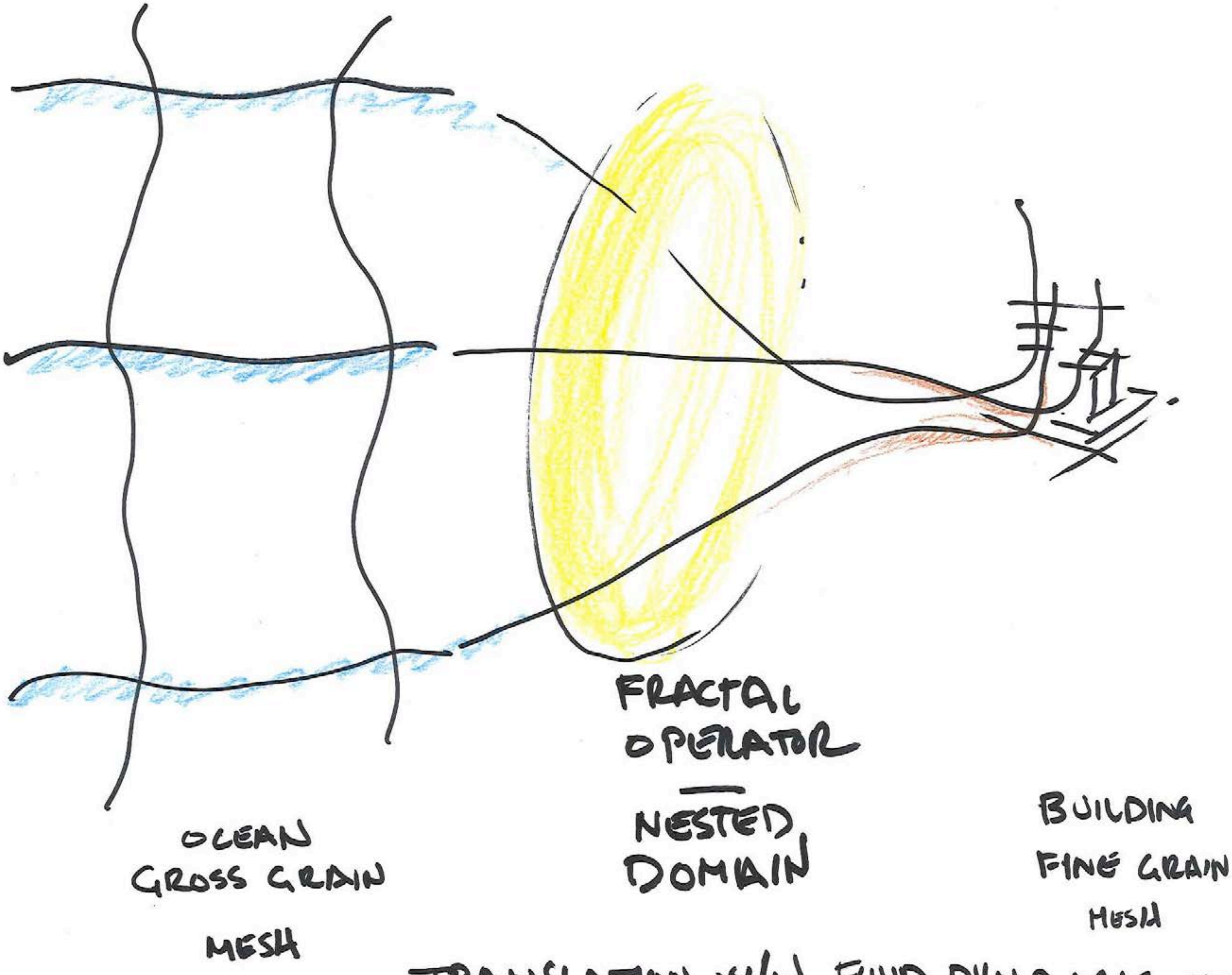


nbbj

gaps: what i wish i knew

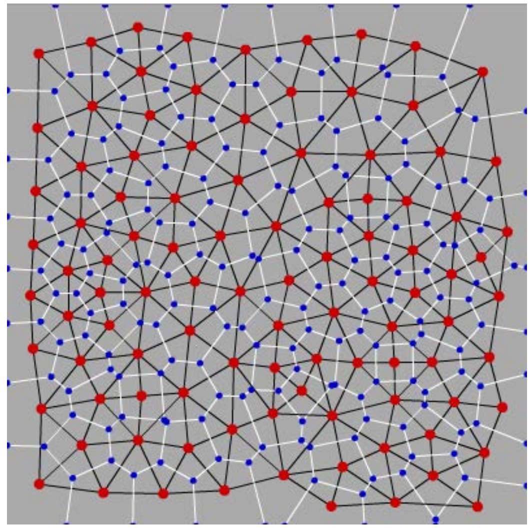
CAN BUILDING AND LANDSCAPE IMPROVEMENTS ON URBAN WATERFRONTS REDUCE THE CONSEQUENCES OF SEA LEVEL RISE AND STORM SURGE ON COASTAL COMMUNITIES?

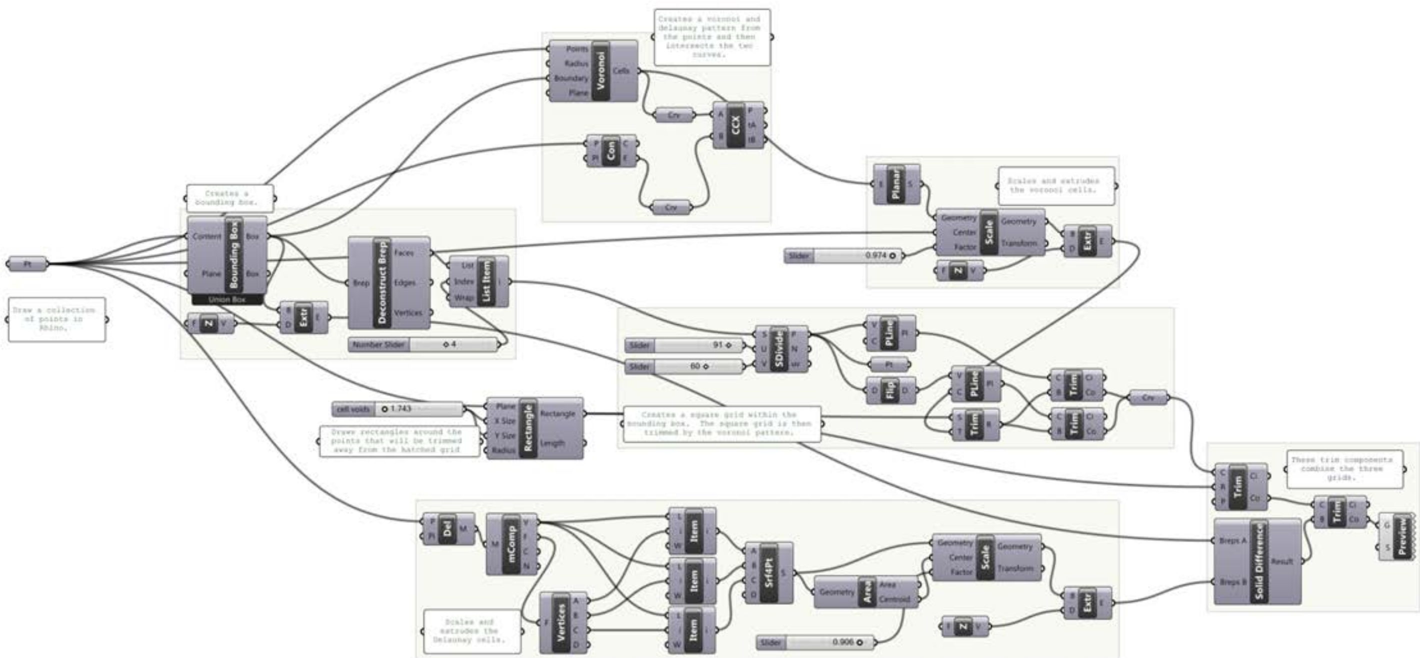
nbbj



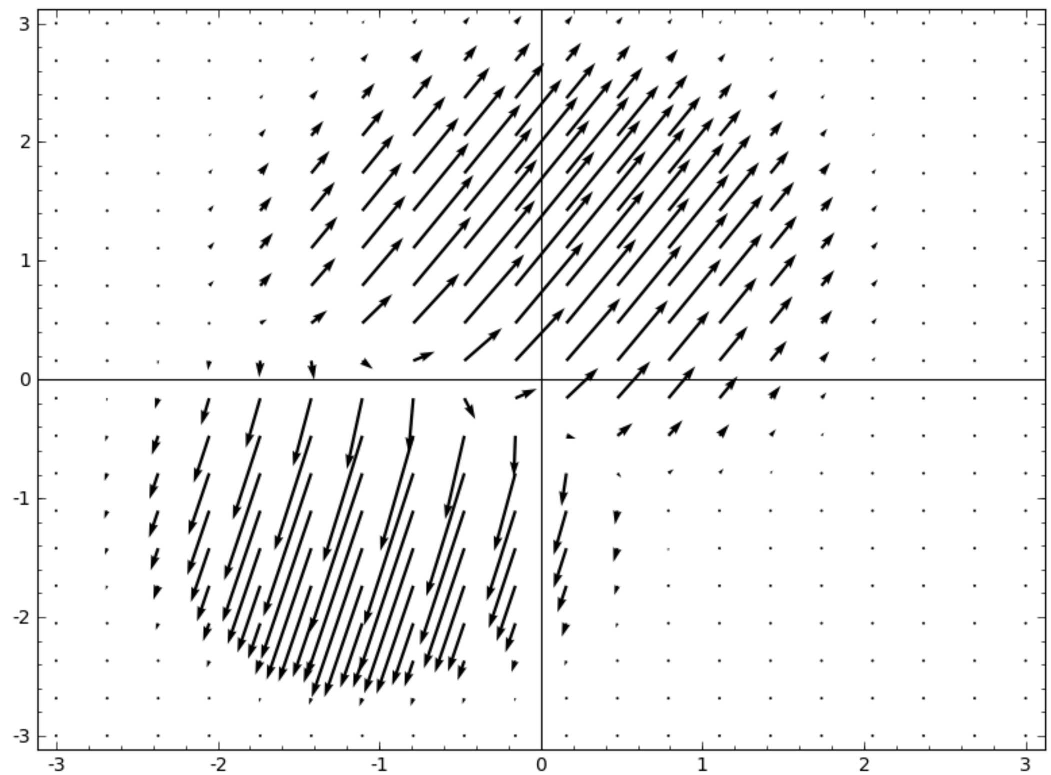
TRANSLATION W/N FLUID DYNAMIC MODEL

DELAUNAY TRIANGULATION AND VORONOI DIAGRAM



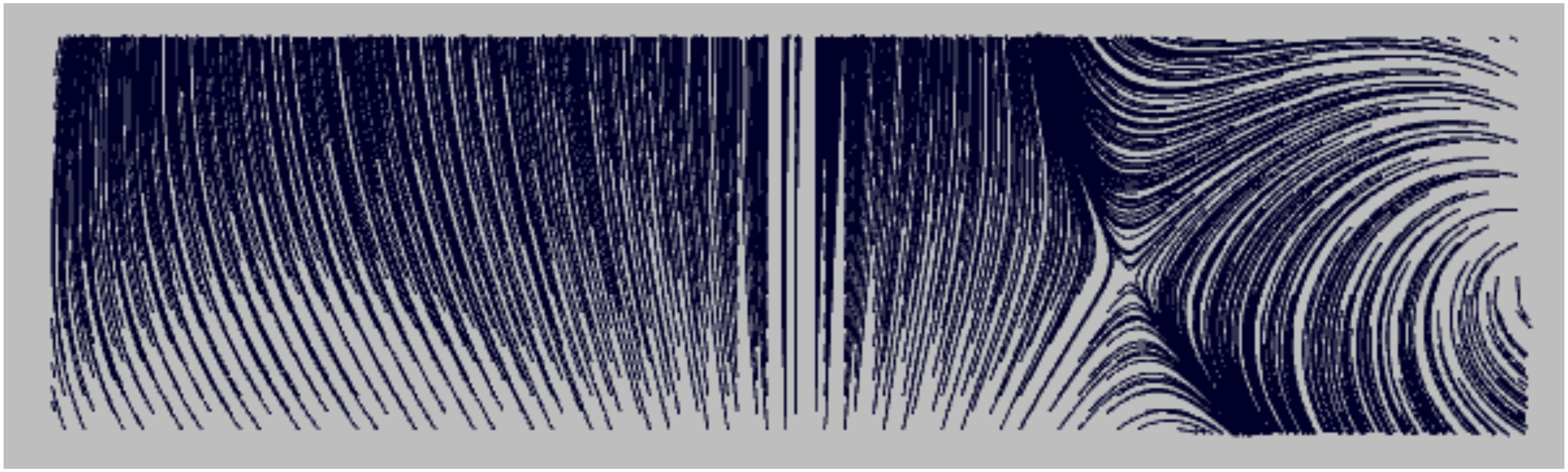


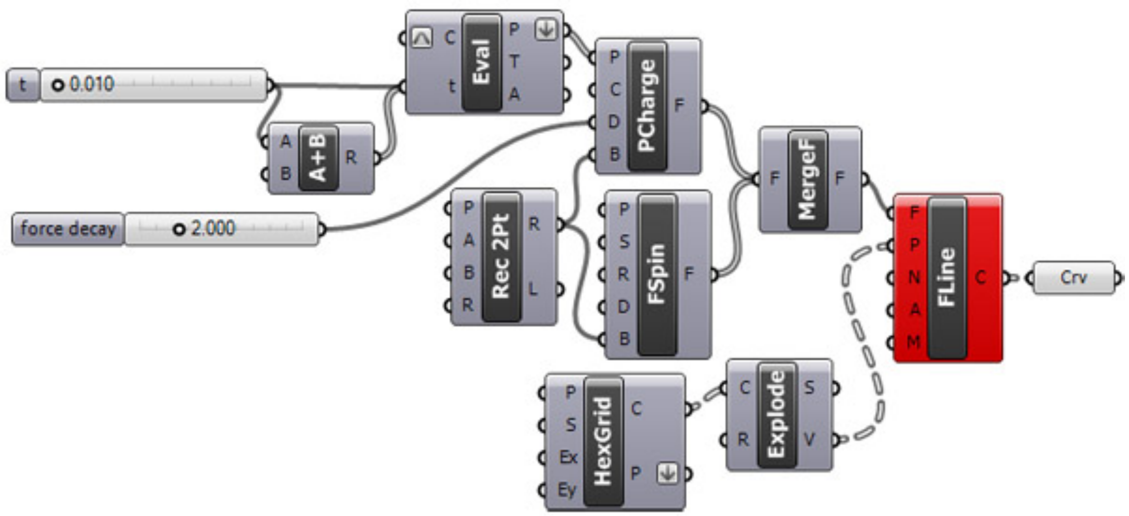
TOPOLOGICAL VECTOR GROUP THEOREM



TOPOLOGICAL VECTOR SET PLOT (MATLAB)

FORCE FIELDS





FORCE FIELD ART IN GRASSHOPPER

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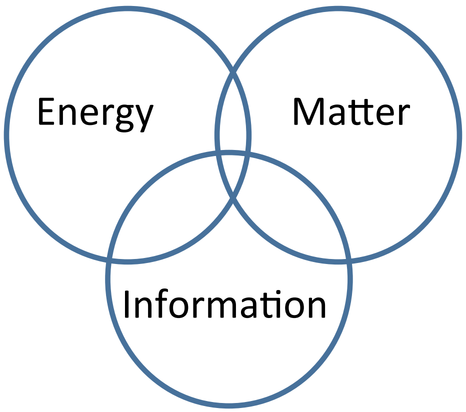
Sensing Dense Urban Environments for Adaptable Buildings of the Future

Mark Arend
Optical Remote Sensing Laboratory
NOAA CREST
City University of New York

What Will the Dense Urban Sensing Systems Look Like in the Future?

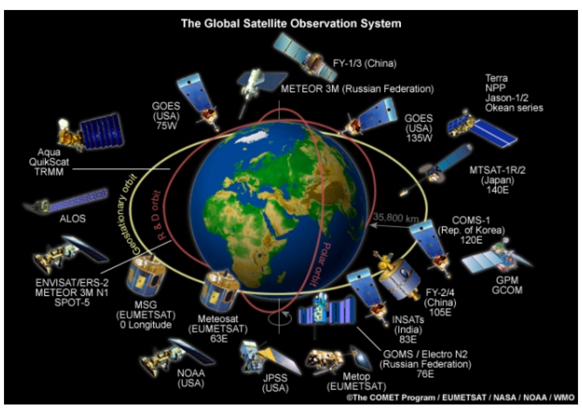


Will the Sensing Systems Adapt as the Human Systems Evolve?

Remote Sensing from Space Will Evolve

"NASA Earth Science Division Operating Missions"

Visible Infrared Imaging Radiometer Suite (VIIRS)
700 m Resolution



Will Governments be responsible for Future Hyperspectral and Environmental Sensing Development?

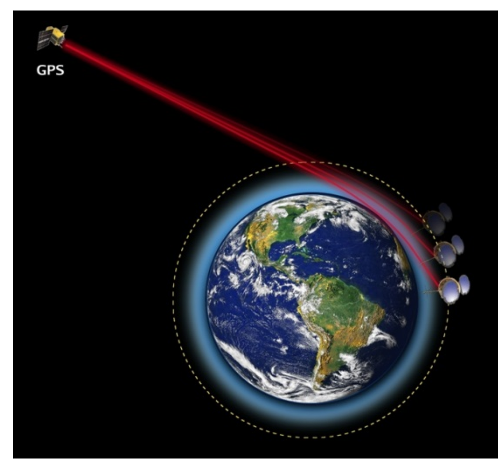
Global Satellite Observing System (Many Countries)

Current Commercial Satellite Sensing

Tempus Global Data and HySpecIQ - focused on hyperspectral atmospheric sounding instruments that would be hosted aboard geostationary-orbiting satellites.

Our desire for mobility has driven the evolution

PlanetiQ, Spire and GeoOptics - Planning constellations of low-orbiting satellites equipped with GPS radio occultation sensors, which measure distortion of GPS signals as they pass through the atmosphere to extrapolate pressure, water vapor and temperature profiles.

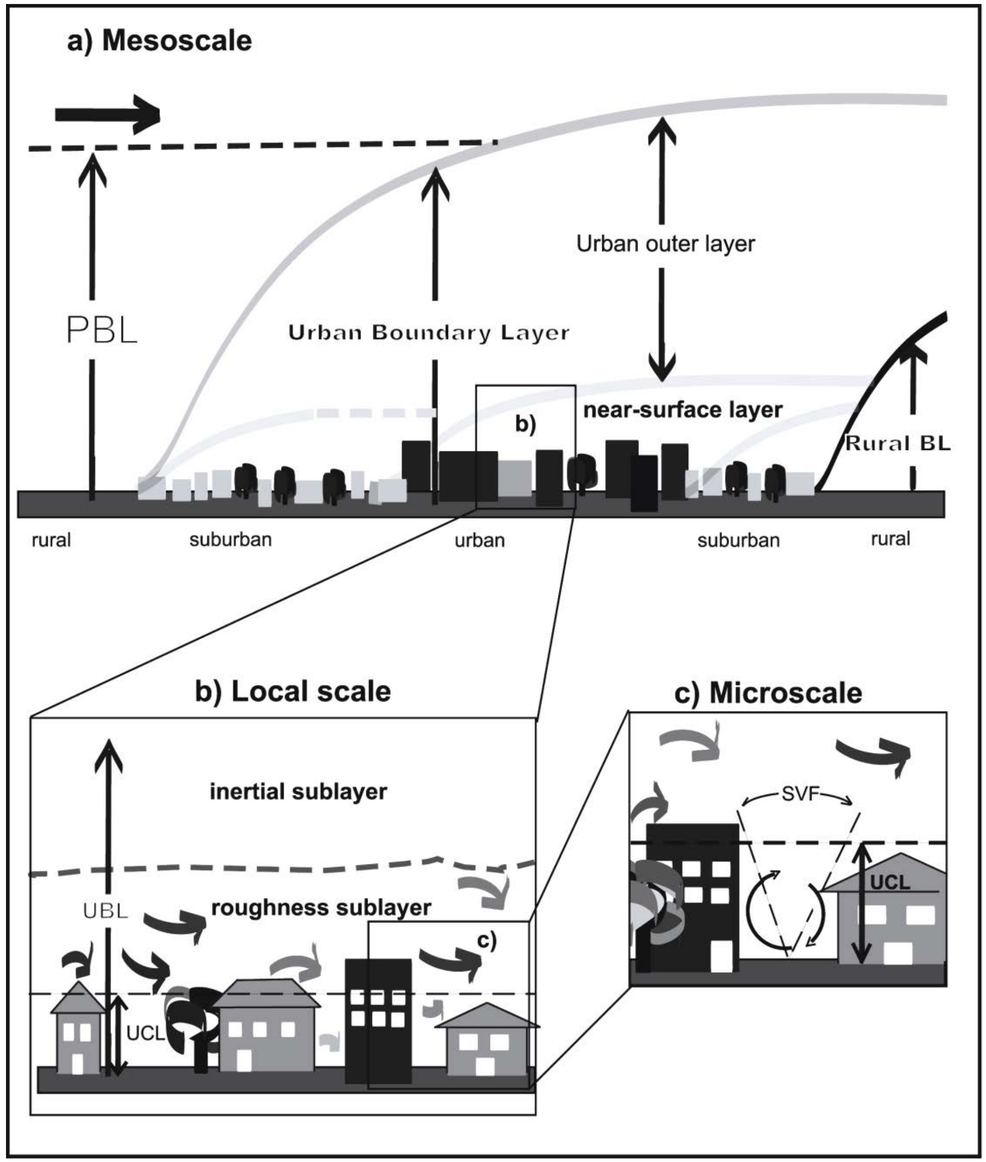


NYCMetNet
Vertical Profilers and Surface Stations
None of the CCNY Operated Rooftop Equipment was Compromised by SANDY

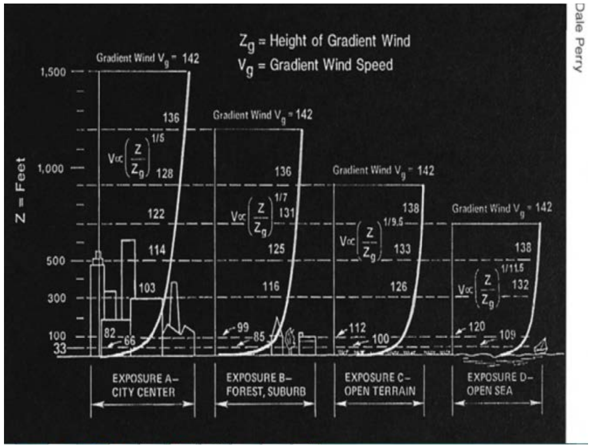
a) Hyper spectral radiometer
b) Sodar to 300 m
c) Radar Wind Proifiler to 2 km

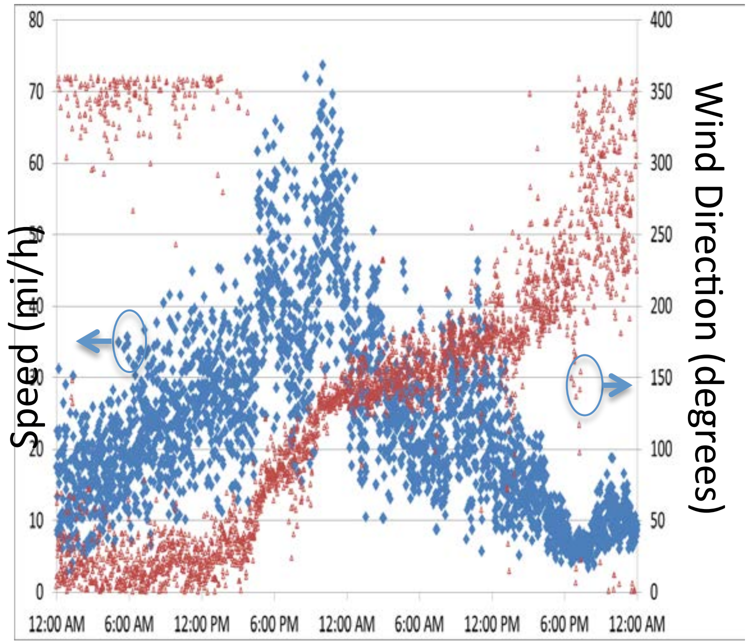
d) Backscatter aerosol Lidar
e) Building top Met Tower
f) Sodar to 400 m

Urban Boundary Layer Dynamics



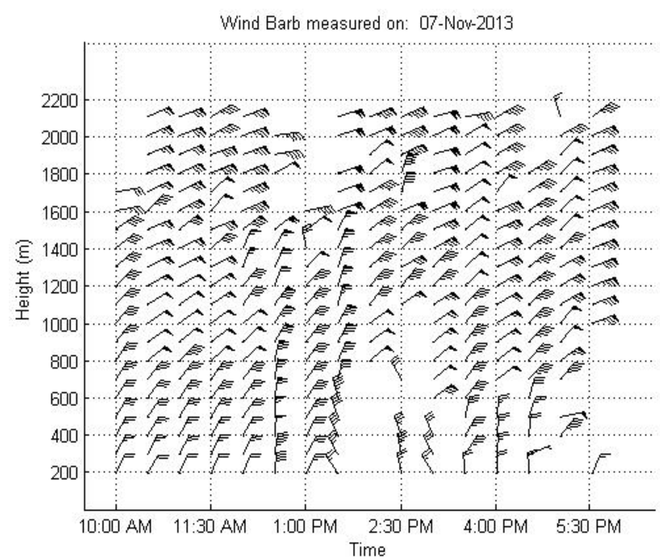
Extreme Weather Case Study Hurricane Sandy





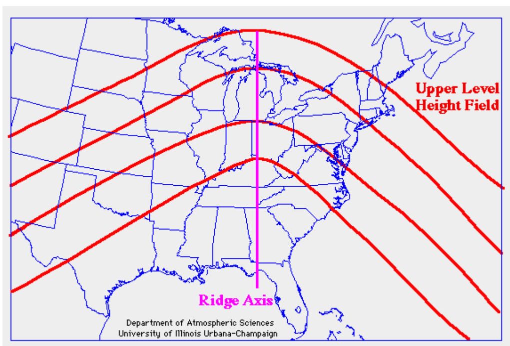
Oct 29 Oct 30 Oct 31

SEI/ASCE 7-02 Second Edition
"Minimum Design Loads for Buildings and Other Structures". Exposure coefficients are applied to adjust for height and terrain dependent wind exposure



The Perfect Storm for Bad Air Quality During Hot Summer Days

Meteorological Conditions



Upper Level Ridge

Sinking air masses

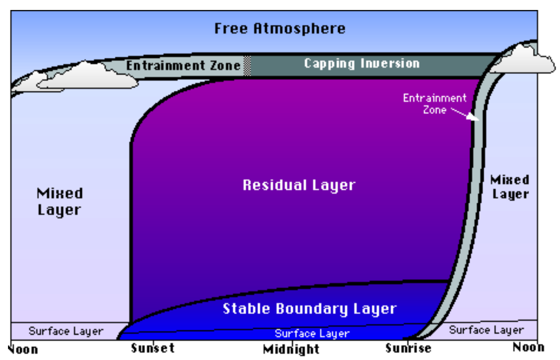
High Pressure

No Clouds

Higher temperatures

Planetary Boundary Layer

"Mixed layer" does not mix much (low to ground level)



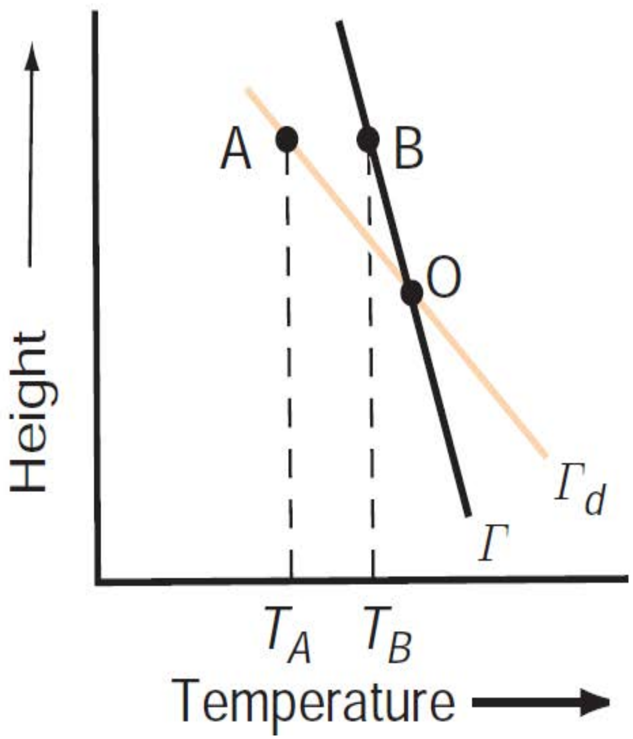
Structure of Planetary Boundary Layer
adapted from Stull, 1988.

Societal Reaction

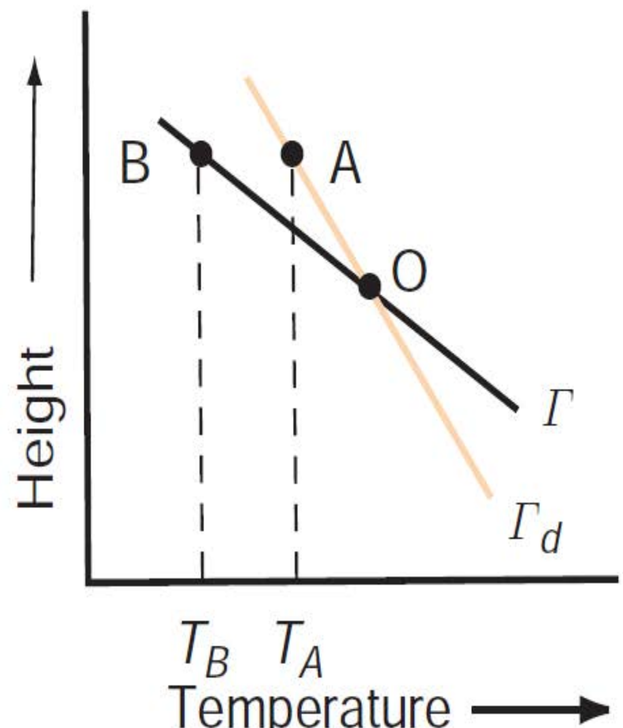
Indoor Air Cooling

Peak Energy Demands Require More Fossil Fuel Burning

Sensing Atmospheric Stability with Ground Based Vertical Profilers
Virtual Potential Temperature
(Normalizes Pressure and Water vapor)

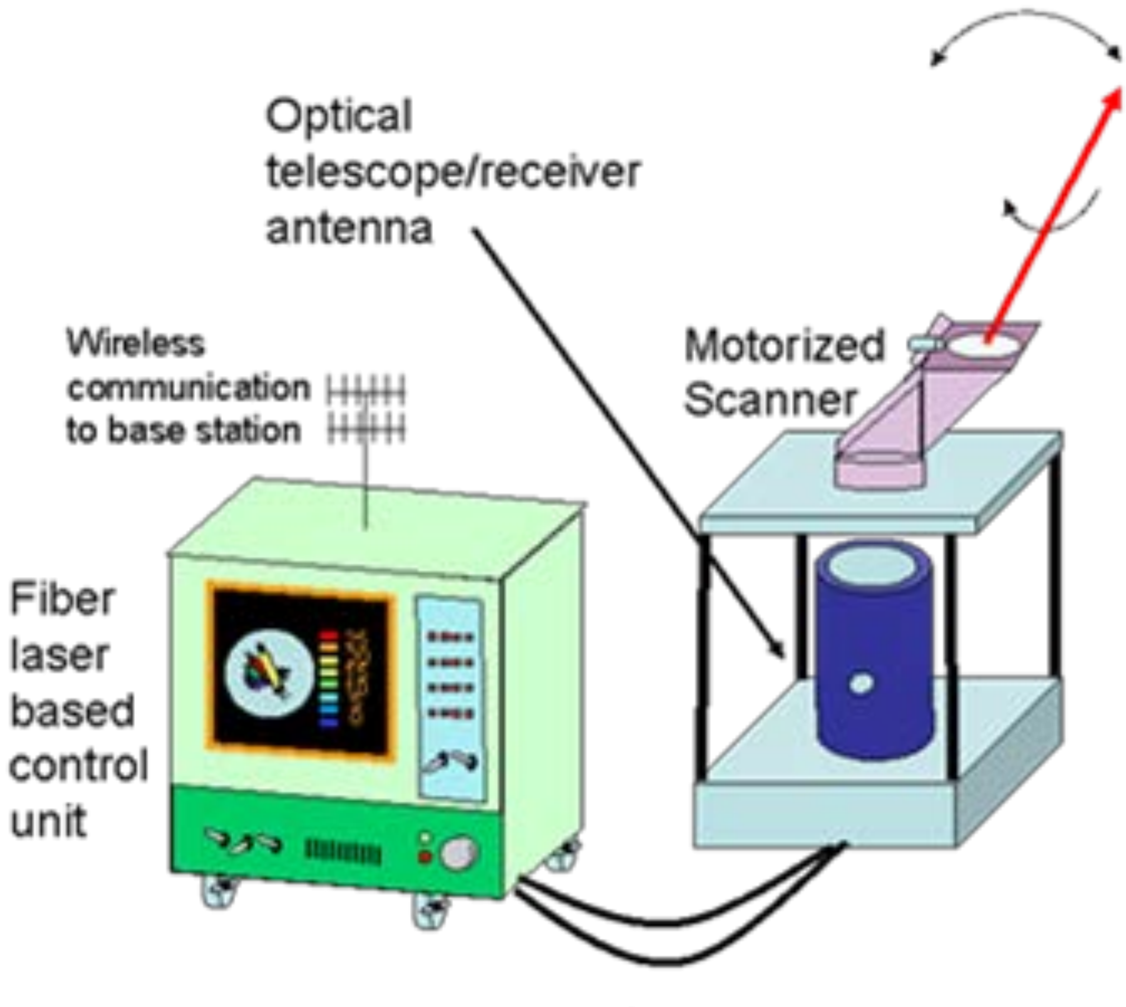


Stable Stratification

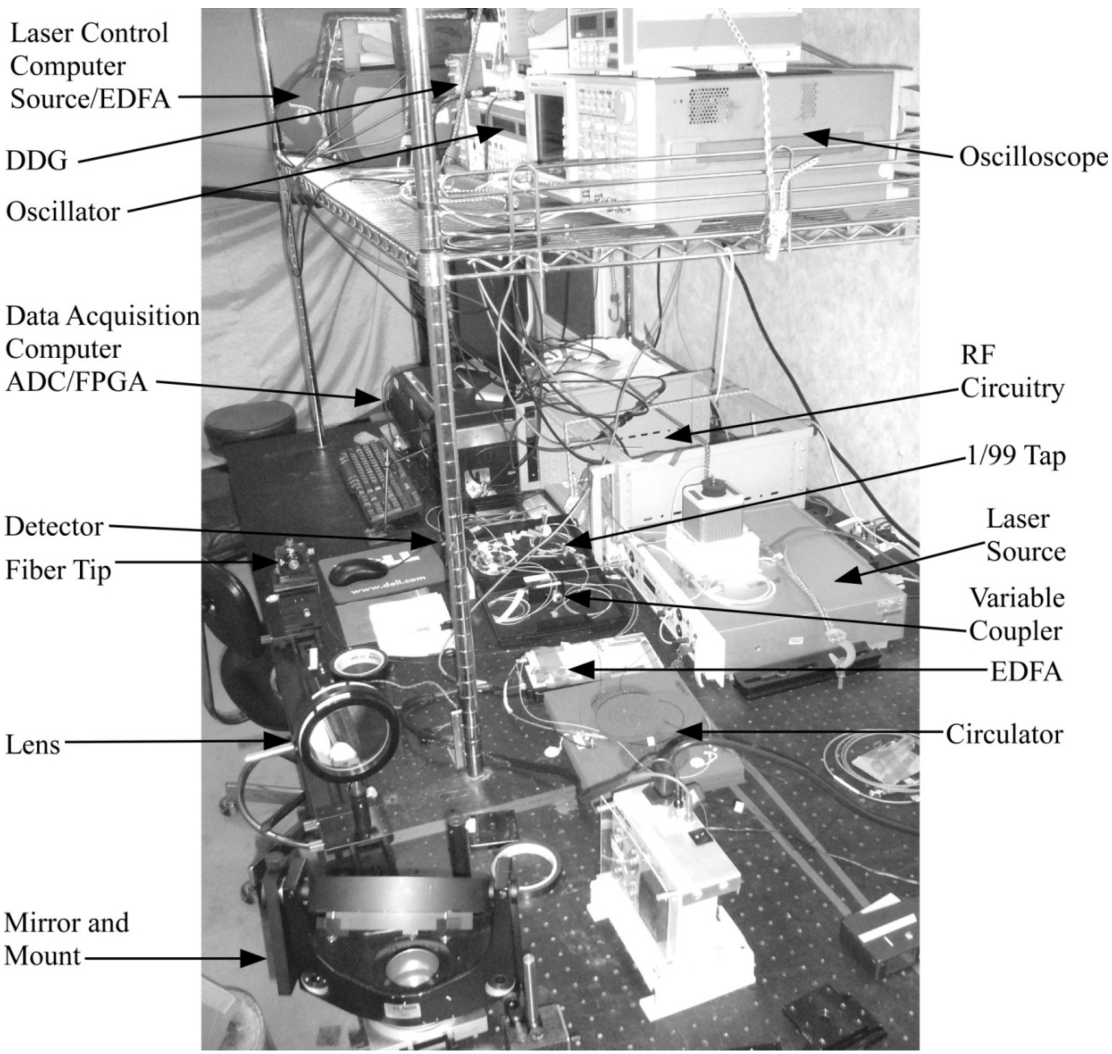


Unstable Stratification

Future Doppler lidar deployment will be autonomous and transportable



Current Doppler lidar deployment is in a mobile laboratory



NYCMetNet
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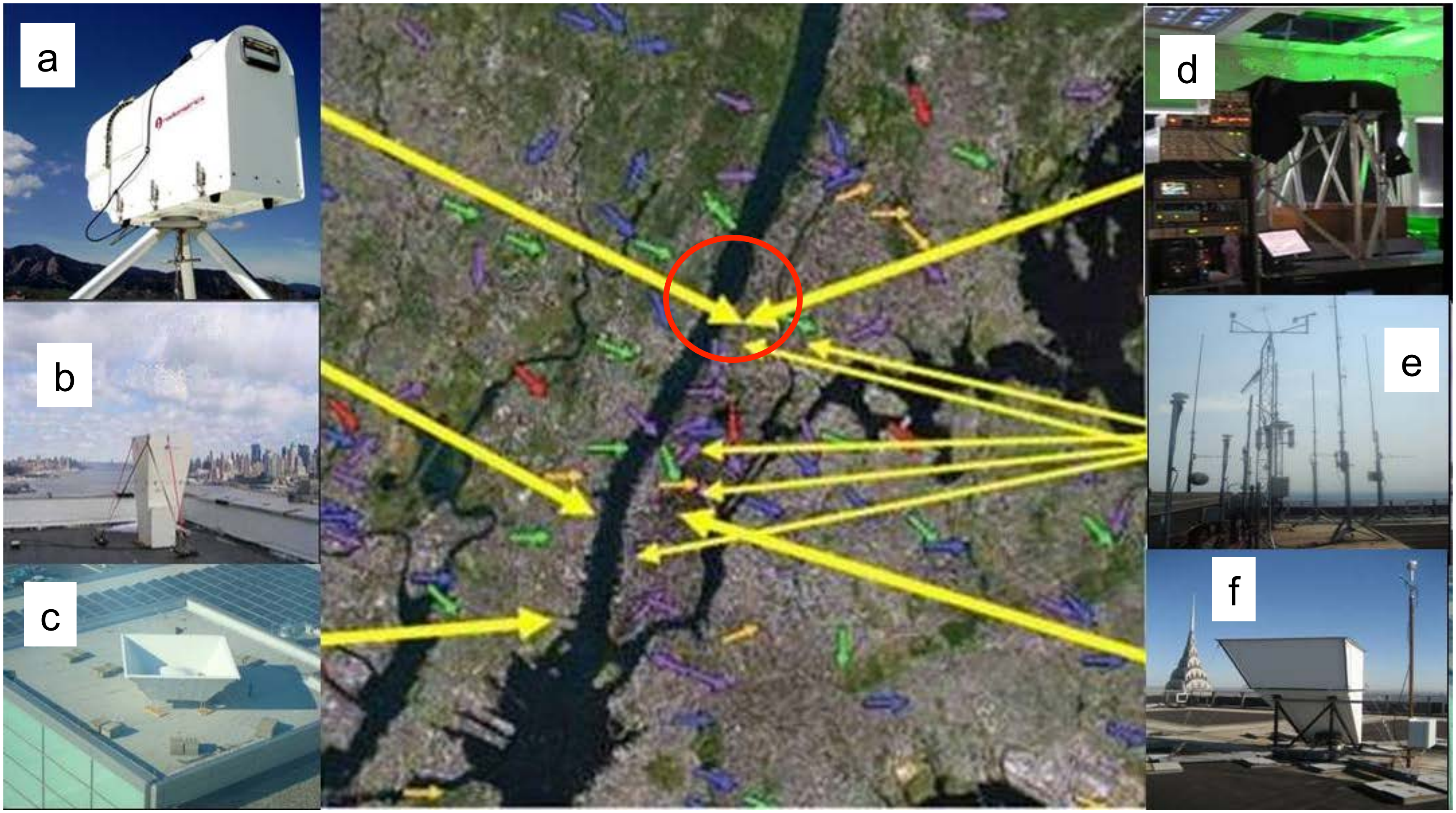

a) Hyper spectral radiometer
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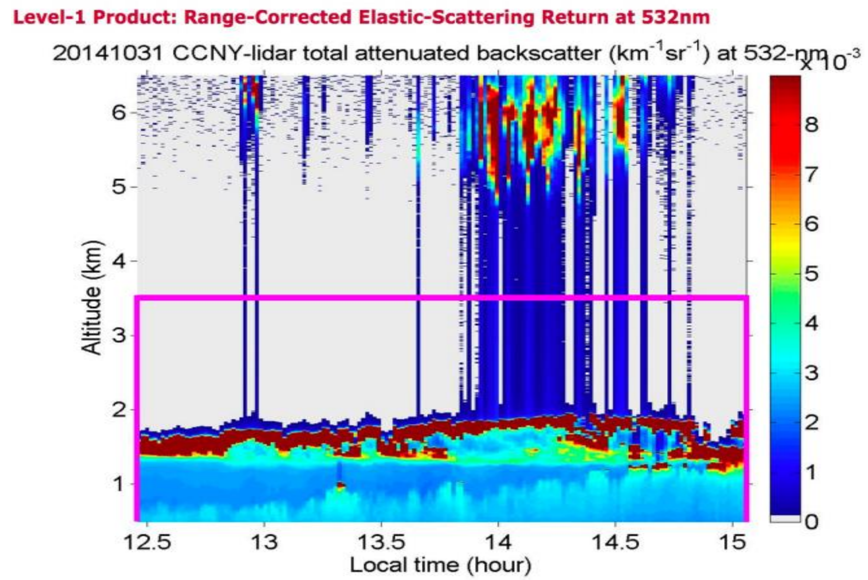
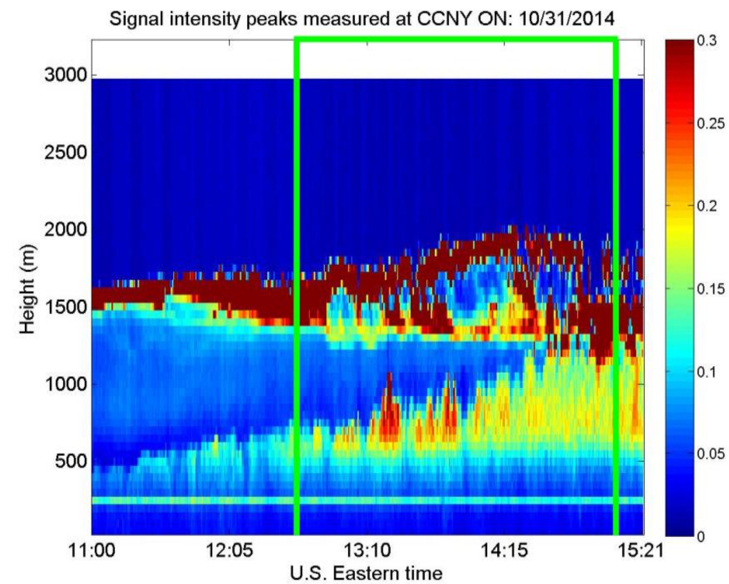
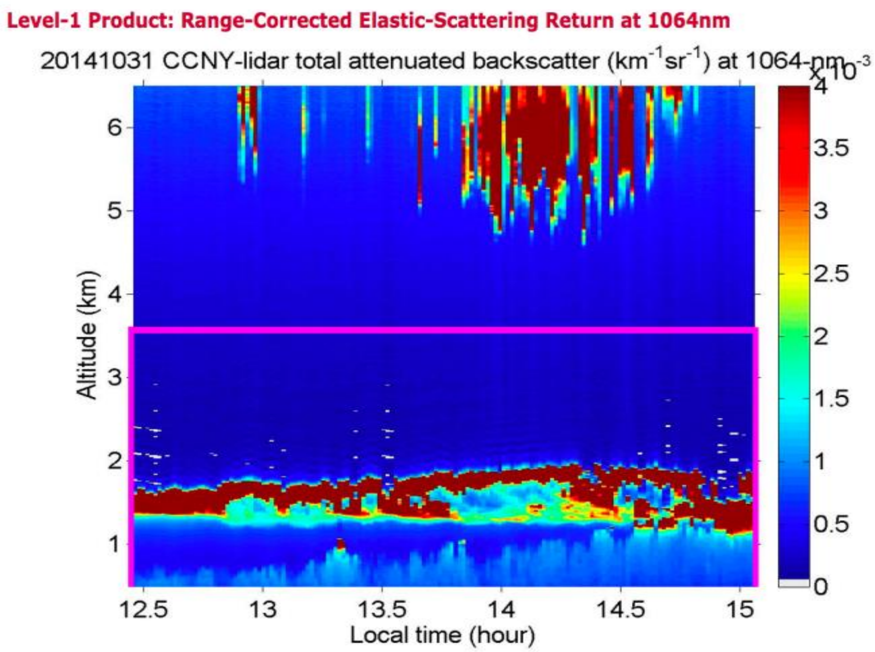
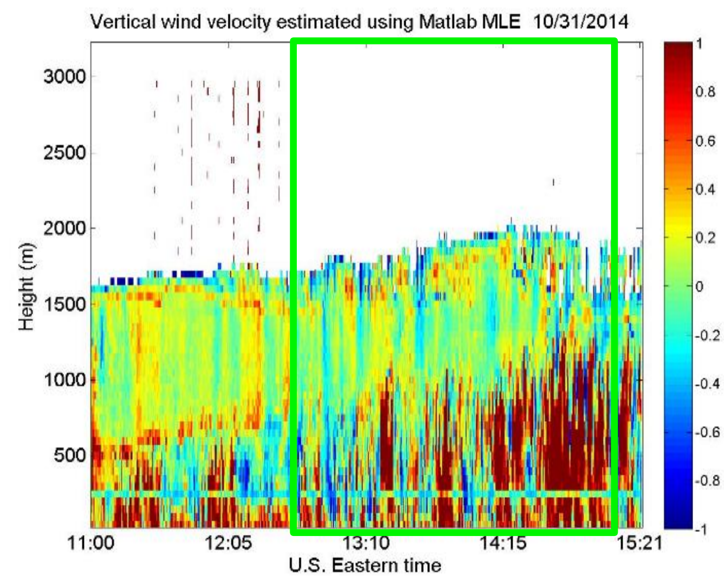
Coherent Doppler Lidar as compared to Direct Detection Lidar





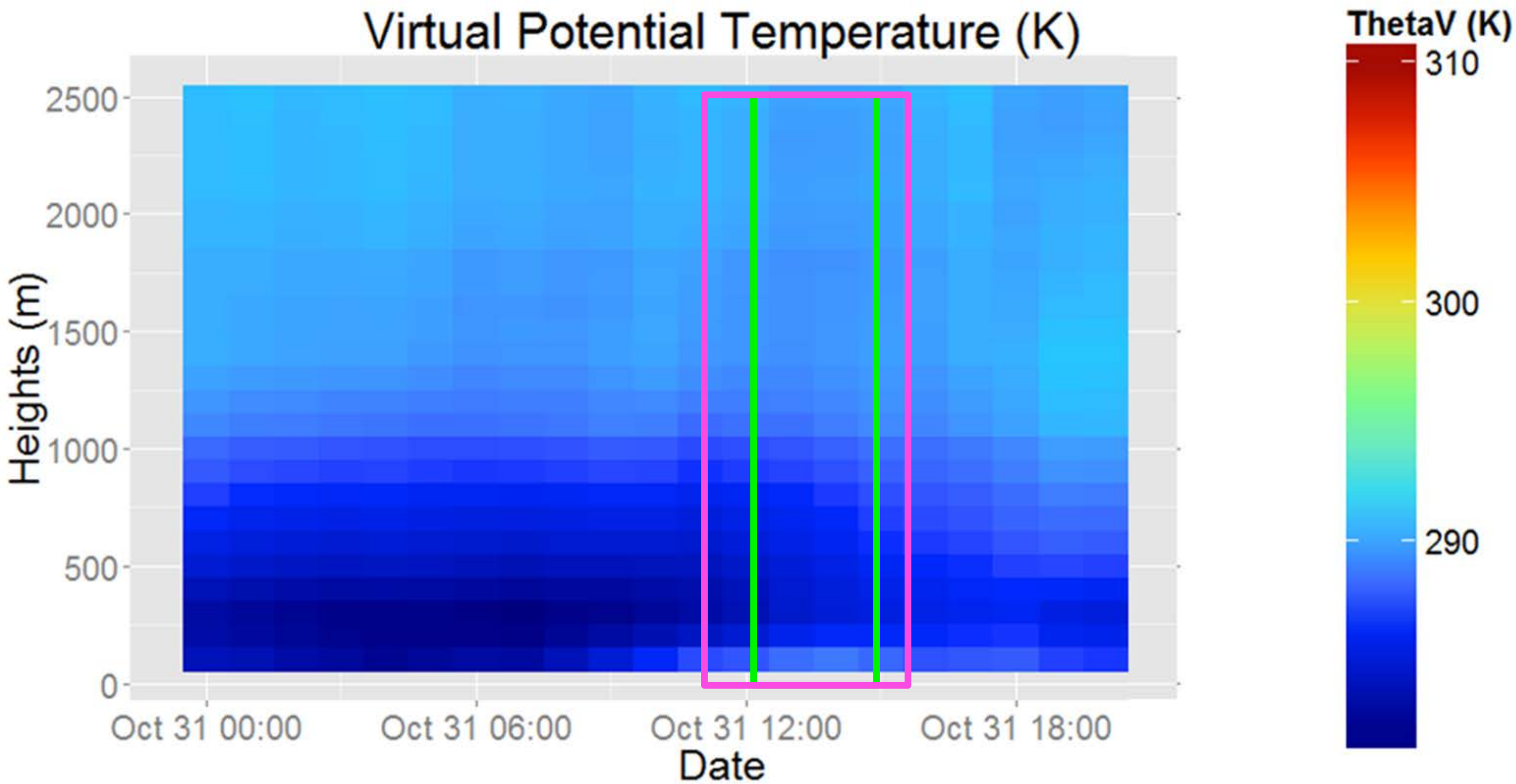


DDL



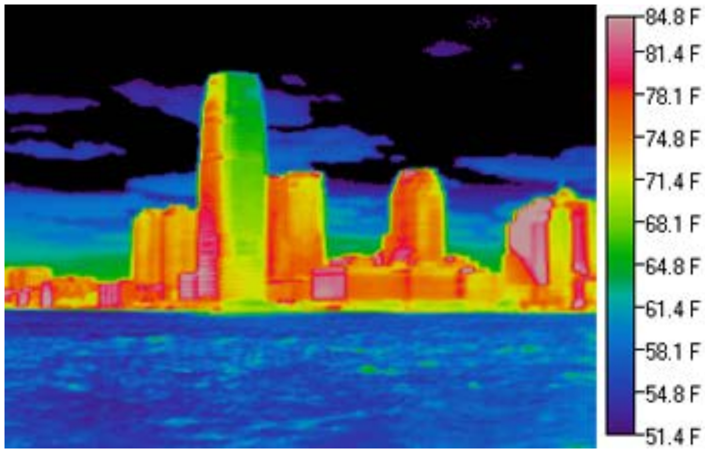
CDL

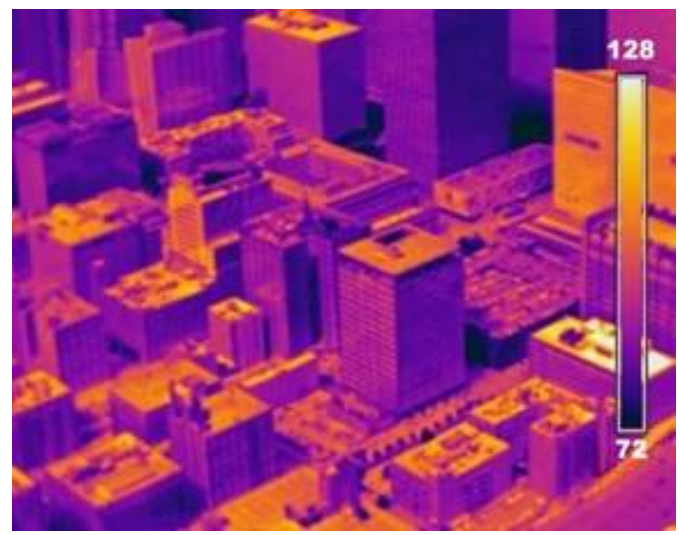
Instability near the surface (up to 200 m) is consistent with vertical velocity lifting.



- This is consistent with the significant aerosol
event and the formation of another (lower) cloud layer at 1400 m

Thermal Imaging of Buildings at High resolutions will evolve and get less expensive

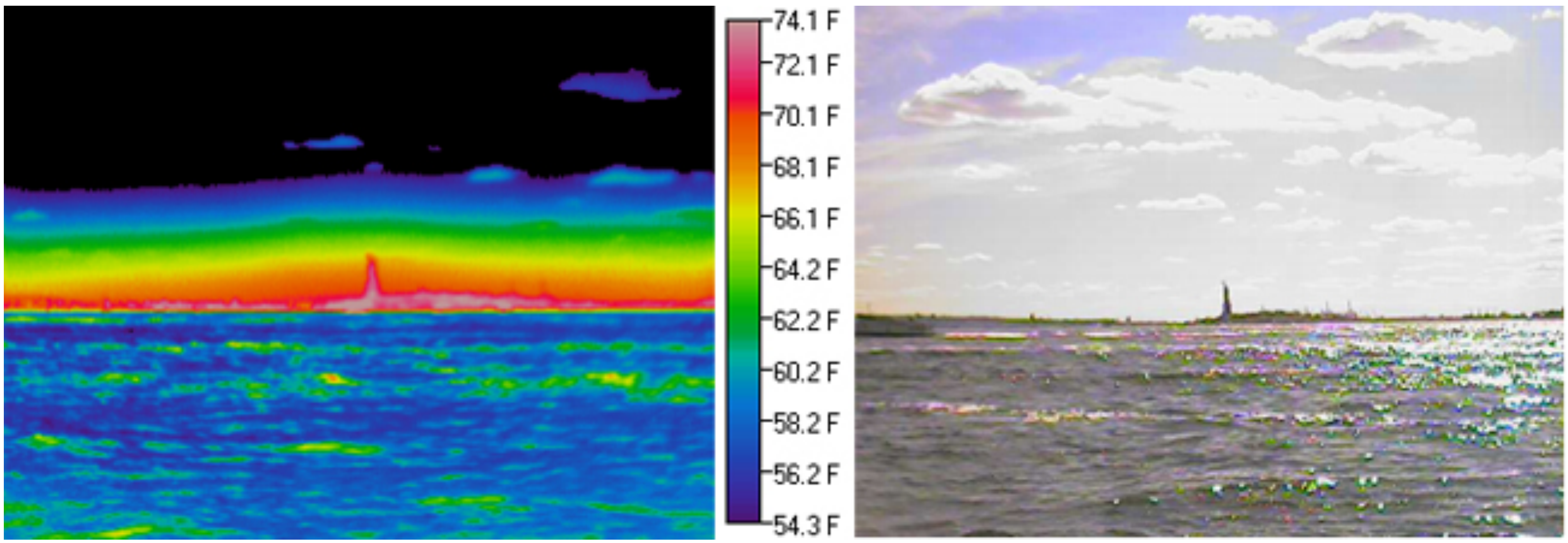




~ $6k now to buy the instrument.

As prices drop who will look at and analyze the information?

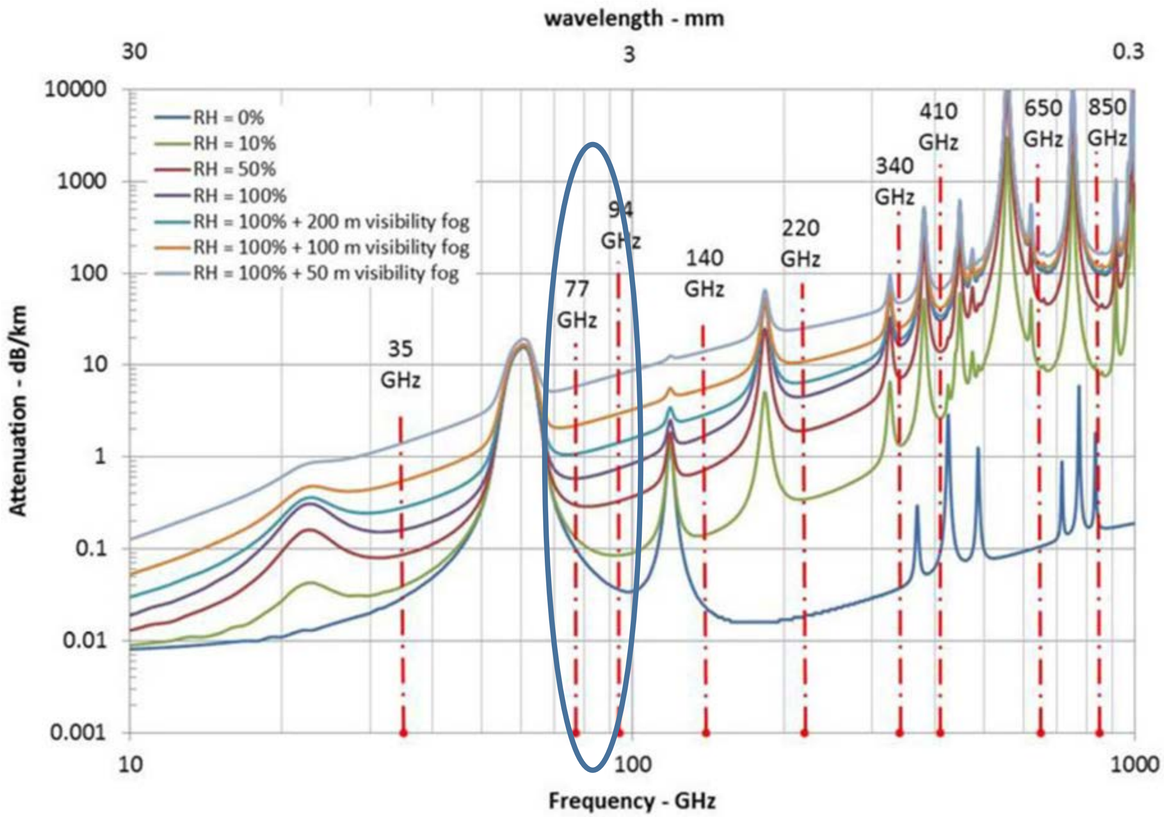
Thermal Imaging of the environment at high resolutions will evolve and get less expensive



Temperature Profile on a hazy day near the statue of liberty

https://www.storagefront.com/therentersbent/why-are-cities-hotter-than-surrounding-areas

Desire for more Bandwidth will open up New Bands for Communication at 80 GHz
This can be Leveraged to Sense



Our desire for mobility and knowledge
will continue to drive the evolution.
But, who will trust the knowledge?

FUTURE CITIES: History and Strategy

ROBERT CAVEY, Partner
Praxis

“Future Cities” = Cities in History

History = Human condition and events over time

Understanding = Causation

Response =

When is which response required?

- To endure
- To administer
- To resist
- To create

What is an Impasse?

The Homeric Challenge

The Achaeans v. Troy: Ten Years on the Beach

. . . *and no change in sight*

at is a Strategic Response to an Impass

The Odysseus Vision – In one night . . .

Same Problem – Radically New Approach

The Carbon Impasse

Development = Electrical Power

Electrical Power = Carbon

Carbon = Greenhouse Gas

Global Development =

Carbon Footprint X 8 Billion

o fundamental change in that equation in sigh

What is Required to Create History?

First: Knowledge

Structure

- Material
- Form

Dynamics

- Forces
- Trajectory

Material: Modern Humanity

Industrious

Selfish

Acquisitive

Ambitious

Forms: Institutions

Modernity → Nationalist, Democratic, Commercial, Socialist, Communist . . .

and

URBAN

Forces: Ideas

- 1600s Scientific
- 1700s Technological
- 1800s Industrial
- 1900s URBAN (population, HVAC, Indoor Water)

Trajectory: Goals and Outcomes

Safety

Opportunity

Prosperity

and

. . . Impasse: ***The Unforeseen Consequence***

Response Options

Endure, Administer, Resist, or *Create*:

1. A Radically New Vision: Less Carbon, Less Energy, Less Prosperity, Less Opportunity . . .

2. Odysseus Principles:

- Eschew the Incremental/Manage the Whole
- Make the Obstacles Work *For* You
- Save the Mission

URBAN DATA AND FUTURE CITIES =

trategic Science, Technology, Industry and Urban Governance

ogether Creating History

hrough Cross-Sector Collaboration

Making it Possible for Modern Humanity to Preserve its Defining Aspiration

With the Basic Knowledge Required

To Administer the Whole Urban Form *Sustainably*

. . . like it or not

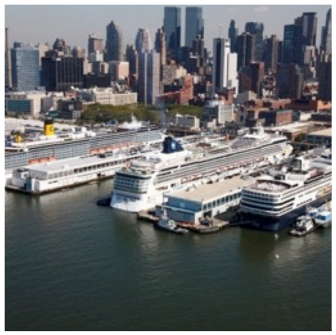
Economic Development & the Future of Buildings

David Gilford, Vice President, New York City Economic Development Corp.

May 4, 2015

Our vision for New York City: the global model for inclusive innovation and economic growth, fueled by the diversity of our people and our businesses.

NYCEDC helps transform NYC's physical and intangible assets



CAPITAL CONSTRUCTION & ASSET MANAGEMENT

MAJOR INITIATIVES: Brooklyn Army Terminal; Cruise Terminals; Public Markets

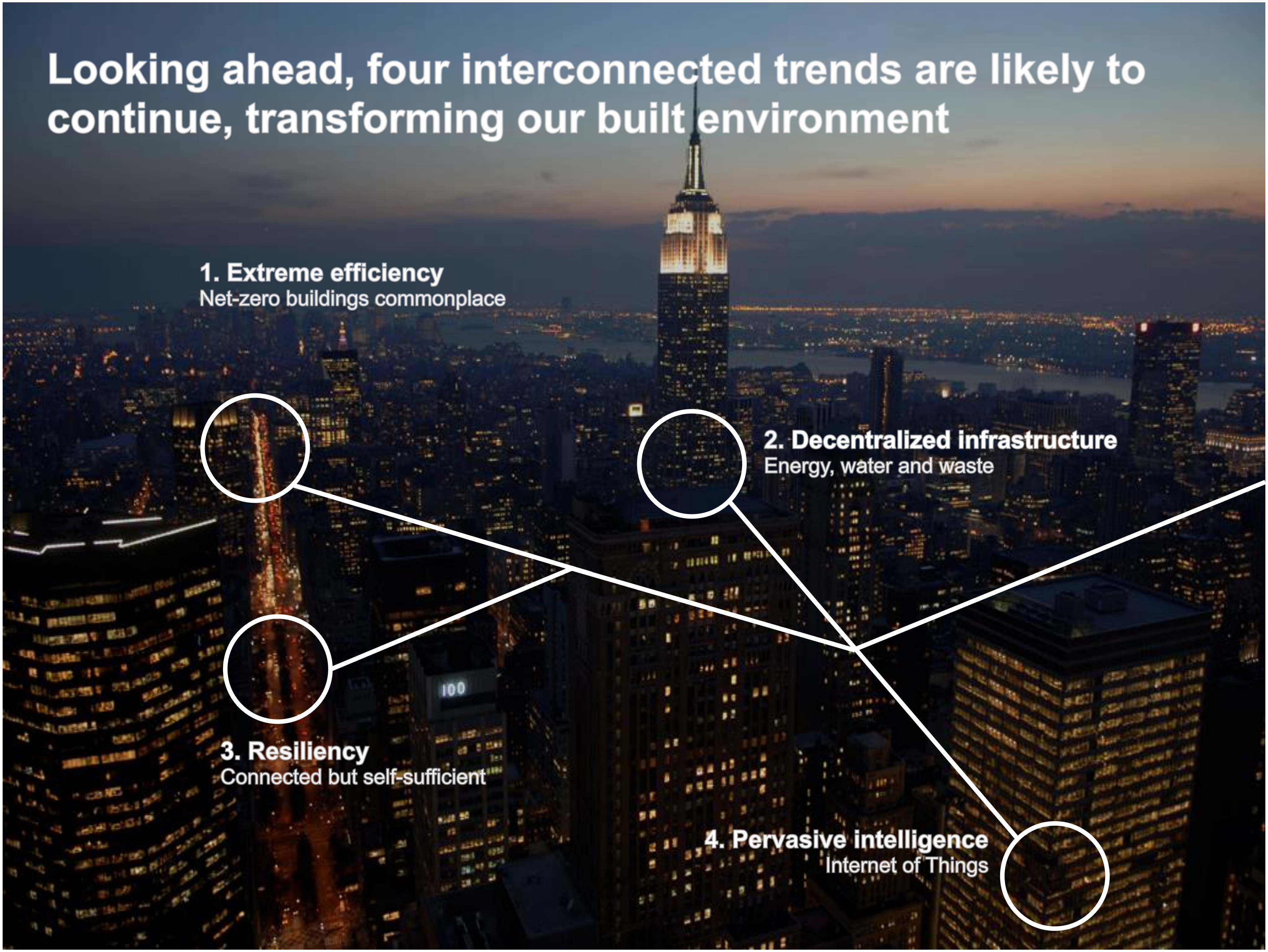
REAL ESTATE DEVELOPMENT

MAJOR INITIATIVES: Jamaica Planning Initiative; High Line Park; Mixed-use Development; Coney Island; JetBlue to LIC

CENTER FOR ECONOMIC TRANSFORMATION

MAJOR INITIATIVES: Applied Sciences NYC; Incubator Network; Tax Credits & Bond Financing

We view meeting the City's sustainability & resiliency challenges as an economic opportunity


Looking ahead, four interconnected trends are likely to continue, transforming our built environment
1. Extreme efficiency
Net-zero buildings commonplace
2. Decentralized infrastructure
Energy, water and waste
3. Resiliency
Connected but self-sufficient
4. Pervasive intelligence
Internet of Things
100

Thank you.

NYCEDC

Contact:

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Center for Economic Transformation
New York City Economic Development Corp.
dgilford@nycedc.com

Links:

- nycedc.com/cleantech
- nyc.gov/onenyc

Buildings Of The Future: NYC Workshop

May 4, 2015

Jin Jin Huang
Con Edison

Agenda

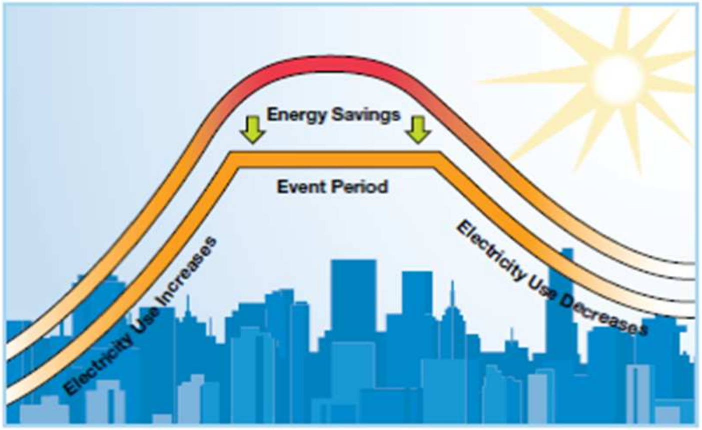
- Demand Management Program- System coincident peak reduction
- Brooklyn Queens Demand Management Program- Network peak reduction

Demand Management Program (DMP)

- Indian Point Energy Center potentially closing:
  - 2 nuclear generating units, approx. 2,000 MW
- 1,450 MW reliability shortfall by summer 2016
- 125 MW carve-out for demand reduction
  - 100 MW energy efficiency/demand reduction
  - 25 MW combined heat and power
- Joint Con Edison-NYSERDA $285M program

DMP Targets Specific Peak Hours

- **Peak Demand Reduction (kW)**
  - projected average system - coincident peak demand reduction that occurs during on-peak hours
- **On-Peak Hours**
  - 2 p.m. – 6 p.m.
  - Monday – Friday (excluding Holidays)
  - June 1 through September 30



Demand Management Program Incentives

Project	Current Incentive	DMP Incentive/kW	Total Customer Benefit
Thermal Storage	*$600/kW*	*$2,000*	*$2,600/kW*
Battery Storage	*$600/kW*	*$1,500*	*$2,100/kW*
Chiller/HVAC/Controls/ Process Efficiency	*$0.16/kWh*	*$1,250*	*$0.16/kWh + $1,250/kW*
Lighting/LED	*$0.16/kWh*	*$800*	*$0.16/kWh + $800/kW*
DR Enablement	*$200/kW*	*$600*	*$800/kW*
Fuel Switching (Non-electric AC)	*Steam AC Program*		*$500-$1,000/kW*
Large Project Bonus			
Projects over 500 kW		*+10% of kW incentive*	*Bonus funds are first installed, first paid.*
Projects over 1MW		*+15% of kW incentive*	

Brooklyn Queens Demand Management (BQDM) Program Funding

- Subtransmission feeders serving two networks in Brooklyn and one network in Queens overloaded
- Targeted peak period:
  - 12pm-12am
- Commission approved:
  - Customer Sided 41 MW ($150m)
  - Utility Sided 11 MW ($50m)

Buildings of the Future Scoping Study
remarks by T. Butcher

May 4, 2015

BROOKHAVEN
NATIONAL LABORATORY

a passion for discovery

Office of Science
U.S. DEPARTMENT OF ENERGY

Connected Systems

•Meters
•Thermostats
•Air Conditioning
•Heating
•Lighting
•Generation Assets
•Energy Storage
•Appliances
•Buildings

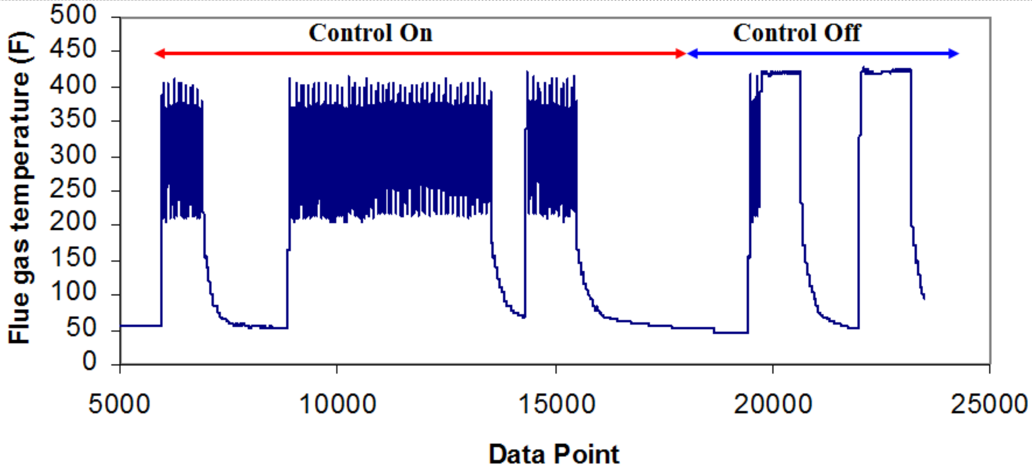
What Can We Do With This?

•Demand Side Management
•Recovery Management
•Networking of Distributed Generation / Storage Assets
•Service – Equipment Efficiency plus Maintenance Operations Efficiency
•Identification of Opportunities for Efficiency Measures
•Field Energy Efficiency Studies
•Live Upgrade of Control Algorithms
•Remote Implementation of Control
•Feed –forward Control Based on Weather Forecasts
•Right-Sizing of Future Equipment Upgrades

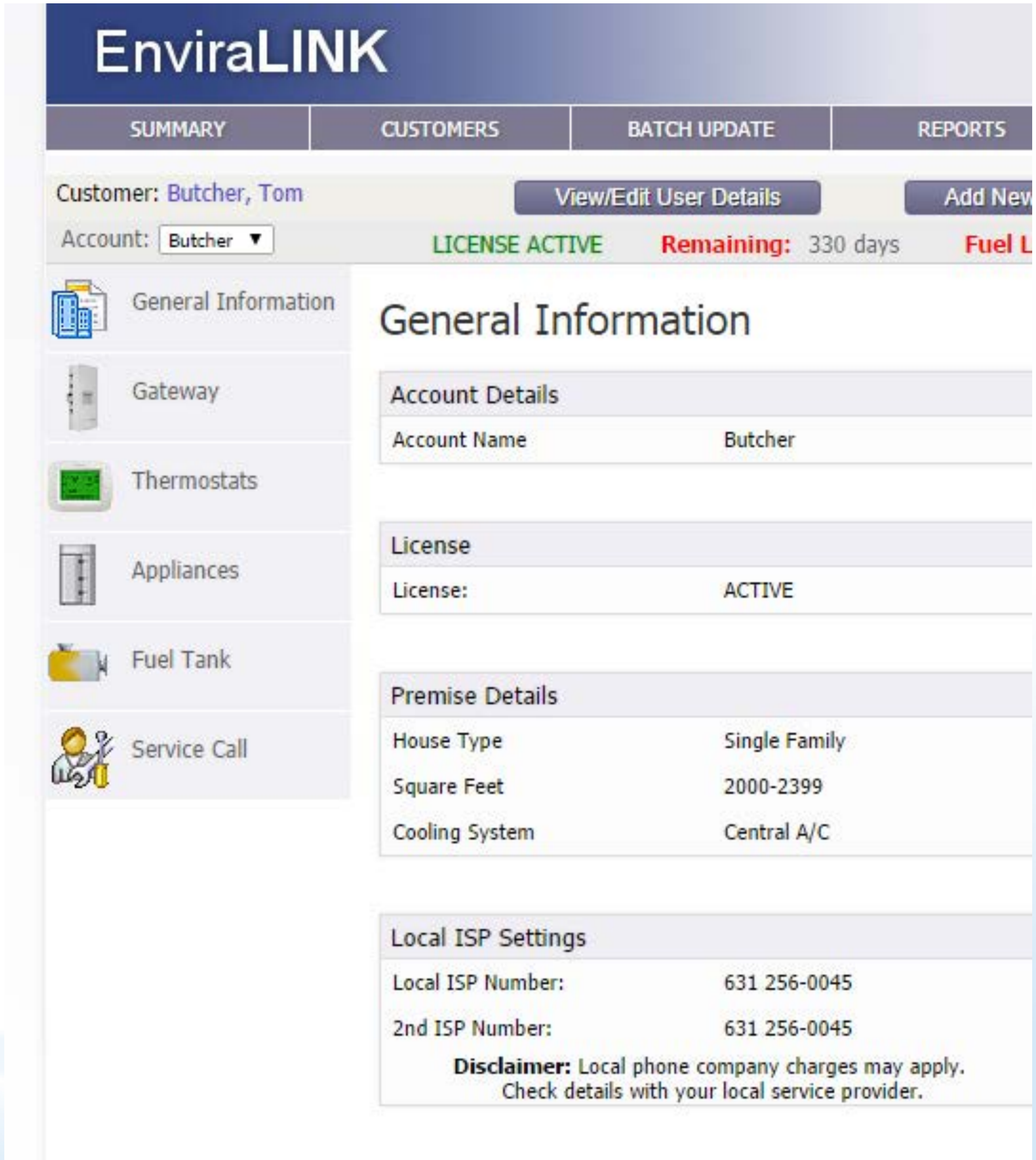
Example Boiler Outdoor Reset

•All new heating boilers are required to have some type of control which changes water temperature based on load
•Involves new operating controls and sensors – fixed algorithm
•In a connected appliance this control function could be implemented remotely
•Could this comply? How would we know system is complying after installation?
•Could we update control algorithm remotely?

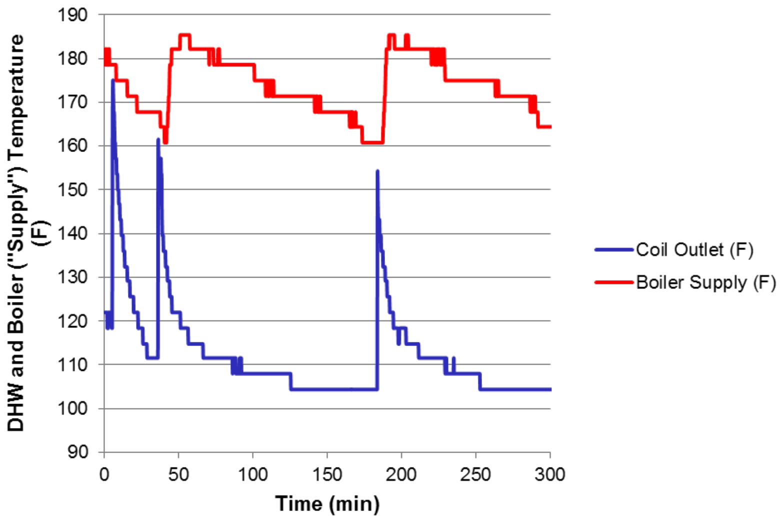
Field Testing / Performance Data

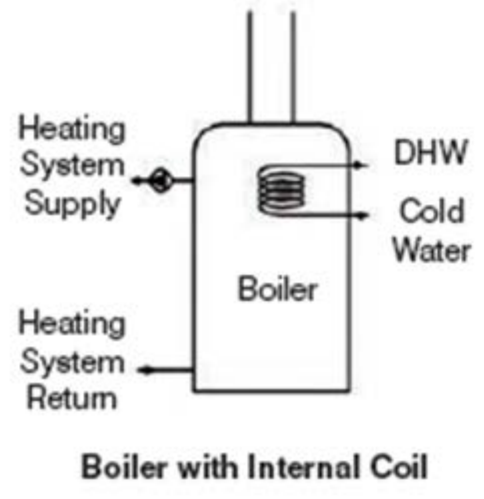


Example - Current Use for Field Tests at BNL



Common Tankless Coil Boiler





- Reduced Idle losses with lower operating temperatures present a great energy savings opportunity
- Control concepts based on use – patterns or current actual
- New controls can save a significant amount but – do they need to be local or can they be implemented remotely?

Appliances

Fuel Tank

Service Call

Show only changed rows:

Show History

Last Value in Selected Range

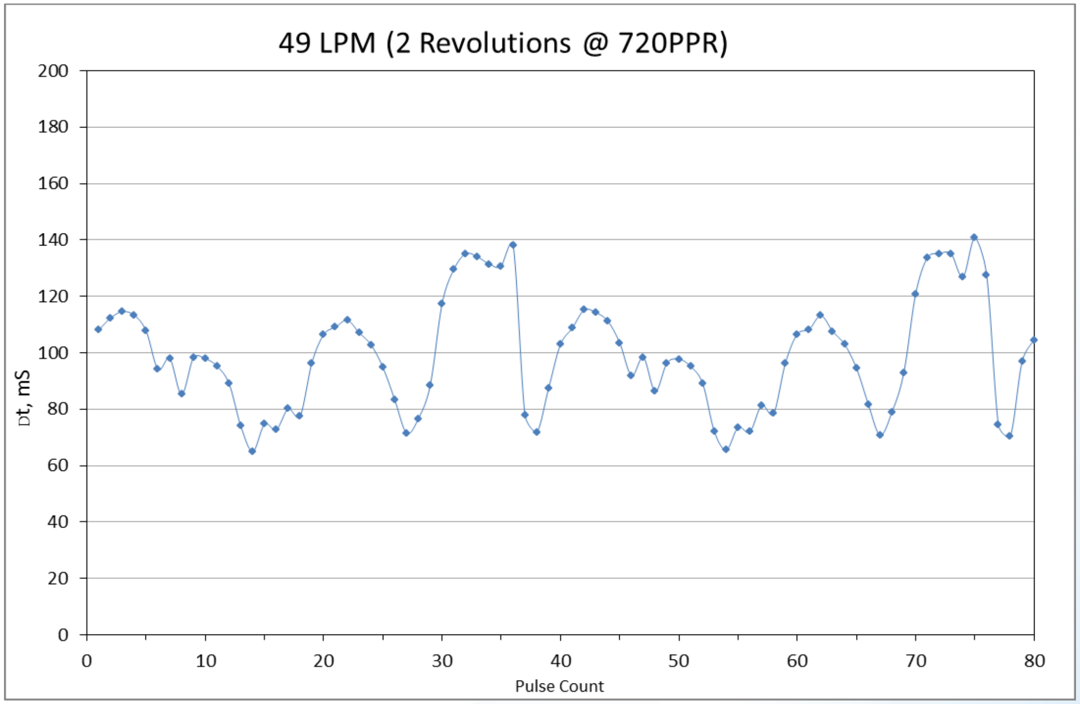
Indoor Temperature	--

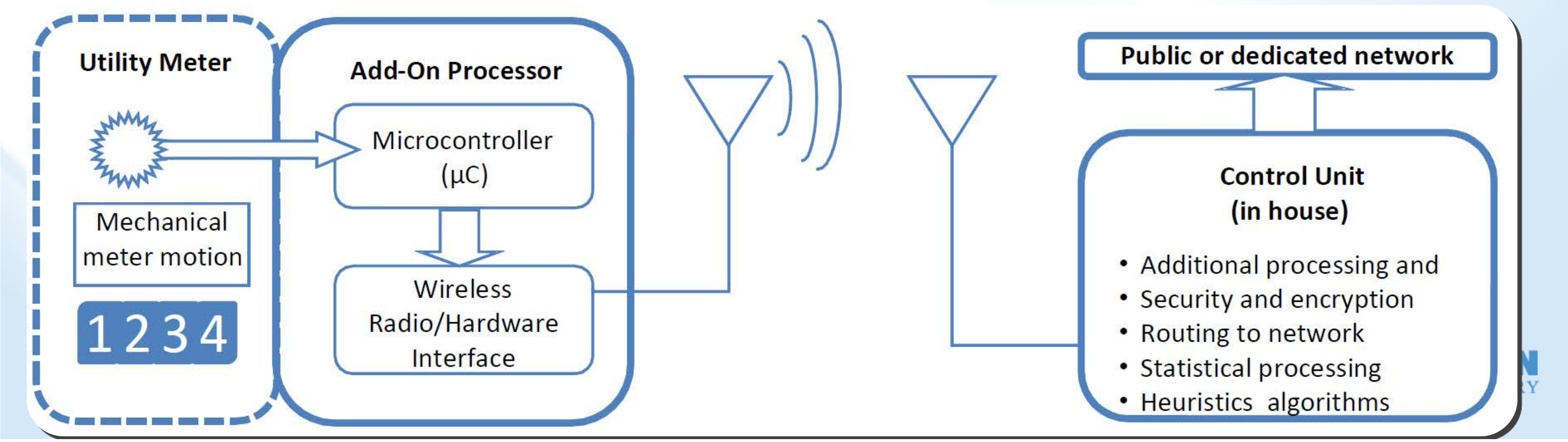
Device History Details - Change Column Settings

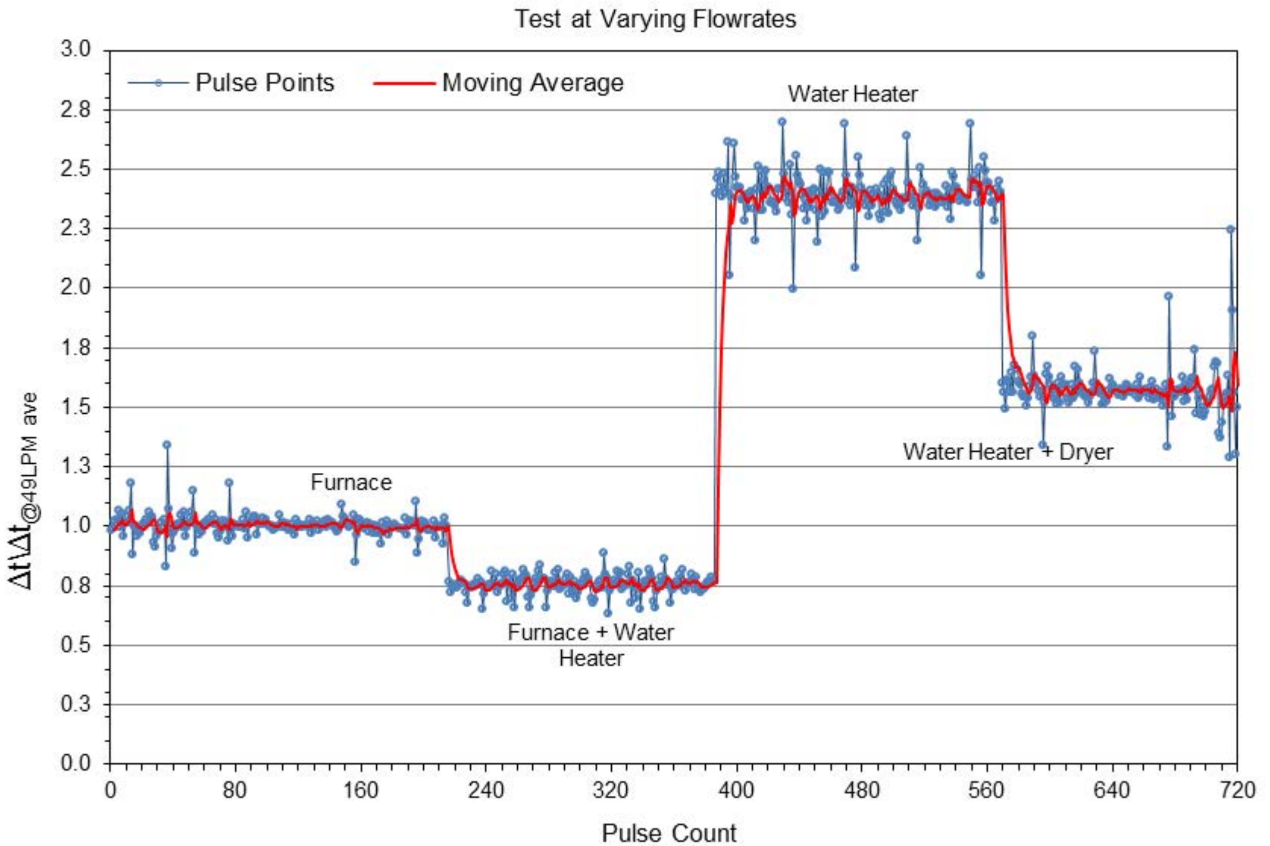
Exp

#	Date Time	Device State	Outdoor Temperature (°F)	Boiler Setpoint (°F)	Water Temperature (°F)	Error Code
101	Oct 12, 2014 8:32:27 AM	Idle	72.2	100.0	167.5	--
102	Oct 12, 2014 8:31:27 AM	Idle	72.2	100.0	174.4	--
103	Oct 12, 2014 8:28:54 AM	Idle	72.2	100.0	183.4	--
104	Oct 12, 2014 8:26:24 AM	Idle	72.2	100.0	189.7	--
105	Oct 12, 2014 8:24:05 AM	Idle	72.2	170.1	189.7	146
106	Oct 12, 2014 8:23:02 AM	Idle	72.2	100.0	189.7	--
107	Oct 12, 2014 8:22:05 AM	Idle	72.2	100.0	183.7	--
108	Oct 12, 2014 8:21:42 AM	Idle	72.2	170.1	183.7	--
109	Oct 12, 2014 8:20:42 AM	Idle	72.2	170.1	171.0	--
110	Oct 12, 2014 8:20:41 AM	Idle	72.2	170.1	156.6	--
111	Oct 12, 2014 8:19:39 AM	Running	72.2	170.1	156.6	--
112	Oct 12, 2014 8:18:39 AM	Running	72.2	170.1	144.1	--
113	Oct 12, 2014 8:16:07 AM	Running	72.2	170.1	137.3	--
114	Oct 12, 2014 8:16:02 AM	Idle	72.2	170.1	137.3	--
115	Oct 12, 2014 8:09:18 AM	Idle	72.2	100.0	137.3	--
116	Oct 12, 2014 7:37:26 AM	Idle	72.2	100.0	142.7	--
117	Oct 12, 2014 7:09:18 AM	Idle	72.2	100.0	148.1	--
118	Oct 12, 2014 6:41:26 AM	Idle	72.2	100.0	153.5	--
119	Oct 12, 2014 6:14:00 AM	Idle	72.2	100.0	159.1	--
120	Oct 12, 2014 5:50:37 AM	Idle	72.2	100.0	164.3	--
121	Oct 12, 2014 5:37:02 AM	Idle	72.2	100.0	169.7	--
122	Oct 12, 2014 5:33:03 AM	Idle	72.2	170.1	169.7	--
123	Oct 12, 2014 5:32:41 AM	Idle	72.2	100.0	169.7	--
124	Oct 12, 2014 5:10:46 AM	Idle	72.2	100.0	175.1	

Example – Stony Brook – common gas meter analysis






Test at Varying Flowrates
Pulse Points
Moving Average
Water Heater
Furnace
Furnace + Water Heater
Water Heater + Dryer
$\Delta t \backslash \Delta t_{@49LPM\ ave}$
Pulse Count
3.0
2.8
2.5
2.3
2.0
1.8
1.5
1.3
1.0
0.8
0.5
0.3
0.0
0
80
160
240
320
400
480
560
640
720

Challenges / Opportunities

- Data ownership, protocols, and access;
- Algorithms for activity recognition and use; analysis based on very limited amounts of data;
- Integrating data with building models- tracking achieved savings;
- Remote /automated energy audits;
- Transforming connected system data into high quality building data use sets;
- Integrate with storm-response programs;
- Integrating with Building Energy Management systems.

Thank you

Dr. Thomas A. Butcher

Deputy Chair – Sustainable Energy Technologies

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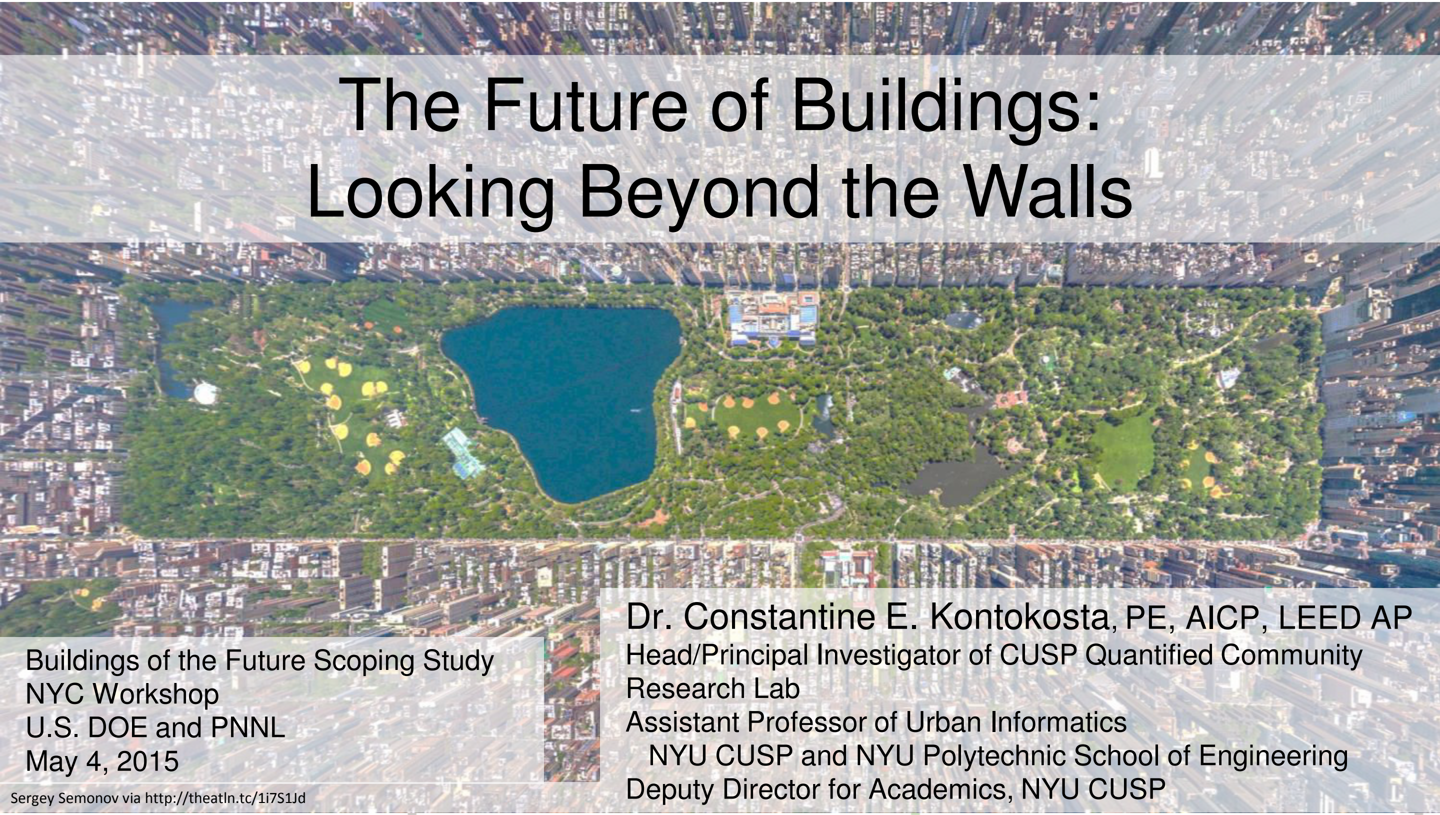
The Future of Buildings: Looking Beyond the Walls



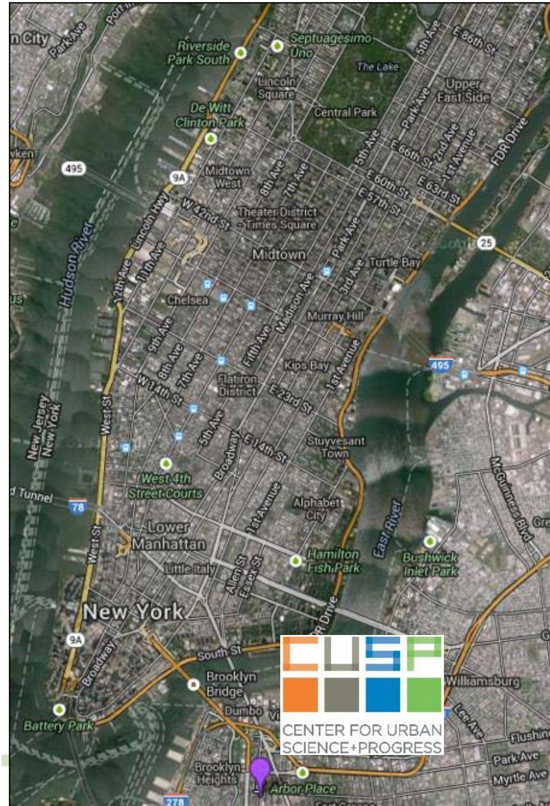
Sergey Semonov via http://theatln.tc/1i7S1Jd

Buildings of the Future Scoping Study
NYC Workshop
U.S. DOE and PNNL
May 4, 2015

Dr. Constantine E. Kontokosta, PE, AICP, LEED AP
Head/Principal Investigator of CUSP Quantified Community Research Lab
Assistant Professor of Urban Informatics
NYU CUSP and NYU Polytechnic School of Engineering
Deputy Director for Academics, NYU CUSP

New York City as a Living Lab

The **Center for Urban Science and Progress (CUSP)** is a unique public-private research center that uses New York City as its laboratory and classroom to help cities around the world become more productive, livable, equitable, and resilient. CUSP observes, analyzes, and models cities to optimize outcomes, prototype new solutions, formalize new tools and processes, and develop new expertise/experts. These activities will make CUSP the world's leading authority in the emerging field of "Urban Informatics".



The CUSP Partnership

University Partners

- NYU (*multiple schools*)
- The City University of New York
- Carnegie Mellon University
- University of Toronto (*Canada*)
- The University of Warwick (*UK*)
- IIT-Bombay (*India*)

Industrial Partners

- IBM
- Microsoft
- Xerox
- Cisco, Con Edison, Lutron, National Grid, Siemens
- AECOM, Arup, IDEO

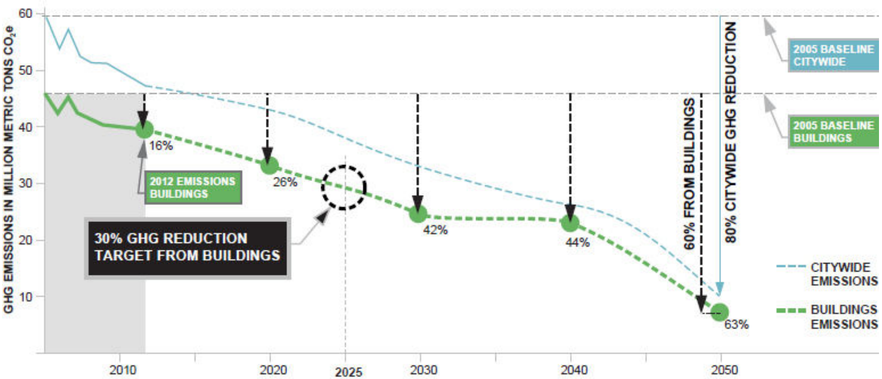
National Laboratories

- Brookhaven
- Lawrence Livermore
- Los Alamos
- Sandia

City & State Agency Partners

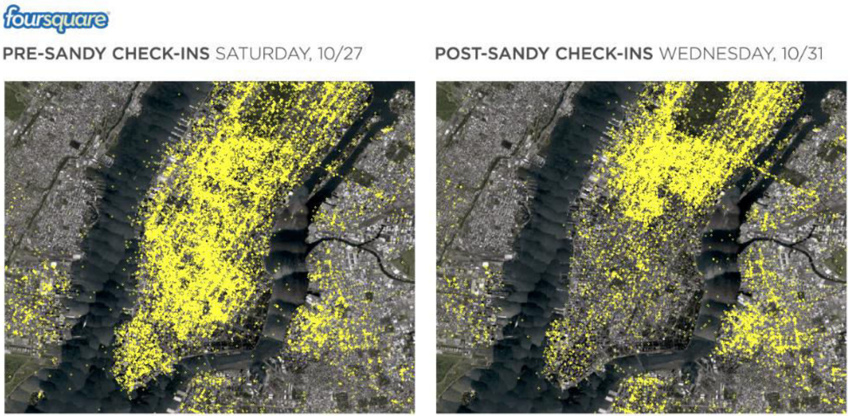
- The City of New York
  - Buildings
  - City Planning
  - Citywide Administrative Services
  - Design and Construction
  - Economic Development
  - Environmental Protection
  - Finance
  - Fire Department
  - Health and Mental Hygiene
  - Information Technology and Telecommunications
  - Parks and Recreation
  - Police Department
  - Sanitation
  - Transportation
- Metropolitan Transportation Authority
- Port Authority of NY & NJ

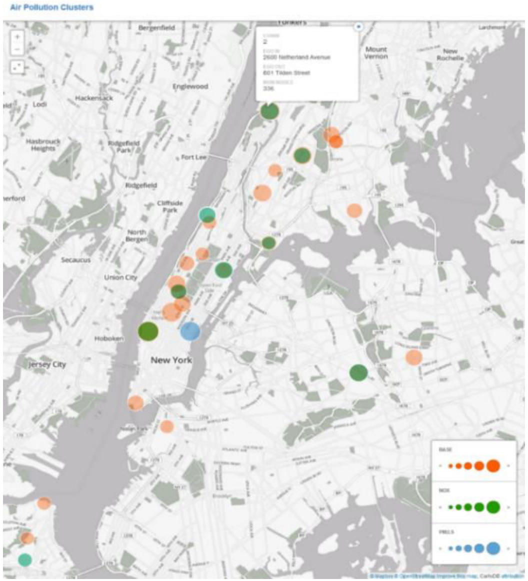
What are the Grand Challenges?



Thoughts on the Future of Buildings

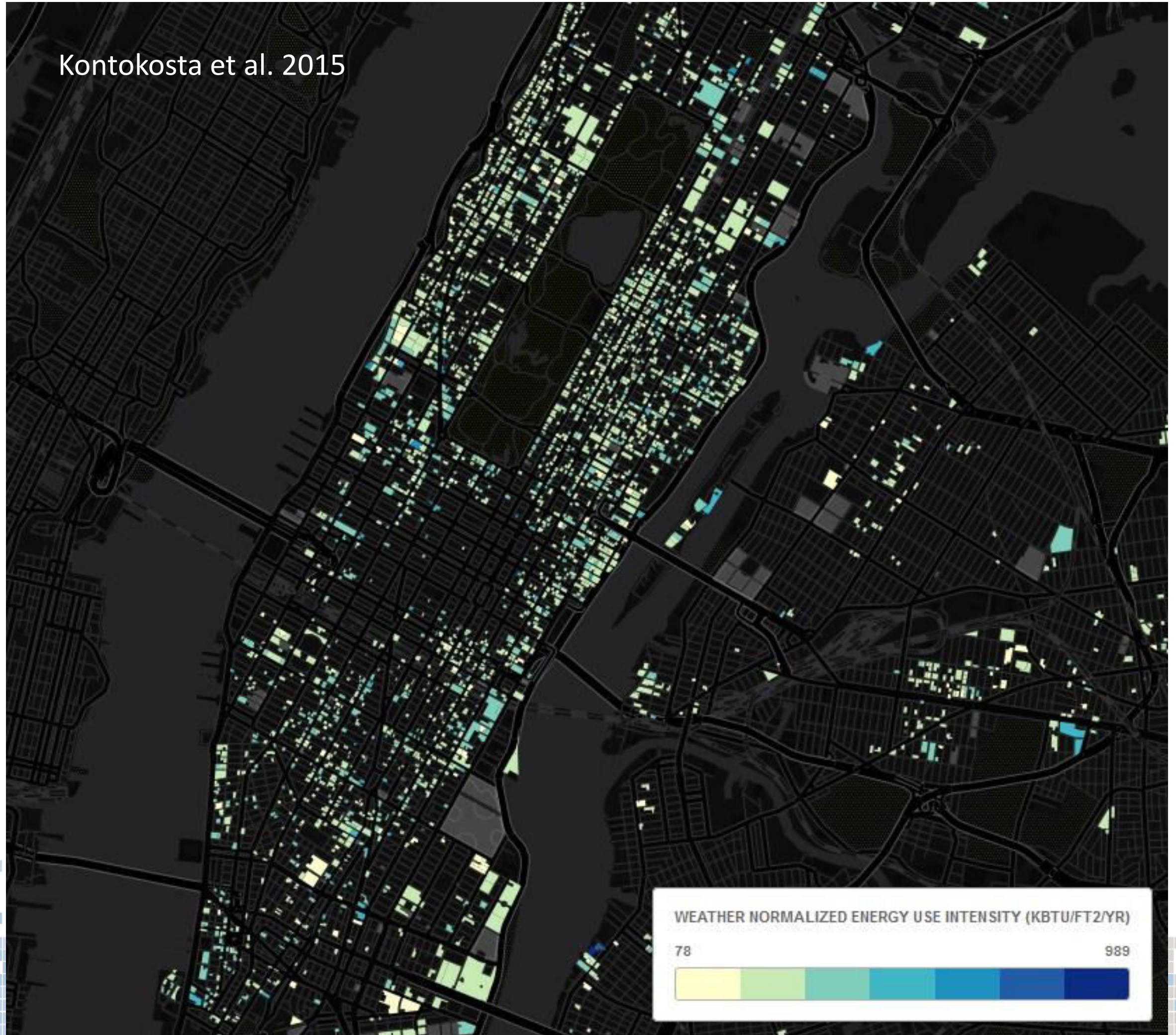
1. **Data**: Reliability, coverage, granularity
2. **Social values, not R-values**: Connecting energy efficiency to housing affordability and social justice; understanding behavior and decision-making
3. **Quality-of-life & continuity**: Linking energy efficiency to resilience, health, and well-being
4. **Quantified Communities**: Dynamic urban energy infrastructure that supports neighborhood-level generation and load sharing (DG, micro-grid, supply-demand optimization) and creates real-world test-beds for emerging technologies



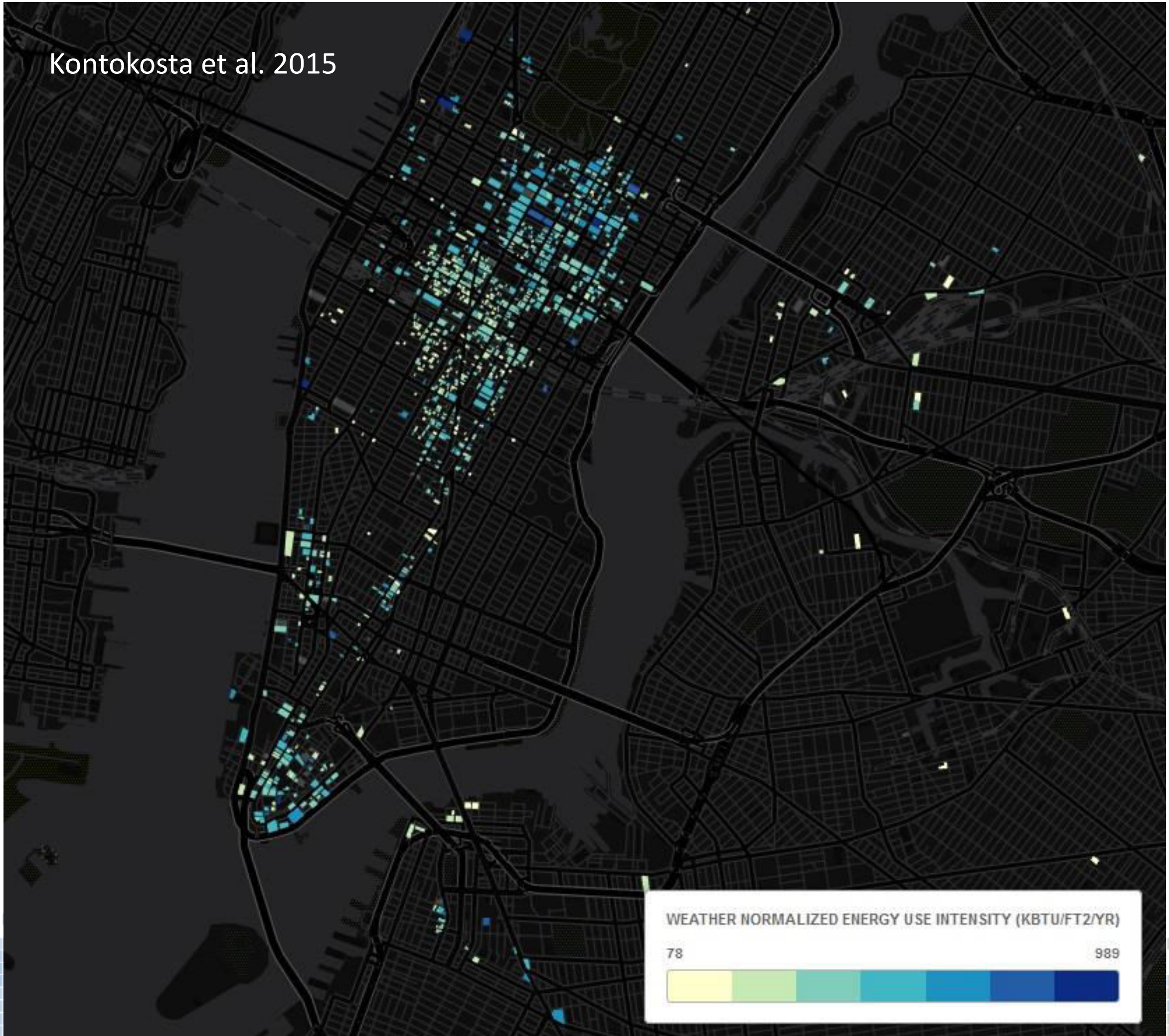


Source: Jain, Moura, Kontokosta 2014

Source: Freire, Claudio Silva, et al, NYU-Poly

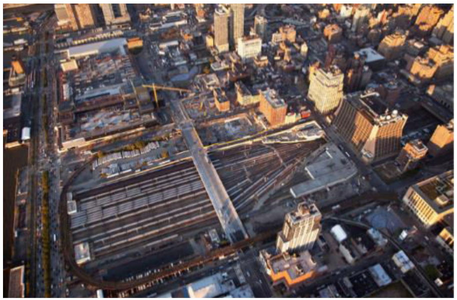

Kontokosta et al. 2015
WEATHER NORMALIZED ENERGY USE INTENSITY (KBTU/FT2/YR)
78
989

Kontokosta et al. 2015



The Quantified Community

Understanding the Patterns of Urban Life

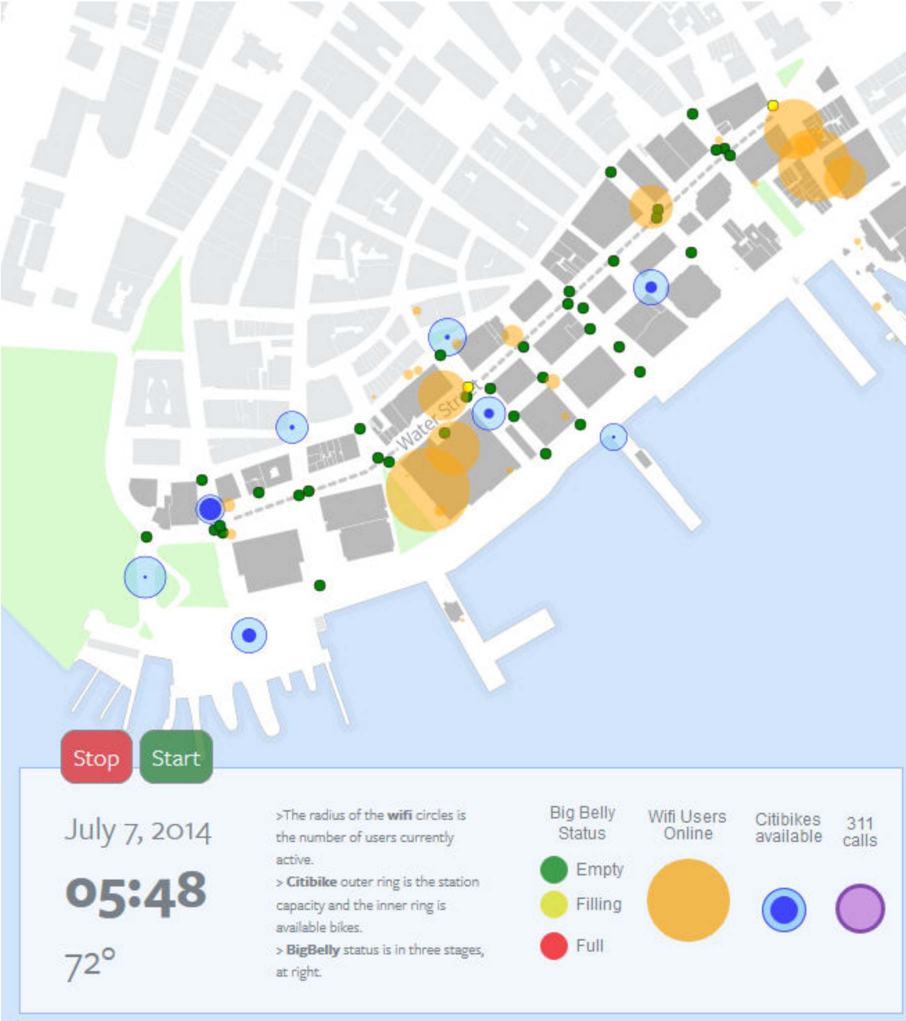


Kontokosta, et al.

The **CUSP "Quantified Community"** (QC) will be a fully instrumented urban neighborhood that uses an **integrated, expandable sensor network and citizen engagement** to support the measurement, integration, and analysis of neighborhood conditions.

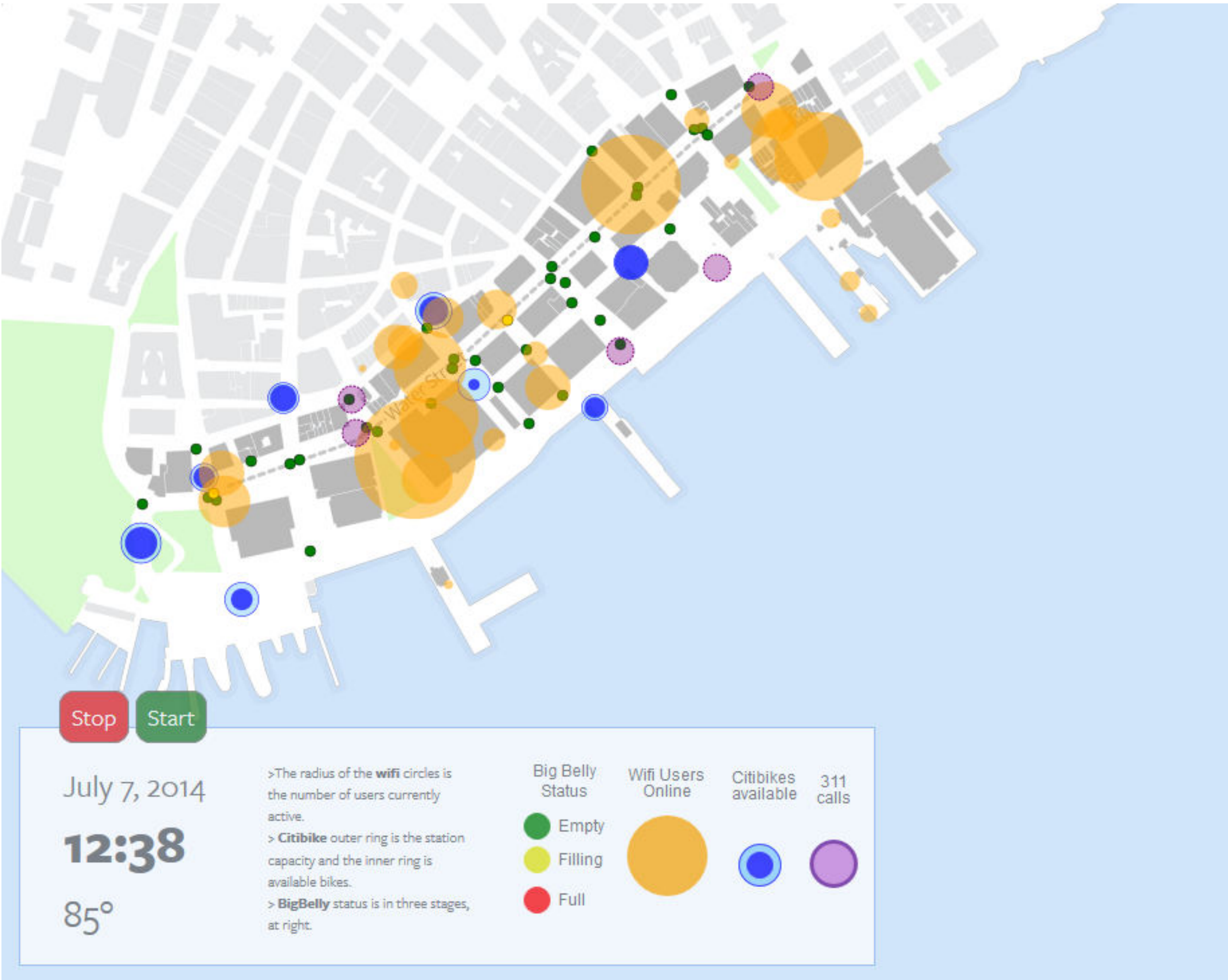
Through an **informatics overlay**, data on physical and environmental conditions and use patterns will be processed in real-time to **improve operational efficiencies, measures of quality of life, and drive evidence-based planning and design.**

A partnership between NYU CUSP, Related Companies, and Oxford Properties Group at ***Hudson Yards***

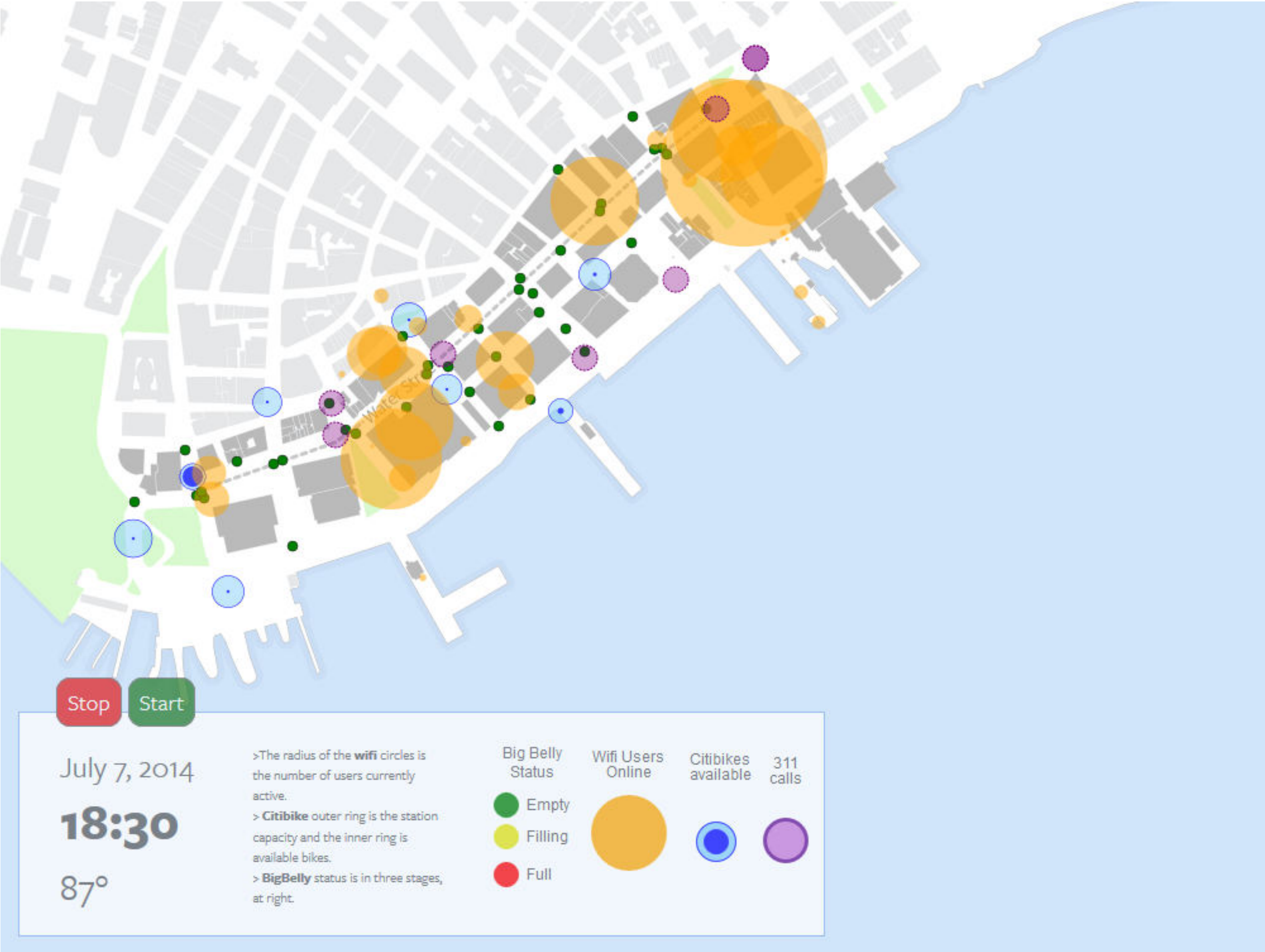


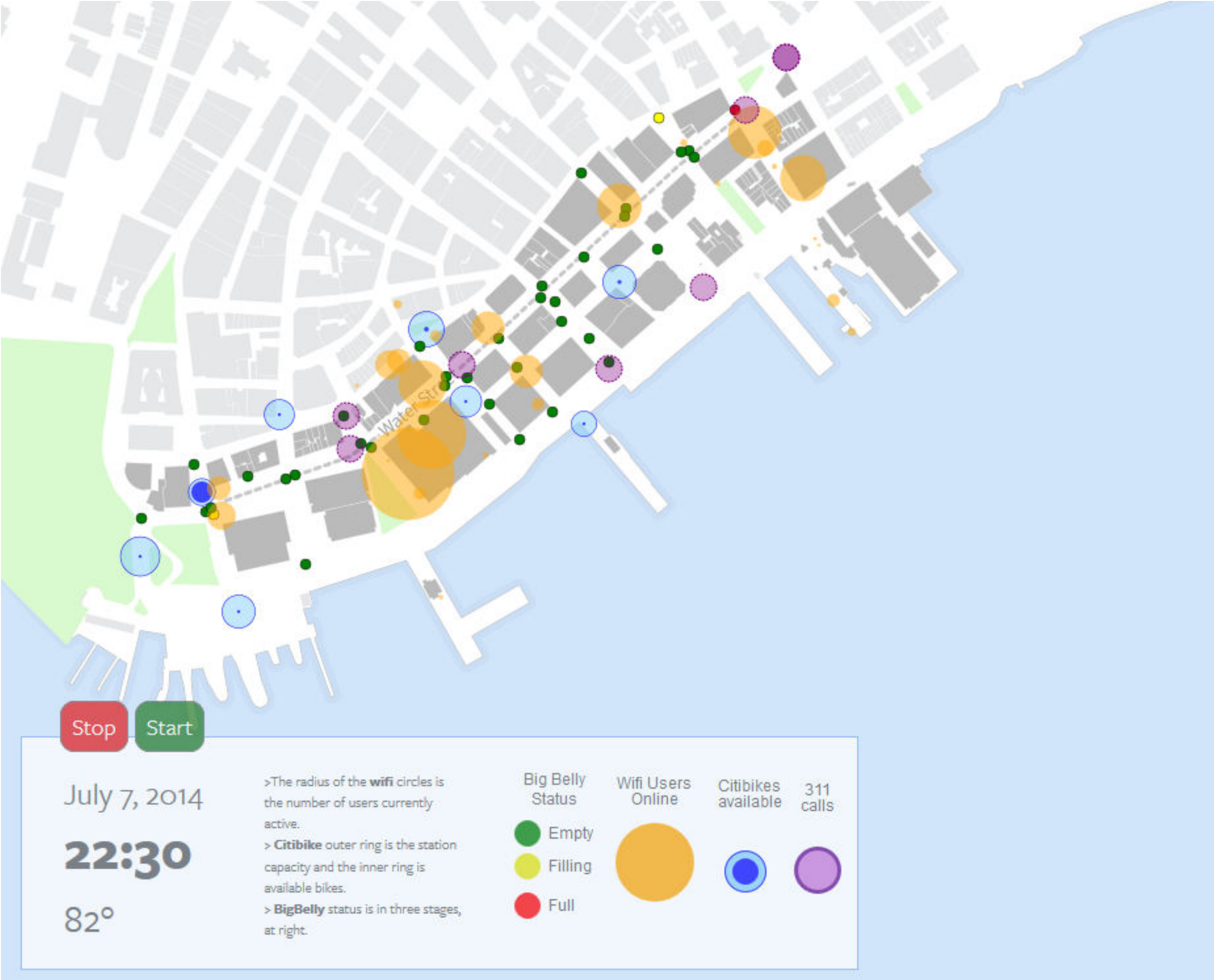
A Day in the Life of Water Street – as Seen through Data

R. Dunks et al.



Stop
Start
July 7, 2014
12:38
85°
>The radius of the **wifi** circles is the number of users currently active.
> **Citibike** outer ring is the station capacity and the inner ring is available bikes.
> **BigBelly** status is in three stages, at right.
Big Belly Status
Empty
Filling
Full
Wifi Users Online
Citibikes available
311 calls


Water St
Stop
Start
July 7, 2014
18:30
87°
>The radius of the wifi circles is the number of users currently active.
> Citibike outer ring is the station capacity and the inner ring is available bikes.
> BigBelly status is in three stages, at right.
Big Belly Status
Empty
Filling
Full
Wifi Users Online
Citibikes available
311 calls



Water Str
Stop
Start
July 7, 2014
22:30
82°
>The radius of the **wifi** circles is the number of users currently active.
> **Citibike** outer ring is the station capacity and the inner ring is available bikes.
> **BigBelly** status is in three stages, at right.
Big Belly Status
Empty
Filling
Full
Wifi Users Online
Citibikes available
311 calls

CITIES ARE AN IMMENSE LABORATORY OF TRIAL AND ERROR, FAILURE AND SUCCESS, IN CITY BUILDING AND CITY DESIGN. THIS IS THE LABORATORY IN WHICH CITY PLANNING SHOULD HAVE BEEN LEARNING AND FORMING AND TESTING ITS THEORIES. INSTEAD THE PRACTITIONERS AND TEACHERS OF THIS DISCIPLINE (IF SUCH IT CAN BE CALLED) HAVE IGNORED THE STUDY OF SUCCESS AND FAILURE IN REAL LIFE….

- Jane Jacobs, *Death and Life of Great American Cities, 1961*

CENTER FOR URBAN SCIENCE+PROGRESS

Thank you

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NYUCUSP

@NYU_CUSP

Occupants of the Future: Moving from "Sick Building Syndrome" to "Healthy Building Syndrome"

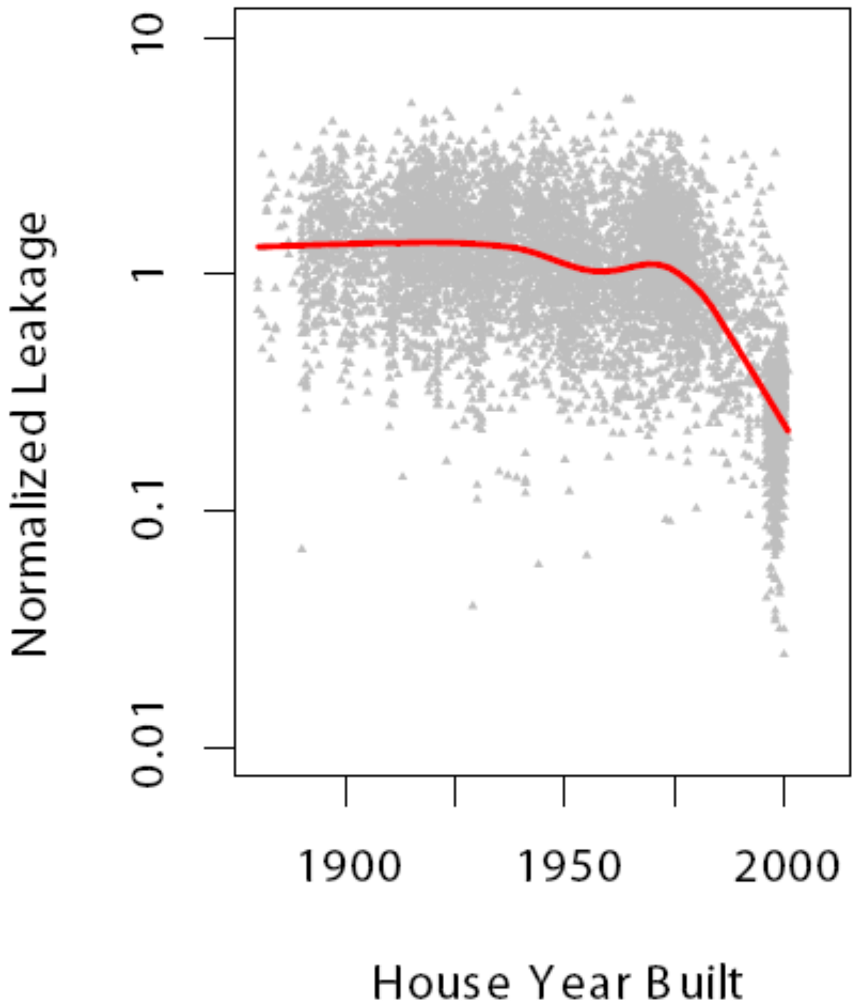
Joseph G. Allen, DSc, MPH

>Assistant Professor, Harvard School of Public Health

>Director, Healthy Buildings Program,
Harvard Center for Health and the Global Environment

HARVARD T.H. CHAN | SCHOOL OF PUBLIC HEALTH

Decreasing air exchange rates in 1970s



- Balance between acceptable indoor air quality and energy
- Low ventilation and health

(From Chan et al. 2003, LBL)

At about this time…

- 1979: Tight Buildings
- 1985: Sick Building Syndrome
- 1990: Building Related Illness
- 2000: Problem Buildings
- 2100: **Healthy Building Syndrome**

What will occupants expect in 100 years?

A Changing (indoor and outdoor) Environment

1) Changing Climate
2) Changing People
3) Changing Technology

1) Changing Climate

$1^{o}C$
increase in global temperature

=

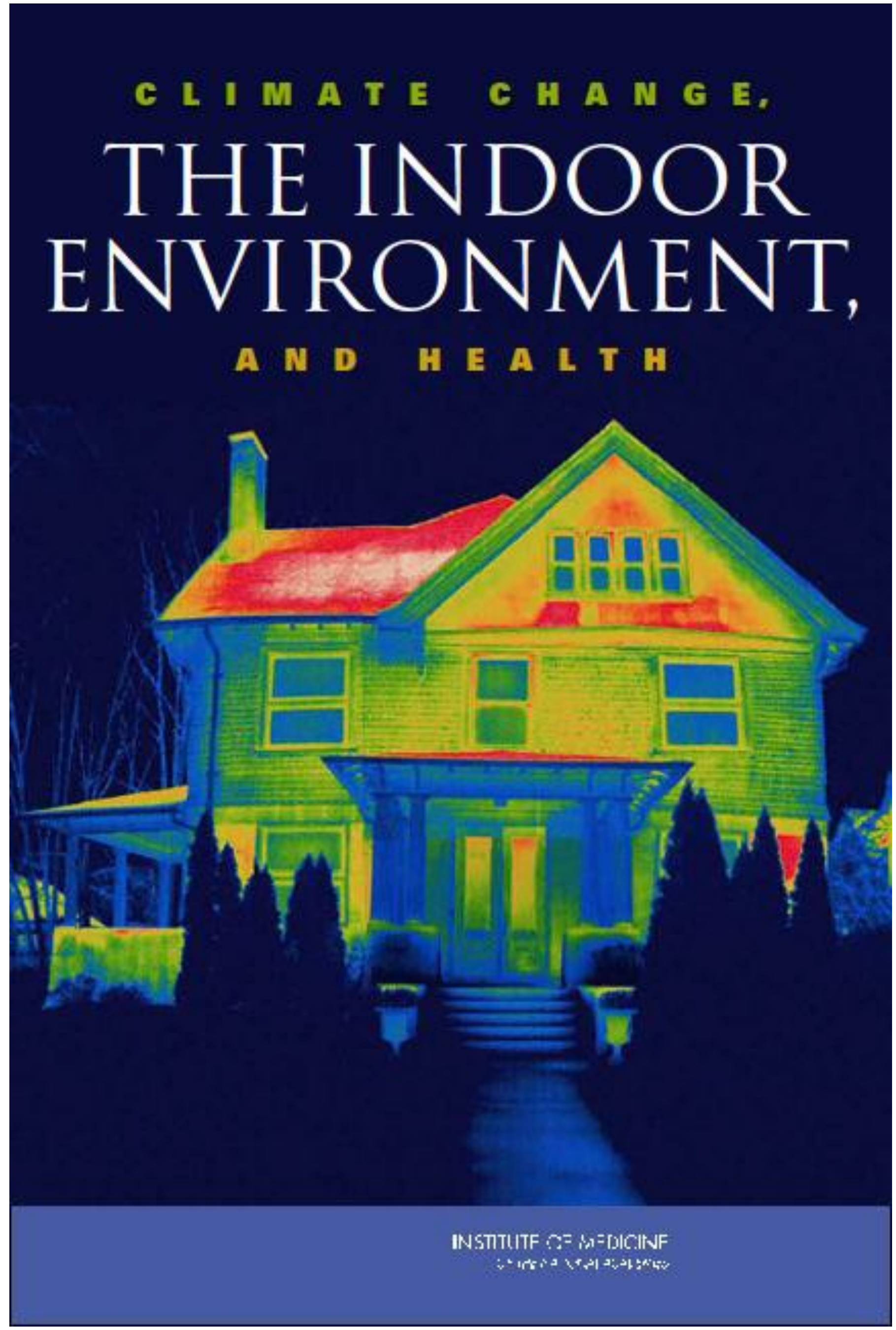
5% increase in moisture in the atmosphere

Climate Change and Indoor Environments and Health

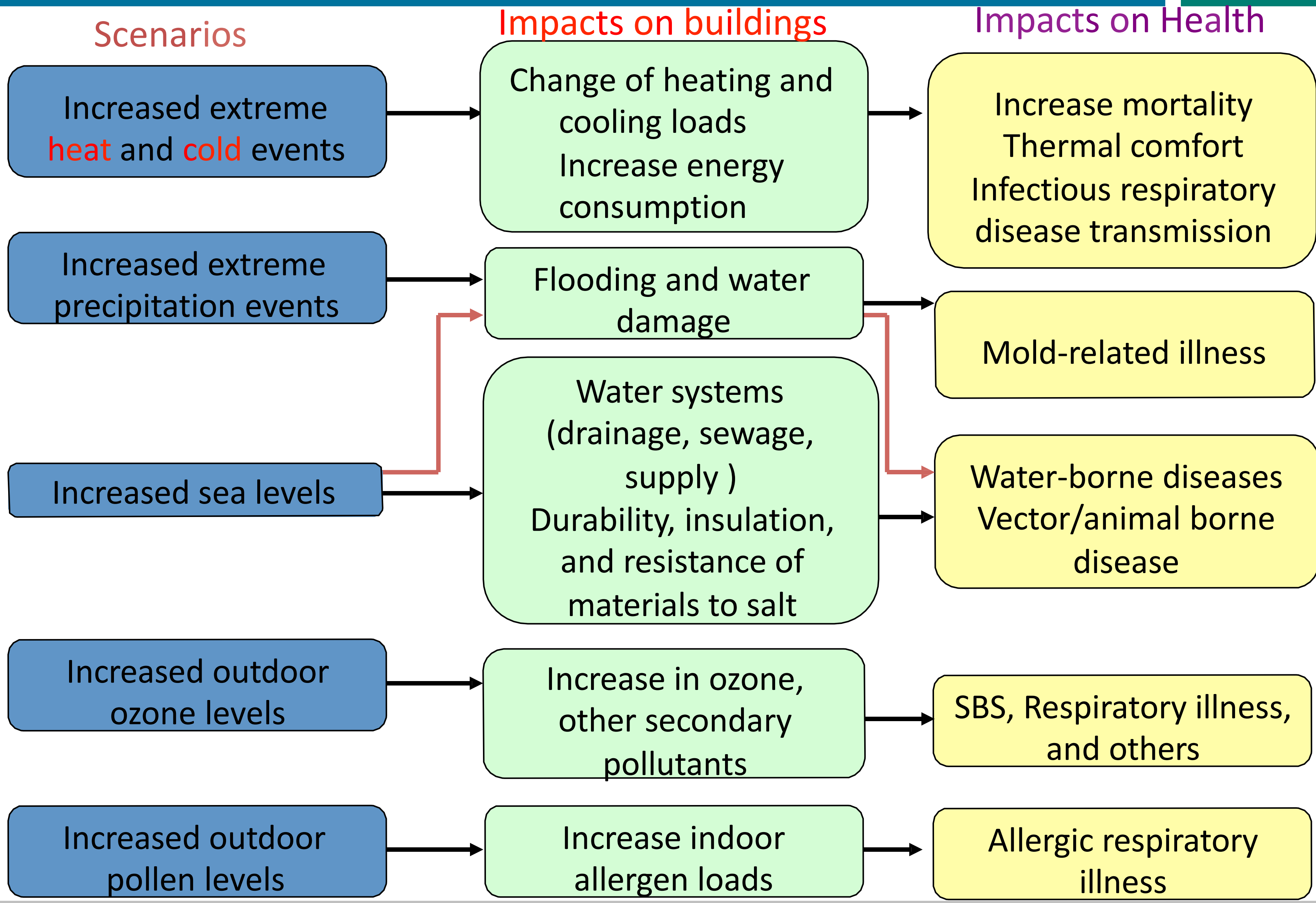
Institute of Medicine
National Academy of Science

Released June 7th, 2011
http://www.nap.edu/catalog/13115/climate-change-the-indoor-environment-and-health

Sponsor: US EPA



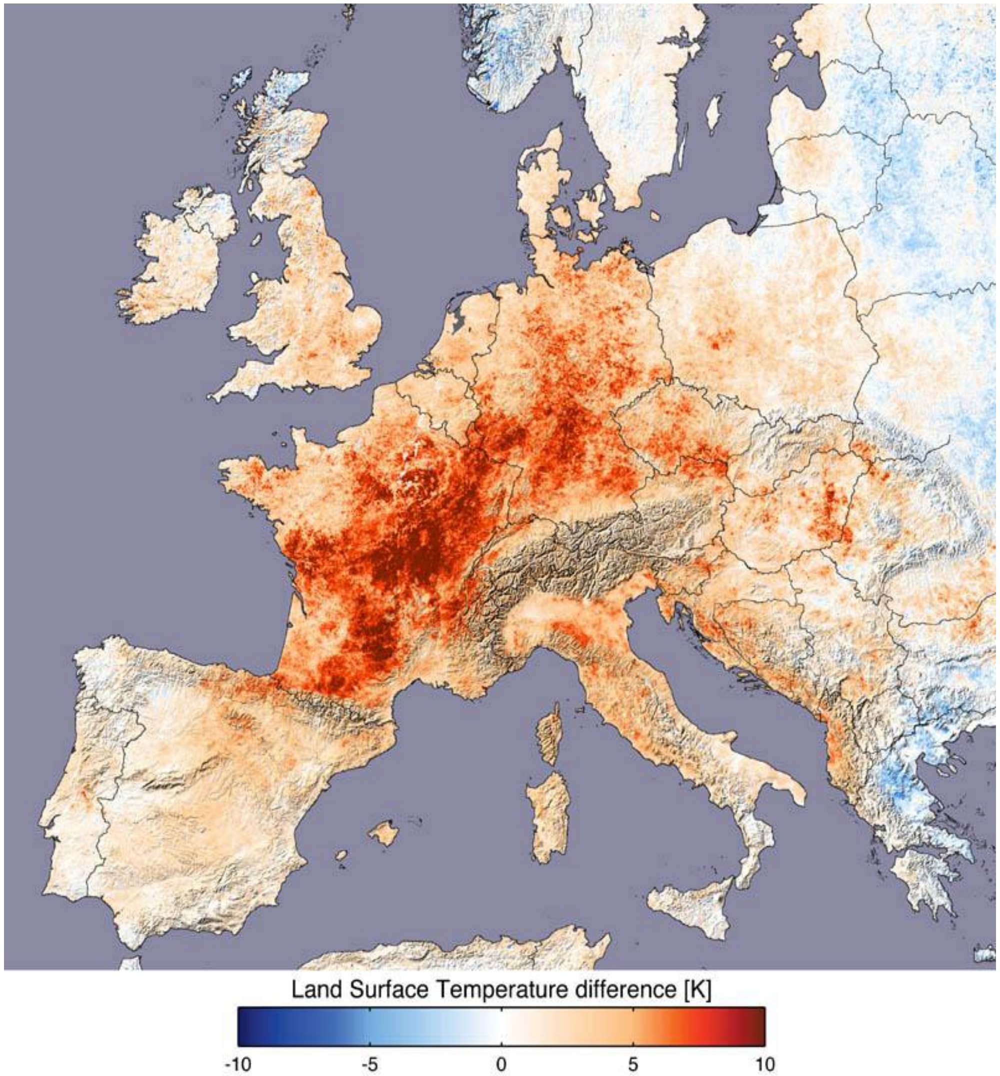
Climate Change, Indoor Env and Health



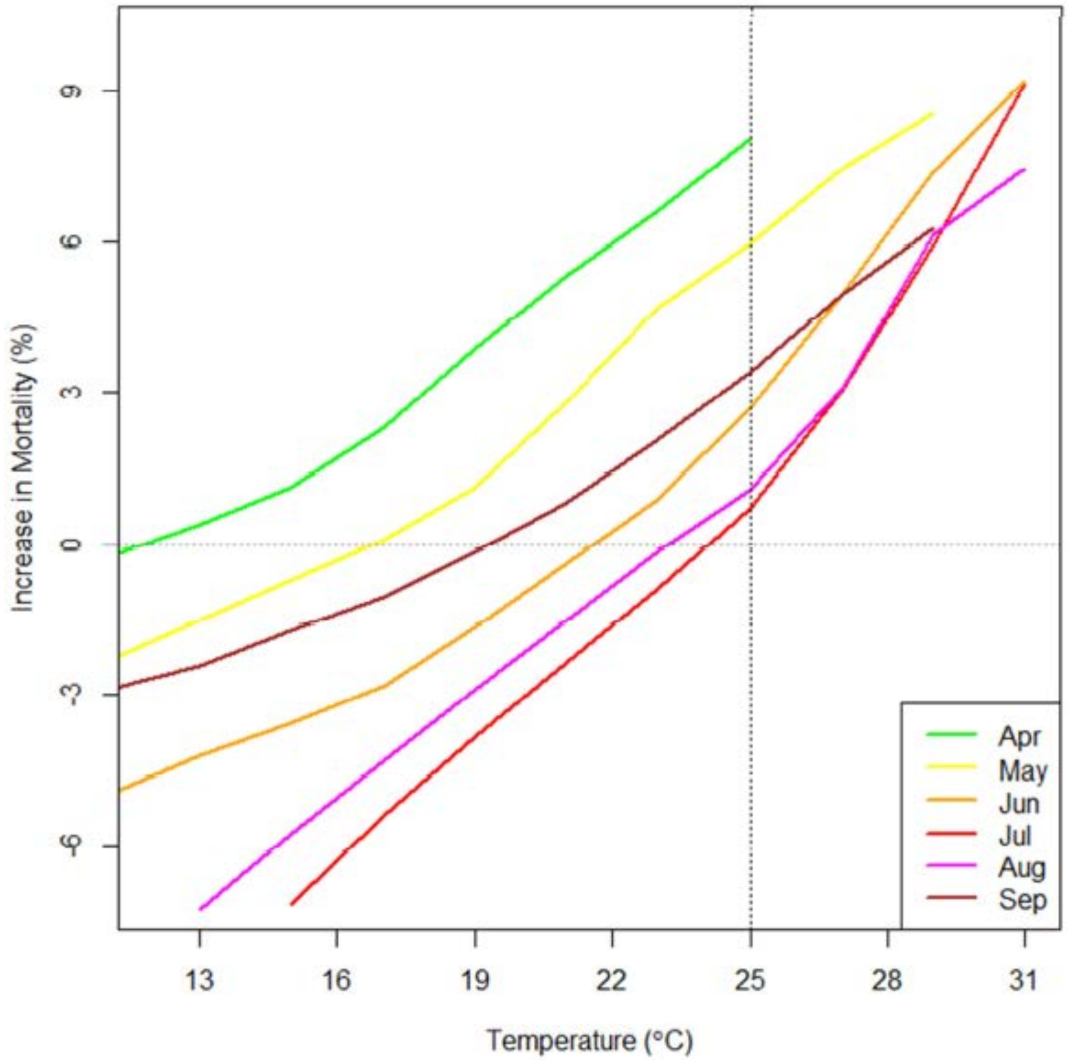
Heat Stress

Killed more than 35,000 people.

These conditions are forecasted to become more common by 2040.



Challenging what we 'know'



Nordio F, Zanobetti A, Schwartz J

Figure 2. Heat Effects by Month in Cluster 1

Challenging what we 'know'

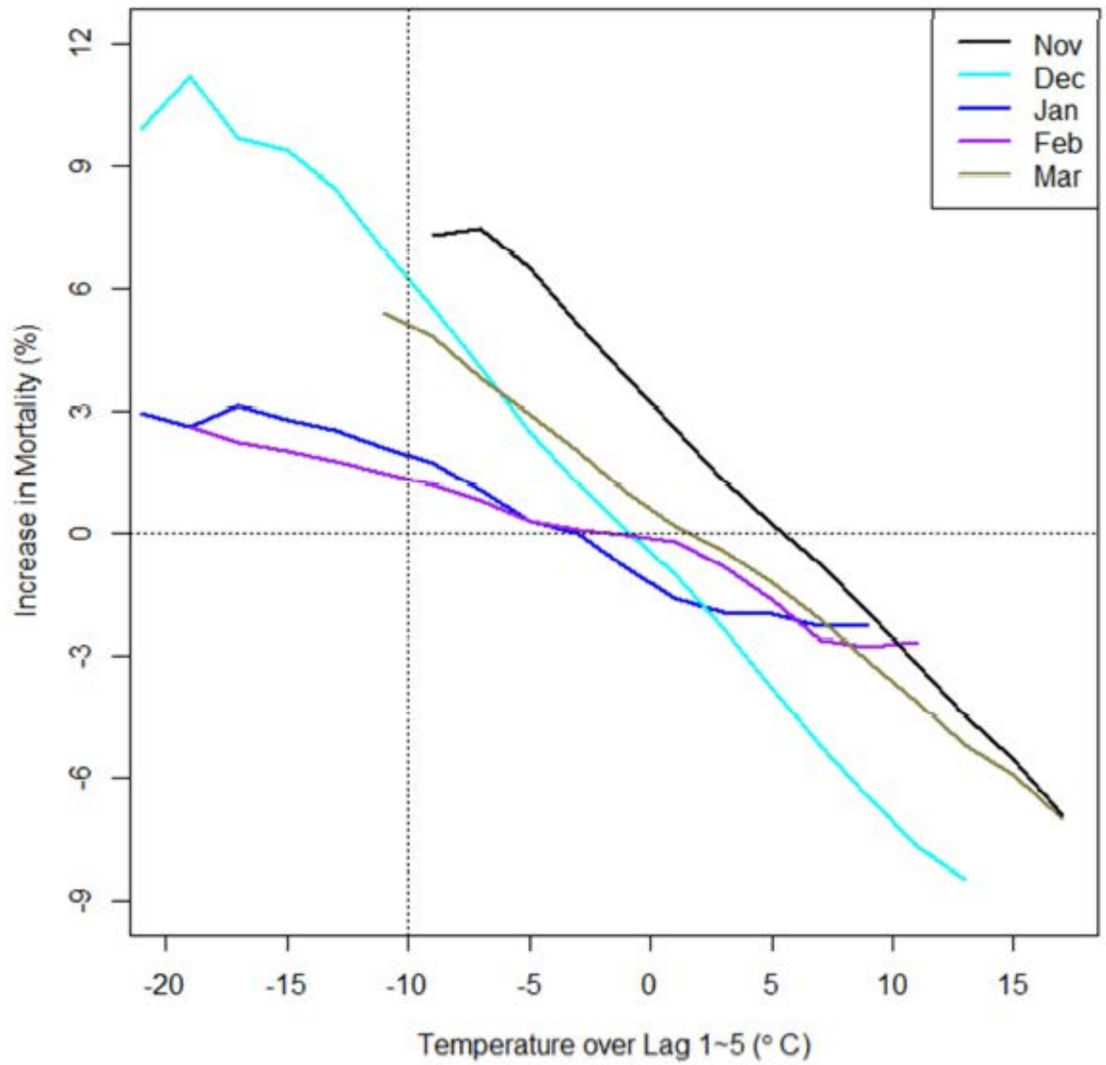
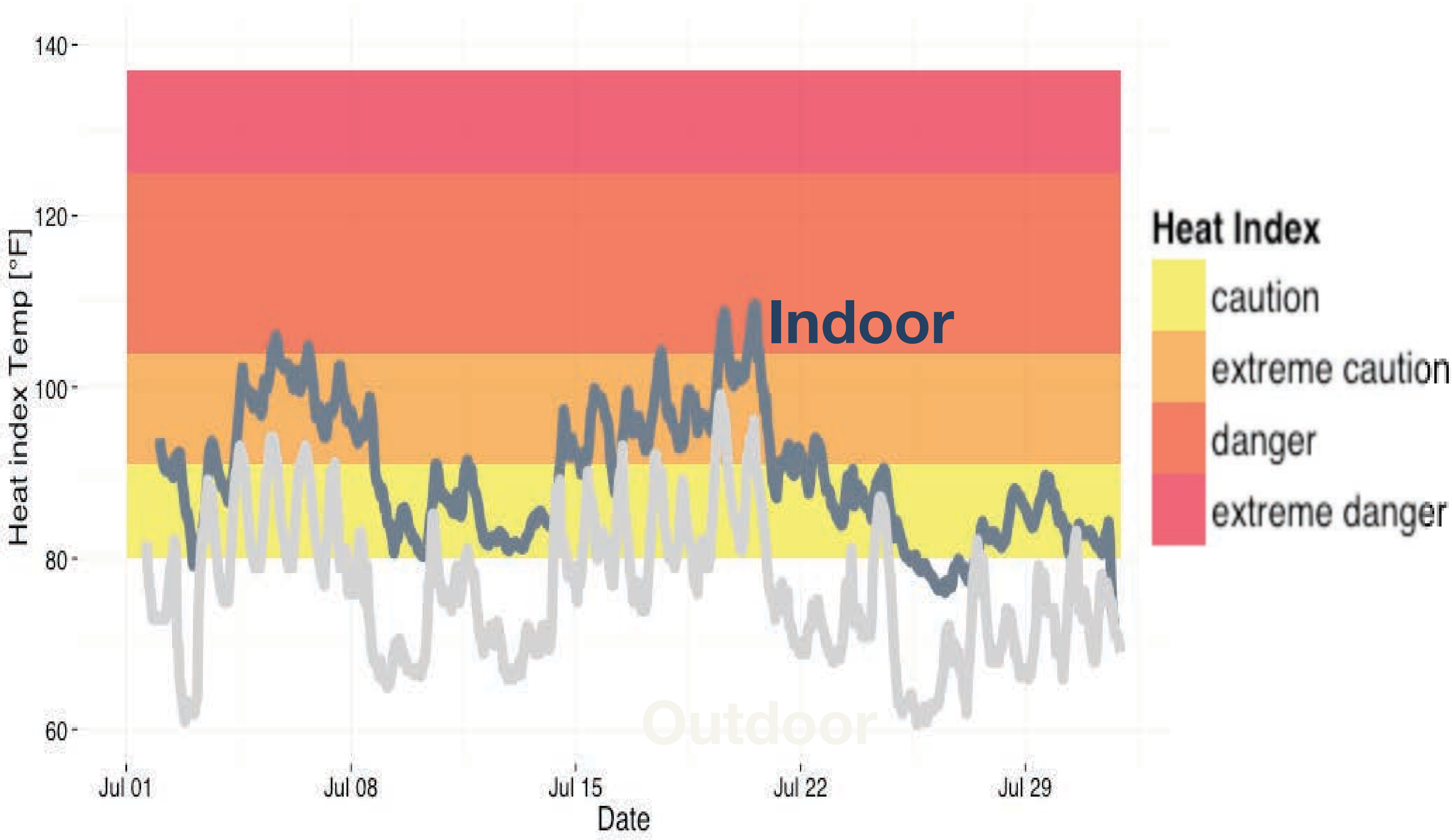


Figure 4. Cold Effects by Month in Cluster 2

Nordio F, Zanobetti A, Schwartz J

In dorms…

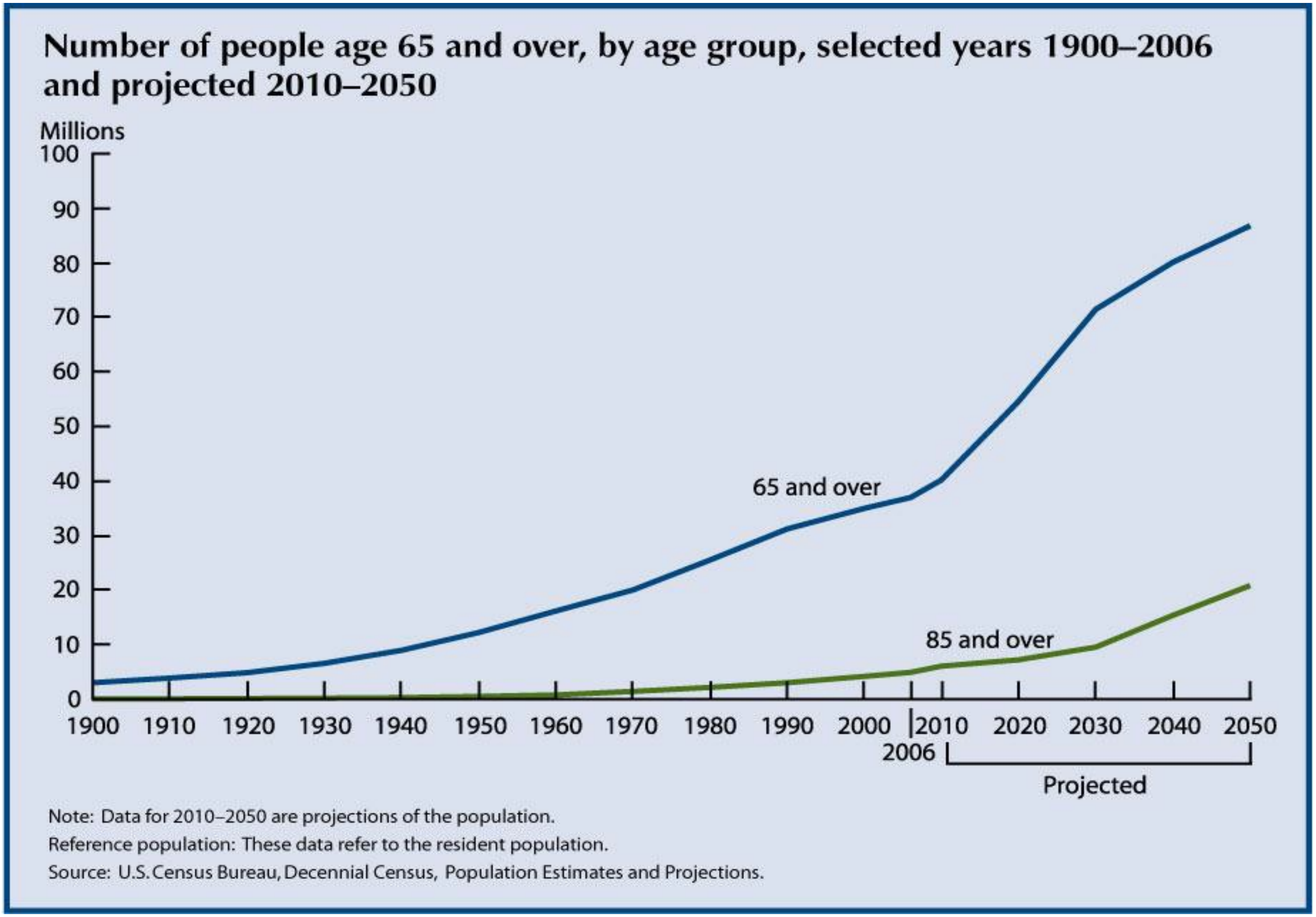
High Indoor Heat Index Values, Heat wave 2013



Occupants will expect…

- Buildings to eliminate contribution to the problem
  - Net zero → negative energy buildings
- Buildings as bastions
  - Places of refuge
  - Will have to be resilient in face of extreme weather, disasters, flooding and sea level rise

2) Changing People



Vulnerable Populations

Biologic Factors

- Increased risk of Disease (including cardiovascular disease, respiratory disease, hypertension, diabetes, and obesity)
- Lower immune response
- Restricted mobility

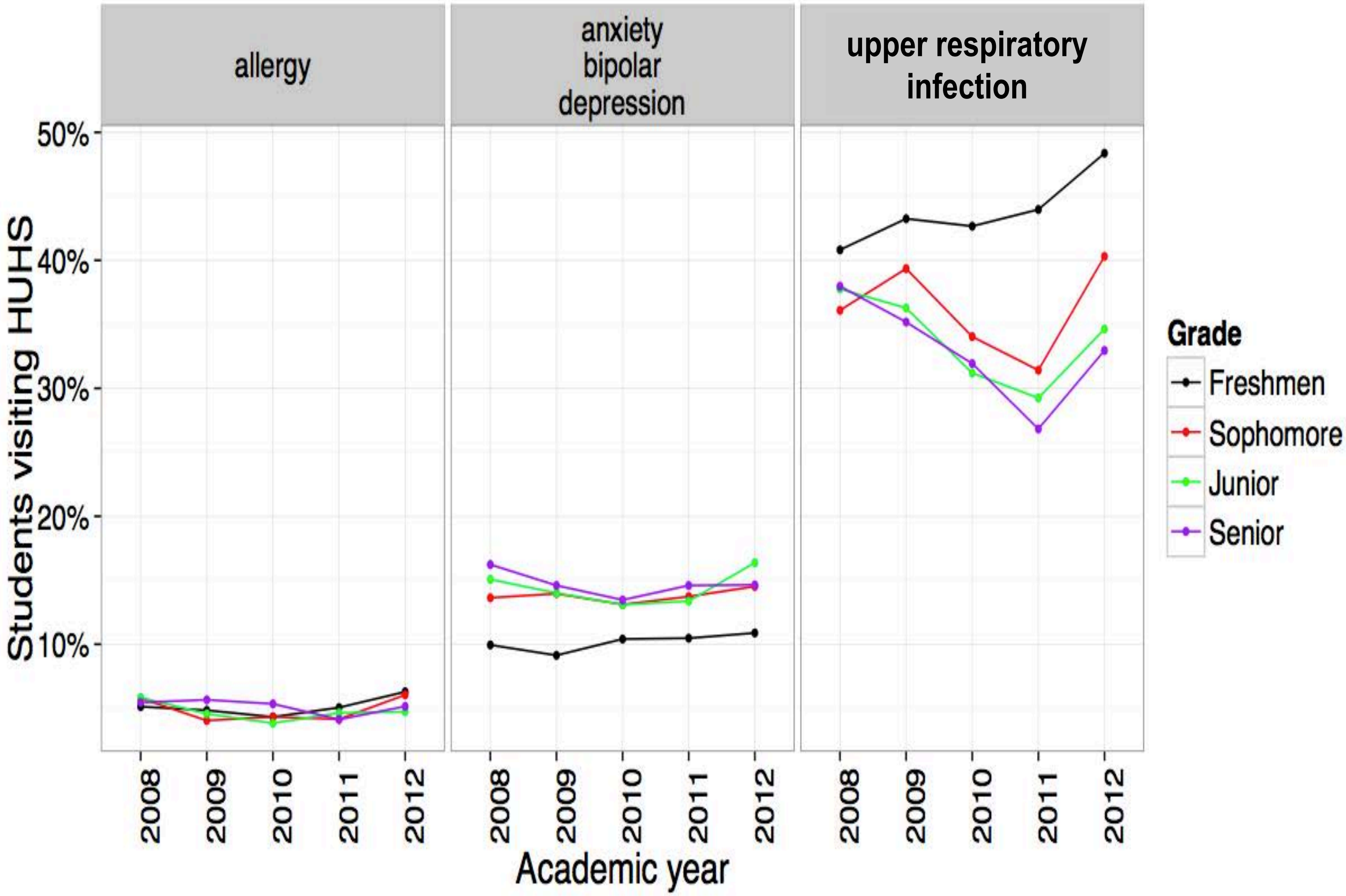
Economic and social factors

- Availability of building air conditioning [AC] or heat
- Availability of natural ventilation (ability to open windows)
- Isolation and Security

Urbanization

What do we know about IAQ?

Buildings +

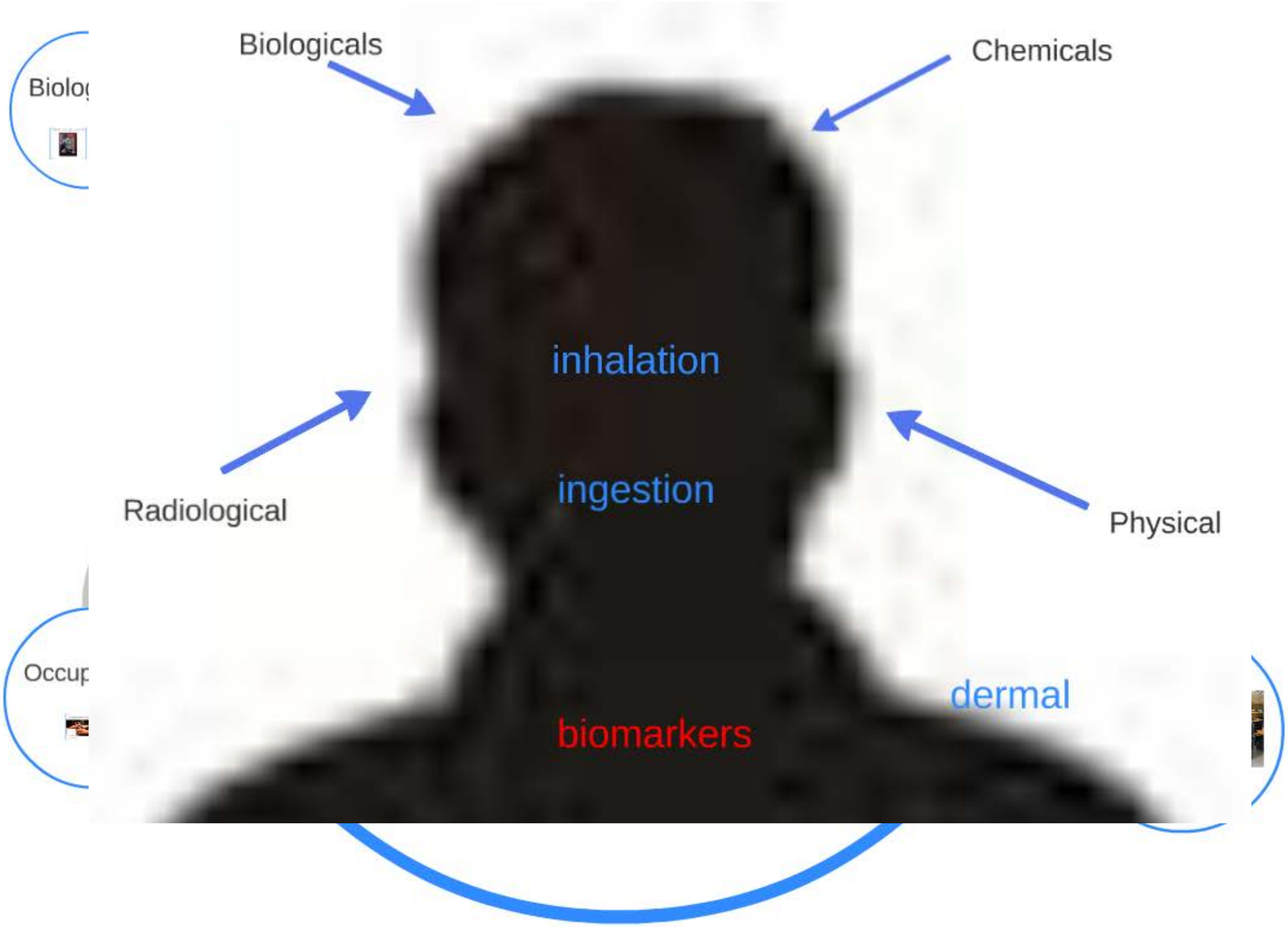


Cedeno et al., 2015. Submitted.

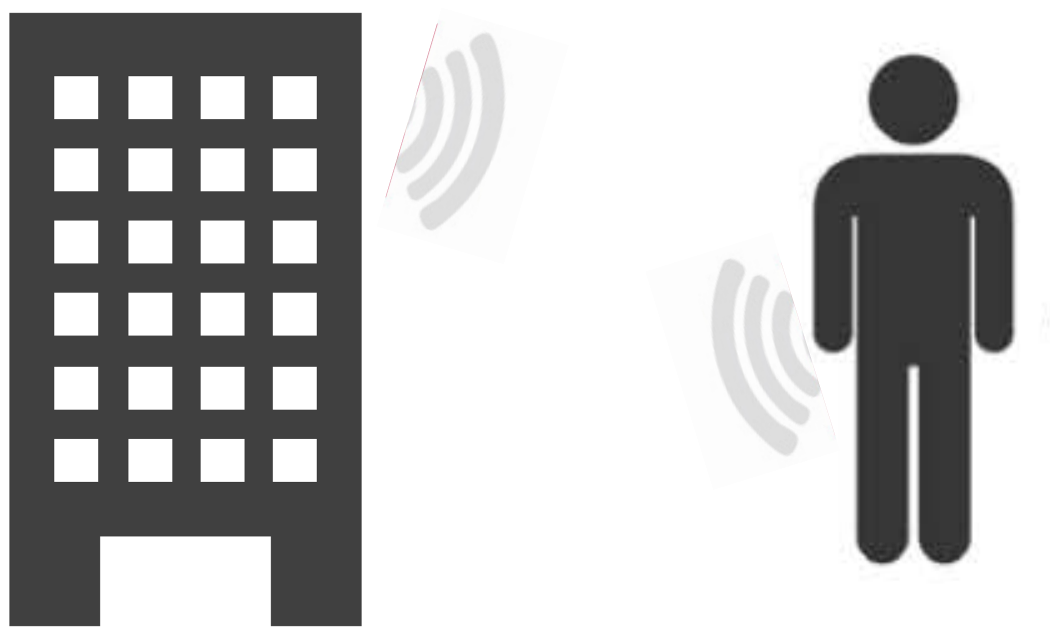
Occupants will expect…

- Buildings that are tailored to their needs
  - 85 yr old + 25 year old
- Buildings that are tailored to their environment
  - Urban v. rural
  - Adaptable based on changing climate
- Buildings not as silos…integrated into surrounding environment
  - schools, green space, neighborhood, safety

3) Changing Technology

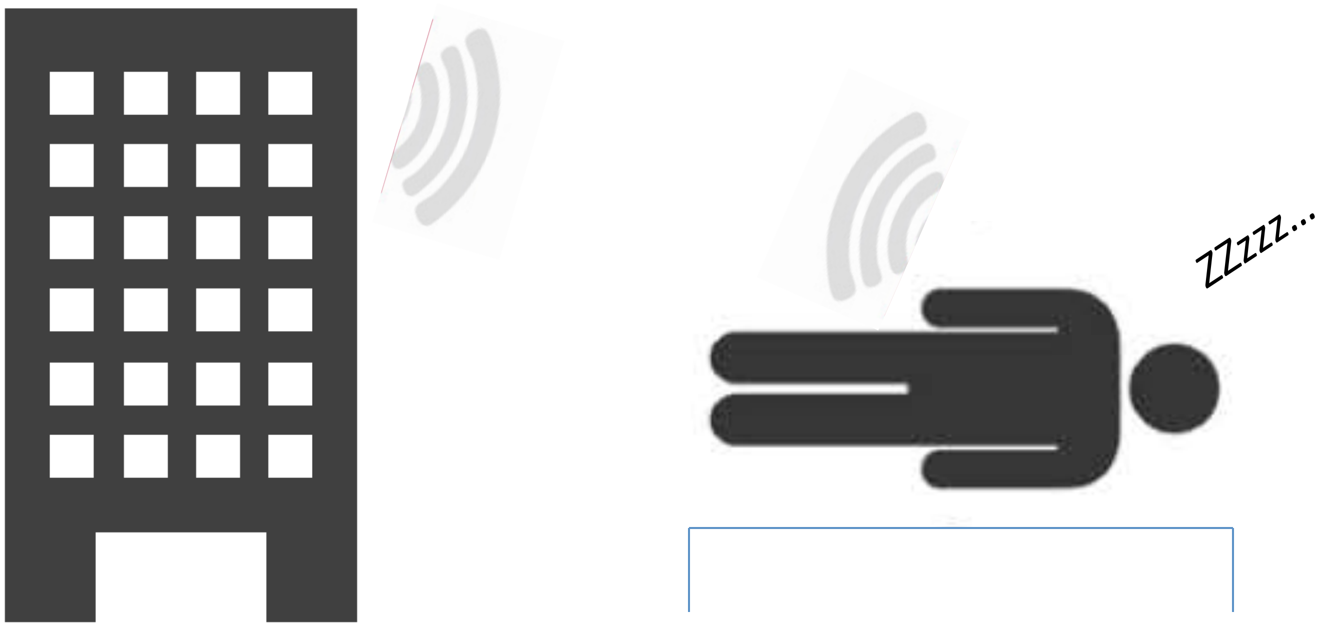


Autonomous control



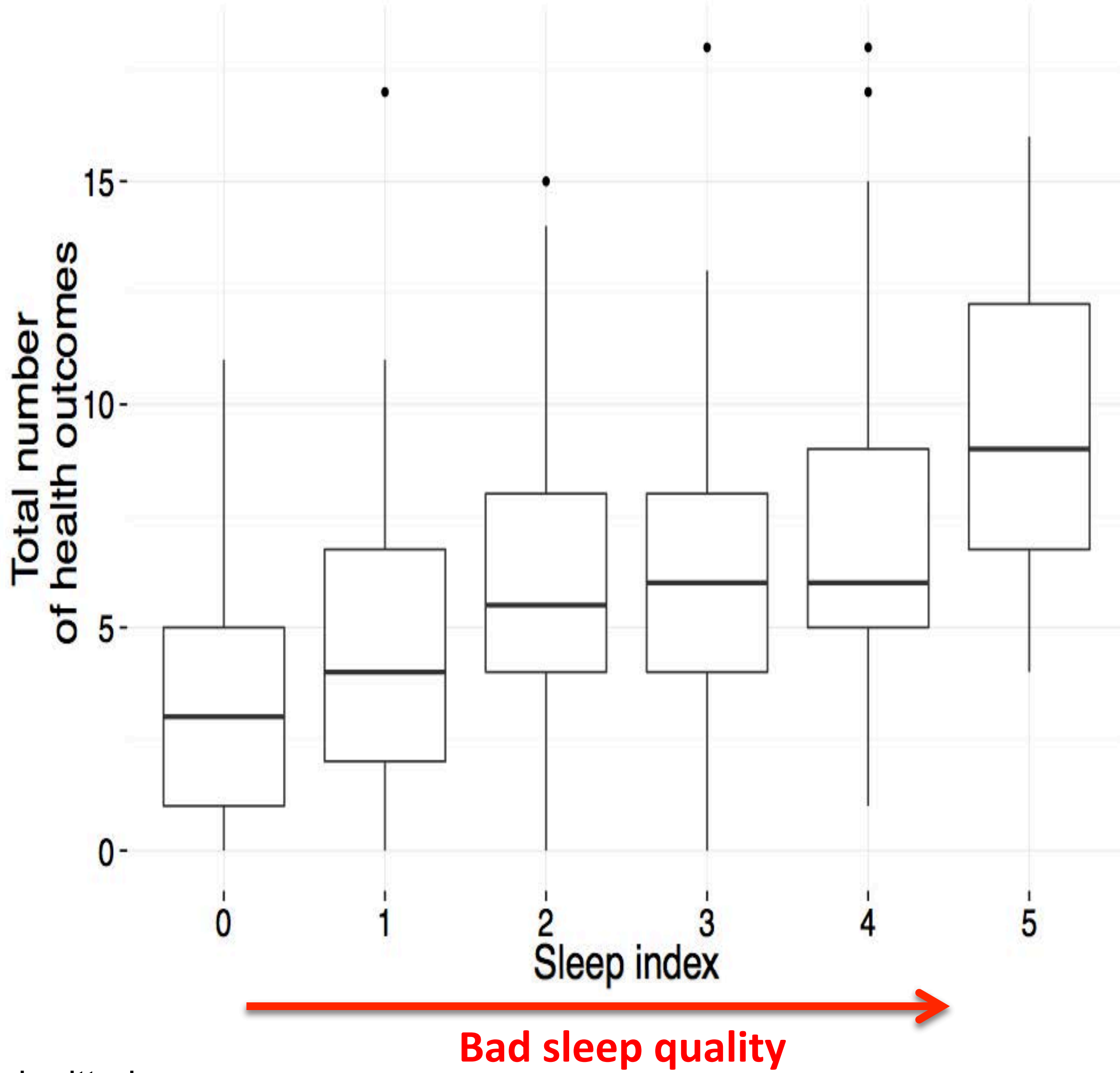
HSH
SENSORS FOR HEALTH

Autonomous control



SENSORS FOR HEALTH

Sleep and Health



Cedeno et al., 2015. Submitted.

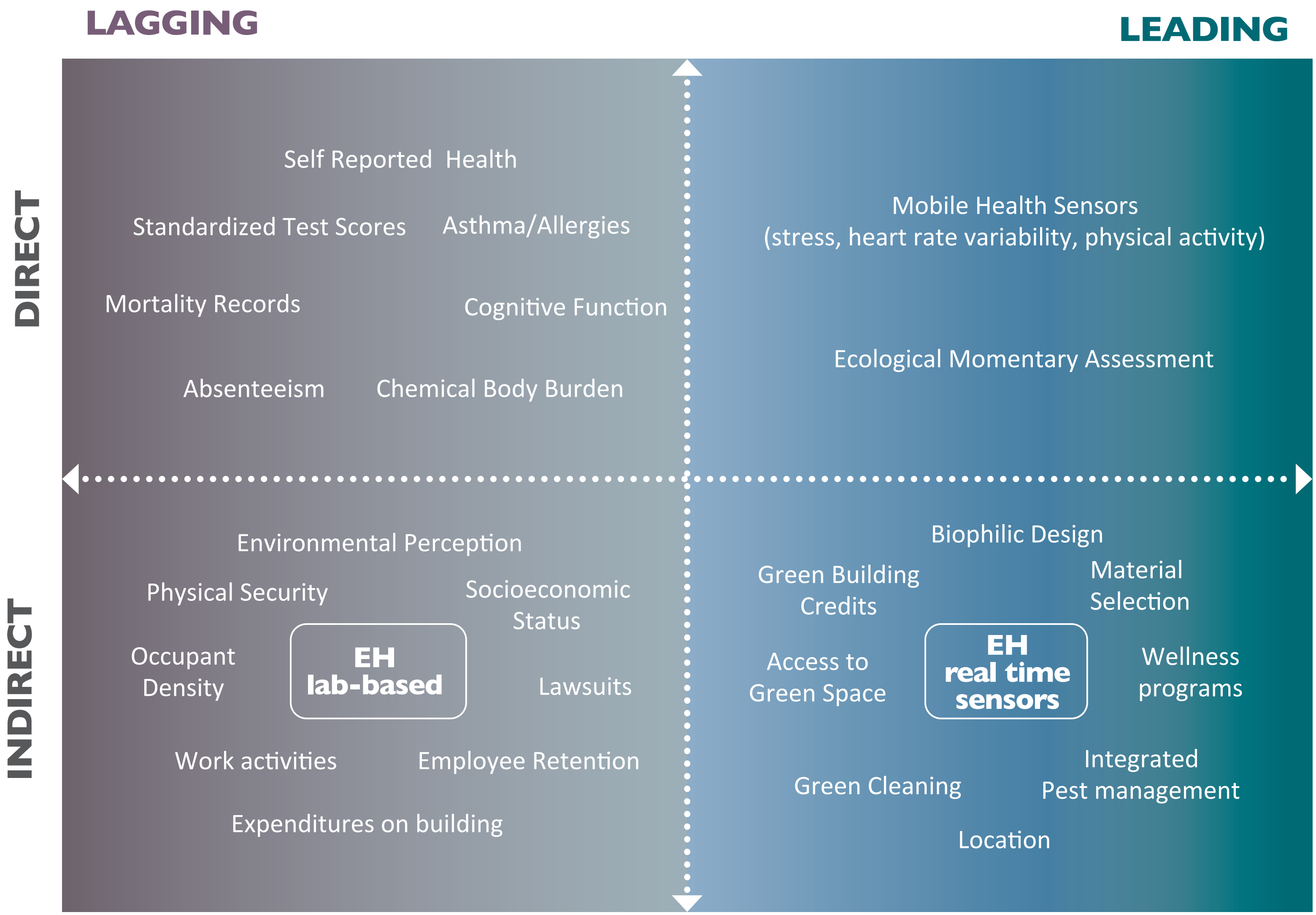
Occupants will expect…

- Buildings that are responsive to their needs
- Buildings that respond autonomously
- Buildings that improve health
  - physical health, mental health, feelings of wellness, cognitive function, safety

How do we get there?

Graphic: deltainitiative.com

Health Performance Indicators



Allen et al., 2015. Submitted

THE IMPACT OF GREEN BUILDINGS ON COGNITIVE FUNCTION

United Technologies | HARVARD T.H. CHAN SCHOOL OF PUBLIC HEALTH | SYRACUSE COE center of excellence | UPSTATE MEDICAL UNIVERSITY

Allen et al., 2015. Submitted.

How will your work impact the world?

Occupants of the Future: Moving from "Sick Building Syndrome" to "Healthy Building Syndrome"

Joseph G. Allen, DSc, MPH

>Assistant Professor, Harvard School of Public Health

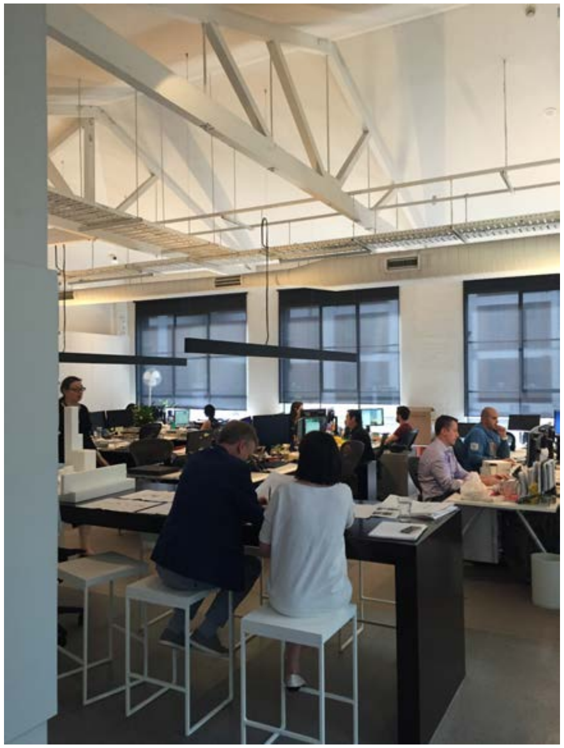
>Director, Healthy Buildings Program,
Harvard Center for Health and the Global Environment

HARVARD T.H. CHAN | SCHOOL OF PUBLIC HEALTH

the internet of things empowers occupants for health, productivity and energy savings

DOE/PNNL Buildings of the Future
City College of New York
May 4, 2015

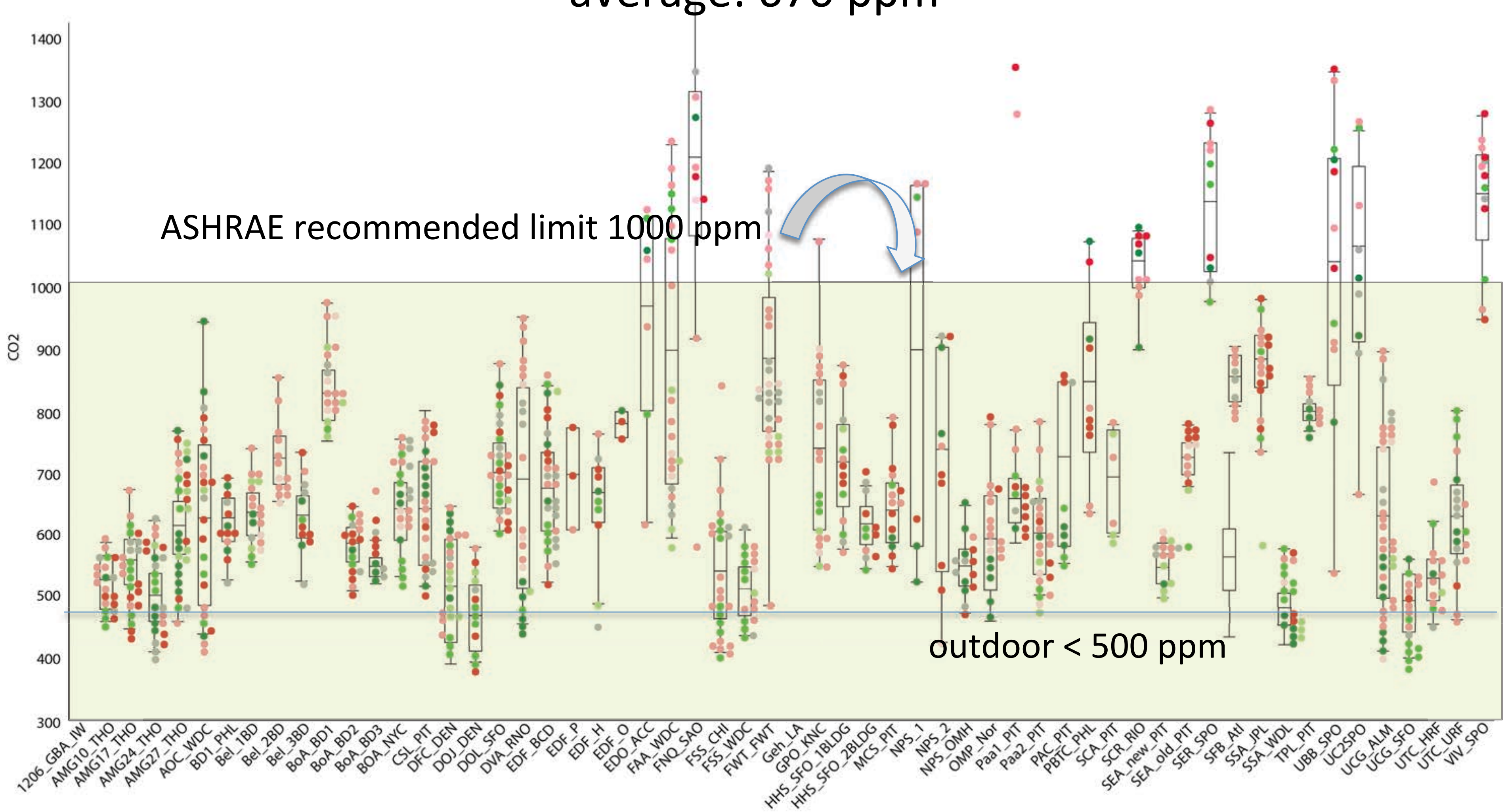
Vivian Loftness, FAIA
University Professor and Paul Mellon Chair of Architecture
Carnegie Mellon University
LEED Fellow & Senior Fellow Design Futures Council

In far far less than 100 years, occupants will expect buildings to support dynamic space uses with the highest air quality, thermal comfort, lighting quality, and connectivity.

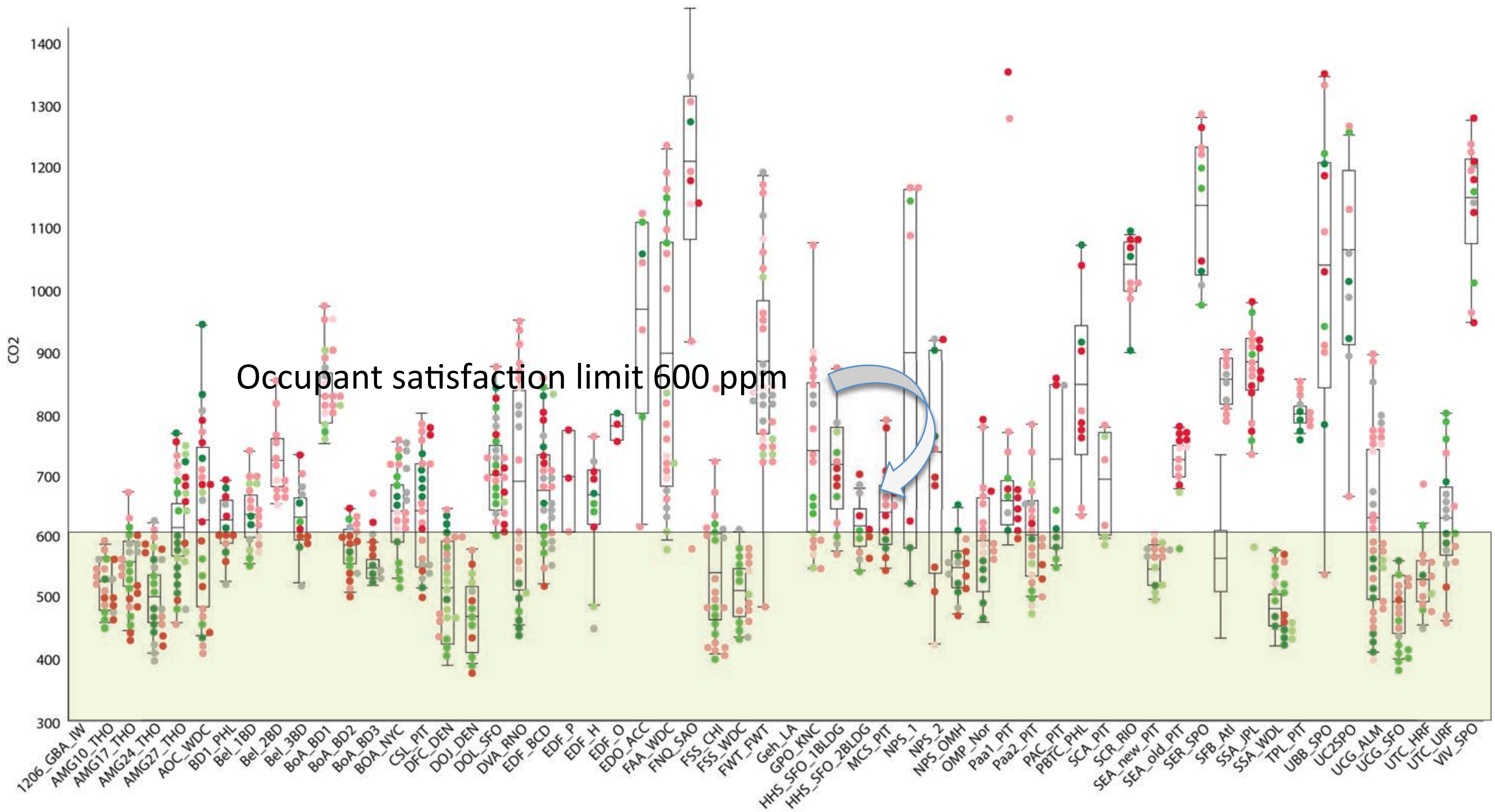
CO2 in US workstations

average: 670 ppm



n=1282 workstations, 64 buildings

CO_2 vs. Satisfaction with Air Quality



n=1282 workstations, 64 buildings

Future Buildings will put **Air Quality**
back in the hands of the occupants by

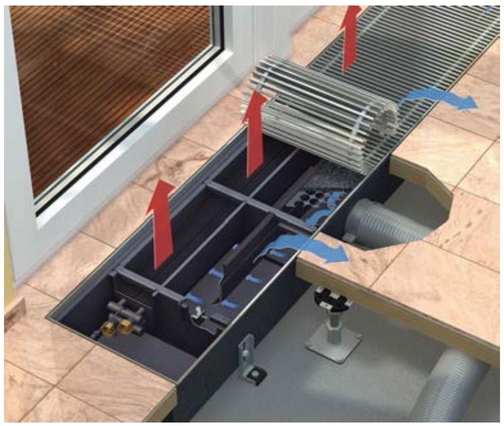
1. separating thermal and air systems

2. providing windows that open
   (with HVAC responding sensors)

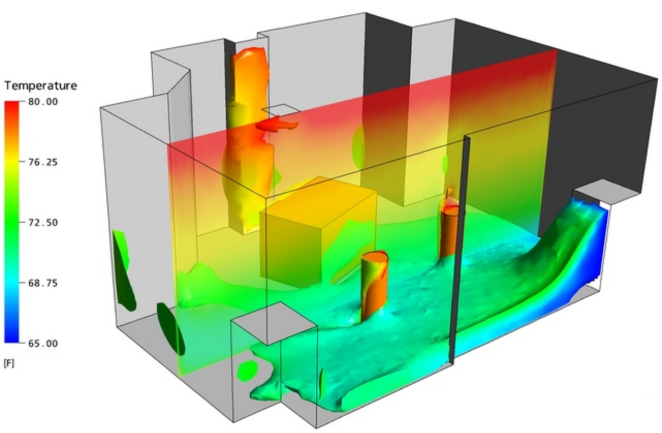
3. integrating IAQ and occupancy sensors.

for health, productivity and energy conservation

the internet of things:
Separating breathing air from thermal conditioning



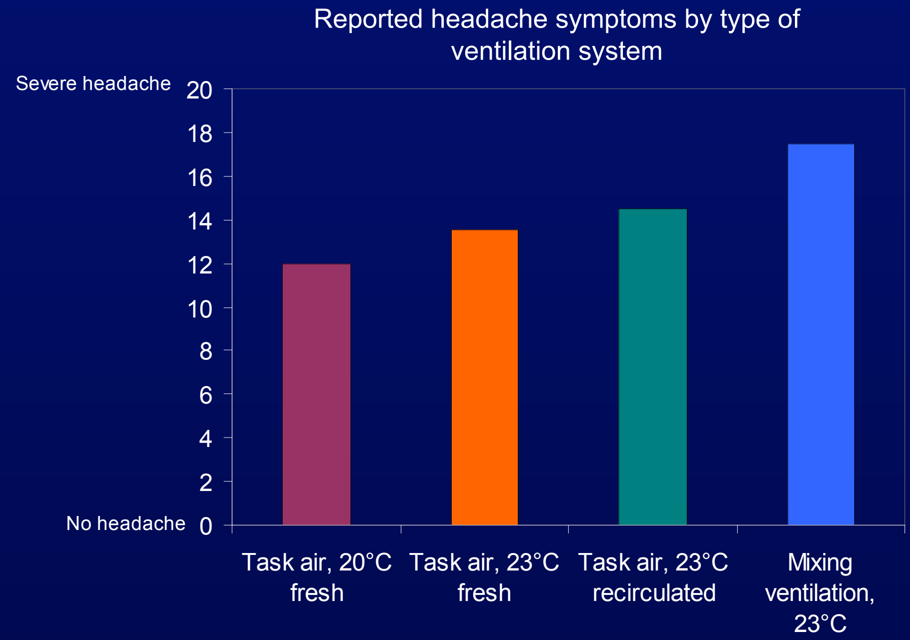
Ventilation air gets lost in the 90-95% of cooling duct air flow. Future offices will provide dedicated outside air with user control of temperature with air or water based cooling.j



Individual air control + Increased outside air = Health

Kaczmarczyk et al 2002

In a 2002 controlled experiment, Kaczmarczyk et al identify a 23.5% reduction in headache symptoms when workers are provided with individually-controlled task air systems supplying outdoor air, as compared to a conventional mixing ventilation system, in a room with a typical office pollutant source.



First cost increase:	$800 / employee
Annual energy cost increase:	$8 / employee
Annual health savings:	$17 / employee
Annual productivity savings:	$106 / employee
ROI:	**14%**

Reference: Kaczmarczyk, J., Zeng, Q., Melikov, A., and Fanger, P.O. (2002) The effect of a personalized ventilation system on perceived air quality and SBS symptoms. In Proceedings of Indoor Air 2002, Monterey, CA, June 30-July 5, 2002; Office of Pollution Prevention and Toxics, U.S. Environmental Protection Agency. Cost of Illness Handbook. http://www.epa.gov/oppt/coi; Schwartz et al (1997) Lost Workdays and Reduced Work Effectiveness Associated with Headache in the Workplace. Journal of Occupational and Environmental Medicine. 39(4), pp. 320-327

the internet of things: windows that open with HVAC response

now: perimeter workstations in 64 buildings

76 %

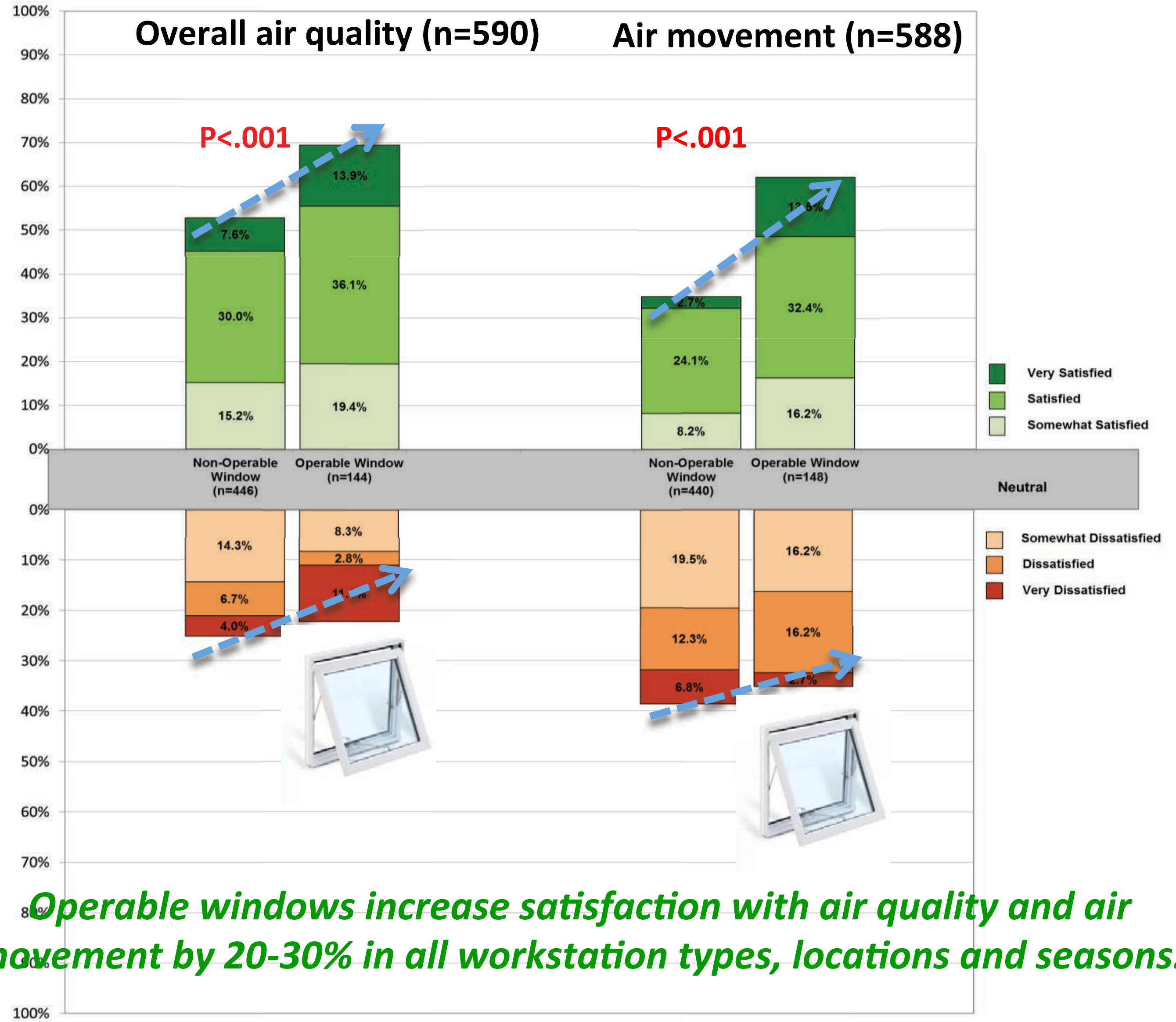
Non operable window

24 %

Operable window

Satisfaction with Air Quality & Movement by Window Type

n=590 in 64 buildings

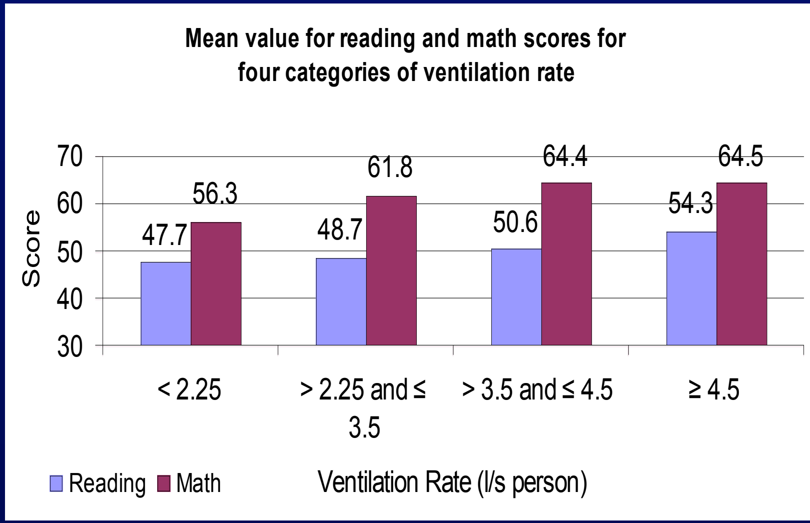


Operable windows increase satisfaction with air quality and air movement by 20-30% in all workstation types, locations and seasons.

Increased outside air = Individual Productivity

Shaughnessy et al 2006 (School)

In a 2006 multiple building study of 54 elementary schools, Shaughnessy et al identify a 14.4% improvement in standardized math test scores in classrooms with a ventilation rate higher than 4.5 l/s-person, as compared to classrooms with a ventilation rate lower than 2.25 l/s-person.

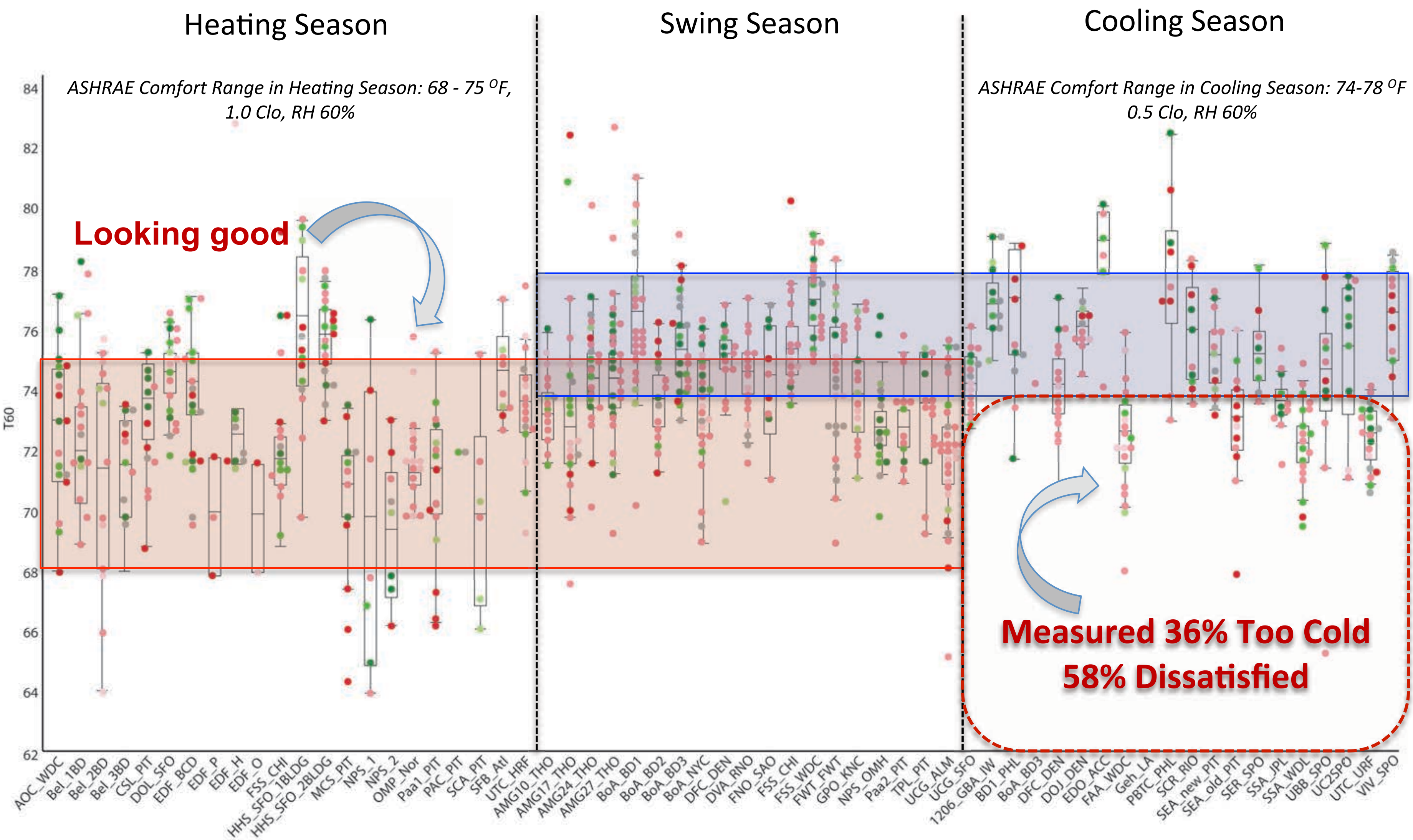


First cost increase:	$13 / student
Annual funding gain:	$158 / student
Annual energy cost increase:	$2 / student
Net savings:	$156
ROI:	**1200%**

R. J. Shaughnessy, U. Haverinen-Shaughnessy, A. Nevalainen, D. Moschandreas (2006) A preliminary study on the association between ventilation rates in classrooms and student performance. Indoor Air, 16, 465-468

Air temperature measurements 0.6 m from the floor

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



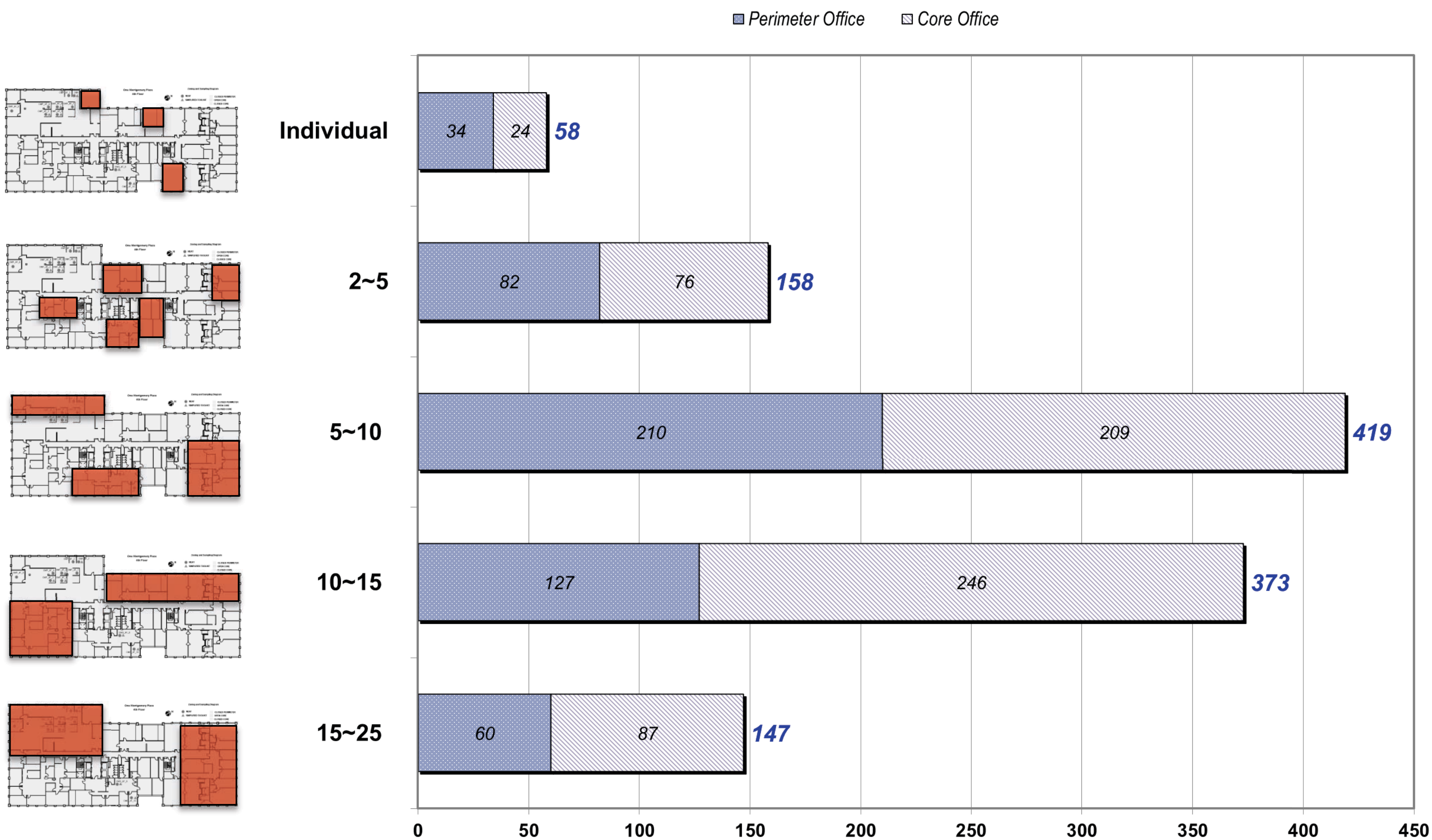
Future Buildings will put **Thermal Comfort**
back in the hands of the occupants by

1. separating thermal and ventilation systems
2. micro-zoning, enriching buildings over time
3. providing individual controls and real feedback

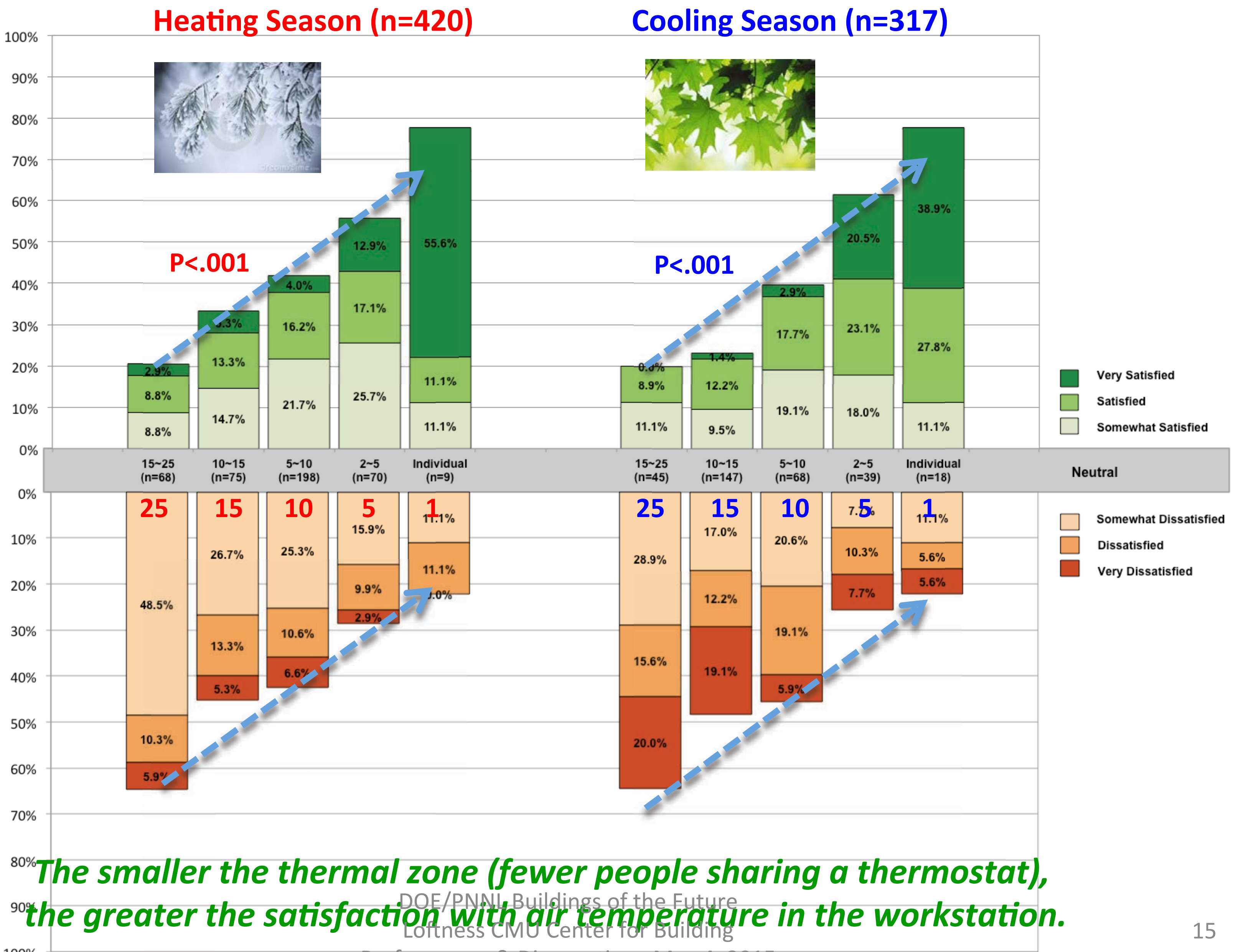
for health, productivity and energy conservation

the internet of things: every diffuser is a zone

zone sizes for combinations of open and closed offices in 64 buildings



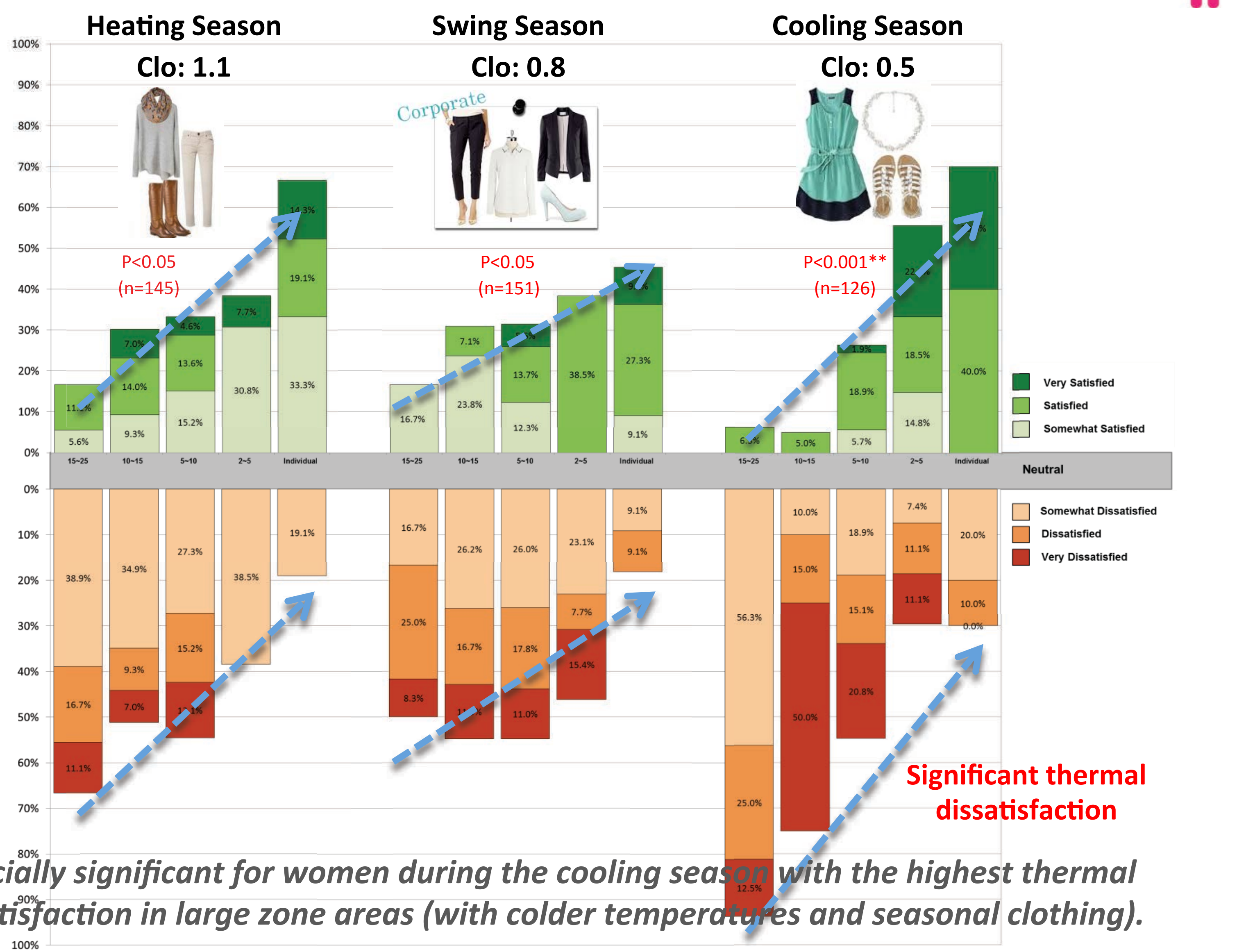
Temperature Satisfaction by "Size of Zone"



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

Temperature Satisfaction by "Size of Zone" by Season

(Female, n= 422)

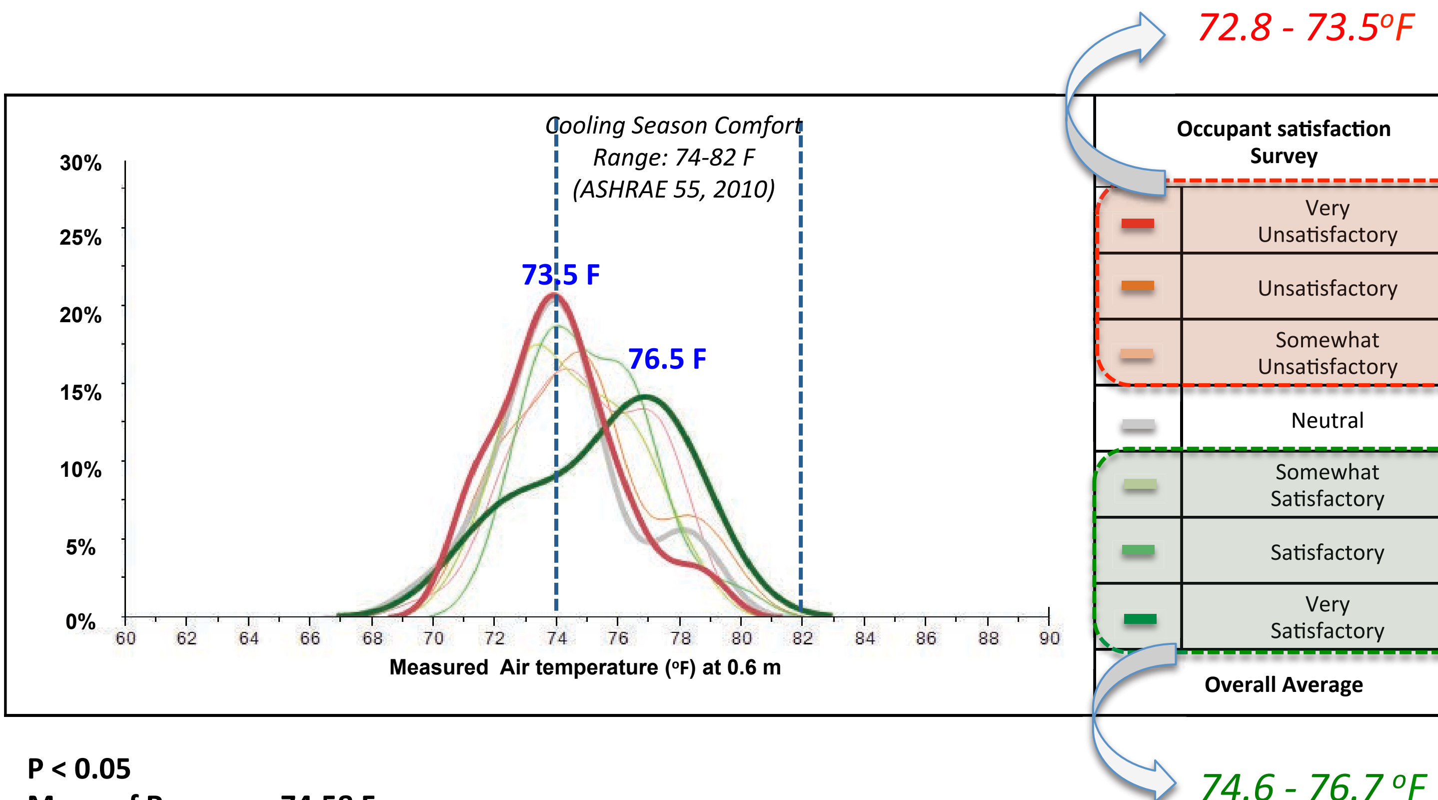


especially significant for women during the cooling season with the highest thermal dissatisfaction in large zone areas (with colder temperatures and seasonal clothing).

Image: http://thecollegejuice.com/tag/dress-for-success/

Cooling season user satisfaction with air temperature at 0.6 m

CBPD, CMU, Cooling Season (n=446)



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**

P < 0.05
Mean of Response 74.58 F

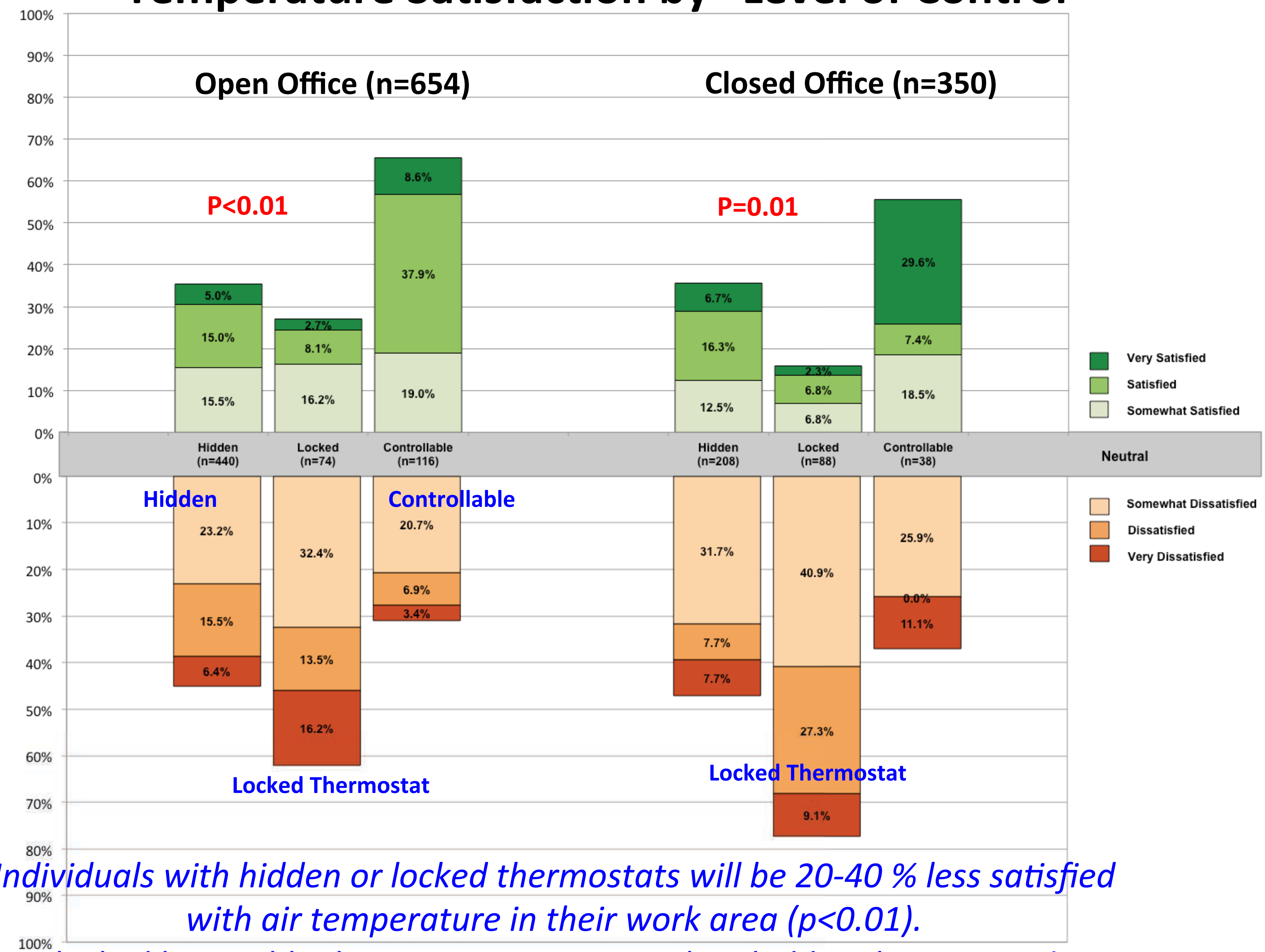
the internet of things: individual sensors and controls

level of control in open and closed offices in 64 buildings

65 %	17 %	18 %
Hidden Thermostat	Visible set-points but locked Thermostat	Controllable Set-points

Hidden Thermostat	Visible set-points but locked Thermostat	Controllable Set-points
484 open offices 172 closed offices	110 open offices 60 closed offices	60 open offices 118 closed offices

Temperature Satisfaction by "Level of Control"



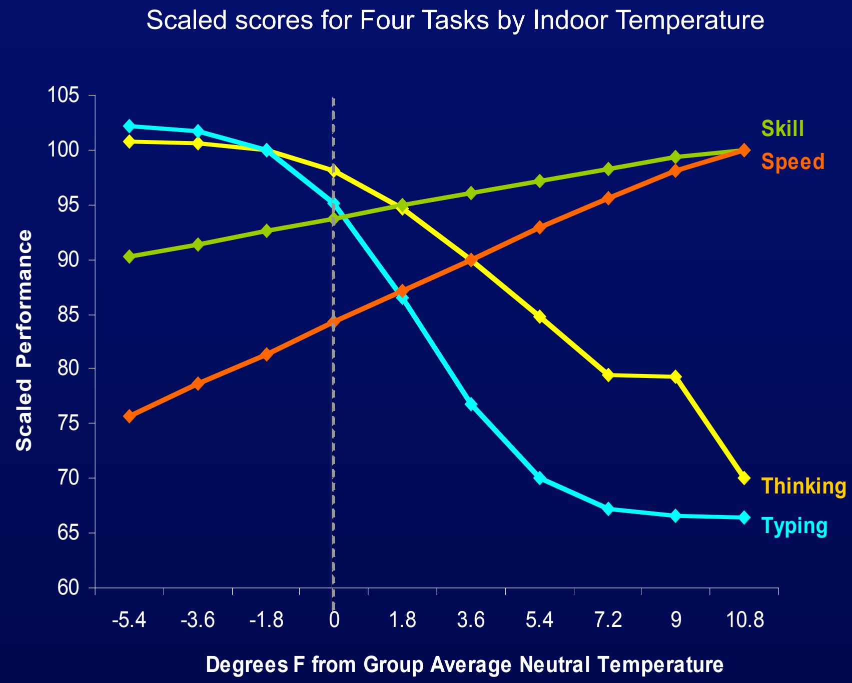
Individuals with hidden or locked thermostats will be 20-40 % less satisfied with air temperature in their work area (p<0.01).

locked but visible thermostats are worse than hidden thermostats!

Temperature Control = Individual Productivity

Wyon 1996

In a 1996 controlled experiment and meta-analysis study, Wyon identifies that providing individual temperature control over a range of 6°K (10.8°F) results in performance improvements of 2.7% on thinking and decision-making tasks, 7% on typing tasks, and 3.4% on skilled manual tasks.



First cost increase:	\$800 / employee
Annual productivity savings:	\$1,035 / employee
ROI:	**129%**

Reference: Wyon, D.P. (1996) Individual microclimate control: required range, probable benefits, and current feasibility.
In Proceedings of Indoor Air ’96: 7th International Conference of Indoor Air Quality and Climate, Nagoya, Vol. 1, pp.1067-1072.

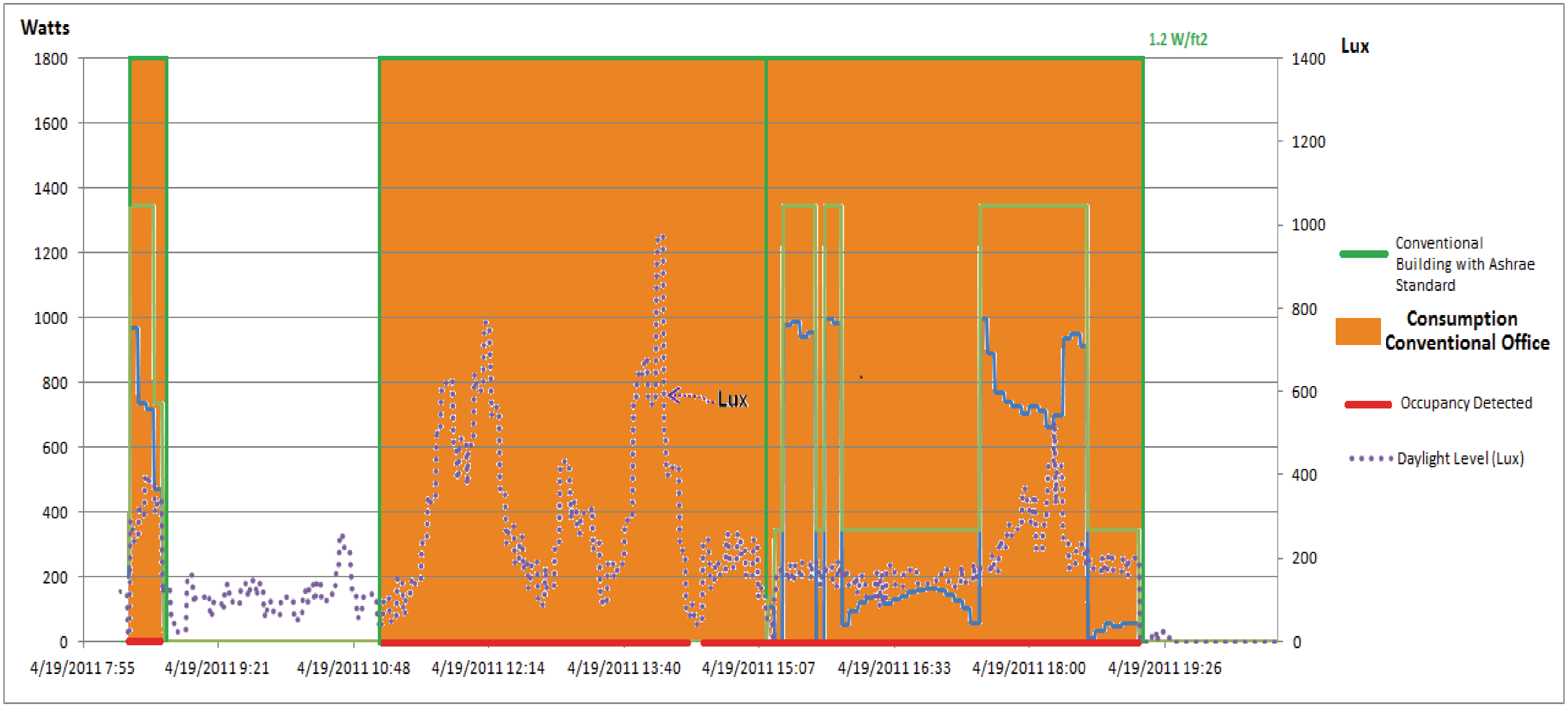
Future Buildings will put **Lighting Quality**
back in the hands of the occupants by

1. micro-zoning lighting controls
2. separating task and ambient lighting
3. supporting daylight with heat gain and glare control

for health, productivity and energy conservation

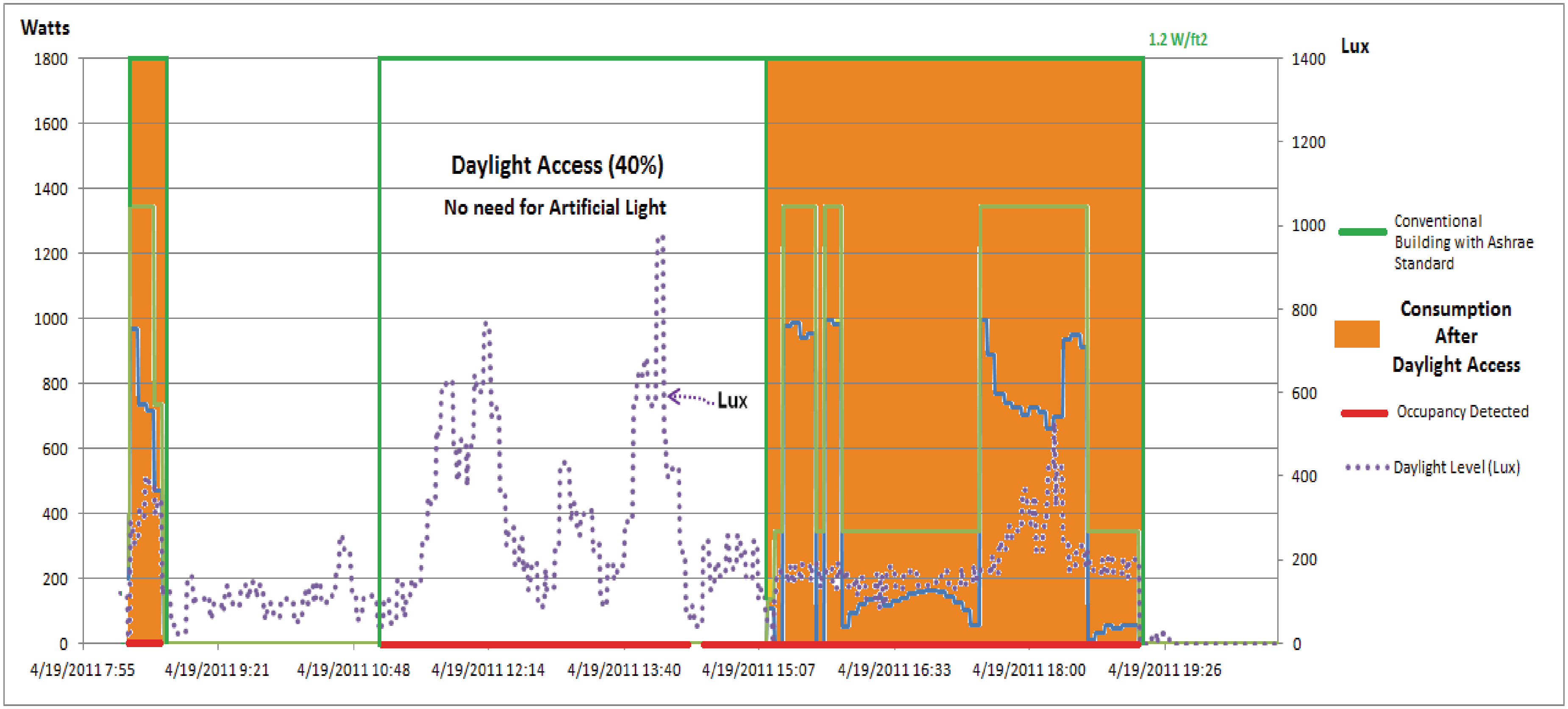
the internet of things: every fixture is a zone

Field Results : Conference Spaces



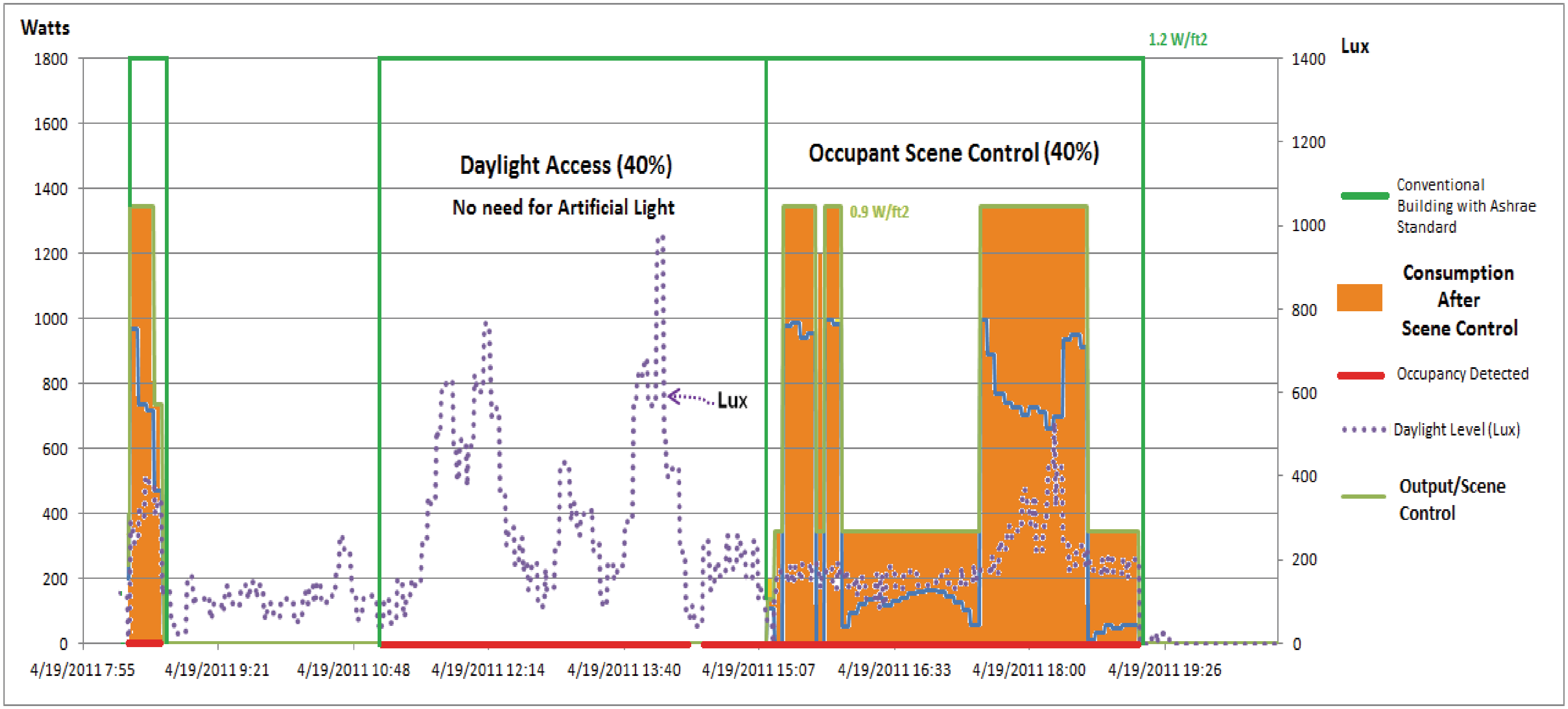
Baseline : Artificial lights on even with occassional occupancy

Field Results : Conference Spaces



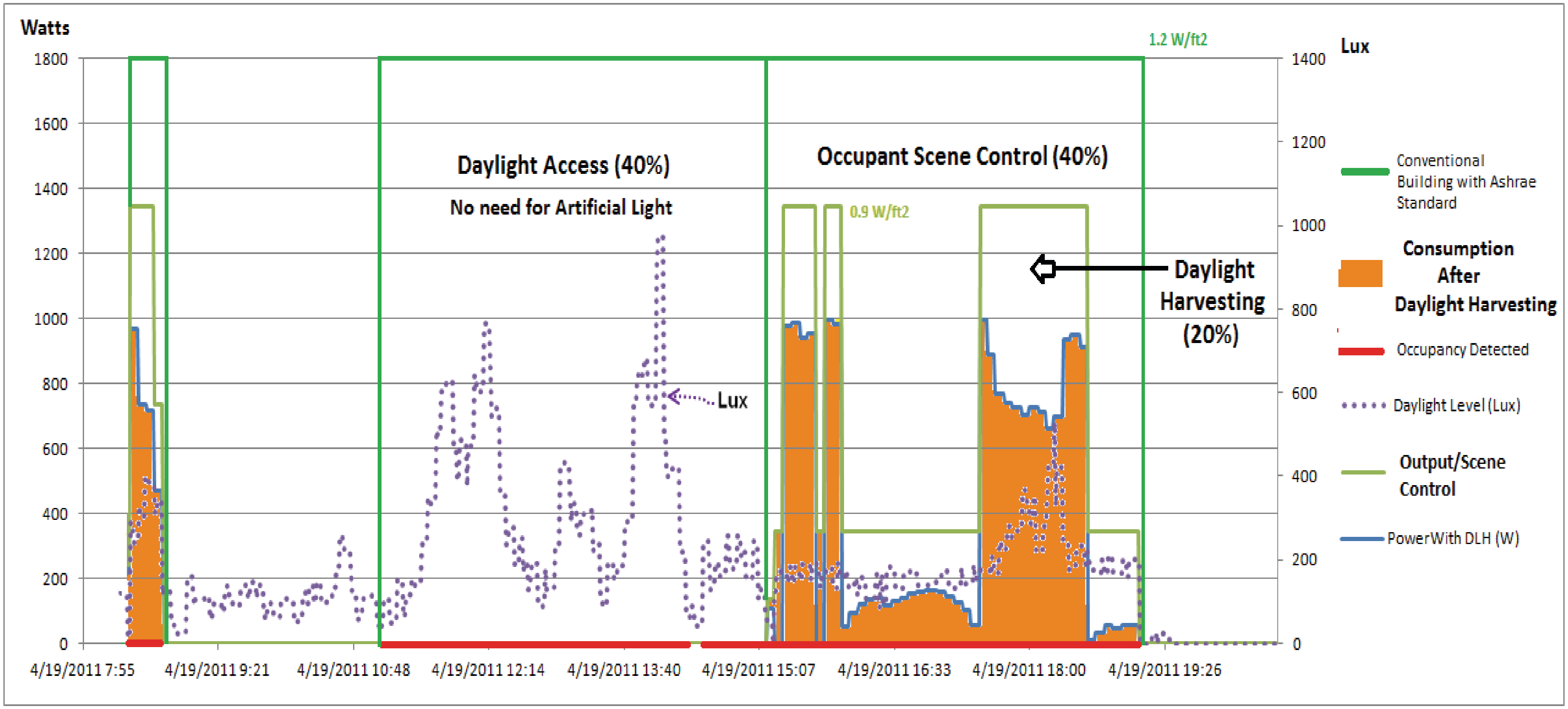
- **40%** Saving By Daylighting

Field Results : Conference Spaces



- ➢**40%** Saving By Daylighting only
- ➢**64%** Saving By Daylighting + Occupant Scene Control

Field Results : Conference Spaces

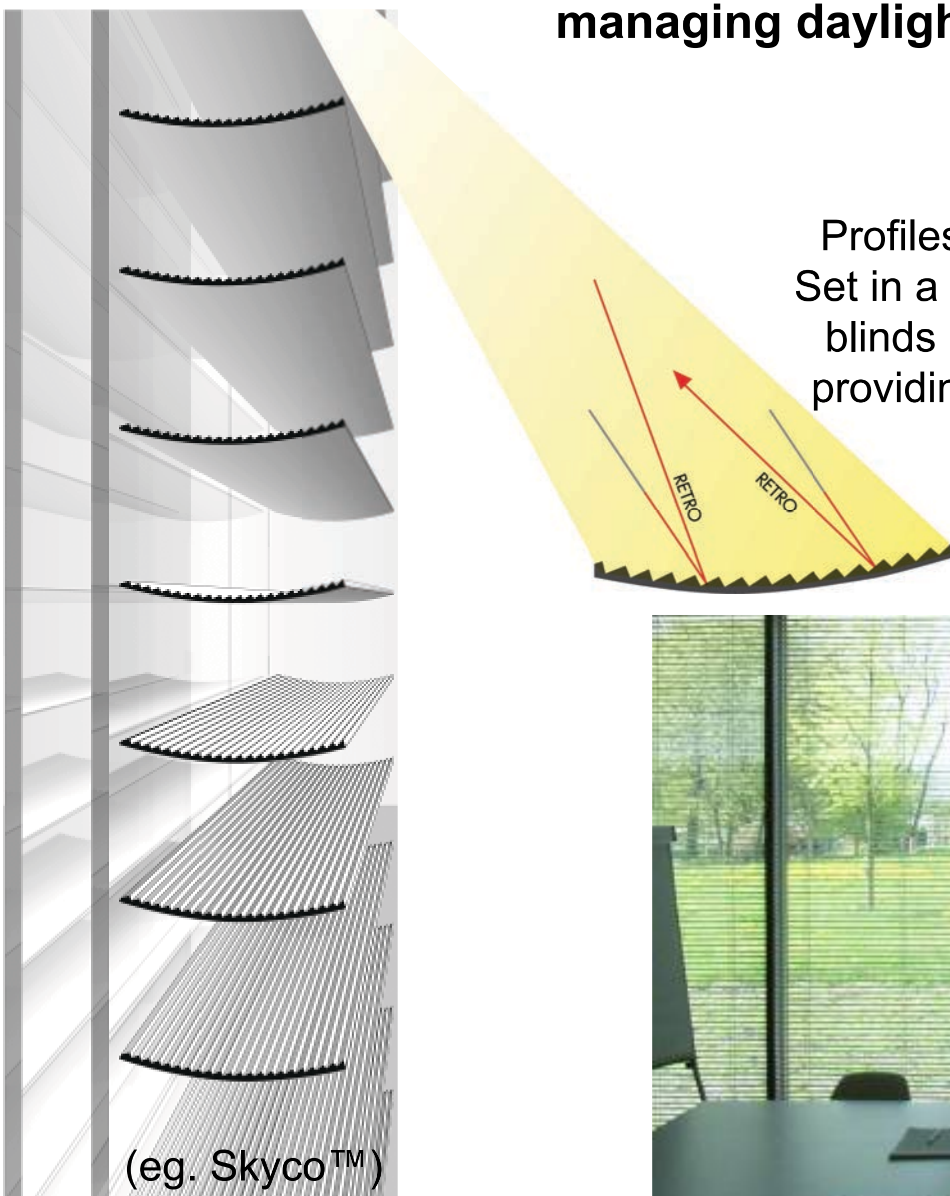


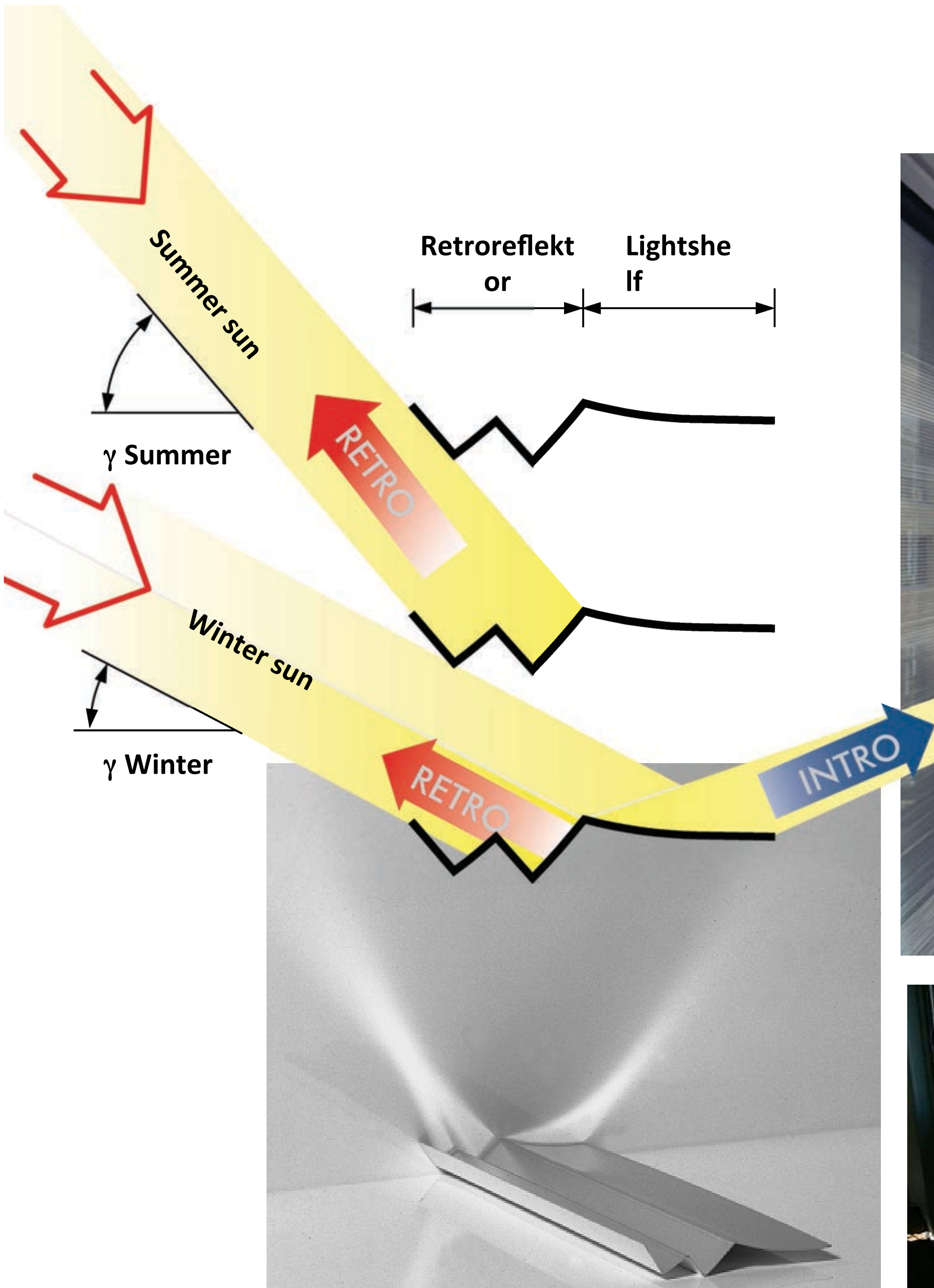
- **40%** Savings By Daylighting
- **64%** Saving By Daylighting + Occupant Scene Control
- **71%** Saving By Daylighting + Occupant Scene Control + Daylight Harvesting

the internet of things: every window is a light fixture

managing daylight, solar heat, glare and views

Profiles must be inverted for daylighting. Set in a horizontal position, these reflective blinds reflect light up to the ceiling while providing clear views and effective shade

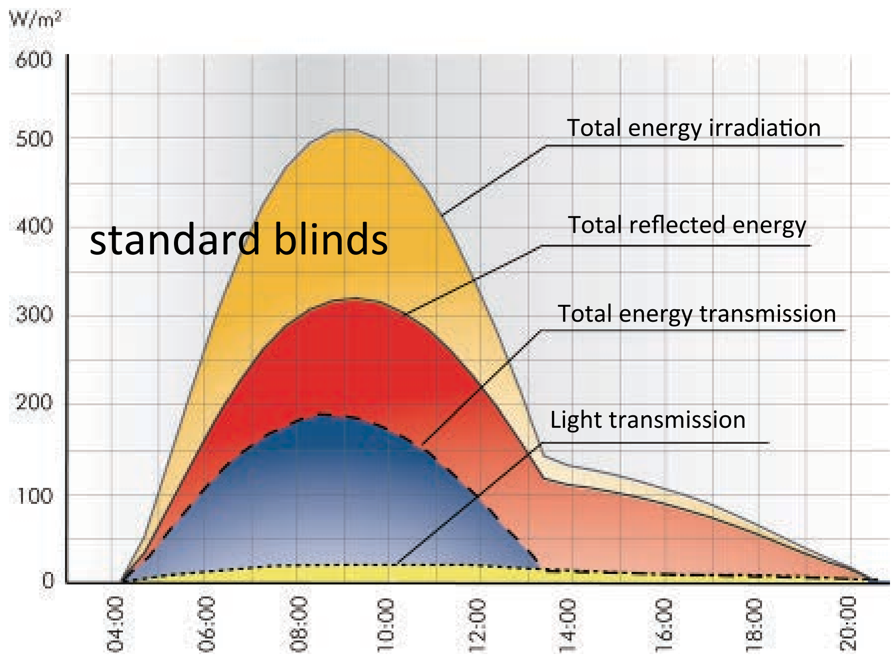




Blinds can even be shaped to vary reflection based on season (eg Retrosolar™)

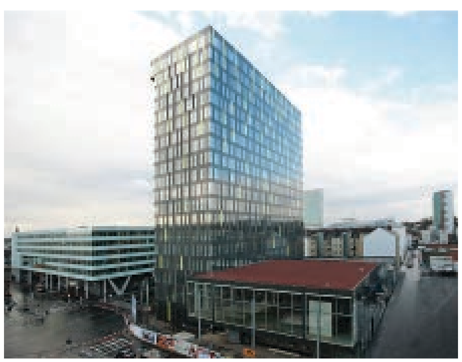
This increases light while significantly decreasing heat

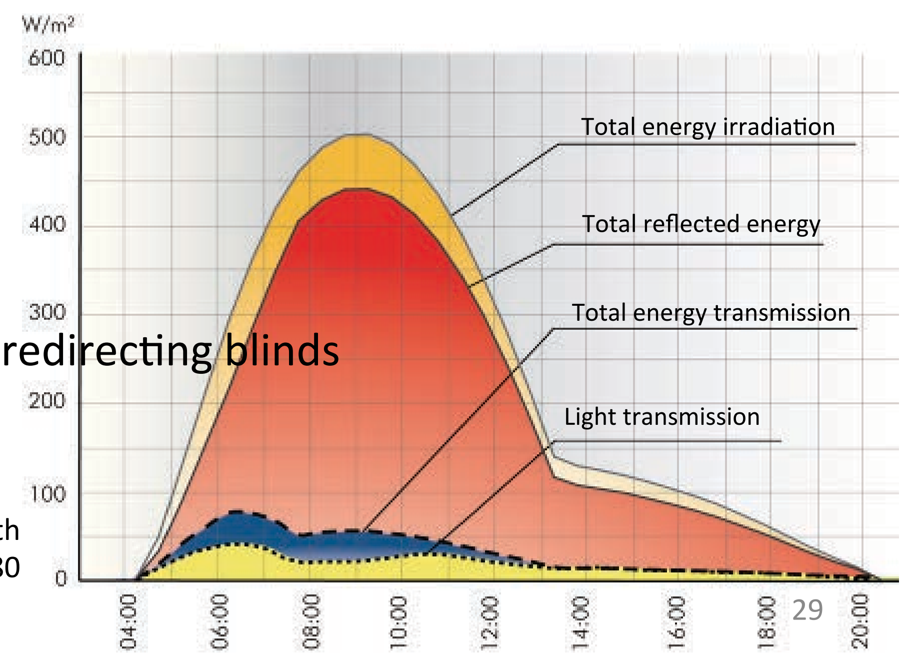
(reference Helmut Koester, Retrosolar)



Time related energy control

Low-e glazing with standard blinds, internal, orient. S-E, 21.06.



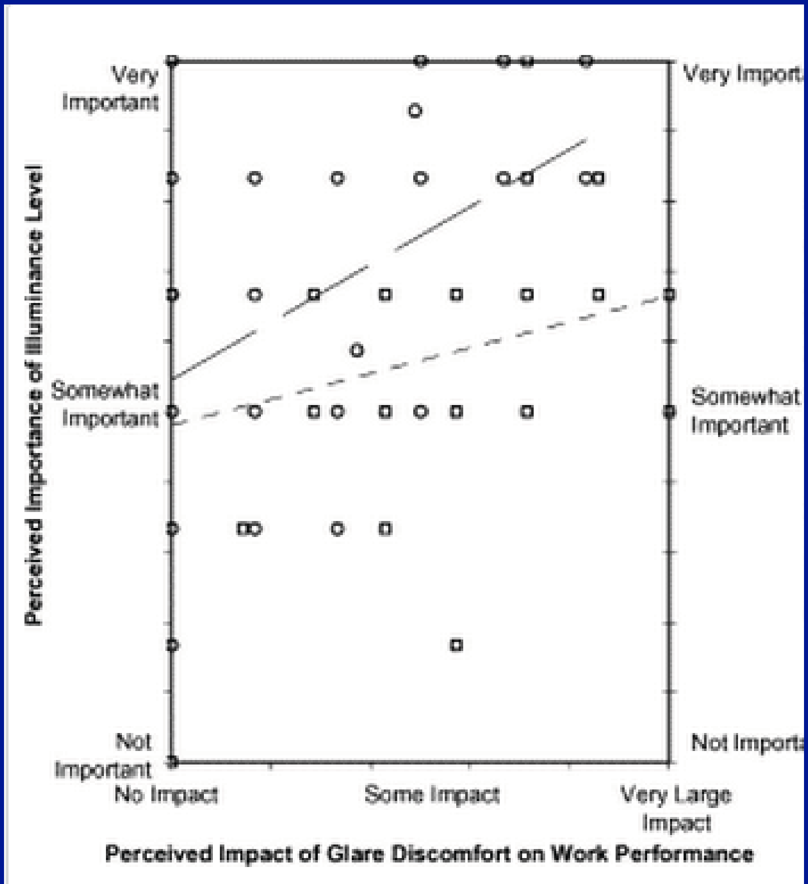


Best practice façade with RETRO*Flex* 80

Glare control = Individual Productivity

Osterhaus and Bailey 1992

In a 1992 lab experiment conducted using 6 female and 20 male subjects, Osterhaus and Bailey found a 3% productivity increase in visual task efficiency at the computer by reducing glare discomfort.



First cost increase:	$1,000 / employee
Annual productivity savings:	$299.73 / employee
ROI:	**30.0%**

Osterhaus, W. and Bailey, I. (1992): Large Area Glare Sources and Their Effect on Discomfort and Visual Performance at Computer Workstations: 1992 IEEE Industry Applications Society Annual Meeting; Houston, TX: LBL-35037.

Seated Views = Individual productivity

SMUD Call Center /Heschong Mahone Group 2003

In a 2003 building case study of the Sacramento Municipal Utility District (SMUD) Call Center, Heschong et al identify a 6% to 7% faster Average Handling Time (AHT) for employees with seated access to views through larger windows with vegetation content from their cubicles, as compared to employees with no view of the outdoors.

First cost increase:	$1,000 / employee
Annual productivity savings:	$2,990 / employee
ROI:	**299%**

Heschong, Mahone Group, Inc. (2003) Windows and Offices : A study of office worker performance and the indoor environments, California Energy Commission Technical Report

the internet of things: separate task and ambient lighting

+

- 200-300 lux for computer based work
- Re-locatable, adjustable arm, 6-8 watt LED task lights for each workstation

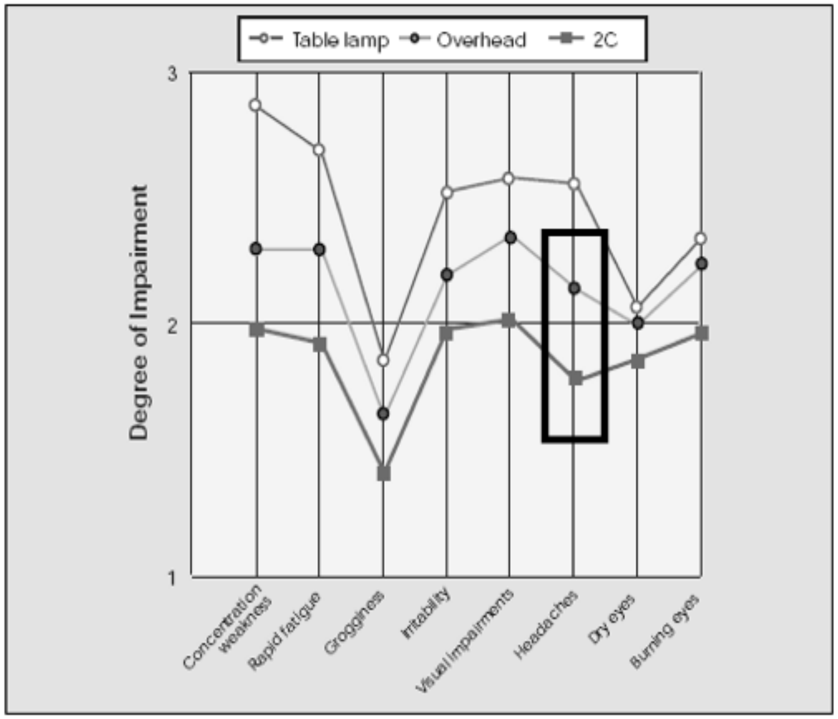
Lighting control = Health + related Individual productivity

Cakir and Cakir 1998

In a 1998 multiple building study in Germany, Çakir and Çakir identify a 19% reduction in headaches for workers with separate task and ambient lighting, as compared to workers with ceiling-only combined task and ambient lighting.

First cost increase:	$314 /employee
Annual health savings:	$14 /employee
Annual productivity savings	$87 /employee
ROI:	**32%**

Fig. 7.7 Influence of type of lighting on the degree of disturbances to health (1 = no disturbance, 4= strong disturbance)



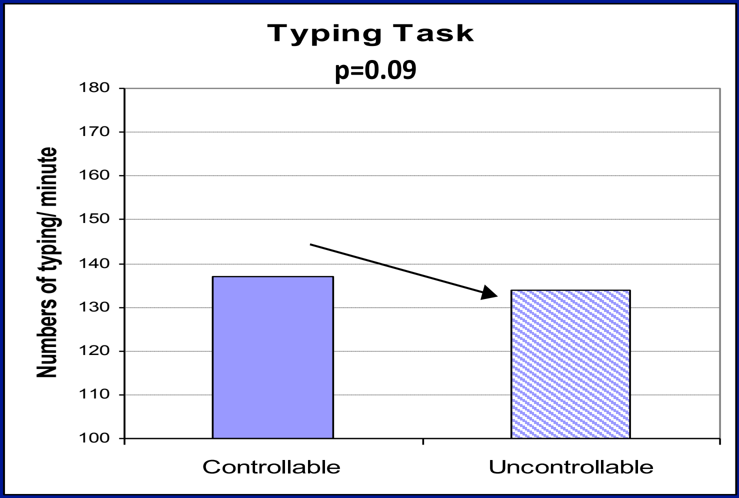
Cakir, A.E. and Cakir, G. (1998) Light and Health: Influences of Lighting on Health and Well-being of Office and Computer Workers, Ergonomic, Berlin.

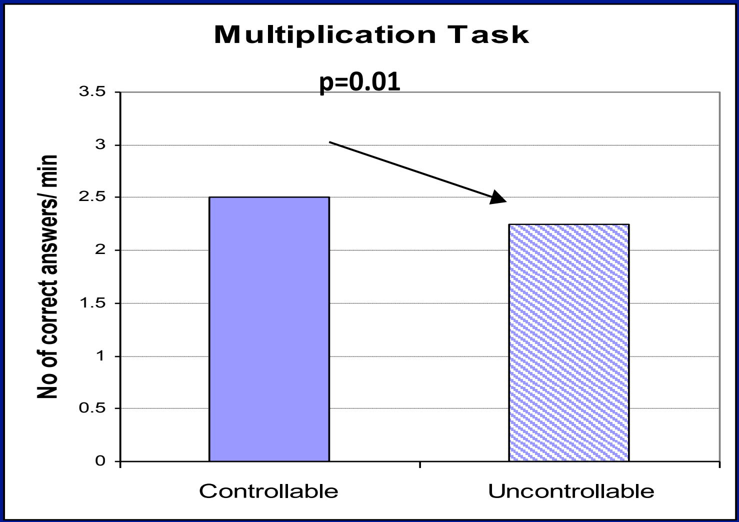
Split Task and Ambient Lighting = Individual productivity

Nishihara et al 2006

In a 2006 experiment at Waseda University in Japan, Nishihara et al identify an 11% improvement on a triple digit multiplication task on computer (p=0.01) when subjects could control their task lights as compared to when they could not. The performance on text typing also tended to be higher (p = 0.09) when task lights were controlled.

First cost increase: $314 / employee
Annual productivity saving: $178 / employee
ROI: **57%**



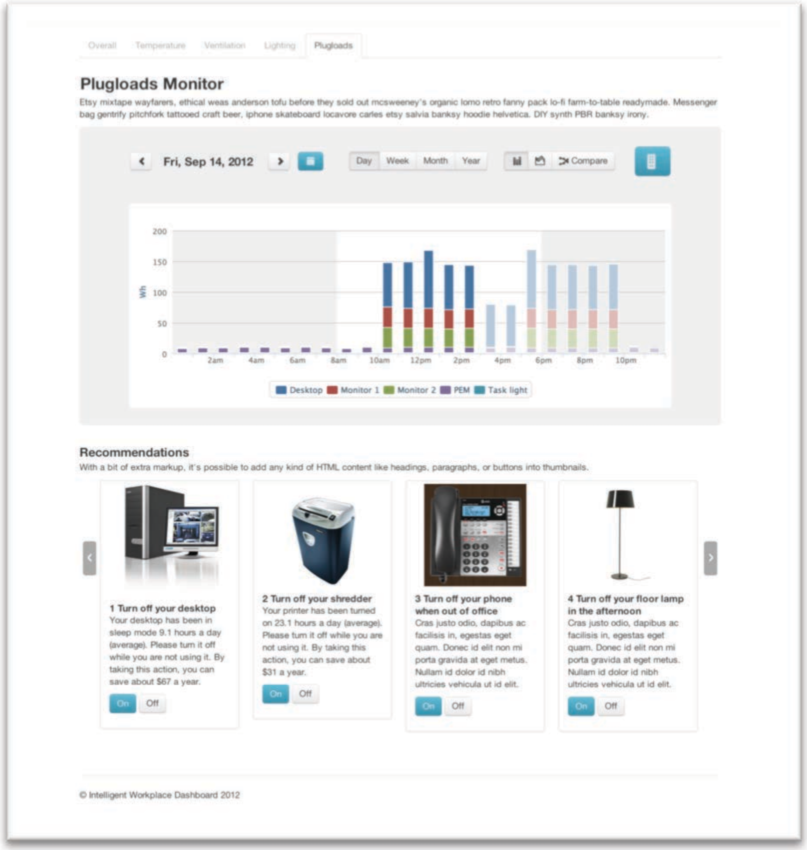


Nishihara, N., Nishikawa, M., Haneda, M., and Tanabe, S. (2006) Productivity with Task and ambient lighting system evaluated by fatigue and task performance, Proceedings of Healthy Buildings 2006, Lisbon, Portugal, pp. 249-252
CBPD/Steffy (1999) Life Cycle comparisons of Direct and Indirect Lighting for Offices - Research Report. CMU Center for Building Performance and Diagnostics

Future Buildings will put **Plug Loads**
back in the hands of the occupants by

1. anticipating smart plugs
2. providing meaningful feedback
3. providing layers of control
4. providing expert consultation

for task performance and energy conservation



CONSORTIUM for BUILDING ENERGY INNOVATION

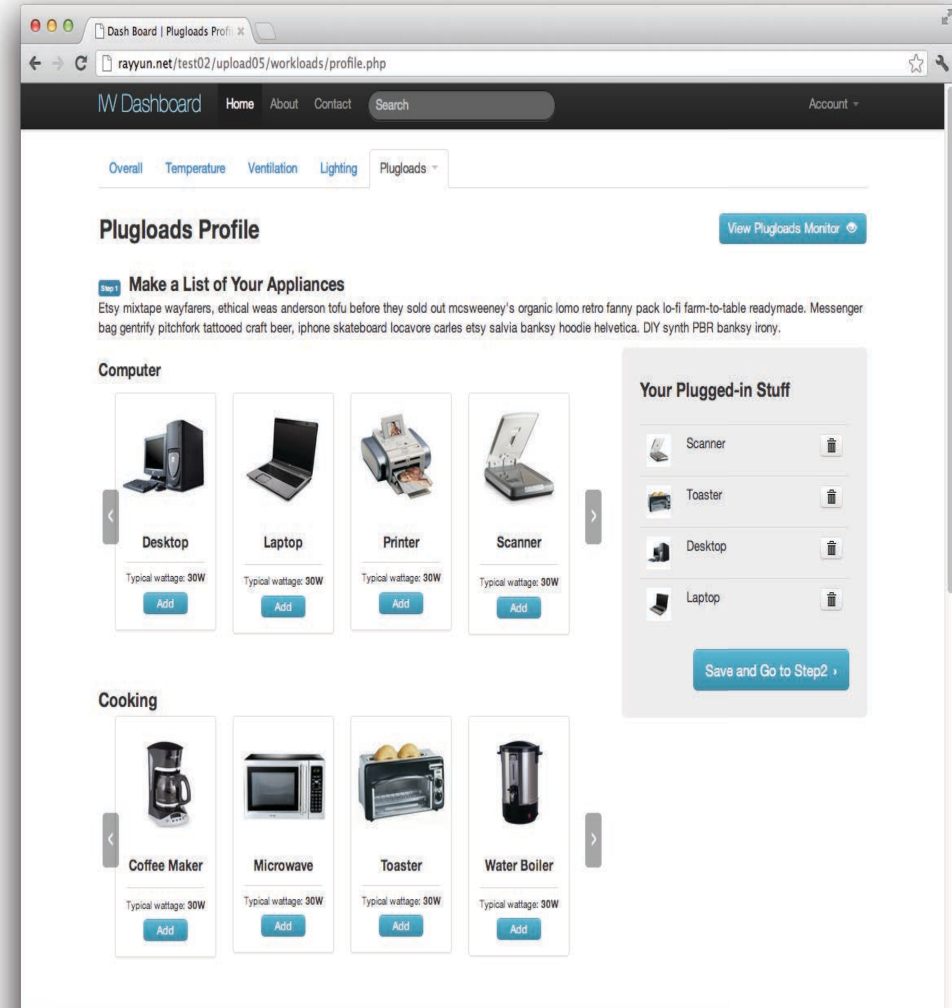
Occupants as Partners in Energy Savings

Dashboards C3

Carnegie Mellon University Professor of Architecture
Center for Building Performance & Diagnostics

Intelligent Dashboards for Occupants

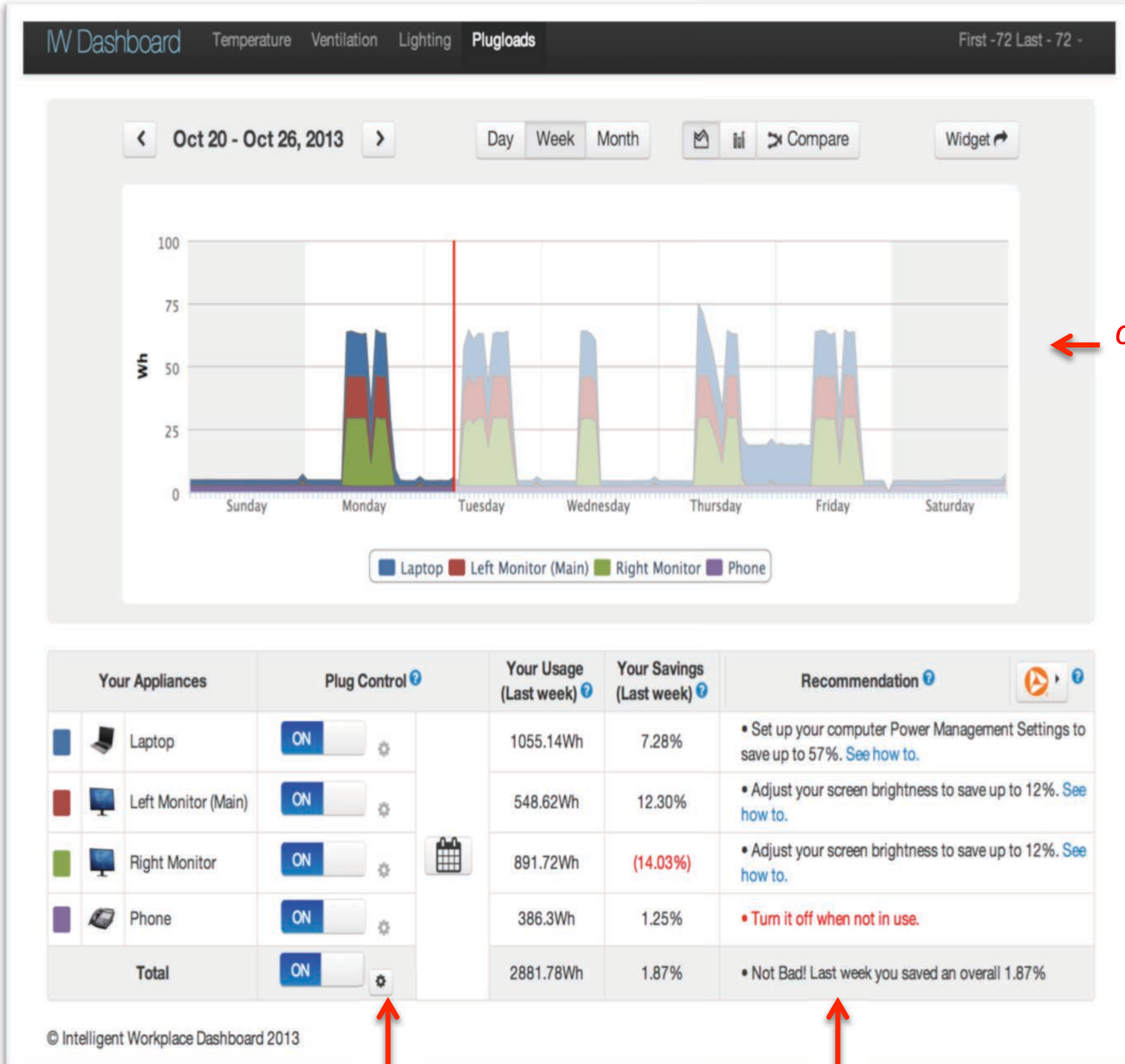
with individualized plug load meter/controllers



setting up
workstation
energy detection

(wow, abandoned technology
is still drawing power)

advancing
C3 qualities



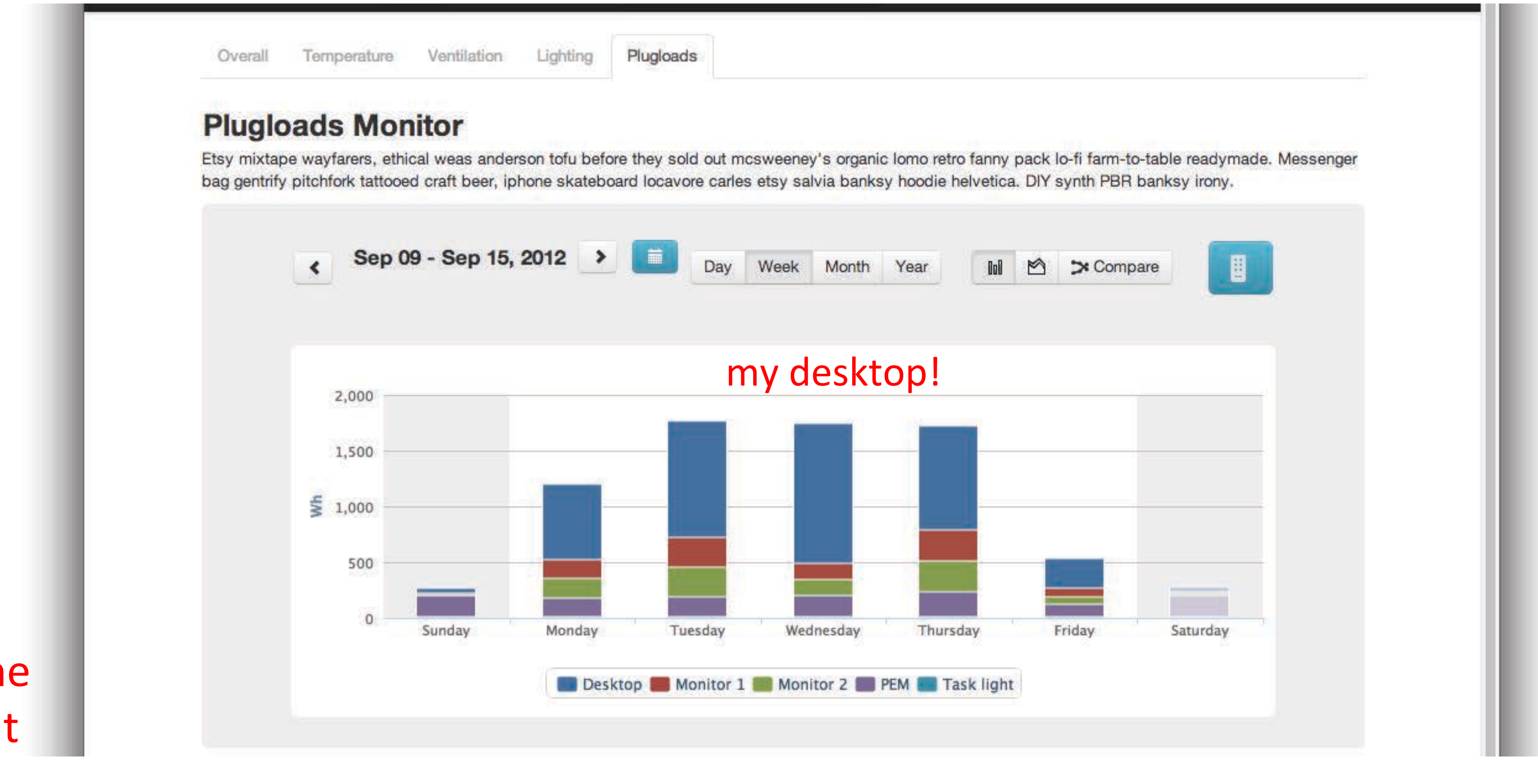
communication

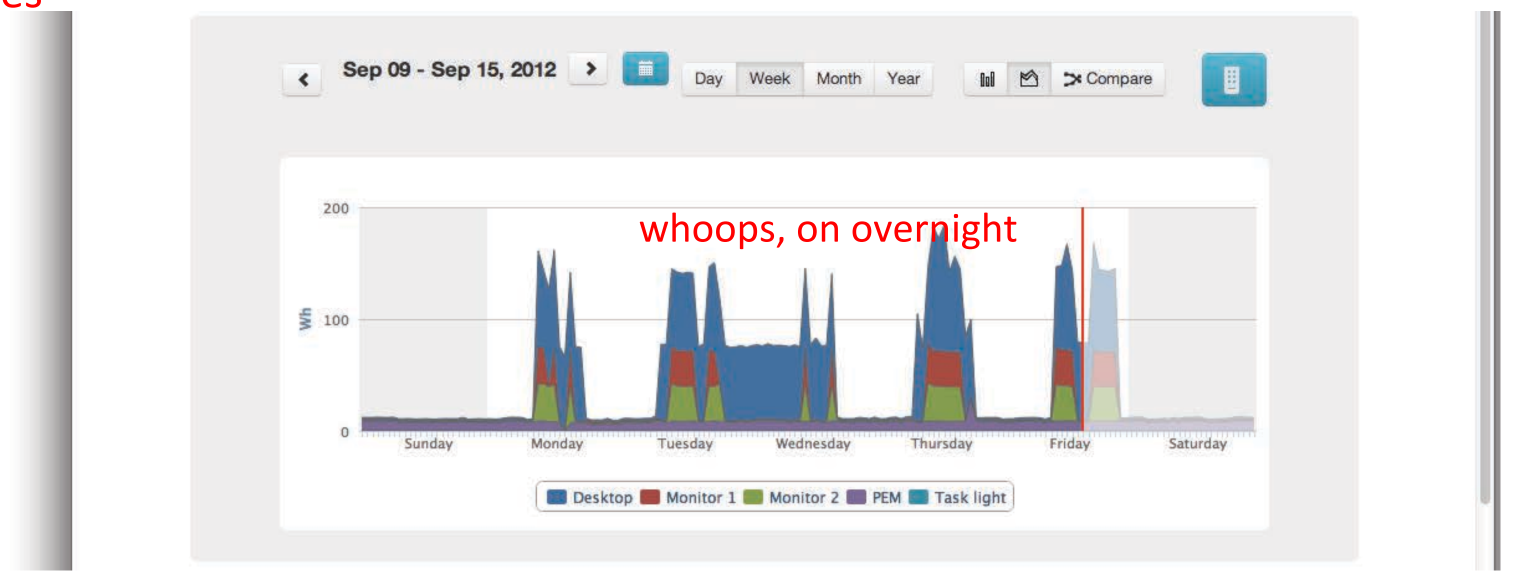
control

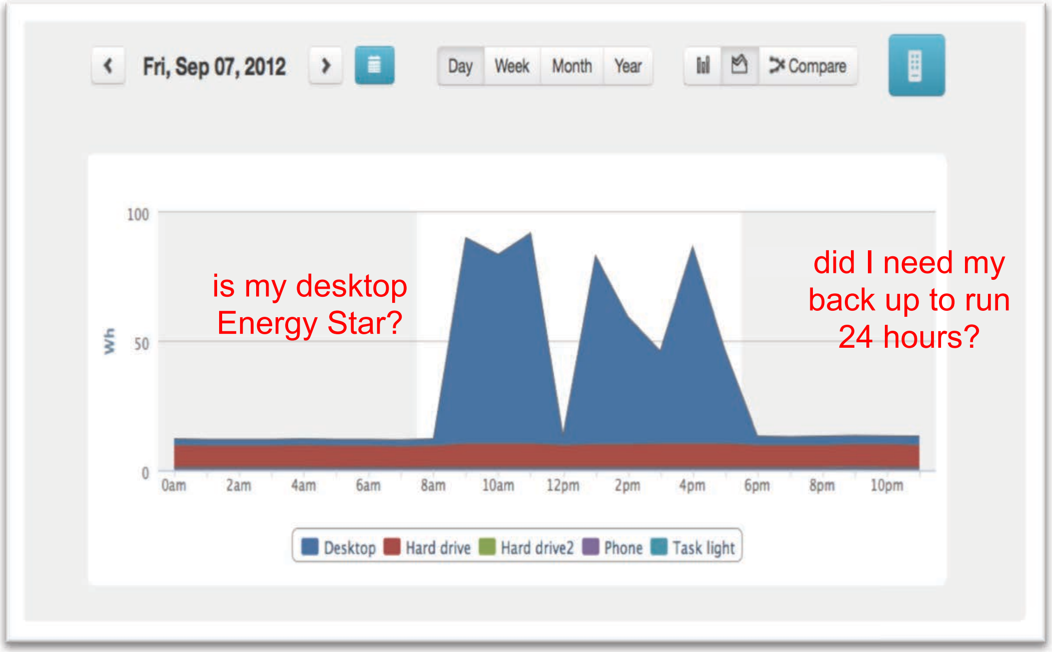
expert consulting

http://dashboard.intelligentworkplace.org/plugloads/

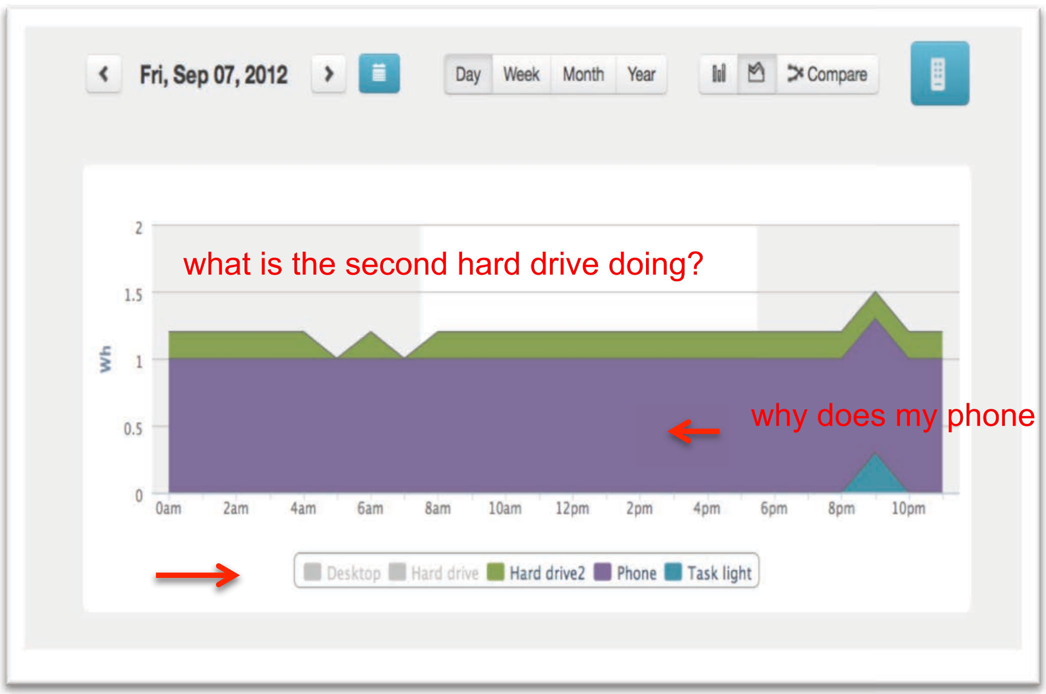
selecting the format that communicates to you



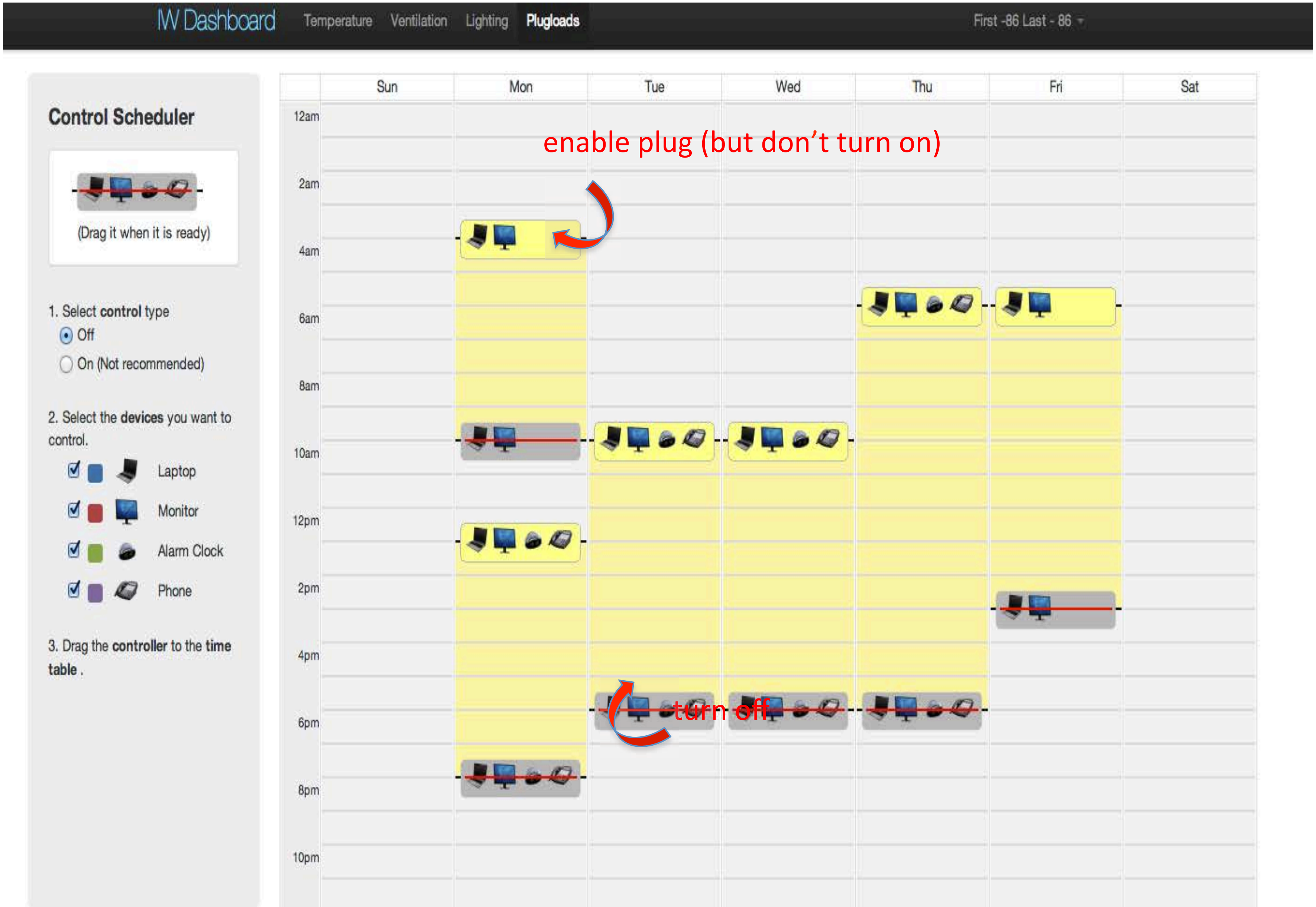




and if I unclick the big energy users...

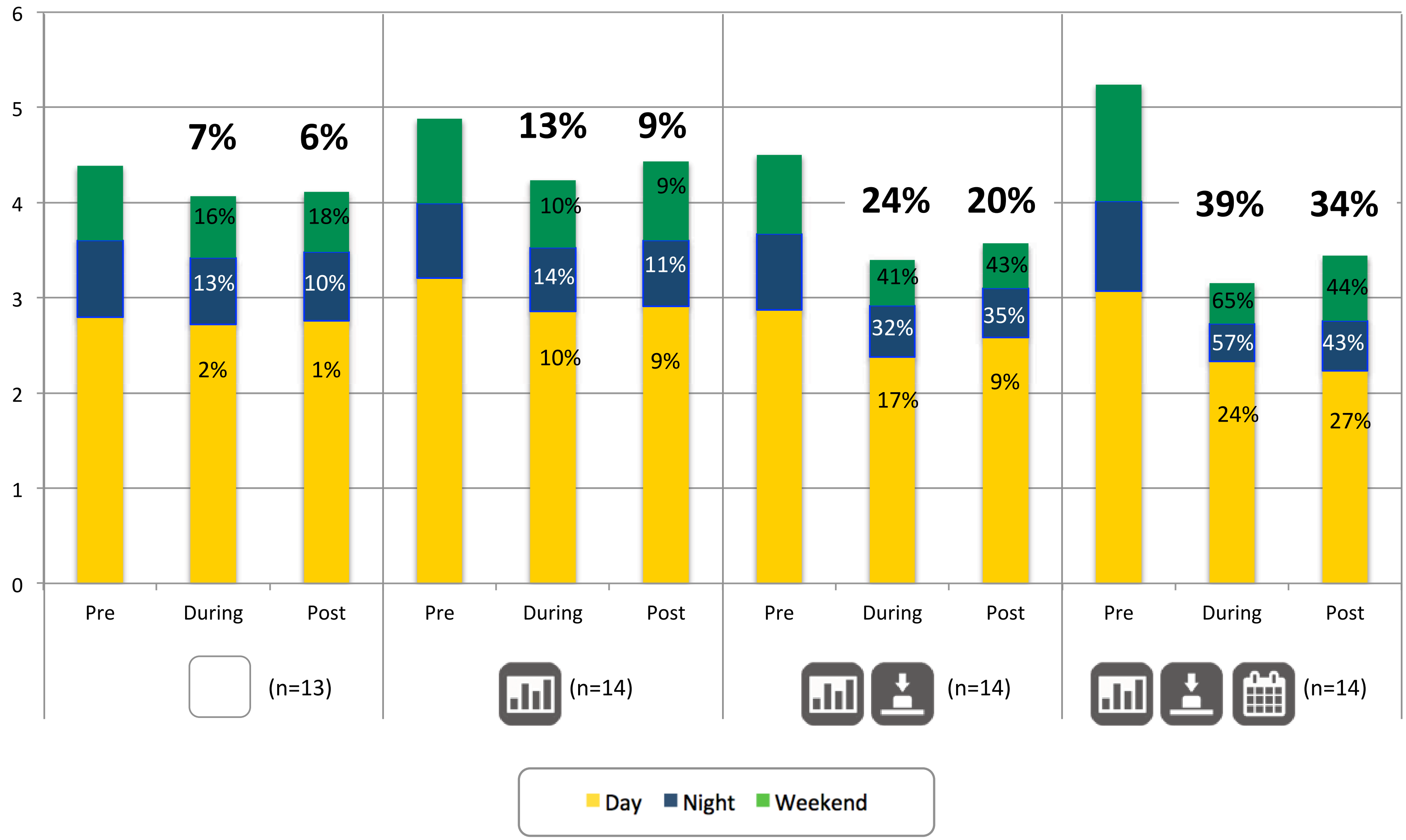


why does my phone have this parasitic load?

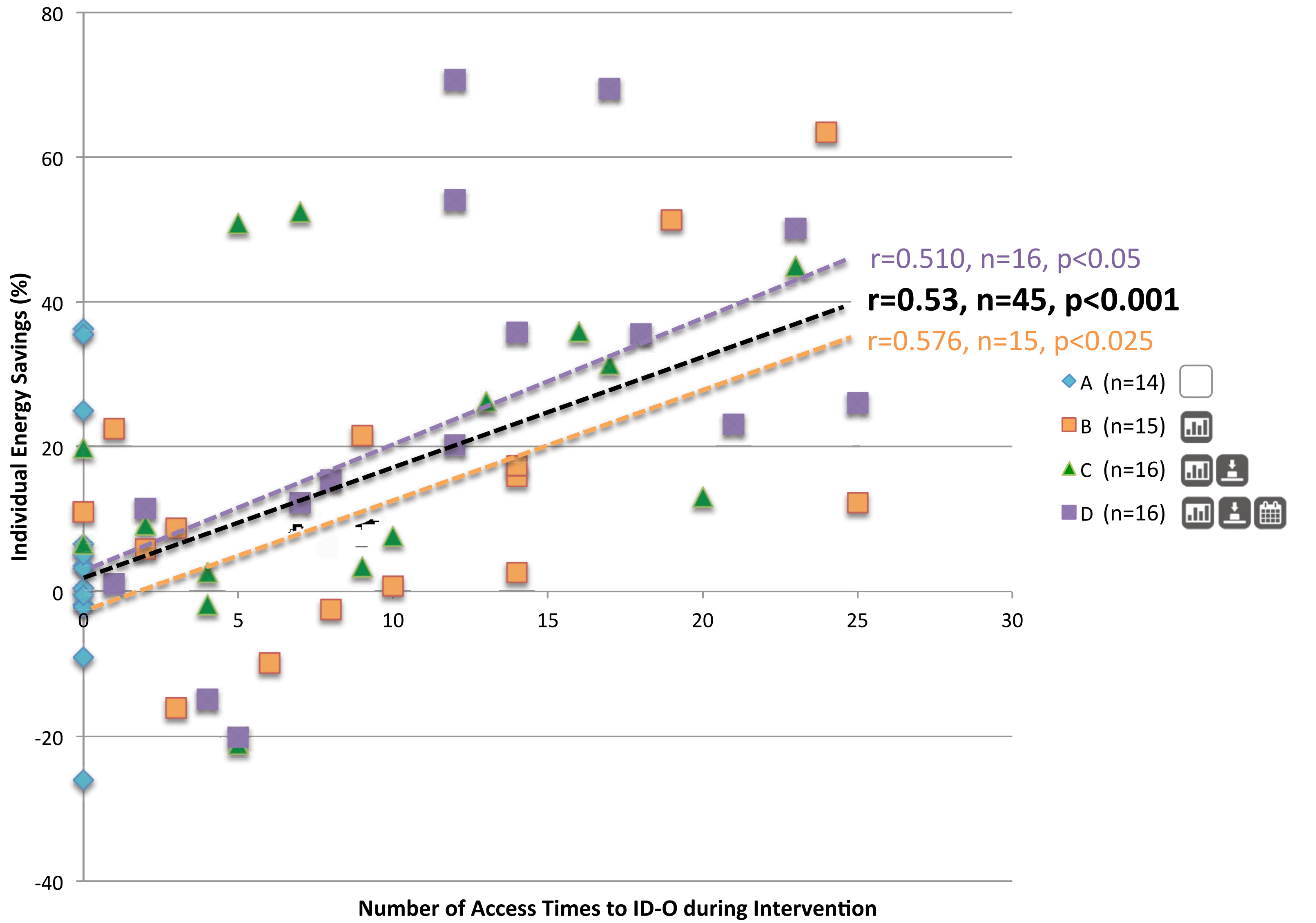


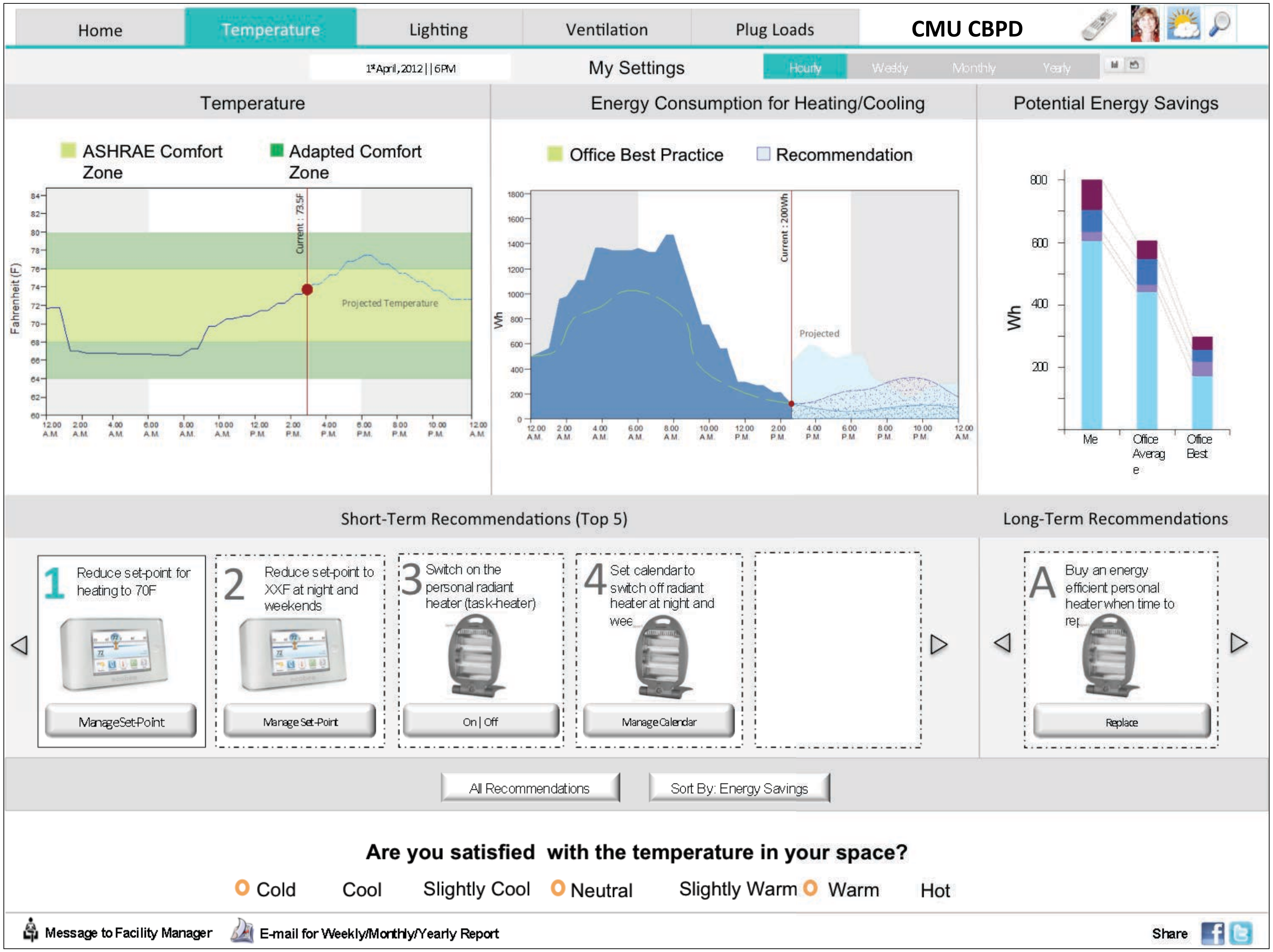
IW Dashboard
Temperature
Ventilation
Lighting
Plugloads
First -86 Last - 86
Control Scheduler
(Drag it when it is ready)
1. Select control type
Off
On (Not recommended)
2. Select the devices you want to control.
Laptop
Monitor
Alarm Clock
Phone
3. Drag the controller to the time table .
Sun
Mon
Tue
Wed
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)



Engagement -User Interaction with Dashboard and Energy Savings





now we need to tackle the bigger energy users: heating, cooling, lighting, ventilation...
for energy conservation *and* increased occupant comfort

Intuitive Control of Smart Buildings

Sebastian Peters, Korbinian Breu, Johannes Lechner, Steffen Bauereiss, Simina Pasat, Matthias Schwab, Masashi Beheim, Arno Schneider, Nadine von Frankenberg **Technical University of Munich**

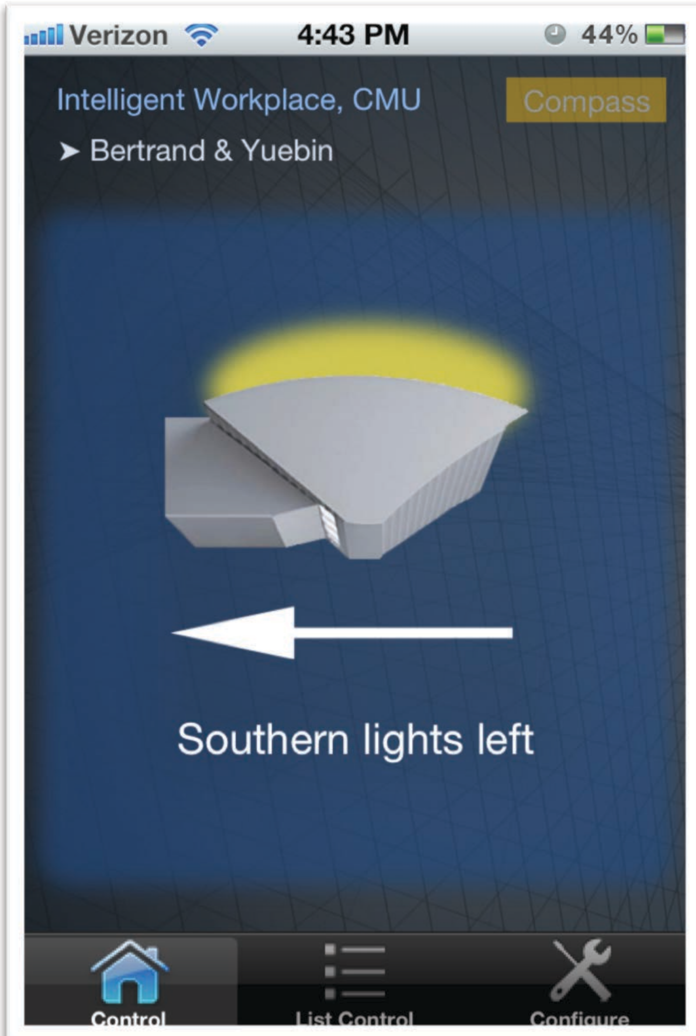
The Idea

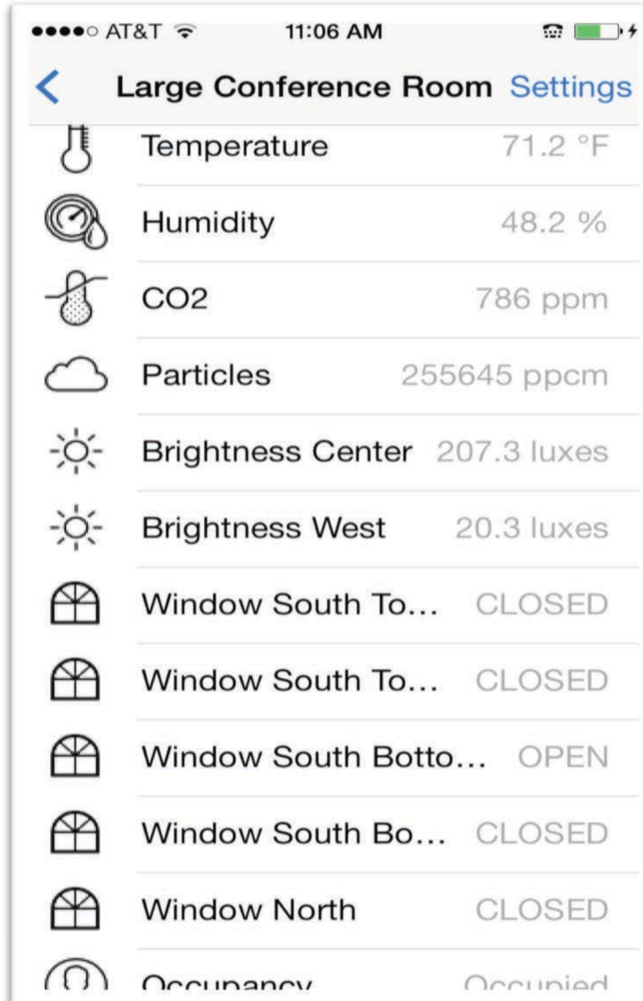
The idea is to control intelligent house equipment like blinds, heating or lights with a mobile device such as the iPhone by simply pointing on the target and doing a specific gesture

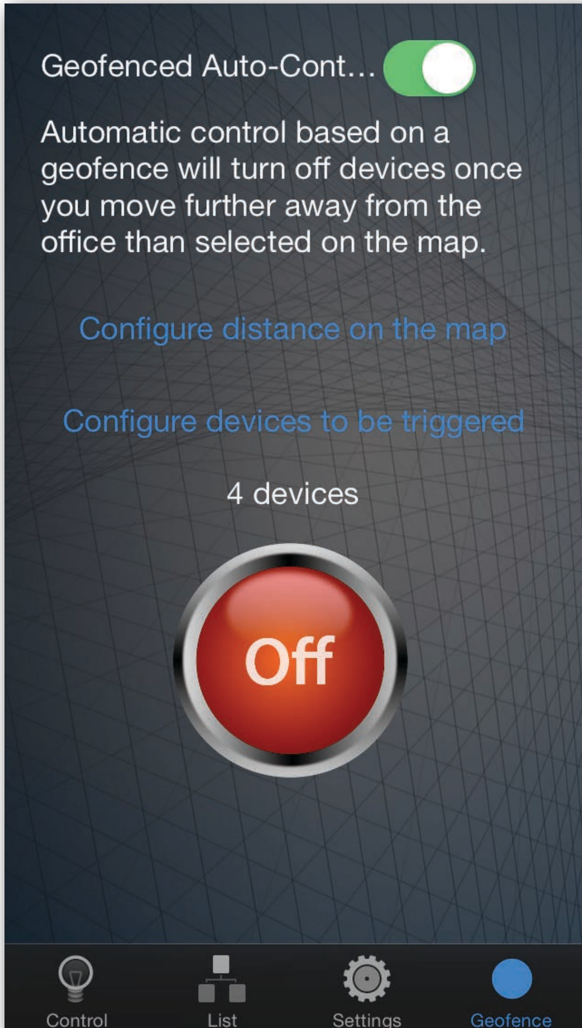
2

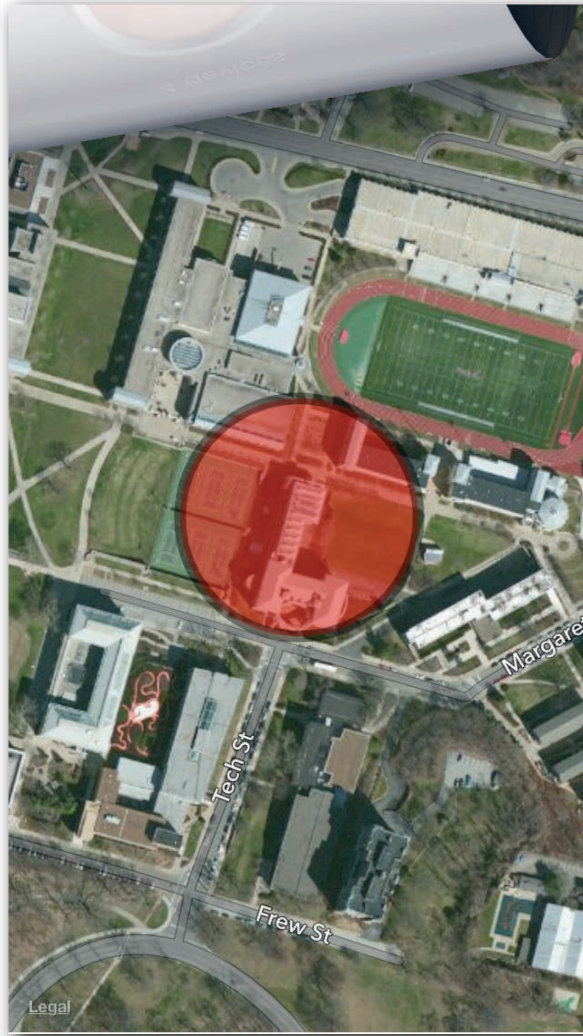
I-Phone User Interface – Sensors, Controllers, Energy

Lights, Blinds, Task Lights, External Louvers & more






Geofenced Auto-Cont...
Automatic control based on a geofence will turn off devices once you move further away from the office than selected on the map.
Configure distance on the map
Configure devices to be triggered
4 devices
Off
Control
List
Settings
Geofence


Margaret
Tech St
Frew St
Legal

faculty/researchers:

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Erica Cochran
Volker Hartkopf
Bertrand Lasternas
Vivian Loftness
Sebastian Peters

PhD Theses:

Ray Yun
Jihyun Park
Rohini Srivastava

The Intelligent Workplace

Carnegie Mellon University

A Living Laboratory for Building Environmental Research

Occupants of the Future: 'Precision IEQ' via Integrated IAQ Strategies and Intelligent Systems

Jensen Zhang

Syracuse University

DOE/PNNL "Buildings of the Future Scoping Study" Workshop
New York, May 4, 2015

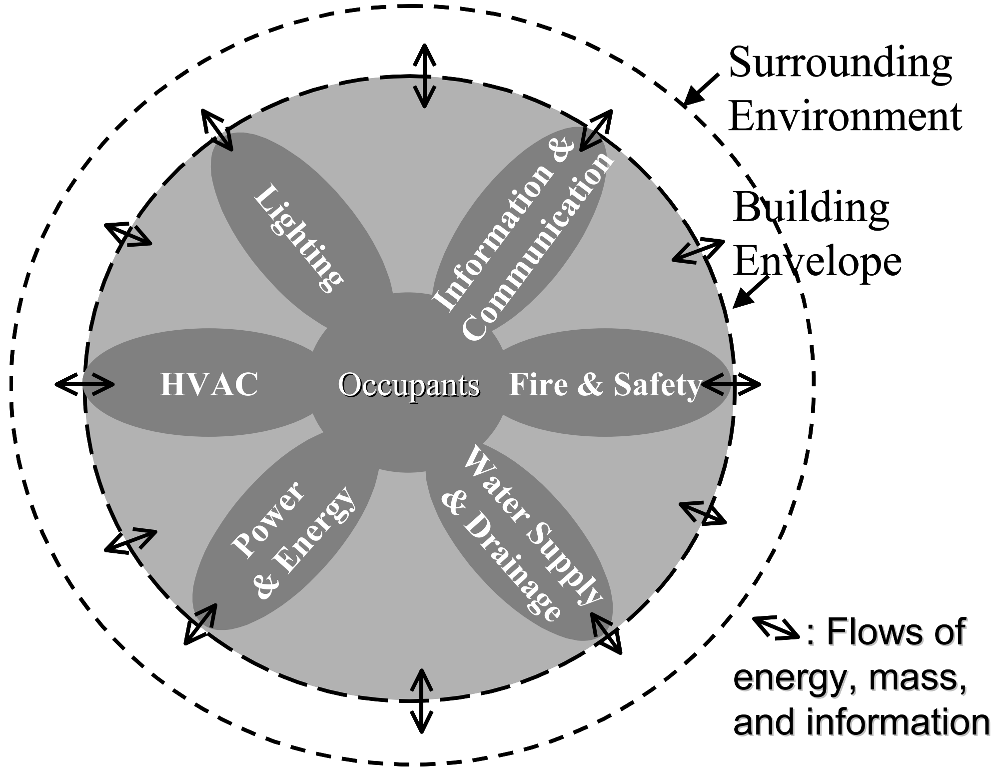
What do occupants want?

100 years ago **Today** **100 years later**
Home/Place
Safe and secure
Healthy
Comfortable
Productive
Creative
Stimulating
Relaxing
Inspiring
Inviting
Connected
Resilient

Not so different in our wishes over time!

Why is it so difficult to satisfy?

- Different needs of occupants
- Variable internal loads
  - *Thermal*
  - *Pollution (many pollutants)*
- Variable external loads
- Multi-scales in nature
  - *Temporal*
  - *Spatial*
- Multi-performance objectives
  - *TIEQ (IAQ, Thermal comfort, lighting, acoustics, and visual)*
  - *Energy*
  - *Water*
  - *Cost*
  - *Carbon emissions*



A conceptual model of built environmental systems (BES)

Integrated strategies and intelligent systems are essential.

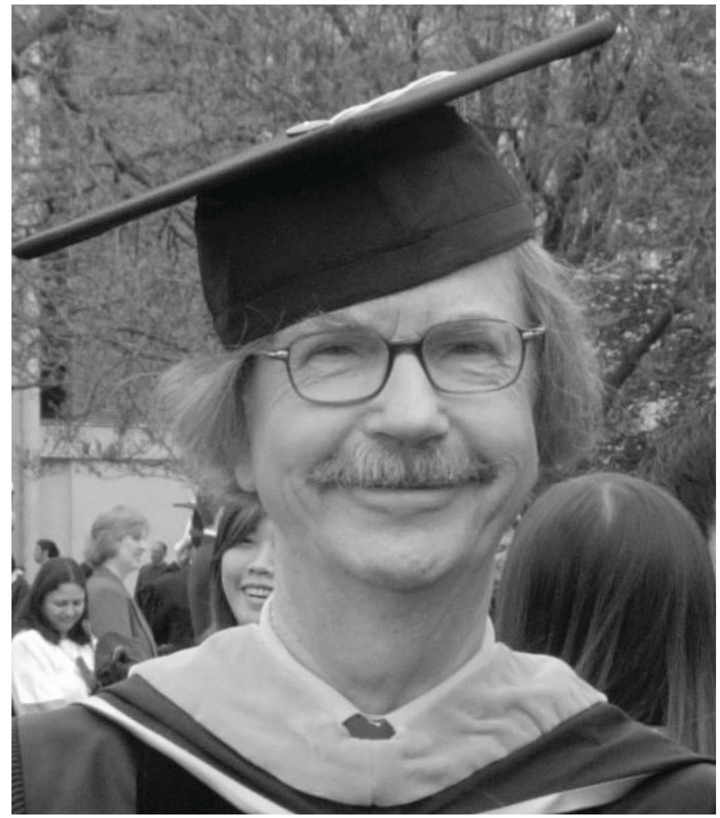
What is IAQ?

"IAQ should be defined in relation to its impact on human health, comfort, productivity, and learning"

-- P. Ole Fanger

Indoor Air 2005,

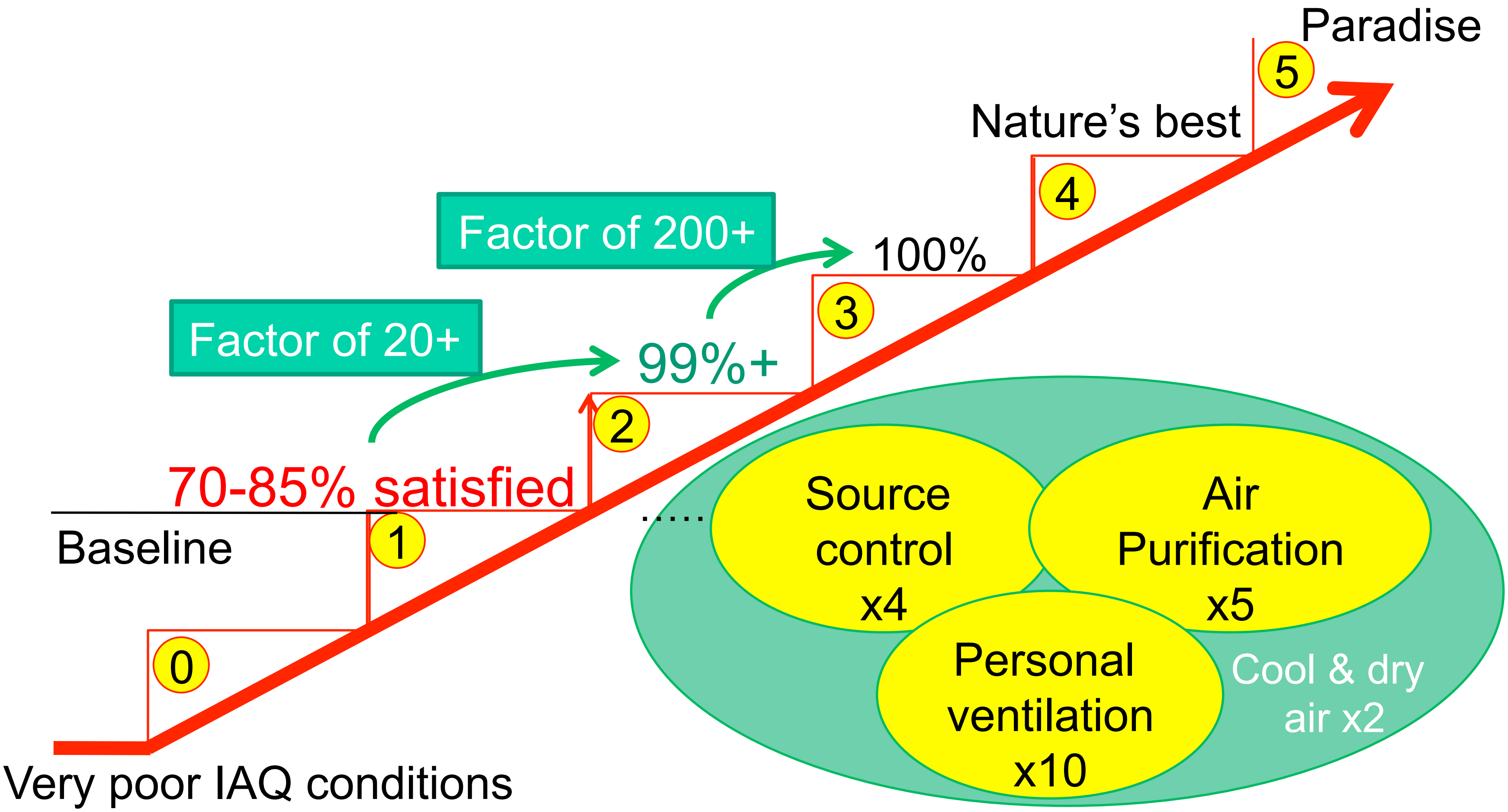
Beijing, China



P. Ole Fanger (1934-2006),
"Father of IAQ & Health"

"The potential benefits for society are enormous", as shown in studies where the IAQ were improved by a factor of 2-7.

Prof. Fanger's Vision (2006)*



"What happens if we simultaneously use all methods to improve IAQ?"

*Fanger, P.O. 2006. What is IAQ?, Indoor Air, Vol 16, No. 5, pp328-334

Air Pollution Processes and Control

Transport

Inhibitors & Sinks

Pollutant Sources

- Outdoor
- Indoor
  - People
  - Materials & equipments
  - Reactive compounds

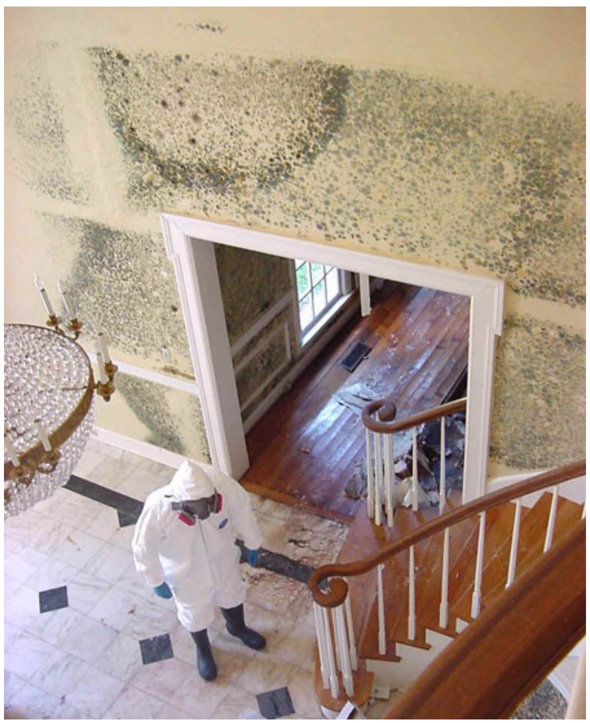
Source controls
- Remove or prevent sources
- Lower source emissions
- Exhaust pollutants locally

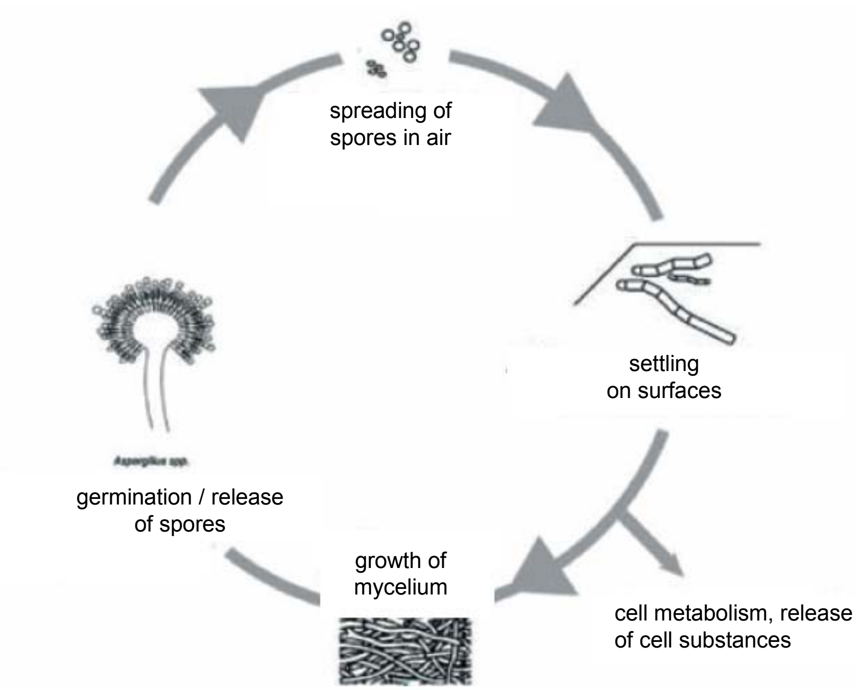
Ventilation
- Delivery clean air
- Dilute pollutants

Air purification

Remove or Prevent Sources

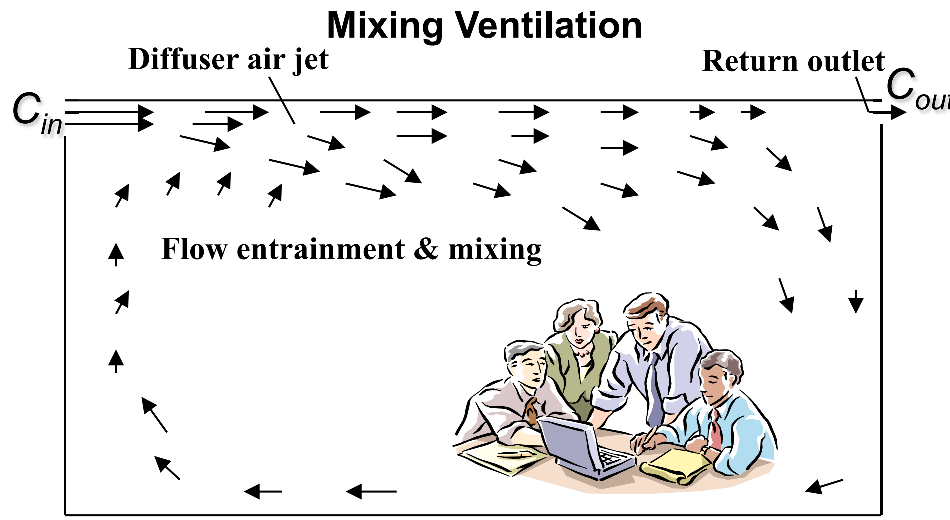
1. Outdoor pollutants
2. Moisture control & mold
3. Contacts between reactants
4. Indoor emission sources
5. Local exhaust

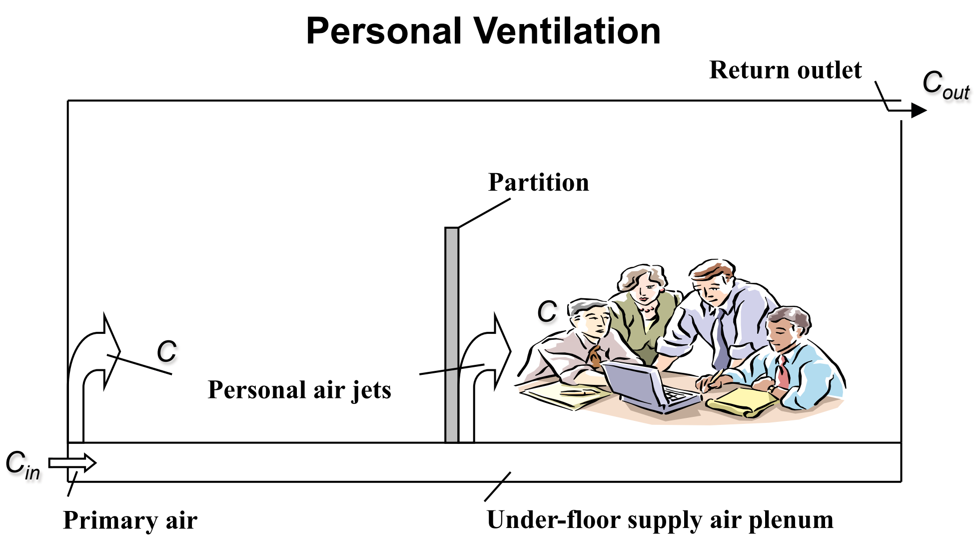


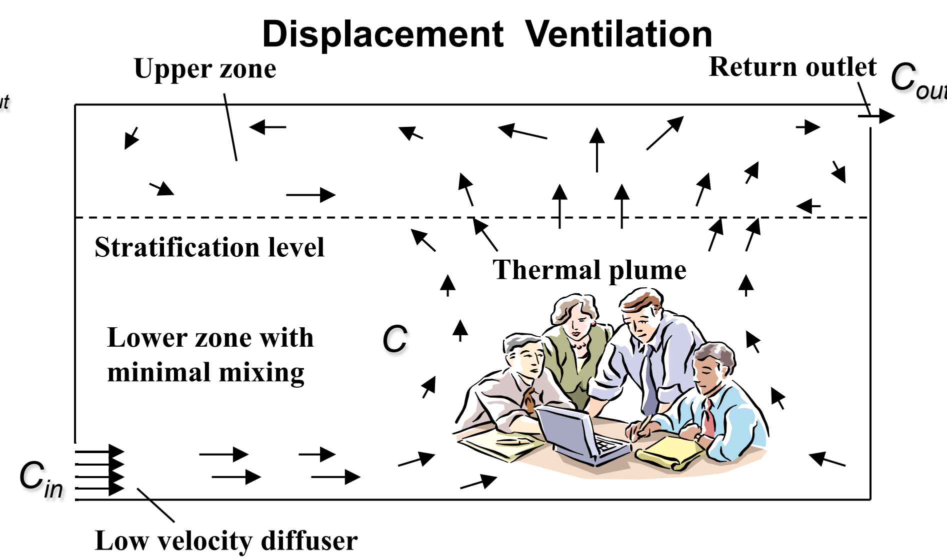


Ventilation

- ❑ Deliver clean air to occupants
- ❑ Dilute/remove pollutants



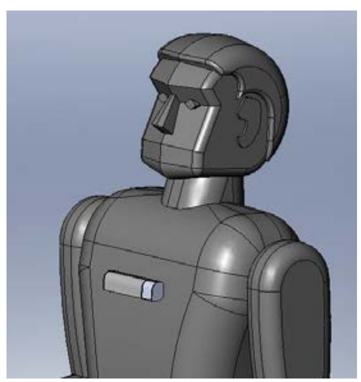




Deliver air only to where it is needed.

Air Purification

- ❑ Outdoor air for ventilation
  - ◆ *In-duct filters/devices*
- ❑ Recirculated air
  - ◆ *In-duct filters/devices*
  - ◆ *Passive materials*
- ❑ Room air
  - ◆ *Standalone air cleaners*
  - ◆ *Passive materials*
- ❑ Personal air



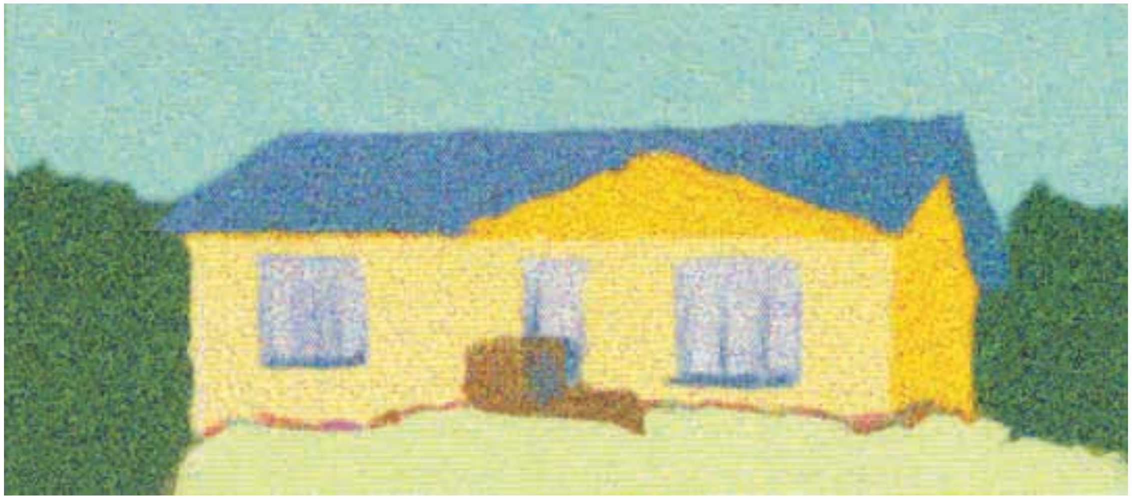
Integrated IAQ Strategies

1) Source control to the extent possible
   - *Removal and prevention of pollutant sources*
   - *Emission reduction*
   - *Local exhaust/suction*
2) Ventilation
   - *Dilution for all pollutants (known or unknown)*
   - *Personal air delivery*
3) Air cleaning/purification
   - *Active or passive*
   - *For target pollutants*
   - *No harmful byproducts allowed*

The goal of integration is to improve IAQ in a most energy-efficient and cost-effective manner.

IAQ Strategies Demonstrated in a Research House*

- Source control
  - *Low emitting materials (e.g., ceramic floor tiles)*
  - *Local exhaust for pollutant sources (cabinets, wall materials, TV, etc.)*
  - *Depressurized the wall cavities*
- Air-tight and well insulated building envelope
  - *Reduce heating & cooling load*
  - *Enable full-exhaust system*
- Ventilation
  - *Heat recovery ventilator with air filters*
  - *Displacement ventilation with radiant floor heating*

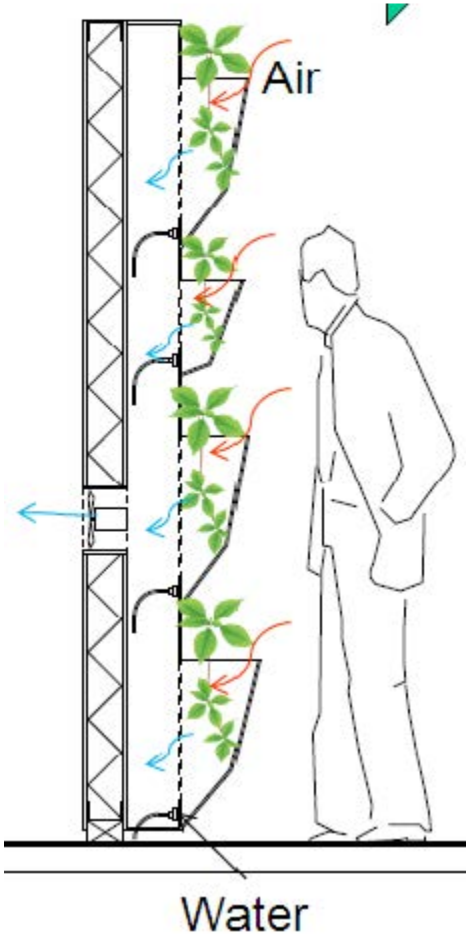


(Courtesy of Canada Mortgage and Housing Corporation)
*Zhang, J.S., B. Magee and C.Y. Shaw. 1996.

Bio-filtration, Ventilation & Enclosure

- ❑ Use bio-filtration to reduce required outdoor airflow rate
- ❑ Incorporate in HVAC system and combine with economizer
- ❑ Incorporate in building enclosures

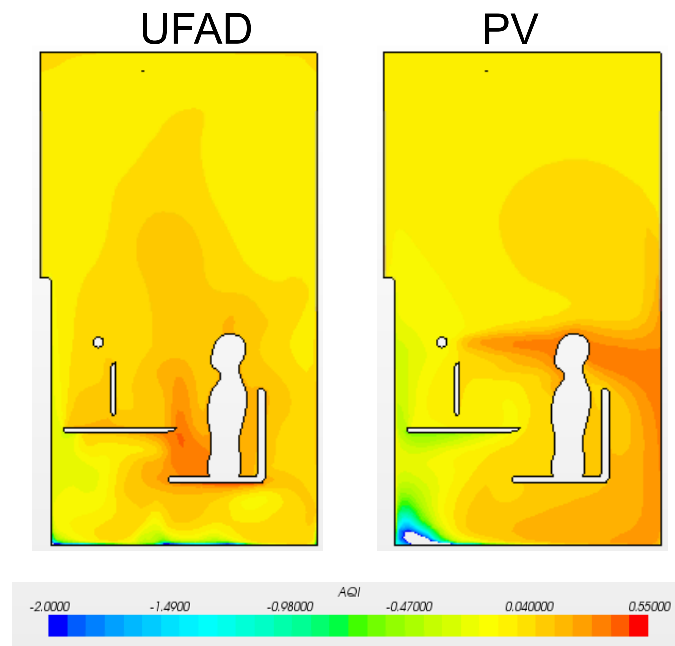
Botanical filter for indoor air treatment (Original idea by Dr. Wolverton developed at NASA)

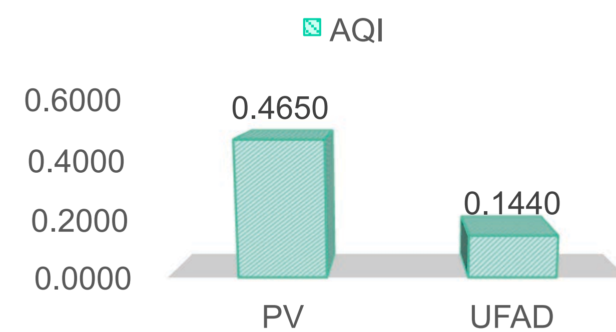


Incorporated to wall system

Personal Environmental Controls

- System Goals
  - *Satisfy every individual's IEQ needs*
  - *Control disease transmission*
- IAQ strategies
  - *Personal air delivery and conditioning*
  - *Local air exhaust/suction*
  - *Local air purification*

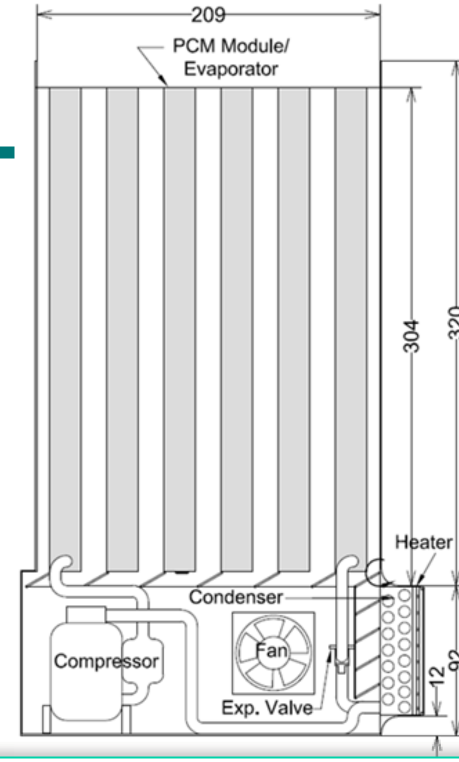




Air Quality Index (AQI)

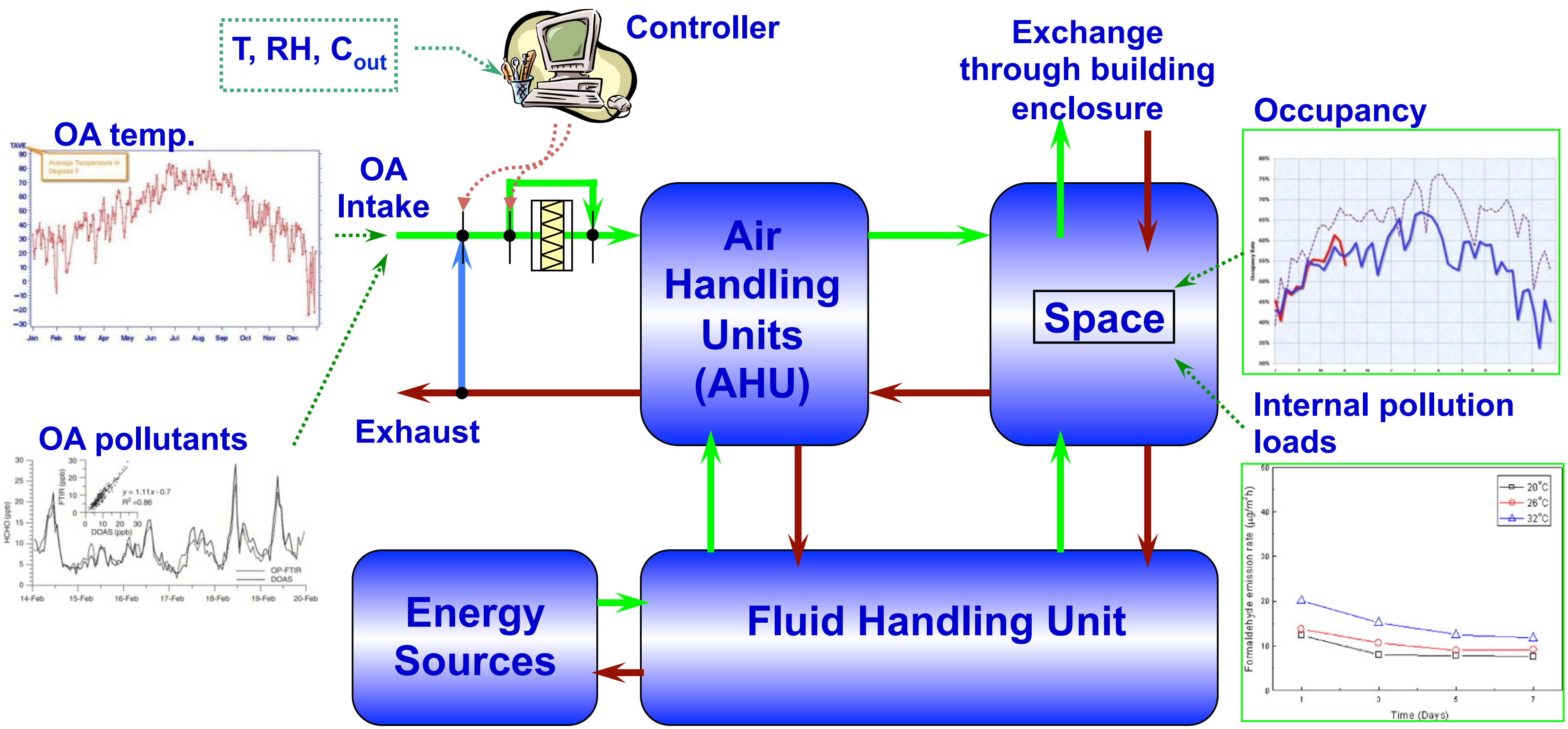
Micro Environmental Control System: µX
Syracuse University

- Syracuse University and partners are developing a transformative micro-environmental control system that will provide 50W of cooling or 60W of heating to a seated office worker for 10 hours/day
- The device will allow the background temperature set-point to be raised from 75F to 79F in the summer or lowered from 70F to 66F in the winter.
- The device uses a high-efficiency micro vapor-compression system whose evaporator is embedded inside a phase-change-material (PCM) thermal storage module.
- The micro vapor-compression system provides both cooling in the summer and heating in the winter (heat pump mode).
- The use of the PCM allows the shifting of undesirable thermal discharge from the system to unoccupied night hours, shifting the electric load to off-peak hours.



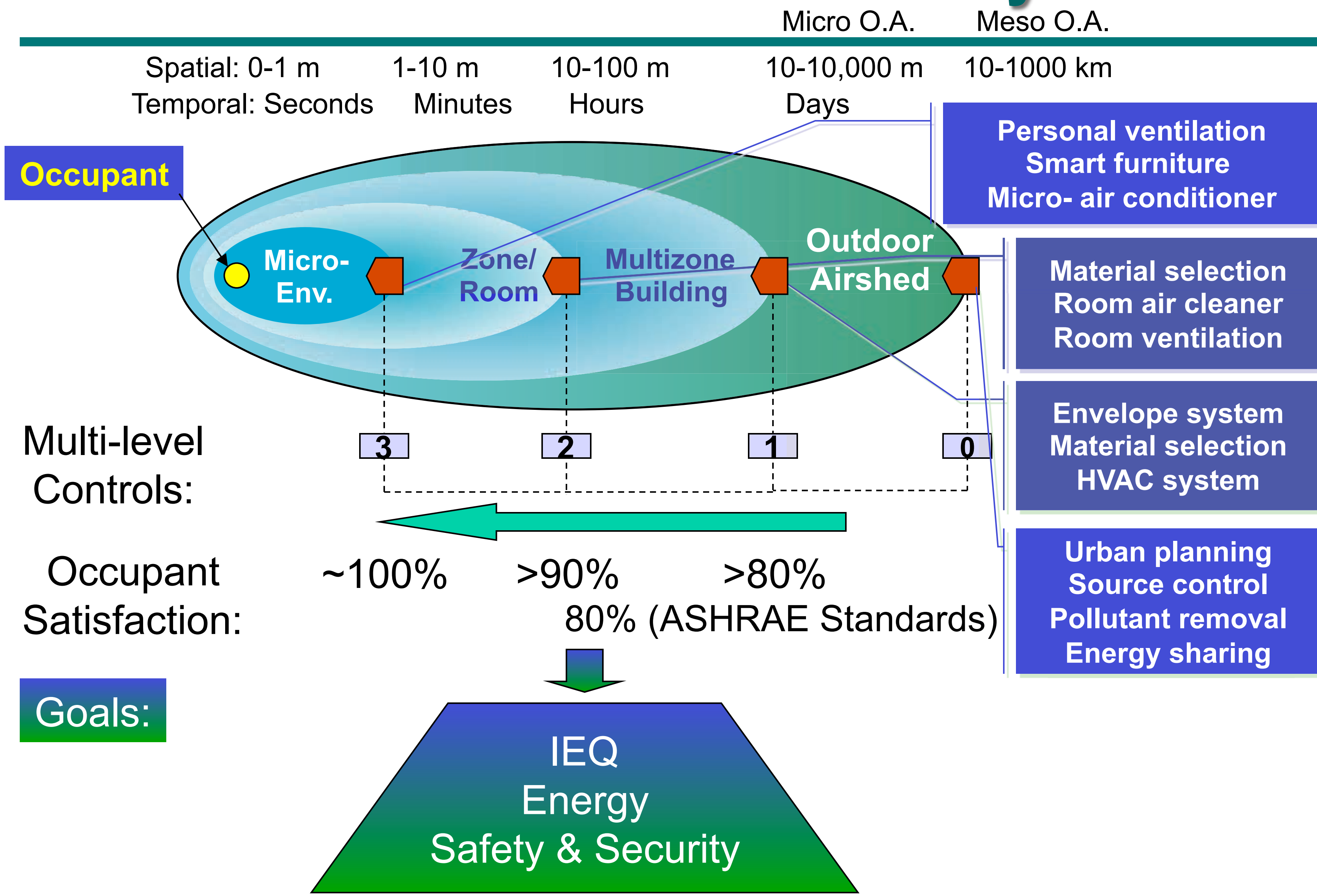
Local thermal management system at >20x performance of state of the art

Integrated Ventilation and Air Cleaning*



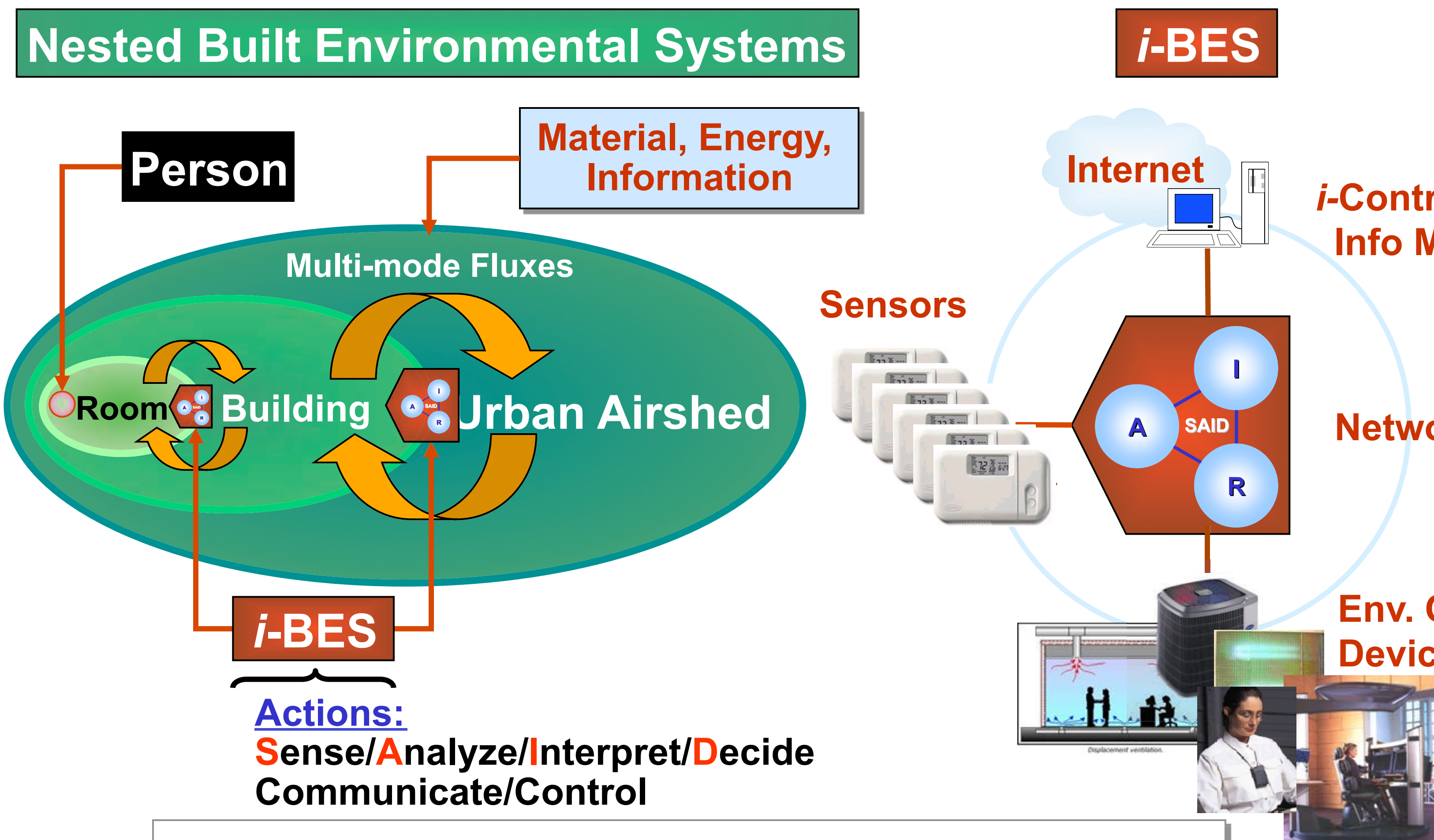
*Han, Kwanghoon; J.S. Zhang; Bing Guo. 2014. A novel approach of integrating ventilation and air cleaning for sustainable and healthy office environments. Energy and Buildings (ENB-D-13-01289R1).

Built and urban environmental system



Intelligent Control of Built Environmental Systems

- Response to occupant's need
- Optimize for predicted internal and external loads
- Coordinate to achieve total performance



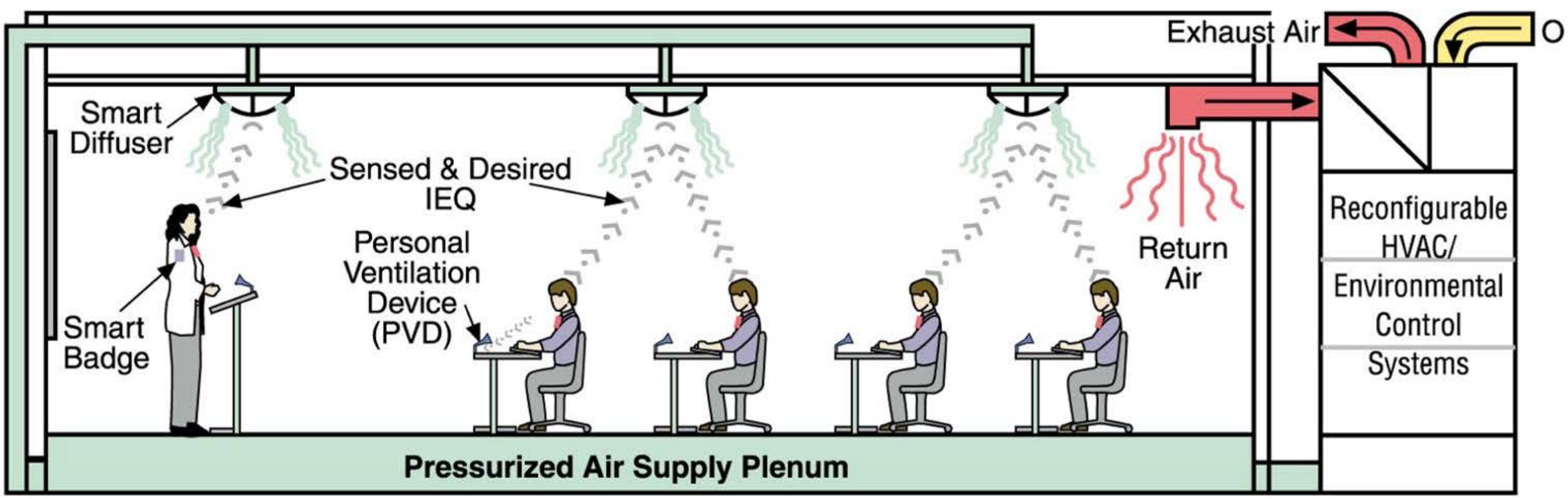
Health, Productivity, Sustainability and Security

Total exposure of occupants in and outside buildings

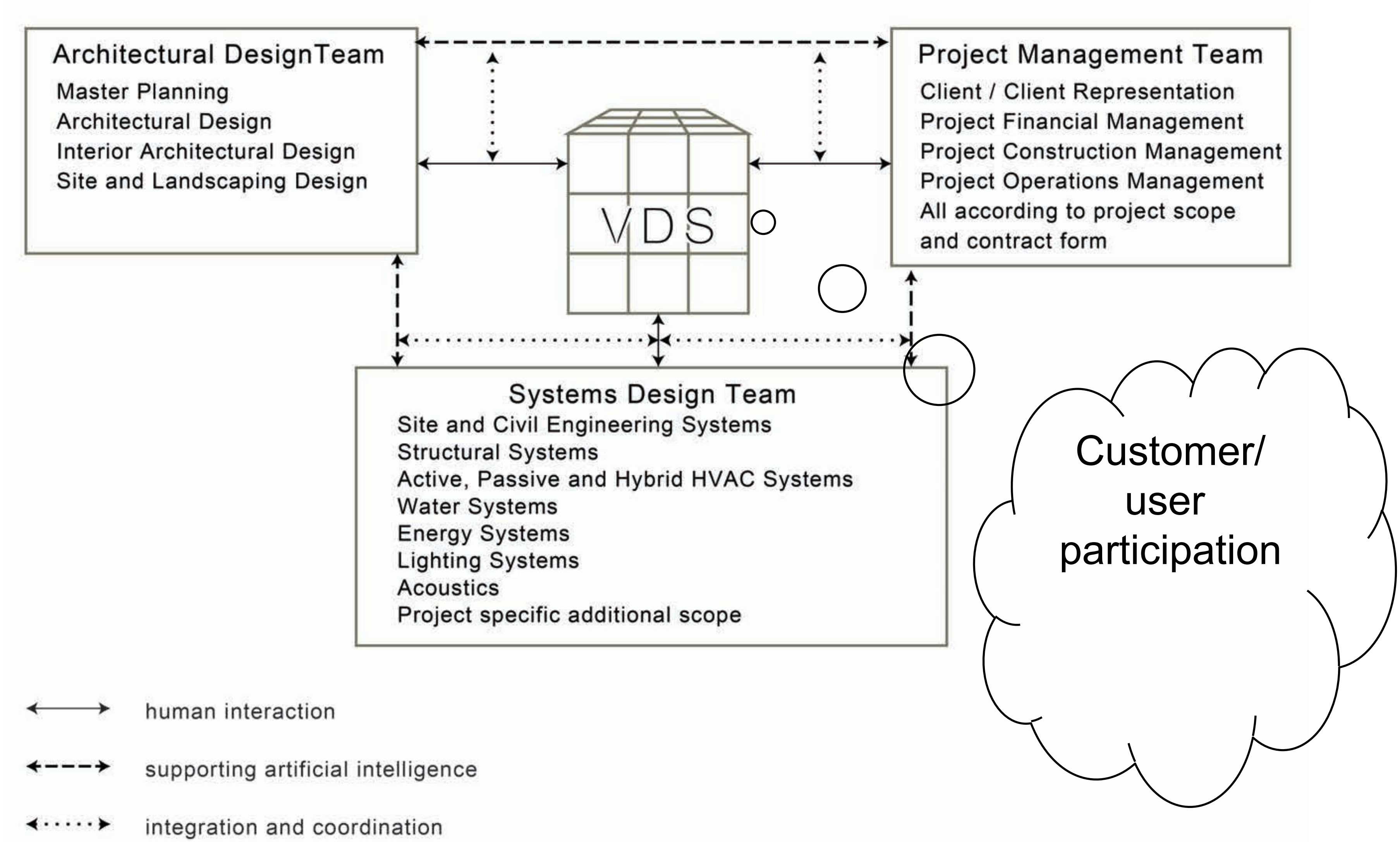
Mobile phone based sensor network
makes the monitoring and predictive control possible.

Smart control of air diffusers for individual needs

- ❑ Recognize the needs of occupants
- ❑ Automatically adjust the air diffusers
- ❑ Coordinate with whole building system control



Integrative design with user participation



Big data technology will make it possible for timely integration of user inputs.

Summary: 'Precision IEQ' via

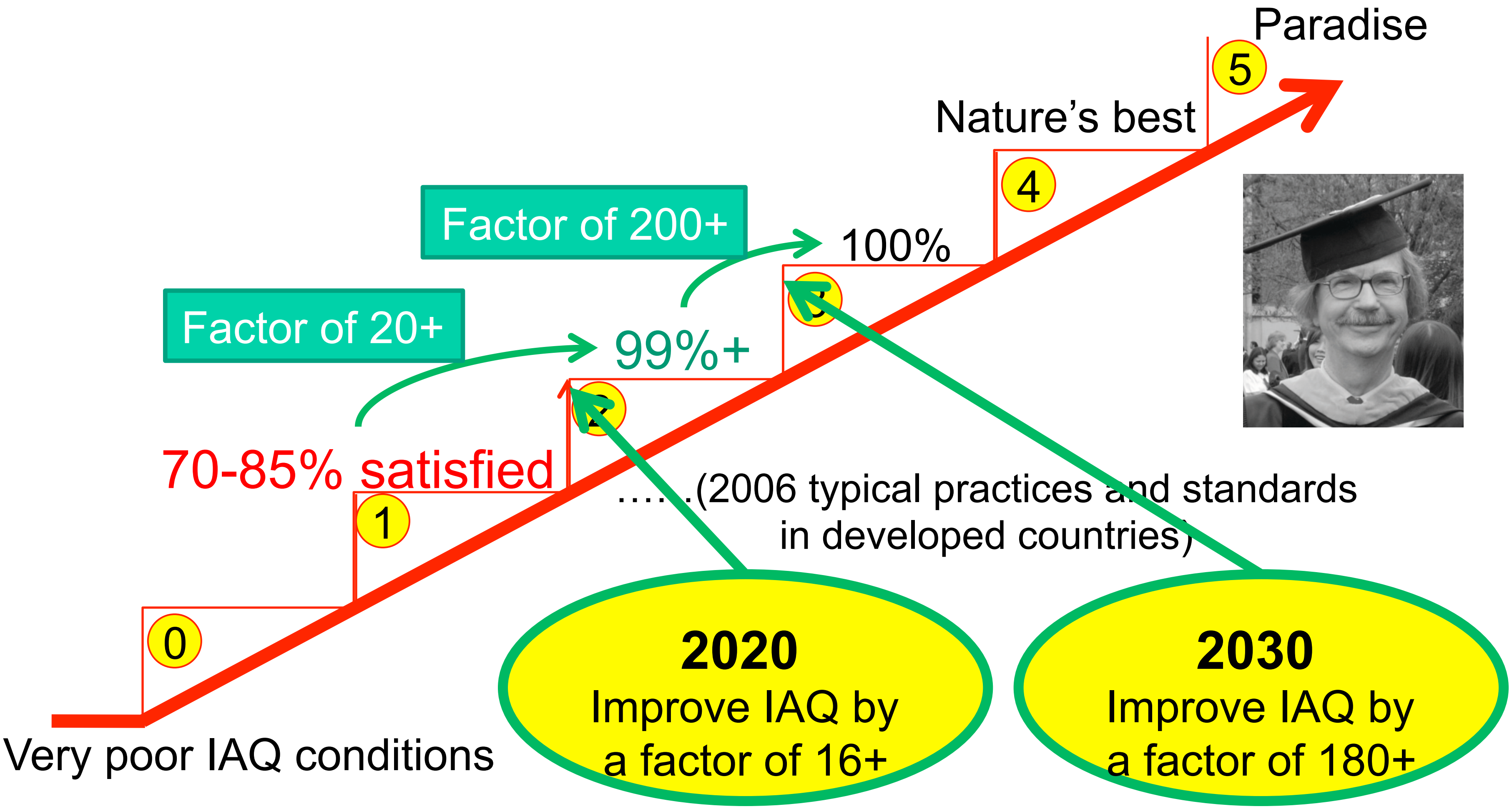
Integrated IAQ strategies:

1. Emission source reduction
   - minimize the pollutant load, and hence reduce the requirements for ventilation and air purification
2. Personal air delivery and local exhaust/suction
   - maximize IAQ benefit for individuals
3. Local air purification
   - reduce infrastructure for distributing personal air
4. Dynamic integration of ventilation and air cleaning
   - save energy and reduce cost while meet the occupants' need
5. Intelligent Built Environmental Systems (i-BES)
   - enable optimization based on dynamic outdoor and indoor conditions

Intelligent systems:

1. Design optimization
   - Involve users and community throughout the design process via crowd sourcing and machine learning (Big Data)
2. Intelligent control
   - Adaptive to the needs of the occupants and optimize based on measured and predicted loads and building dynamics

Comparison with Prof. Fanger's Vision (2006*)



*Fanger, P.O. 2006. What is IAQ?, Indoor Air, Vol 16, No. 5, pp328-334

What can occupants expect in future buildings?

Future buildings (in a 100 years?)
Home/Place
Safe and secure
Healthy
Comfortable
Productive
Creative
Stimulating
Relaxing
Inspiring
Inviting
Connected
Resilient

Wishes come true!

Acknowledgement

- Thanks to Dr. Ed Bogucz for helpful suggestions on the presentation. His paper on 'Precision IEQ' can be found in http://www.usgbc.org/articles/fit-princess-next-generation-personal-controls-deliver-whole-building-energy-savings-and-%E2%80%98p
- Thanks to Dr. Chetna Khosla Chianese, who provided the summary slide on the Syracuse University APAR-E project on Micro Environmental Control System: μX

AirTest Technologies Inc.

Harvesting hidden operational & energy waste in buildings through advanced measurement & monitoring technologies.

Building Control For The Future

Mike Schell
VP Marketing & Business Development
AirTest Technologies Inc.
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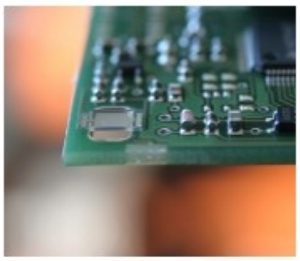
AirTest Sensor Products

OEM Sensors



CO2 DCV

Parking Ventilation

Outdoor Air

Air Velocity

Data Logging

Agriculture

Refrigerant Detection

Health & Safety

Calibration

https://airtest.com/product/index.html

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Sensors That Make Buildings Smart!

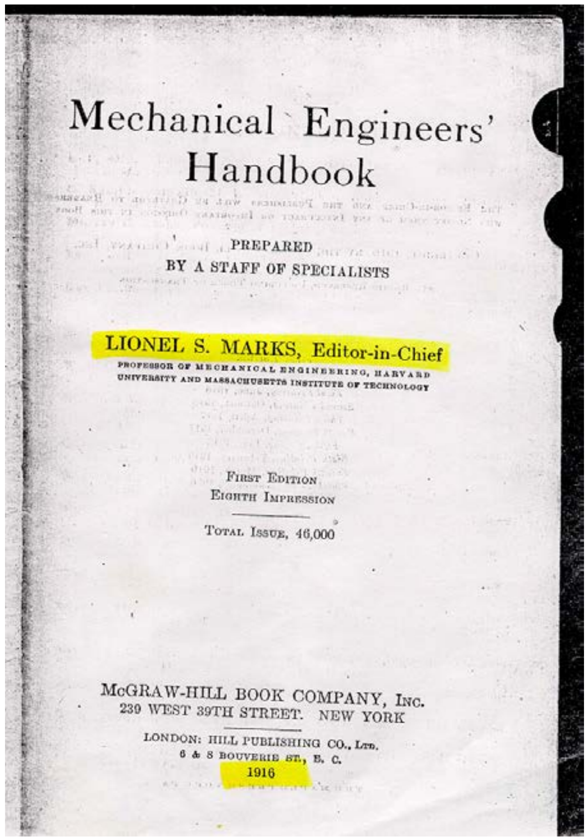
The Future Viewed From 1925

The Isolator

By HUGO GERNSBACK
MEMBER AMERICAN PHYSICAL SOCIETY

The author at work in his private study aided by the Isolator. Outside noises being eliminated, the worker can concentrate with ease upon the subject at hand.

Evolution Of Ventilation Control



Mechanical Engineers' Handbook

PREPARED
BY A STAFF OF SPECIALISTS

LIONEL S. MARKS, Editor-in-Chief
PROFESSOR OF MECHANICAL ENGINEERING, HARVARD UNIVERSITY AND MASSACHUSETTS INSTITUTE OF TECHNOLOGY

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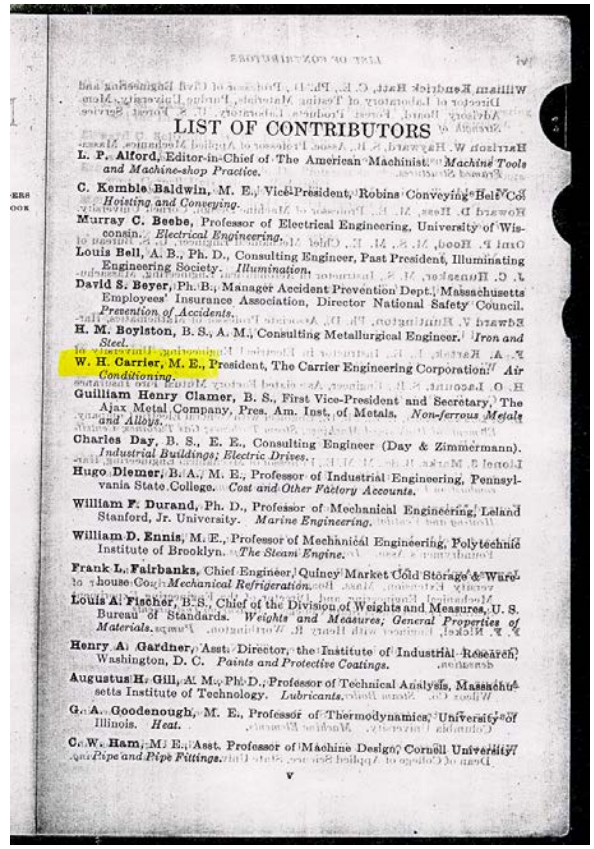
1916



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v

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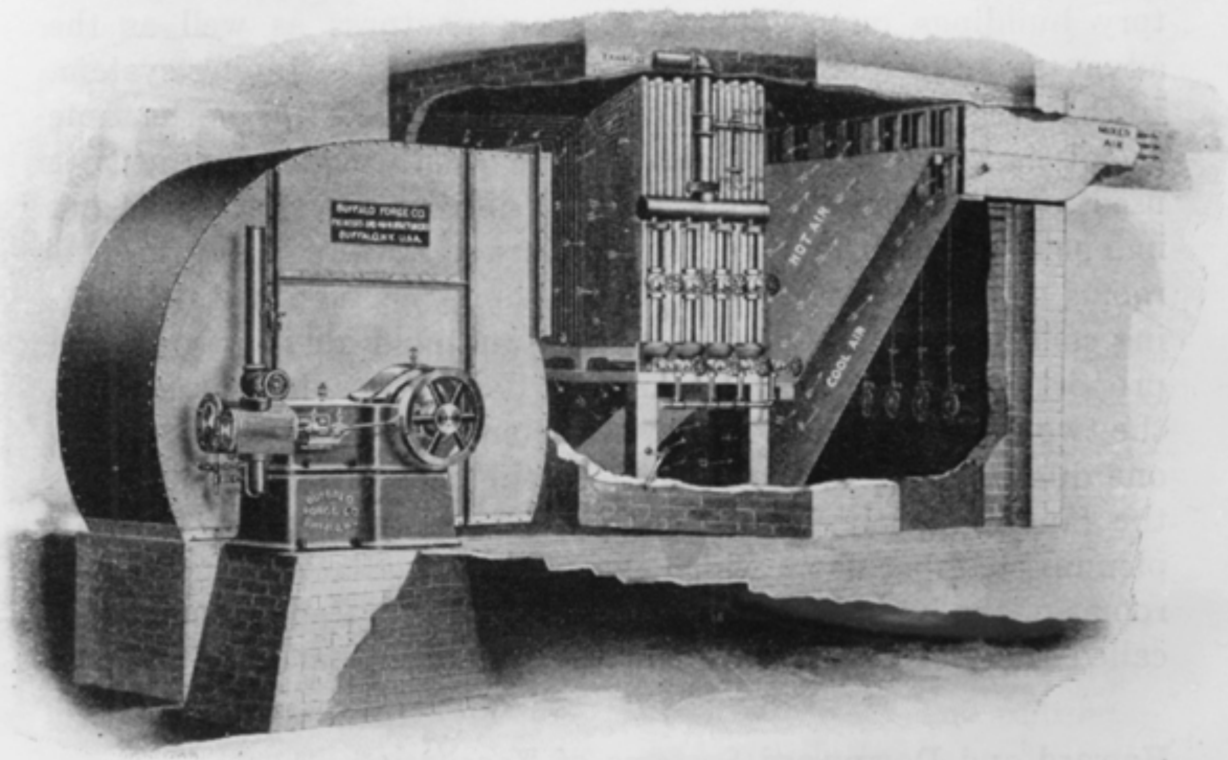
Brooklyn Printing Company… 1902

1st AC System… Carrier's Goal Was to Control Humidity

VENTILATION



Three-Quarter Housing Fan, Left-Hand Top Horizontal Discharge, Blowing Air Through and Underneath Heater into Brick Plenum Chamber

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St Francis Hotel… 1902

CO_2 Ventilation Control In 1916?

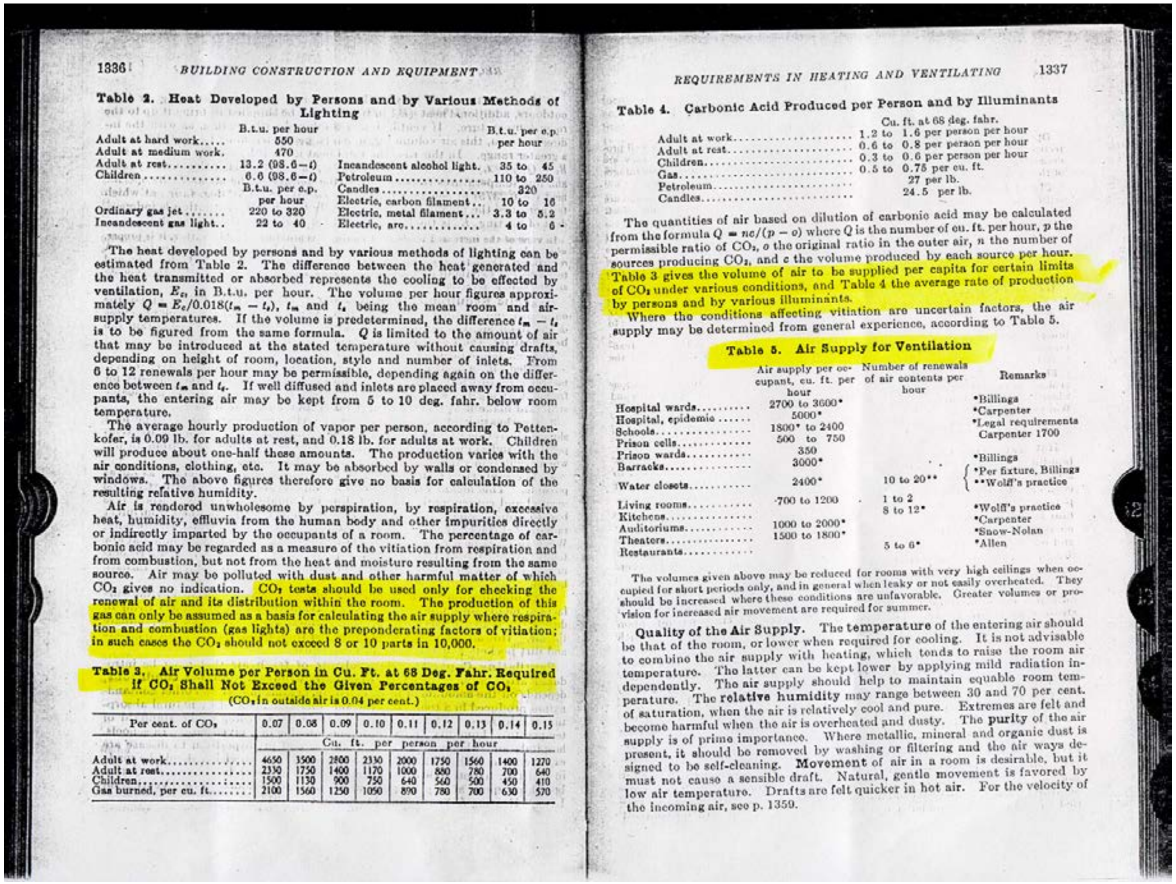

Table 2. Heat Developed by Persons and by Various Methods of Lighting

	B.t.u. per hour		B.t.u. per c.p. per hour
Adult at hard work	550		
Adult at medium work	470		
Adult at rest	13.2 (98.6−t)	Incandescent alcohol light	35 to 45
Children	6.6 (98.6−t)	Petroleum	110 to 250
	B.t.u. per c.p. per hour	Candles	320
		Electric, carbon filament	10 to 16
Ordinary gas jet	220 to 320	Electric, metal filament	3.3 to 5.2
Incandescent gas light	22 to 40	Electric, arc	4 to 6

The heat developed by persons and by various methods of lighting can be estimated from Table 2. The difference between the heat generated and the heat transmitted or absorbed represents the cooling to be effected by ventilation, E_c, in B.t.u. per hour. The volume per hour figures approximately $Q = E_c/0.018(t_m - t_s)$, t_m and t_s being the mean room and air-supply temperatures. If the volume is predetermined, the difference $t_m - t_s$ is to be figured from the same formula. Q is limited to the amount of air that may be introduced at the stated temperature without causing drafts, depending on height of room, location, style and number of inlets. From 6 to 12 renewals per hour may be permissible, depending again on the difference between t_m and t_s. If well diffused and inlets are placed away from occupants, the entering air may be kept from 5 to 10 deg. fahr. below room temperature.

The average hourly production of vapor per person, according to Pettenkofer, is 0.09 lb. for adults at rest, and 0.18 lb. for adults at work. Children will produce about one-half these amounts. The production varies with the air conditions, clothing, etc. It may be absorbed by walls or condensed by windows. The above figures therefore give no basis for calculation of the resulting relative humidity.

Air is rendered unwholesome by perspiration, by respiration, excessive heat, humidity, effluvia from the human body and other impurities directly or indirectly imparted by the occupants of a room. The percentage of carbonic acid may be regarded as a measure of the vitiation from respiration and from combustion, but not from the heat and moisture resulting from the same source. Air may be polluted with dust and other harmful matter of which CO_2 gives no indication. CO_2 tests should be used only for checking the renewal of air and its distribution within the room. The production of this gas can only be assumed as a basis for calculating the air supply where respiration and combustion (gas lights) are the preponderating factors of vitiation; in such cases the CO_2 should not exceed 8 or 10 parts in 10,000.

Table 3. Air Volume per Person in Cu. Ft. at 68 Deg. Fahr. Required if CO_2 Shall Not Exceed the Given Percentages of CO_2

(CO_2 in outside air is 0.04 per cent.)

Per cent. of CO_2	0.07	0.08	0.09	0.10	0.11	0.12	0.13	0.14	0.15
	Cu. ft. per person per hour								
Adult at work	4650	3500	2800	2330	2000	1750	1560	1400	1270
Adult at rest	2330	1750	1400	1170	1000	880	780	700	640
Children	1500	1130	900	750	640	560	500	450	410
Gas burned, per cu. ft.	2100	1560	1250	1050	890	780	700	630	570

Table 4. Carbonic Acid Produced per Person and by Illuminants

	Cu. ft. at 68 deg. fahr.
Adult at work	1.2 to 1.6 per person per hour
Adult at rest	0.6 to 0.8 per person per hour
Children	0.3 to 0.6 per person per hour
Gas	0.5 to 0.75 per cu. ft.
Petroleum	27 per lb.
Candles	24.5 per lb.

The quantities of air based on dilution of carbonic acid may be calculated from the formula $Q = nc/(p - o)$ where Q is the number of cu. ft. per hour, p the permissible ratio of CO_2, o the original ratio in the outer air, n the number of sources producing CO_2, and c the volume produced by each source per hour. Table 3 gives the volume of air to be supplied per capita for certain limits of CO_2 under various conditions, and Table 4 the average rate of production by persons and by various illuminants.

Where the conditions affecting vitiation are uncertain factors, the air supply may be determined from general experience, according to Table 5.

Table 5. Air Supply for Ventilation

	Air supply per occupant, cu. ft. per hour	Number of renewals of air contents per hour	Remarks
Hospital wards	2700 to 3600*		*Billings
Hospital, epidemic	5000*		*Carpenter
Schools	1800* to 2400		*Legal requirements Carpenter 1700
Prison cells	500 to 750		
Prison wards	350		
Barracks	3000*		*Billings
Water closets	2400*	10 to 20**	*Per fixture, Billings **Wolff's practice
Living rooms	700 to 1200	1 to 2	
Kitchens		8 to 12*	*Wolff's practice
Auditoriums	1000 to 2000*		*Carpenter
Theaters	1500 to 1800*		*Snow-Nolan
Restaurants		5 to 6*	*Allen

The volumes given above may be reduced for rooms with very high ceilings when occupied for short periods only, and in general when leaky or not easily overheated. They should be increased where these conditions are unfavorable. Greater volumes or provision for increased air movement are required for summer.

Quality of the Air Supply. The **temperature** of the entering air should be that of the room, or lower when required for cooling. It is not advisable to combine the air supply with heating, which tends to raise the room air temperature. The latter can be kept lower by applying mild radiation independently. The air supply should help to maintain equable room temperature. The **relative humidity** may range between 30 and 70 per cent. of saturation, when the air is relatively cool and pure. Extremes are felt and become harmful when the air is overheated and dusty. The **purity** of the air supply is of prime importance. Where metallic, mineral and organic dust is present, it should be removed by washing or filtering and the air ways designed to be self-cleaning. **Movement** of air in a room is desirable, but it must not cause a sensible draft. Natural, gentle movement is favored by low air temperature. Drafts are felt quicker in hot air. For the velocity of the incoming air, see p. 1359.

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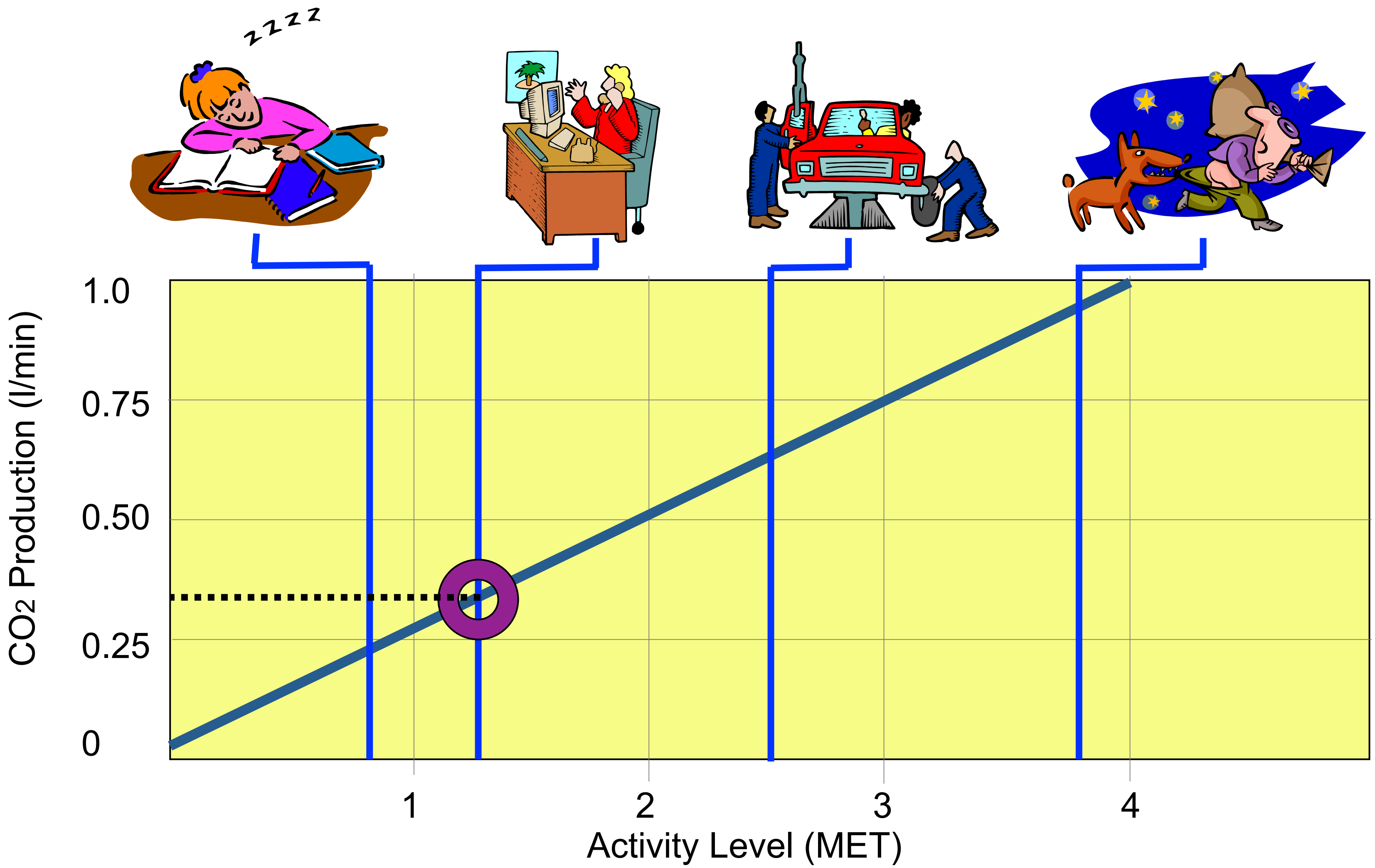
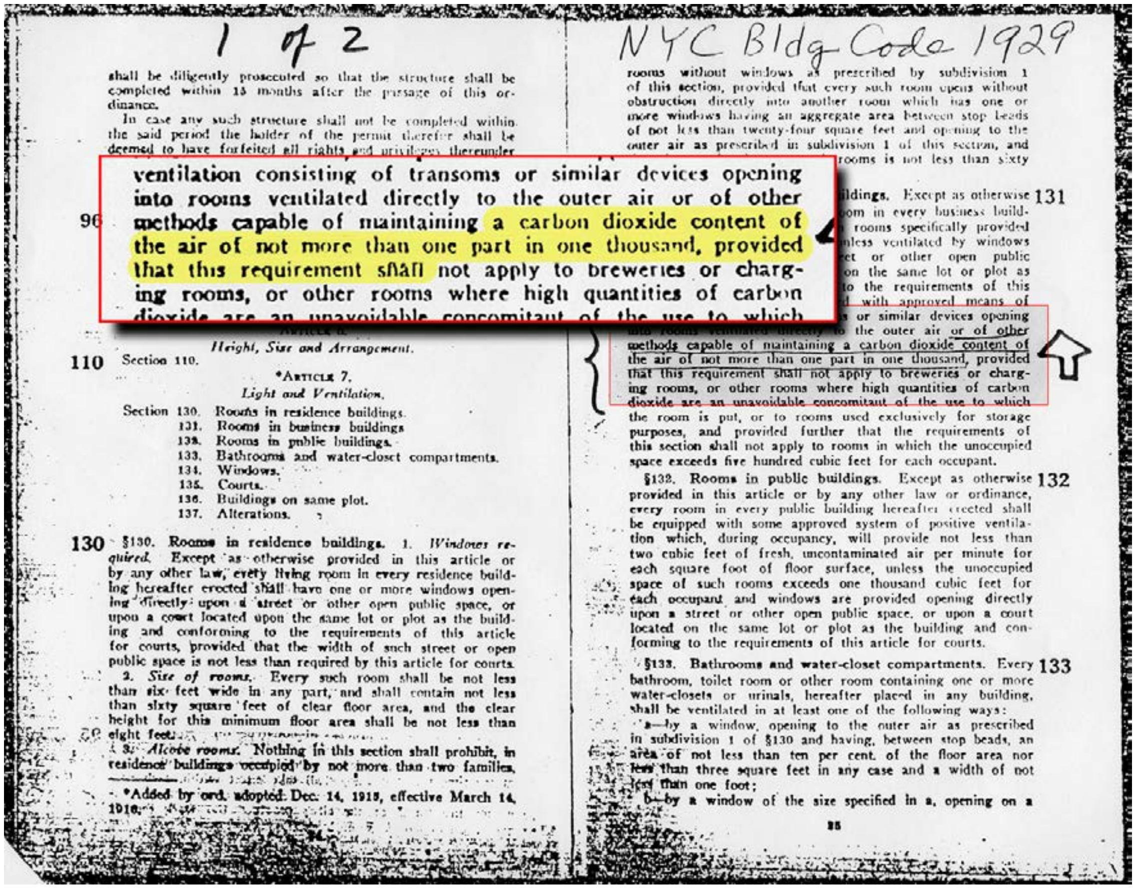
CO_2 & Human Activity



Source:ASHRAE Standard 62-2000 Appendix D

1929 NY City Building Code



1 of 2

NYC Bldg Code 1929

shall be diligently prosecuted so that the structure shall be completed within 15 months after the passage of this ordinance.

In case any such structure shall not be completed within the said period the holder of the permit therefor shall be deemed to have forfeited all rights and privileges thereunder

96 ventilation consisting of transoms or similar devices opening into rooms ventilated directly to the outer air or of other methods capable of maintaining a carbon dioxide content of the air of not more than one part in one thousand, provided that this requirement shall not apply to breweries or charging rooms, or other rooms where high quantities of carbon dioxide are an unavoidable concomitant of the use to which

Article 6.

Height, Size and Arrangement.

110 Section 110.

*Article 7.

Light and Ventilation.

Section 130. Rooms in residence buildings.
131. Rooms in business buildings.
132. Rooms in public buildings.
133. Bathrooms and water-closet compartments.
134. Windows.
135. Courts.
136. Buildings on same plot.
137. Alterations.

130 §130. **Rooms in residence buildings.** 1. *Windows required.* Except as otherwise provided in this article or by any other law, every living room in every residence building hereafter erected shall have one or more windows opening directly upon a street or other open public space, or upon a court located upon the same lot or plot as the building and conforming to the requirements of this article for courts, provided that the width of such street or open public space is not less than required by this article for courts.

2. *Size of rooms.* Every such room shall be not less than six feet wide in any part, and shall contain not less than sixty square feet of clear floor area, and the clear height for this minimum floor area shall be not less than eight feet.

3. *Alcove rooms.* Nothing in this section shall prohibit, in residence buildings occupied by not more than two families,

*Added by ord. adopted Dec. 14, 1915, effective March 14, 1916.

rooms without windows as prescribed by subdivision 1 of this section, provided that every such room opens without obstruction directly into another room which has one or more windows having an aggregate area between stop beads of not less than twenty-four square feet and opening to the outer air as prescribed in subdivision 1 of this section, and ... rooms is not less than sixty

...ildings. Except as otherwise 131
...om in every business build-
... rooms specifically provided
...nless ventilated by windows
...et or other open public
...on the same lot or plot as
...to the requirements of this
...d with approved means of
...s or similar devices opening into rooms ventilated directly to the outer air or of other methods capable of maintaining a carbon dioxide content of the air of not more than one part in one thousand, provided that this requirement shall not apply to breweries or charging rooms, or other rooms where high quantities of carbon dioxide are an unavoidable concomitant of the use to which the room is put, or to rooms used exclusively for storage purposes, and provided further that the requirements of this section shall not apply to rooms in which the unoccupied space exceeds five hundred cubic feet for each occupant.

§132. **Rooms in public buildings.** Except as otherwise 132 provided in this article or by any other law or ordinance, every room in every public building hereafter erected shall be equipped with some approved system of positive ventilation which, during occupancy, will provide not less than two cubic feet of fresh, uncontaminated air per minute for each square foot of floor surface, unless the unoccupied space of such rooms exceeds one thousand cubic feet for each occupant and windows are provided opening directly upon a street or other open public space, or upon a court located on the same lot or plot as the building and conforming to the requirements of this article for courts.

§133. **Bathrooms and water-closet compartments.** Every 133 bathroom, toilet room or other room containing one or more water-closets or urinals, hereafter placed in any building, shall be ventilated in at least one of the following ways:

a—by a window, opening to the outer air as prescribed in subdivision 1 of §130 and having, between stop beads, an area of not less than ten per cent. of the floor area nor less than three square feet in any case and a width of not less than one foot;

b—by a window of the size specified in a, opening on a

35

AirTest™
Sensors That Make Buildings Smart!

CO_2 Measurement

Circa 1890 - 1935

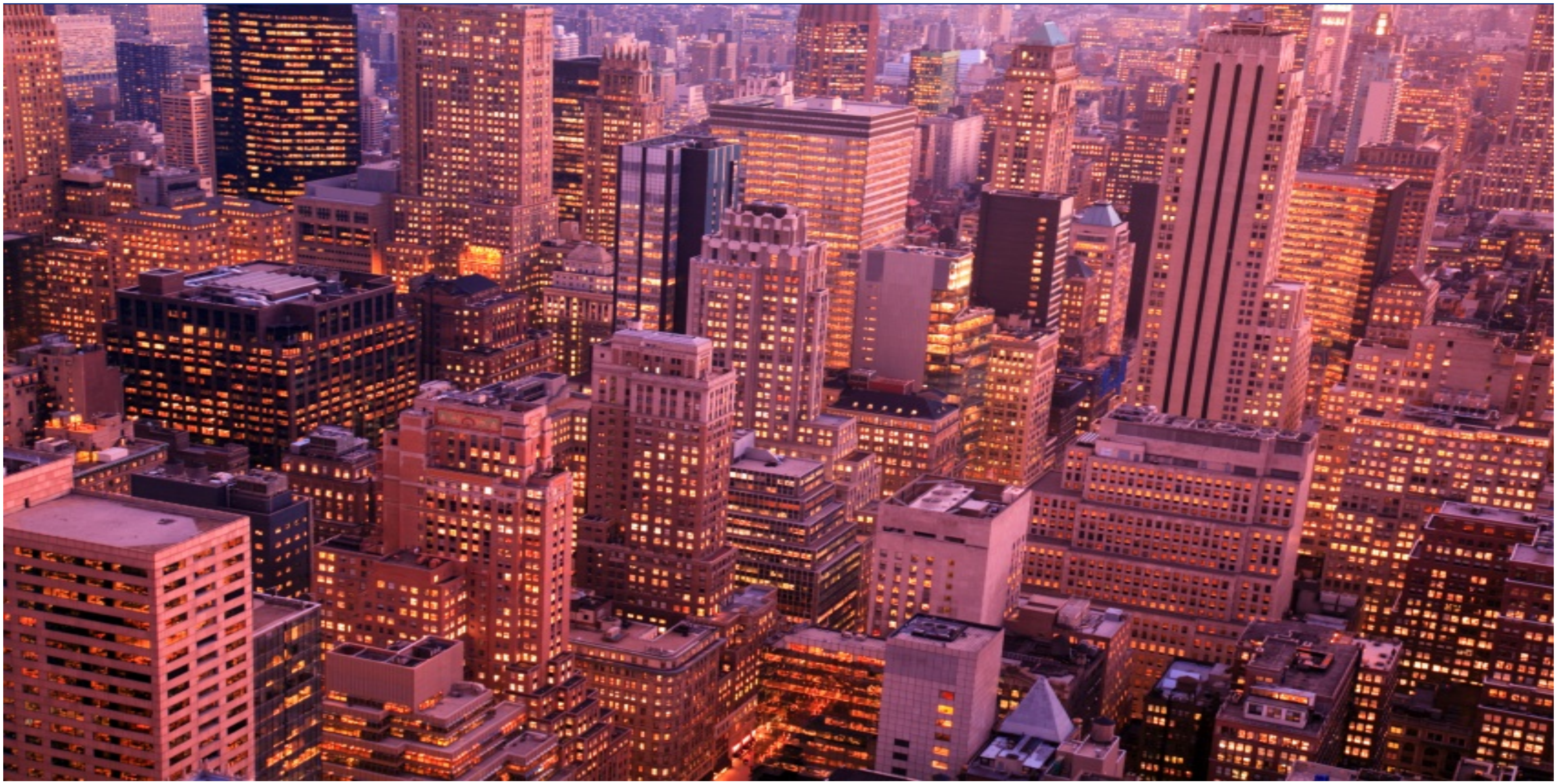
Circa 1992

Telaire 1050
1st CO_2 Sensor for Demand Controlled Ventilation

Circa 2014

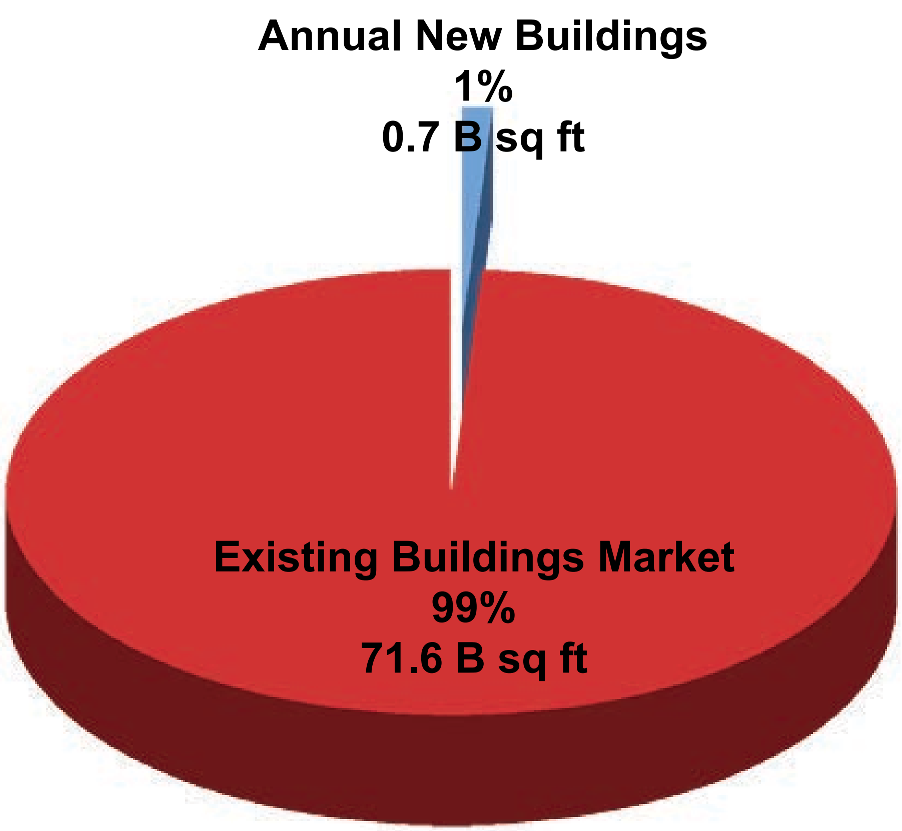
TR9299-WiFi CO_2 & Temp

So What Are The Buildings Of The Future?



They Are The Buildings We Have Today!

The Buildings Market…



Source: US Energy Information Administration
(Figures for 2003)

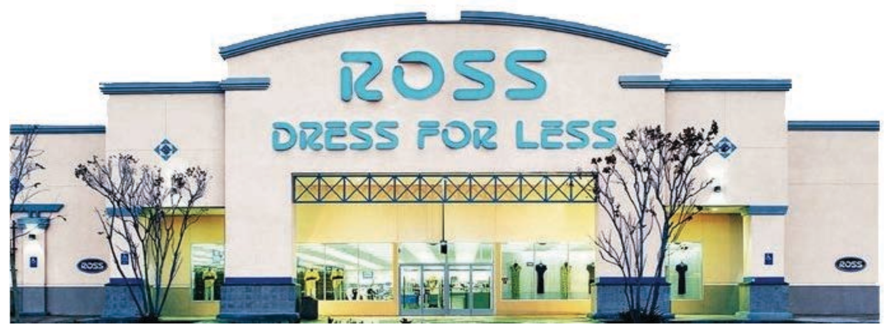
Existing Buildings:

- 35.5% of US Electricity
- 21% of US primary energy
- 1,330 billion kWh
- 400 billion kWh for HVAC

Motivation:

- Must stay competitive with new buildings.
- Highly motivated to reduce operating costs.
- Low hanging fruit has been picked (energy savings), need to dig deeper

Wired CO_2 Retrofits



Why WiFi Wireless?

1. WiFi is widespread & dependable.
2. Network hardware is low cost, available everywhere.
3. Widely understood how to set up and troubleshoot networks.
4. Proven security and encryption methods.
5. Data can be sent anywhere on the internet.
6. Lowest cost installation option.

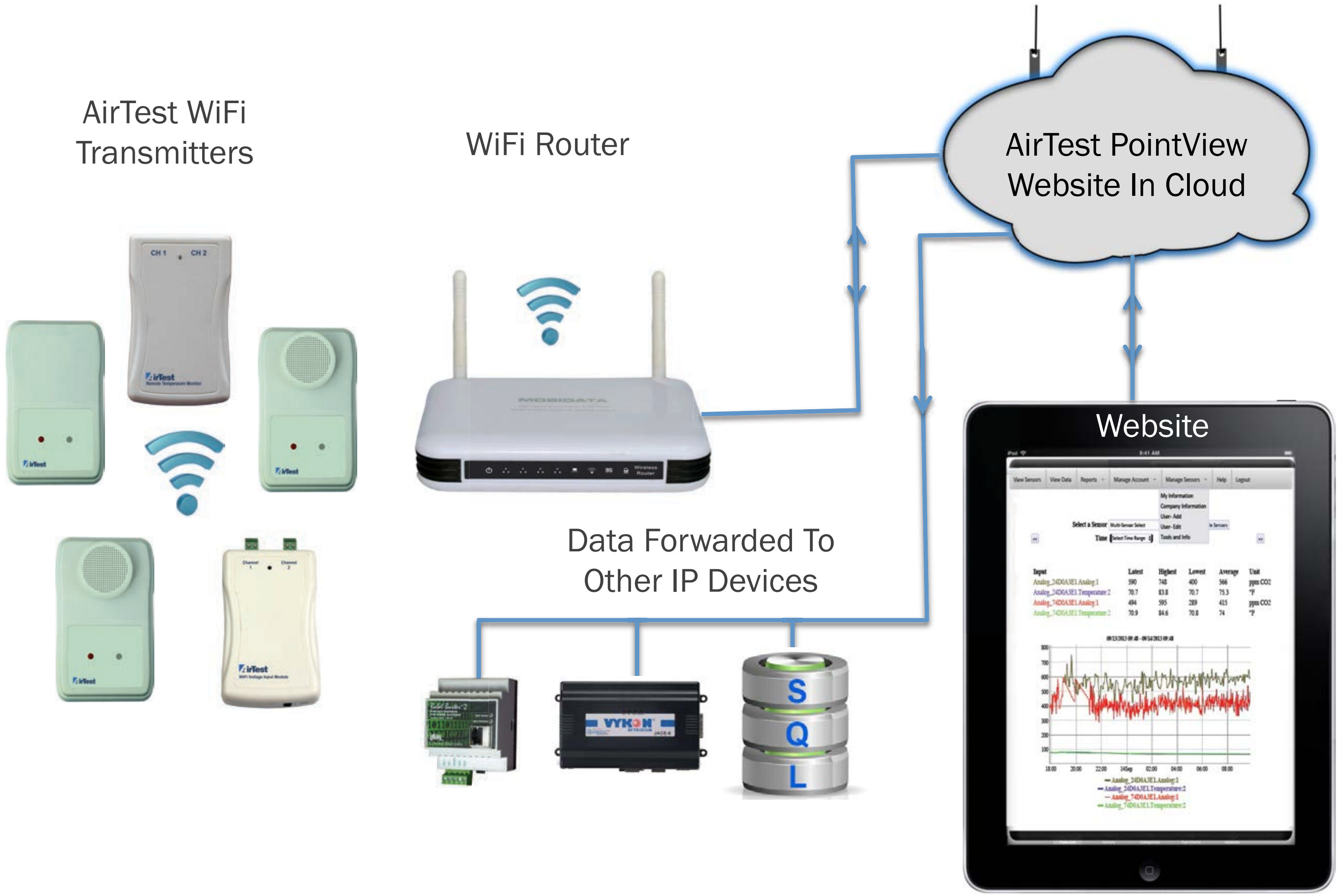
AirTest Wireless Sensors

- CO_2 & Temp
- Indoor Dew Point/RH & Temp
- Outdoor Dew Point/Enthalpy & Temp
- Remote Temperature Probes
- Room/Building Differential Pressure
- Power Monitoring For Rooftop Air Handlers
- Fault Detection For Rooftop Air Handlers
- Thermostats

WiFi Challenge

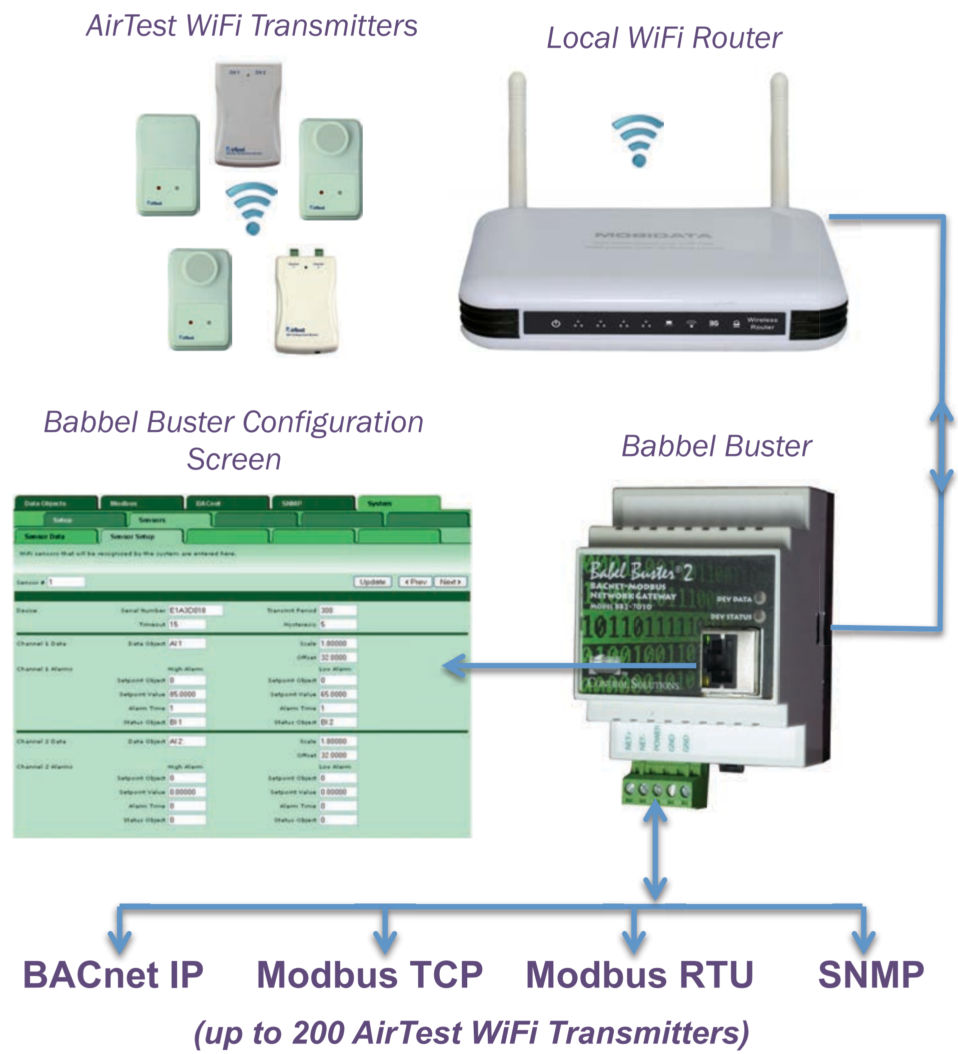
Integration To The Existing Building

1. Wifi-2-Cloud



2. WiFi-2-Wire

- Easy way of integrating AirTest WiFi sensors into a existing wired control system.
- Uses the Babbel Buster to communicate to a wired BACnet or Modbus control systems.
- Supports up to 200 AirTest WiFi transmitters.



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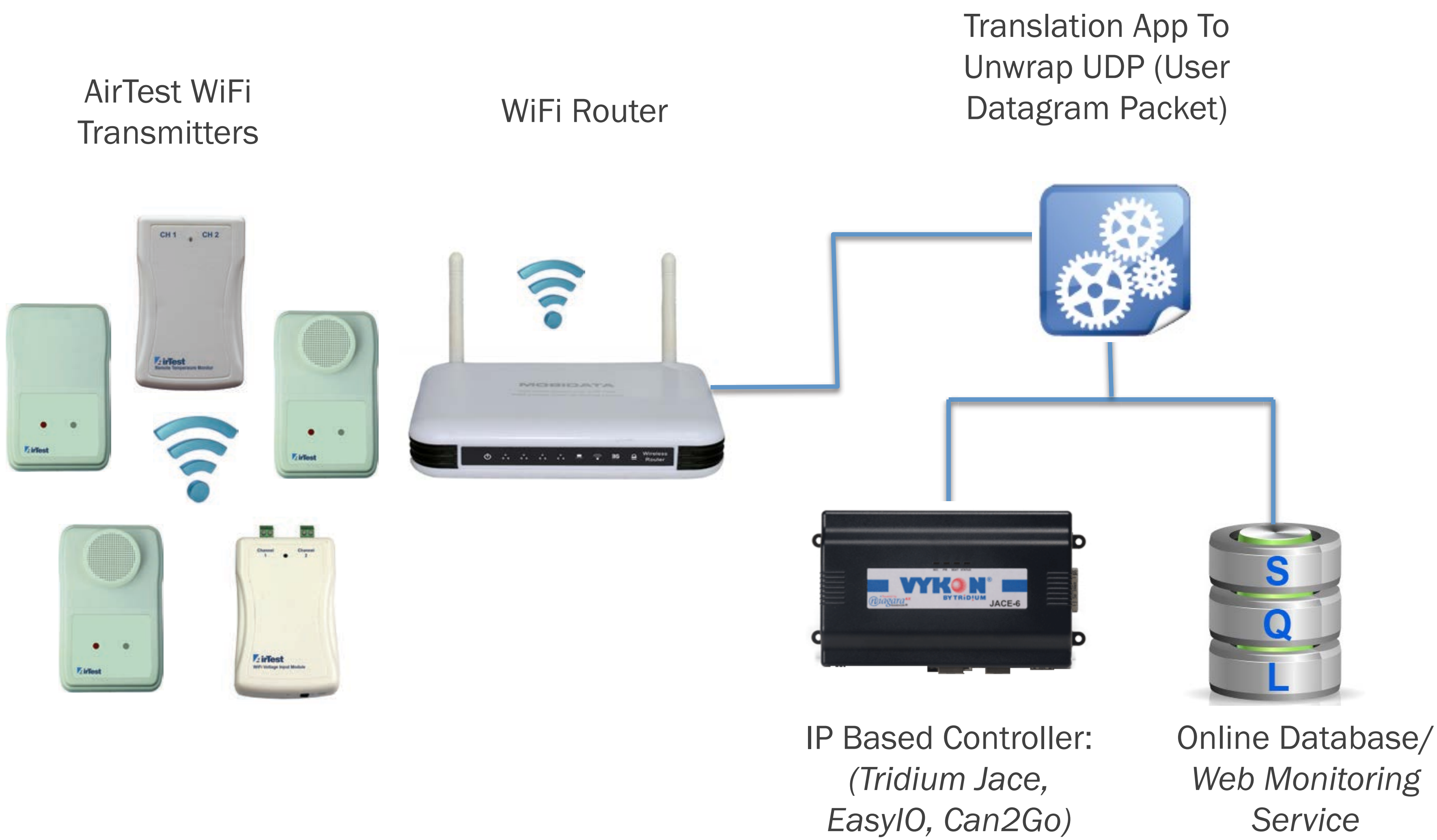
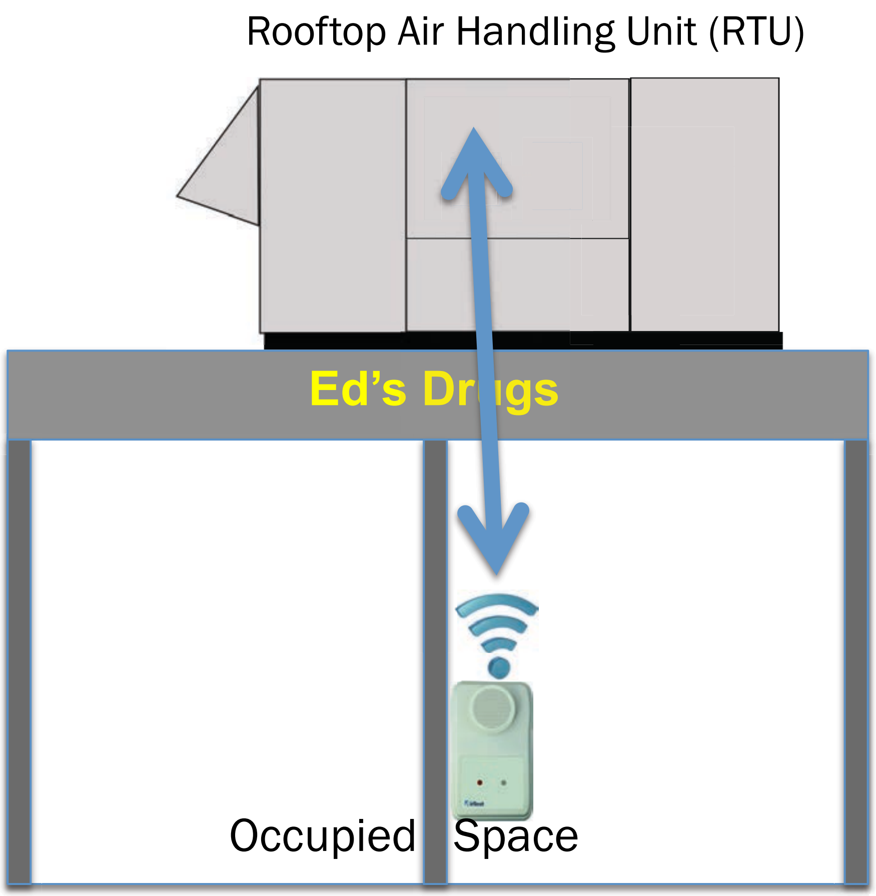
3. WiFi-2-Web



4. Point-2-Point (Targeting RTUs)

1. AirTest's TR9299-Wifi CO_2 sensor Is placed in the space.
2. AirTest GW4201 wireless gateway is placed in the RTU.
3. A secure, stand-alone WiFi network is created between the CO_2 sensor and RTU.
4. The Gateway mounted in the RTU provides a 0-10 VDC CO_2 input to the RTU.



Wireless RTU Gateway Capabilities

- Fast, ***low cost*** method to install CO_2 on a stand-alone rooftop air handler.
- Add other ***Bluetooth*** communicating sensors placed in the RTU for fault detection and energy monitoring.
- Has ***Smartphone*** WiFi access to CO2 readings, fault detection data and Belimo Zip Economizer.
- RTU data is *internet accessible* using the AirTest WiFi/Cellular Gateway for up to 20 RTUs.

Future Challenge

- Energy conservation has created a problem…
- Most conservation methods affect "sensible load" moisture load has not changed.
- Proliferation of moisture and mold problems in buildings is the canary!
- Building temperature control no longer controls moisture.
- Moisture will have to be measured and controlled separately.
- Must move away from RH… an impossible control parameter!
- Dew Point/Mixing Ratio is a better direct measure but in the past has been prohibitively expensive.
- Cost is not a problem now, but this is new territory for the industry.
- Technology is easier to develop than changing a paradigm!

Smart Buildings and Smart Controls

Marc Thuillard

Head Research

Belimo Automation

Buildings of the Future Scoping Study:

NYC Workshop

Today’s main issues

- **Sub-optimal energy usage in building**
- **Lifelong stability of a control system in building (Complexity)**
- **Outside air quality is in many countries quite bad**

Today’s main issues

- **Sub-optimal energy usage in building**
- **Lifelong stability of a control system in building (Complexity)**
- **Outside air quality is in many countries quite bad**

Sub-optimal energy usage in building : Some solutions

- **Optimize energy usage in building**
    - Use appropriate energy source (Exergy)
    - **Use energy only when required (Energy Monitoring, Intelligent Demand Control)**
    - **Optimize energy distribution in buildings**

Optimize energy usage in buildings

Position Control

Flow Control

(Pressure independent)

Energy Control

(Pressure and water temperature independant)

Optimize energy distribution in buildings

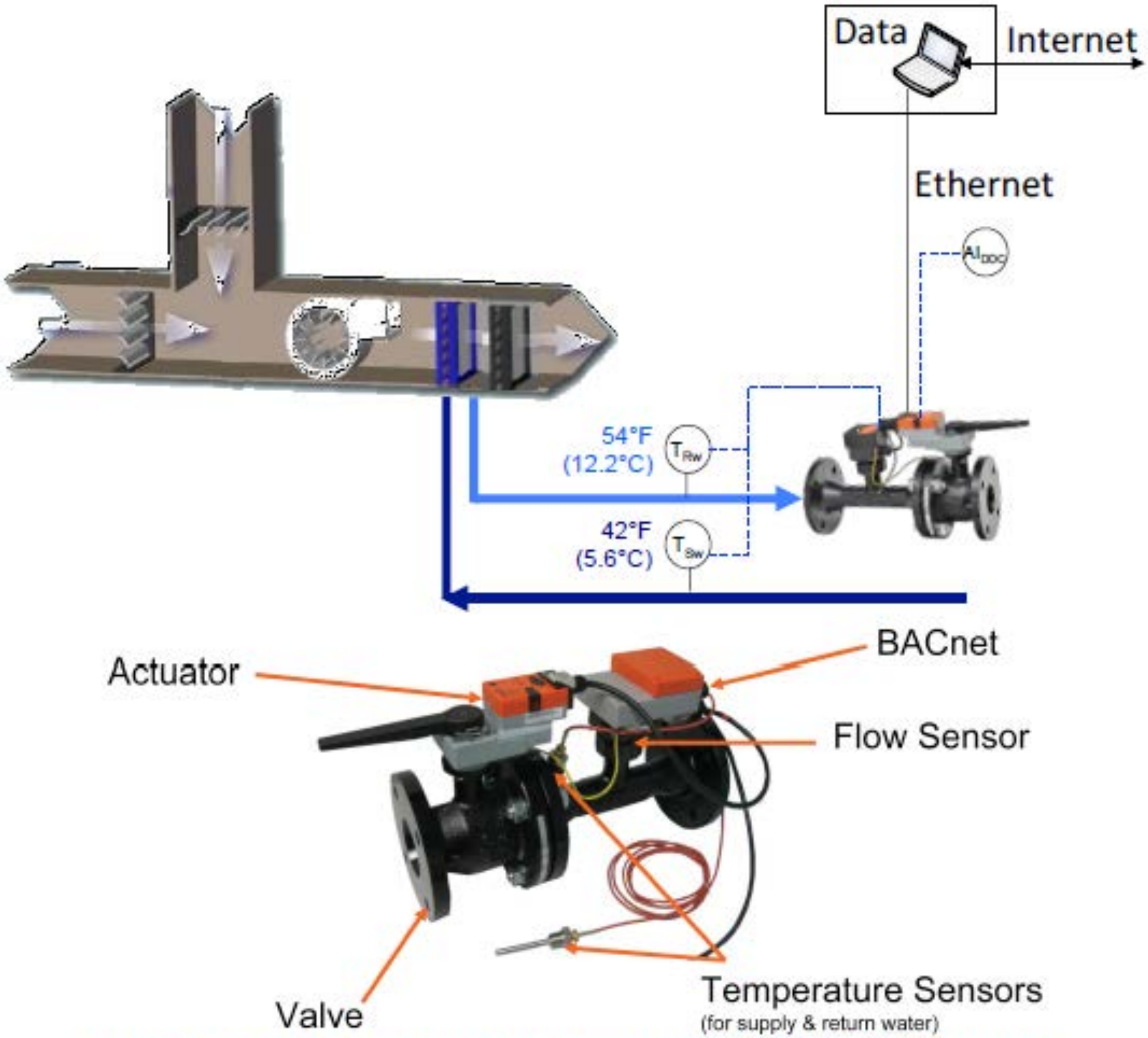
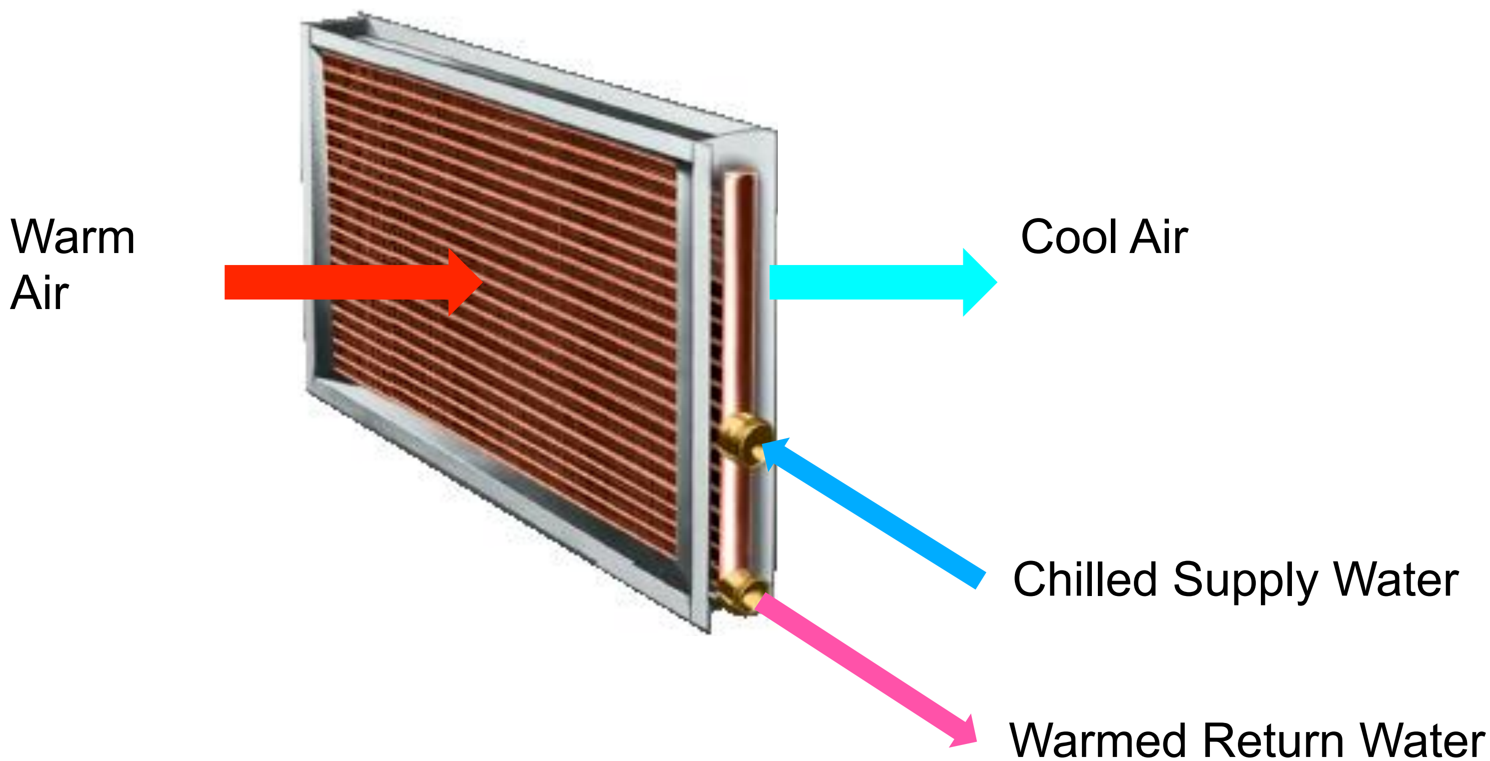
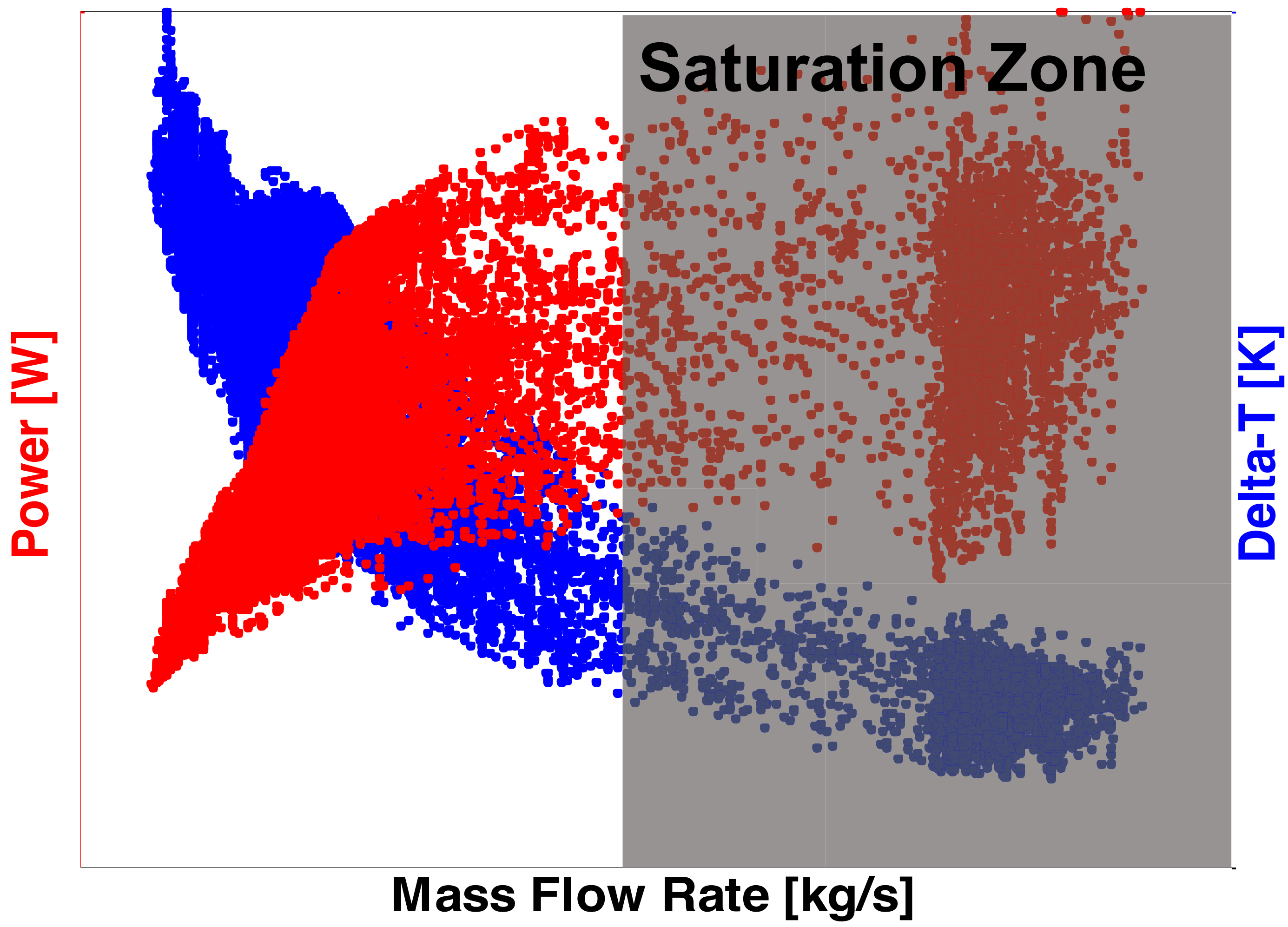


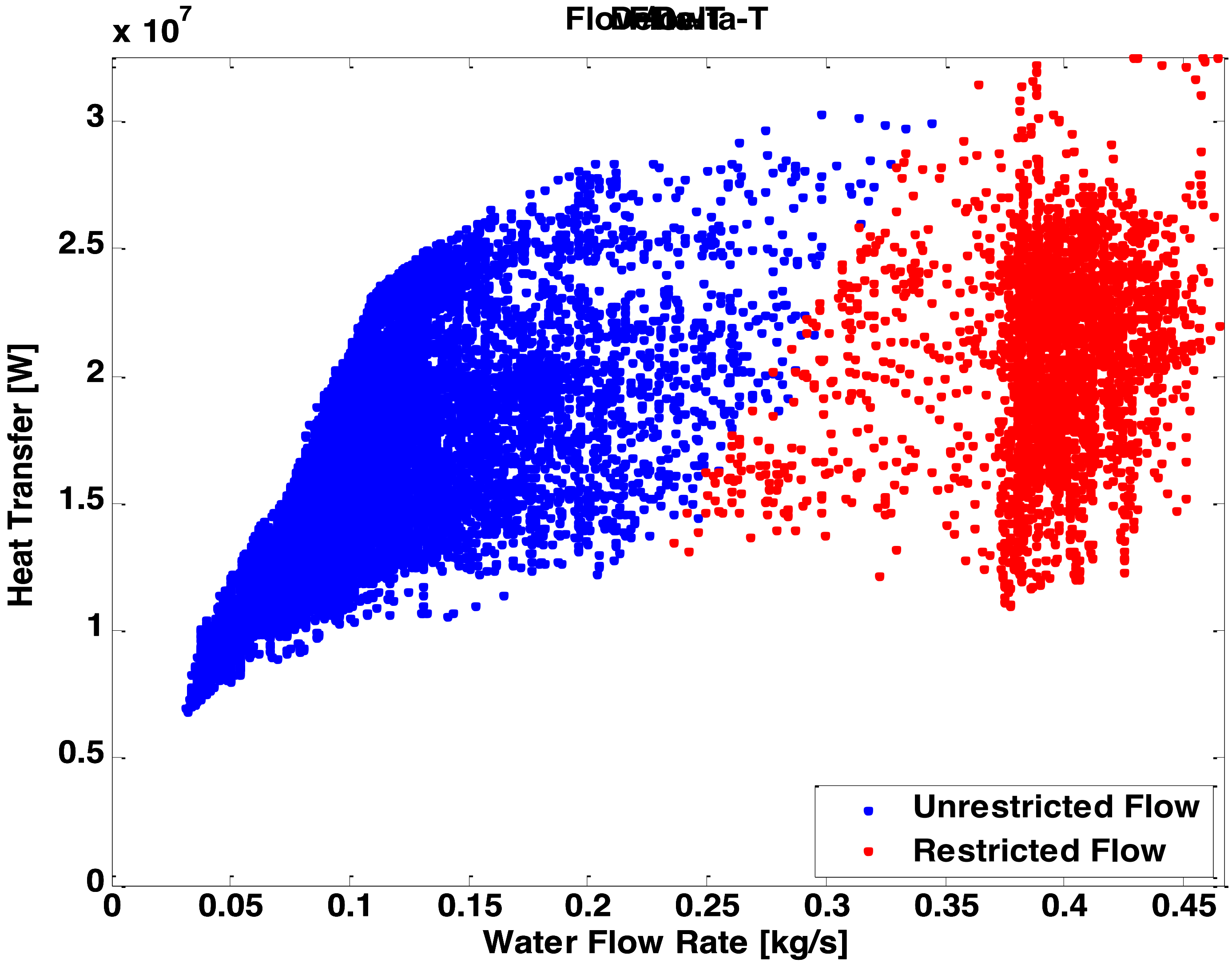
Figure 2: Case Study Experimental Setup (top) and Energy Valve (bottom)

Optimize energy usage in buildings: Delta-T Syndrome



Optimize energy distribution in buildings





Case Study I: Florida

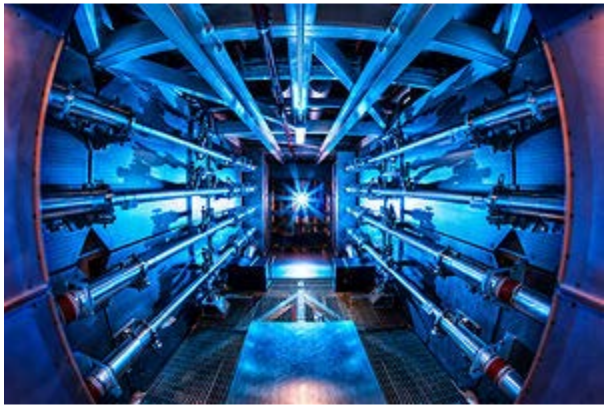
Future (…almost there):

- IoT: integration of data from wearable, intelligent clothings in BMS?
- Integration of «mood» of building occupants in building control?
- New «sensors»: internet traffic analysis

In 100 years

Scenario 1: Energy is readily available through fusion:

Today 20 EJ/yr → Increase by factor 100-1000; Thermal waste becomes a global issue.



Scenario 2: planet is green and energy is not wasted

Sensors are everywhere!

Today's main Issues

- **Sub-optimal energy usage in building**
- **Lifelong stability of a control system in building (Complexity)**
- **Outside air quality is in many countries quite bad**

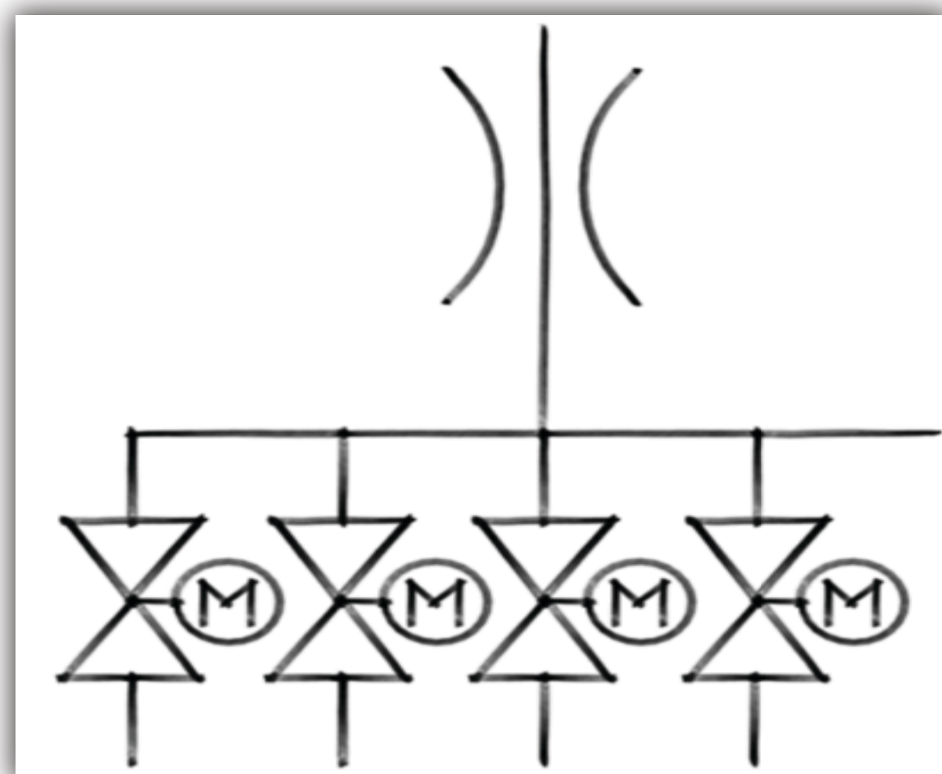
Lifelong stability of a control system in building (Complexity)

BELIMO

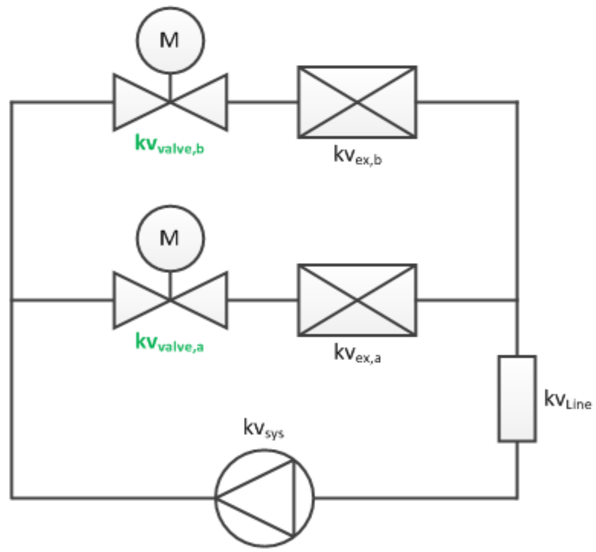
- **High flexibility is rquired. Buildings' physical parameters are constantly changing (ocupants, activities,…)**
- **Buildings must be capable of learning and self-healing**

Lifelong stability of a control system in building (Complexity): Learning Systems

1 flow sensor + bus communication with actuators + Computational Intelligence → Learn hydraulic network



Lifelong stability of a control system in building (Complexity): Self- healing system



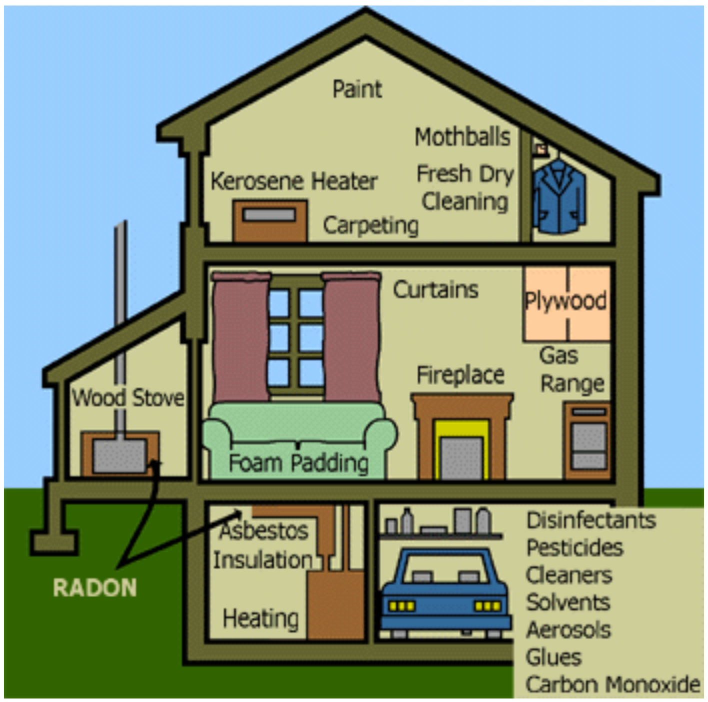
$$\frac{1}{\sqrt{\frac{1}{Kvs_{a,3}^2}+\frac{1}{Kv_a^2}}}+\frac{1}{\sqrt{\frac{1}{Kvs_{b,3}^2}+\frac{1}{Kvs_{a,1}^2}-\frac{1}{Kvs_{b,2}^2}+\frac{1}{Kv_a^2}}}=\frac{1}{\sqrt{\frac{1}{Kvs_{a,4}^2}+\frac{1}{Kv_a^2}}}+\frac{1}{\sqrt{\frac{1}{Kvs_{b,4}^2}+\frac{1}{Kvs_{a,1}^2}-\frac{1}{Kvs_{b,2}^2}+\frac{1}{Kv_a^2}}}$$

- **Detection & Correction possibilities**
  - Changes in the System can be detected and corrected
  - Coil fouling detection possible
  - US Patent pending

Today's main Issues

- **Sub-optimal energy usage in building**
- **Lifelong stability of a control system in building (Complexity)**
- **Outside air quality is in many countries quite bad**

Indoor and Outdoor Pollution



10-50 years

- Air has become, like water, a commodity
- Air cleaning/purifying is a booming business
- Intensive usage of bio-sensors

We all need air to live!

Bibliography

- **Henze, G.P., Henry, W., and M. Thuillard. 2013. Improving Campus Chilled Water Systems with Intelligent Control Valves: A Field Study, pp. 103-112. Proceedings of the 2013 ASCE Architectural Engineering Conference, April 2-5, 2013, State College, PA.**
- **Taylor, S.T. 2002. Degrading Chilled Water Plant Delta-T: Causes and Mitigation. ASHRAE Transactions. 108(1): 641-653.**
- **Thuillard, M., Reider, F., Henze, G.P. 2014. Energy Efficiency Strategies for Hydronic Systems through Intelligent Actuators. *ASHRAE Transactions 119(1) (pending publication)*.**

High-Density Urban Environments and Buildings of the Future

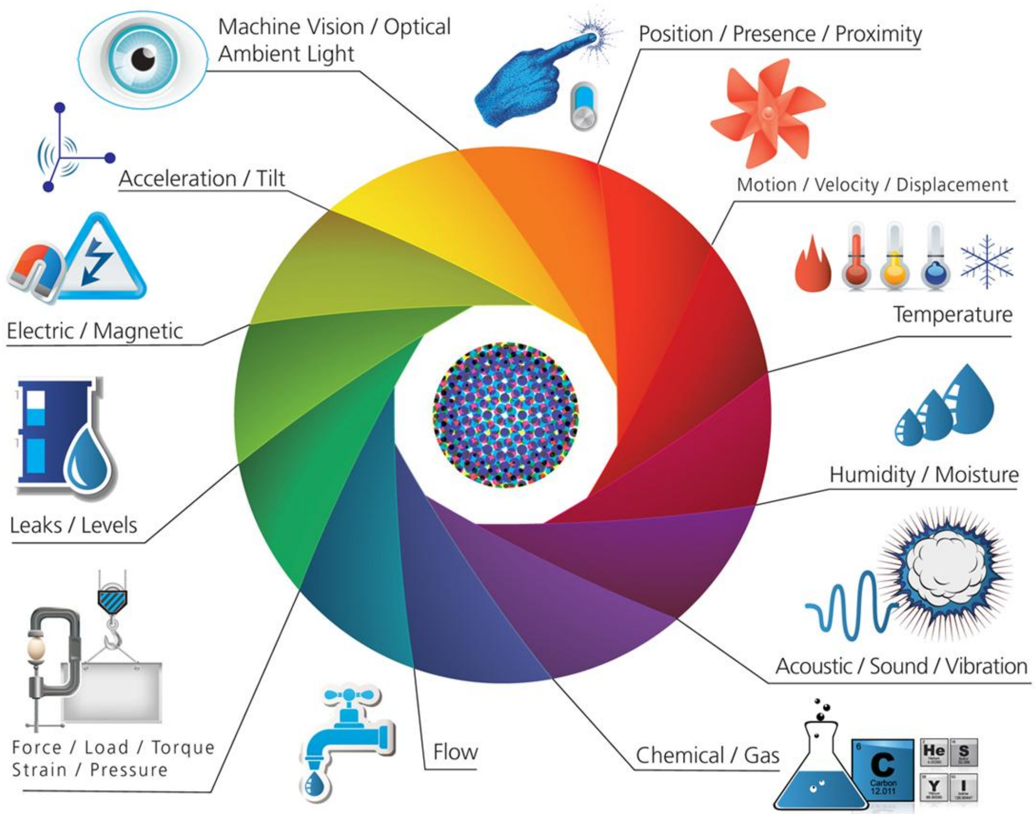
Sensors, Connectivity, Applications and the Internet of Things (IoT)

The City College of New York
May 4, 2015

Sensing

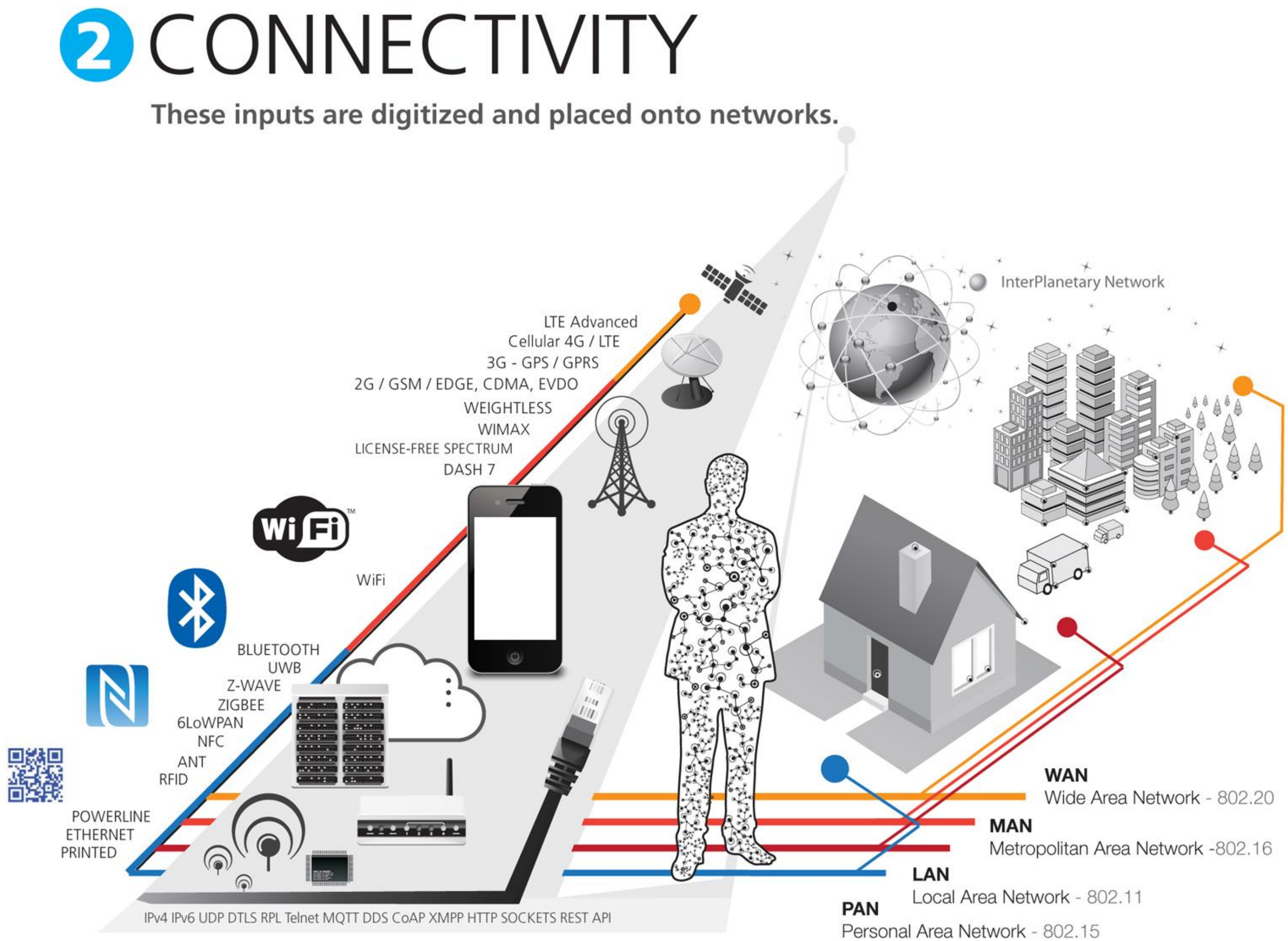
1 SENSORS & ACTUATORS

We are giving our world a digital nervous system. Location data using GPS sensors. Eyes and ears using cameras and microphones, along with sensory organs that can measure everything from temperature to pressure changes.



Source: What Exactly is the Internet of Things?
http://www.slideshare.net/Postscapes/what-exactly-is-the-internet-of-things-44450482?related=1

Connections



Source: What Exactly is the Internet of Things?
http://www.slideshare.net/Postscapes/what-exactly-is-the-internet-of-things-44450482?related=1

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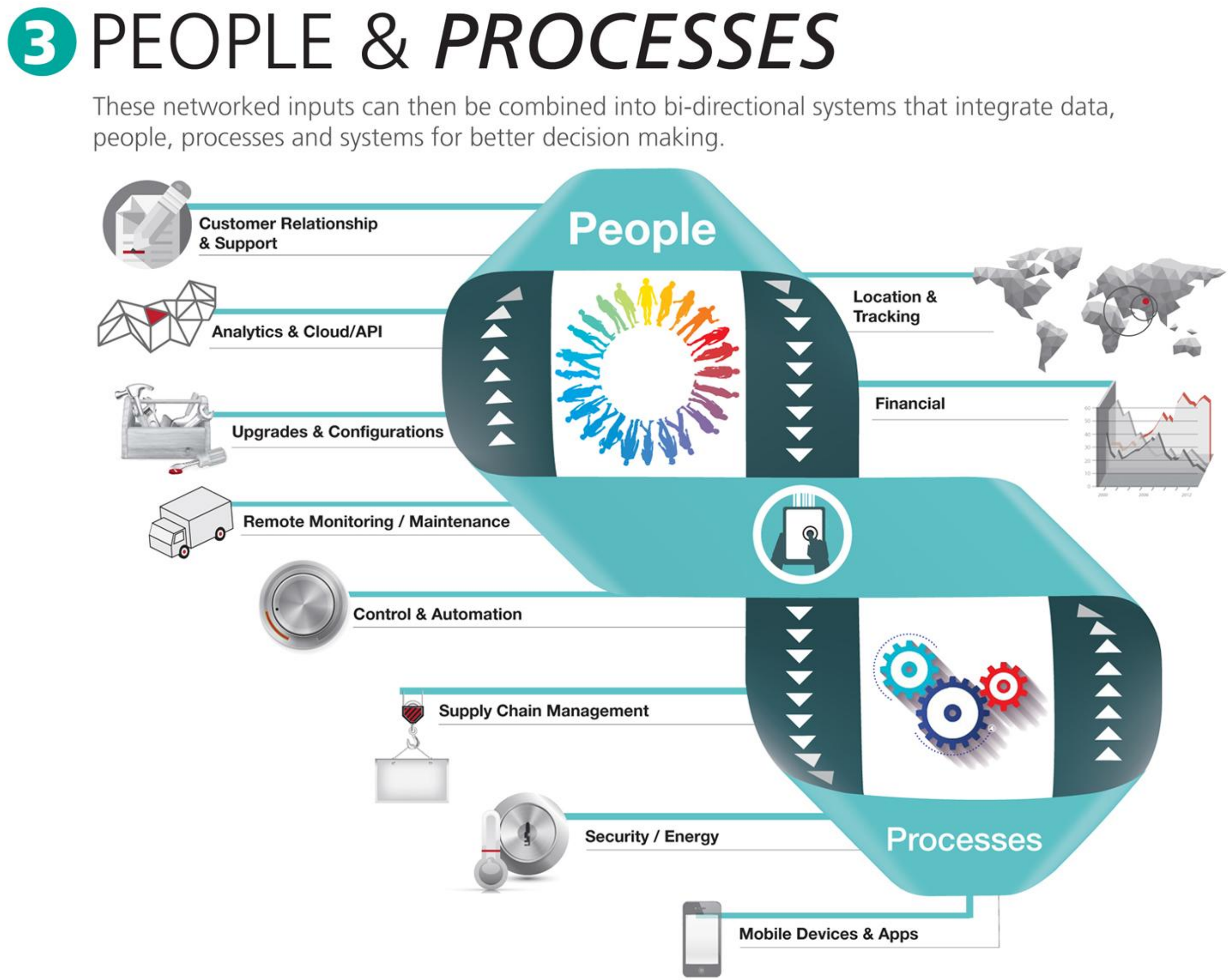
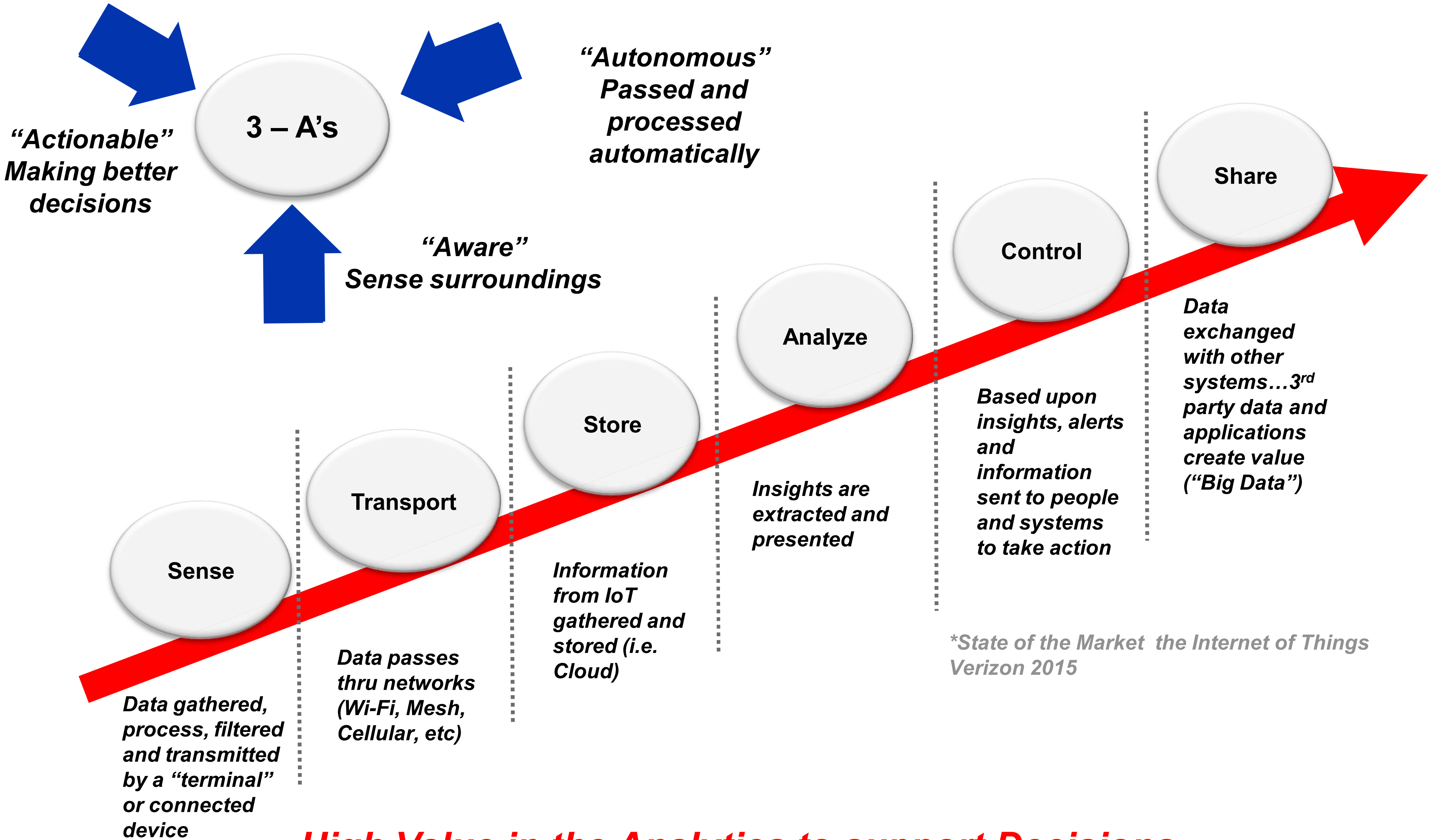
Applications/Processes



Source: What Exactly is the Internet of Things?
http://www.slideshare.net/Postscapes/what-exactly-is-the-internet-of-things-44450482?related=1

IoT Solutions…many moving parts

Honeywell



High Value in the Analytics to support Decisions

Smart Sensors and Building Automation Systems (BAS)

Honeywell

- **What is a Smart Sensor?**
  a) It is exposed on the network as a separate device (it's own device address)
  b) It can be programmed or configured as a separate entity from a tool or has a predetermined role (self configuration)
  c) It has some form of a control sequence or participates in a system and is responsible for a subset of a distributed control scheme
  d) It can be added cost effectively to controller without explicitly being seen on the main control network (exists on a controllers local "sensor bus")
- **Unitary Controllers**
  a) Exists as a separate device on the network
  b) It can be programmed or configured as a separate entity from a tool or has a predetermined role (self configuration)
  c) Has limited control and I/O (low cost)

This implies that for:

- a), b), and c) a smart sensor and a unitary are architecturally the same.

- d) implies a non-flat physical architecture of which we already have many instances of.

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It's Flat, now what? A BAS perspective…

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Is Flat better? – It depends.

Hardware cost – MAC/PHY higher cost

Installation cost + simpler routers (throughput planning easier), - application/trade interdependence, - address assignment problems

Tool complexity +/- (Time to market vs. ease of installation vs. flexibility)

- **Advantages**
  - **Good for an energy analyst (physical)**
    - If you can justify the cost on installation ease then can sell added software services easily (no hardware upgrades needed)
  - **Good for an expert operator (logical)** **(Building operator is a BACnet expert)**
    - Generic method of accessing data for changing operator needs (adding/deleting trends, alarms, graphics i.e. BACnet DeviceID/ObjectID)
- **Considerations**
  - **What it means for the facility maintenance man (physically flat)?**
    - Complexity - system management / data context (Think internet without a search engine)
    - Retrofit still needs gateways to isolate incompatible legacy devices that lack throughput and proper context
    - Integration still requires isolation from less capable subsystems
  - **What it means non-expert operator (logically flat)?** **(Building operator is not a BACnet expert)**
    - Complexity - A janitor doesn't want to see a protocol hierarchy, wants an application hierarchy (Building1_floor2_HVAC_zone1)

Understanding the Spectrum of Applications

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H

Efficiency: Control and React

Gathered data is actioned more systemically, with greater automation, remote control, and some trend analysis/reporting

Innovation: Transform and Explore

Data and insights are used to support entirely new business models, products and services

Degree of Action

Visibility: Connect and Monitor

Gathered data is actioned more systemically, with greater automation, remote control, and some trend analysis/reporting

Agility: Predict and Adapt

Sensed data is augmented by external data sets for complex predictive analysis and action.

L

L

H

Degree of Sensing

Figure: Verizon's IoT Sophistication Model 2015

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