Sustainable Design for Health & Productivity

Brown University
November 21, 2008

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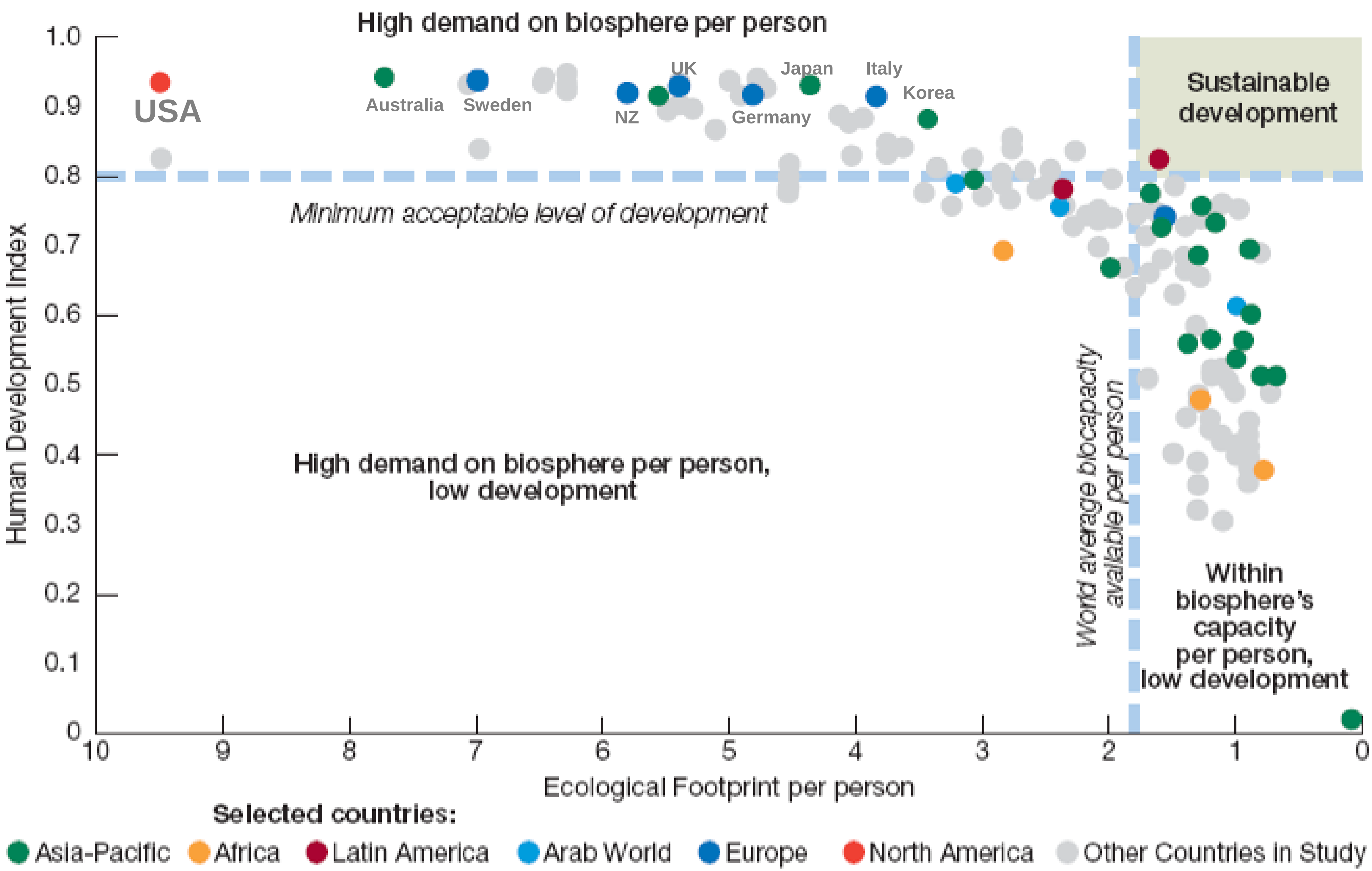
CMU Center for Building Performance & Diagnostics
With the Advanced Building Systems Integration Consortium

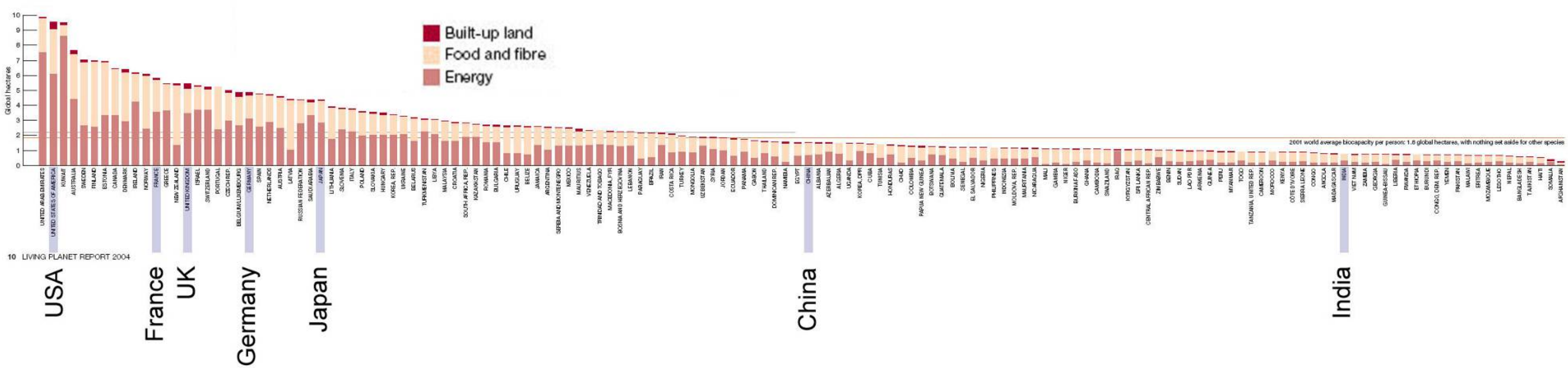

Wealth
Food
Health
Peace
Environment
Jobs

Fig. 21: **MATCHING HUMAN DEVELOPMENT AND ECOLOGICAL FOOTPRINTS,**
Asia-Pacific and selected countries, 2001



Data Source: WWF, 2005, ASIA-PACIFIC 2005 The Ecological Footprint and Natural Wealth

Fig. 15: ECOLOGICAL FOOTPRINT PER PERSON, by country, 2001

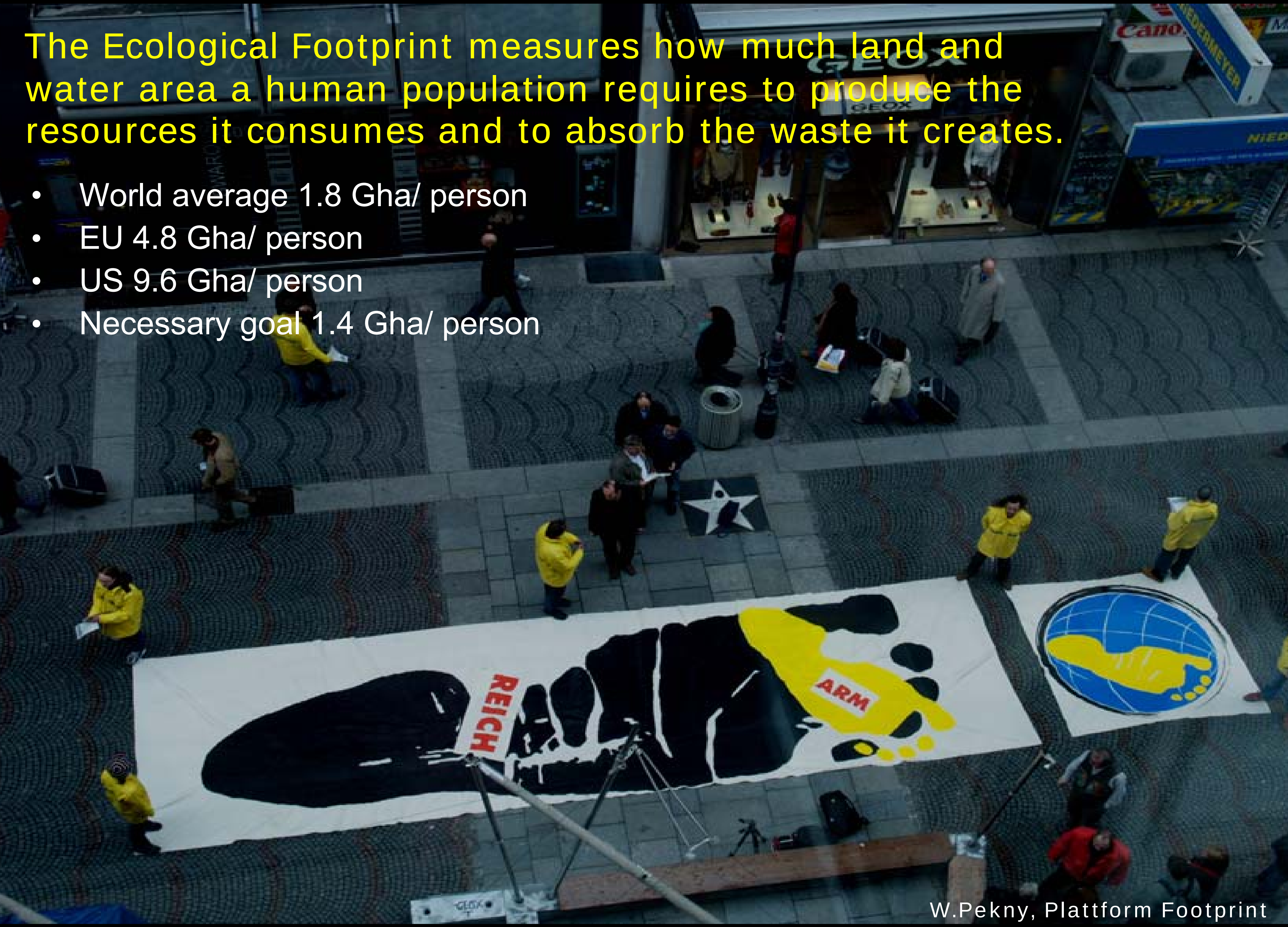


Data Source: UNU, 2004, World Urbanization Prospects The 2003 Revision Data Tables and Highlights,

WWF, 2005, LIVING PLANET REPORT2004

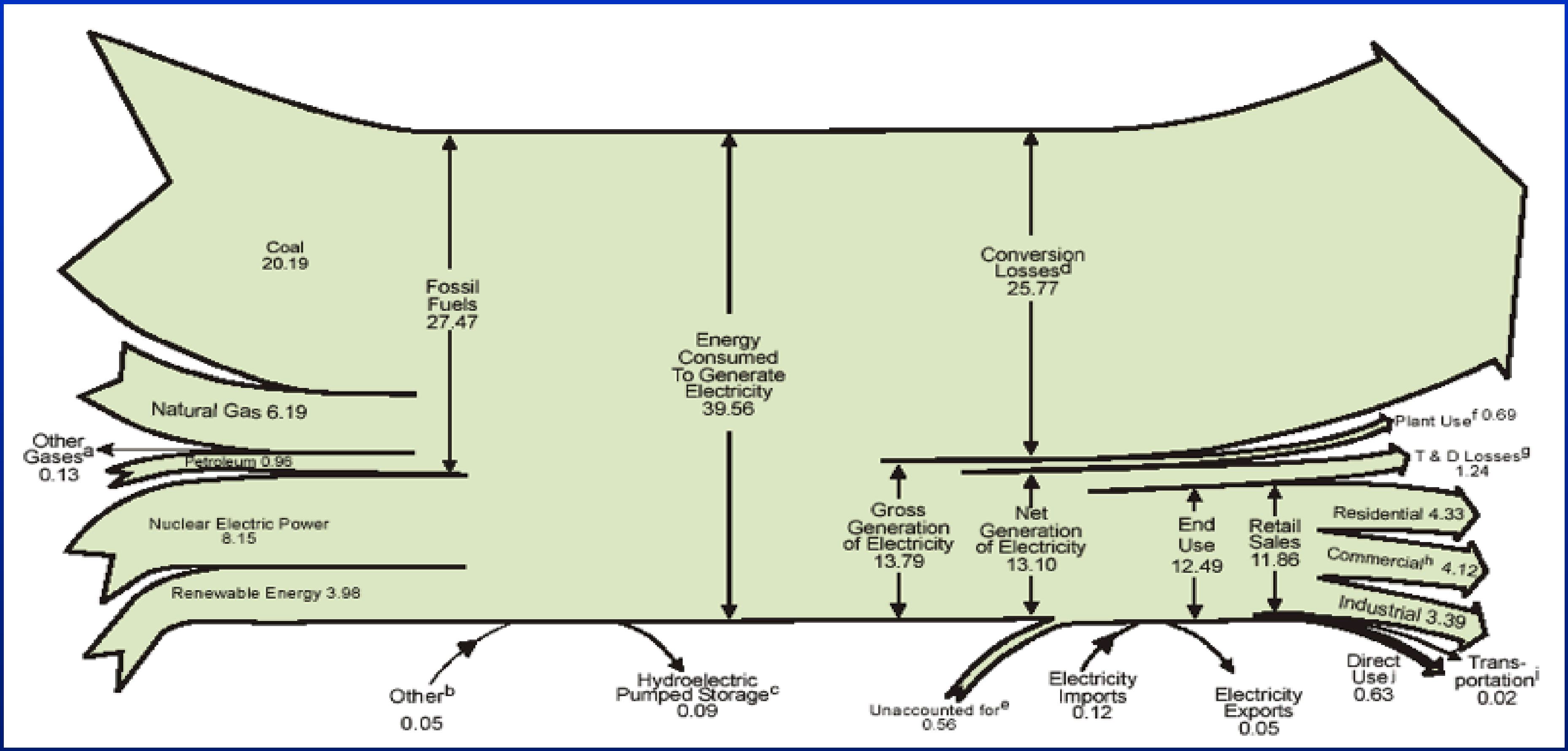
The Ecological Footprint measures how much land and water area a human population requires to produce the resources it consumes and to absorb the waste it creates.

- World average 1.8 Gha/ person
- EU 4.8 Gha/ person
- US 9.6 Gha/ person
- Necessary goal 1.4 Gha/ person



W.Pekny, Plattform Footprint

The True Cost of Least-cost Buildings: Annual Energy Costs

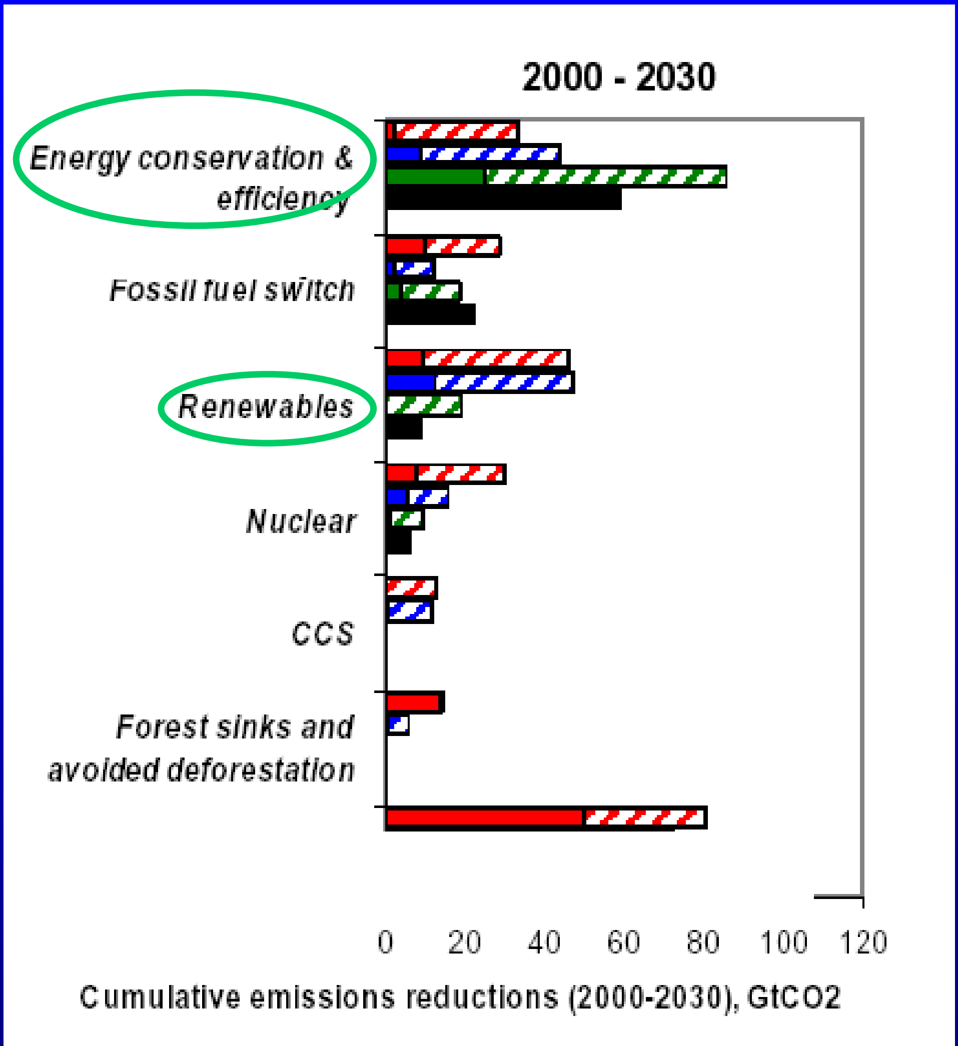


2002 US Electricity Flow, in Quadrillion Btu[1]

1 BTU=2.928x10-4kWh; 1kWh=3,413BTUs

Energy Information Administration. Annual Energy Review 2002

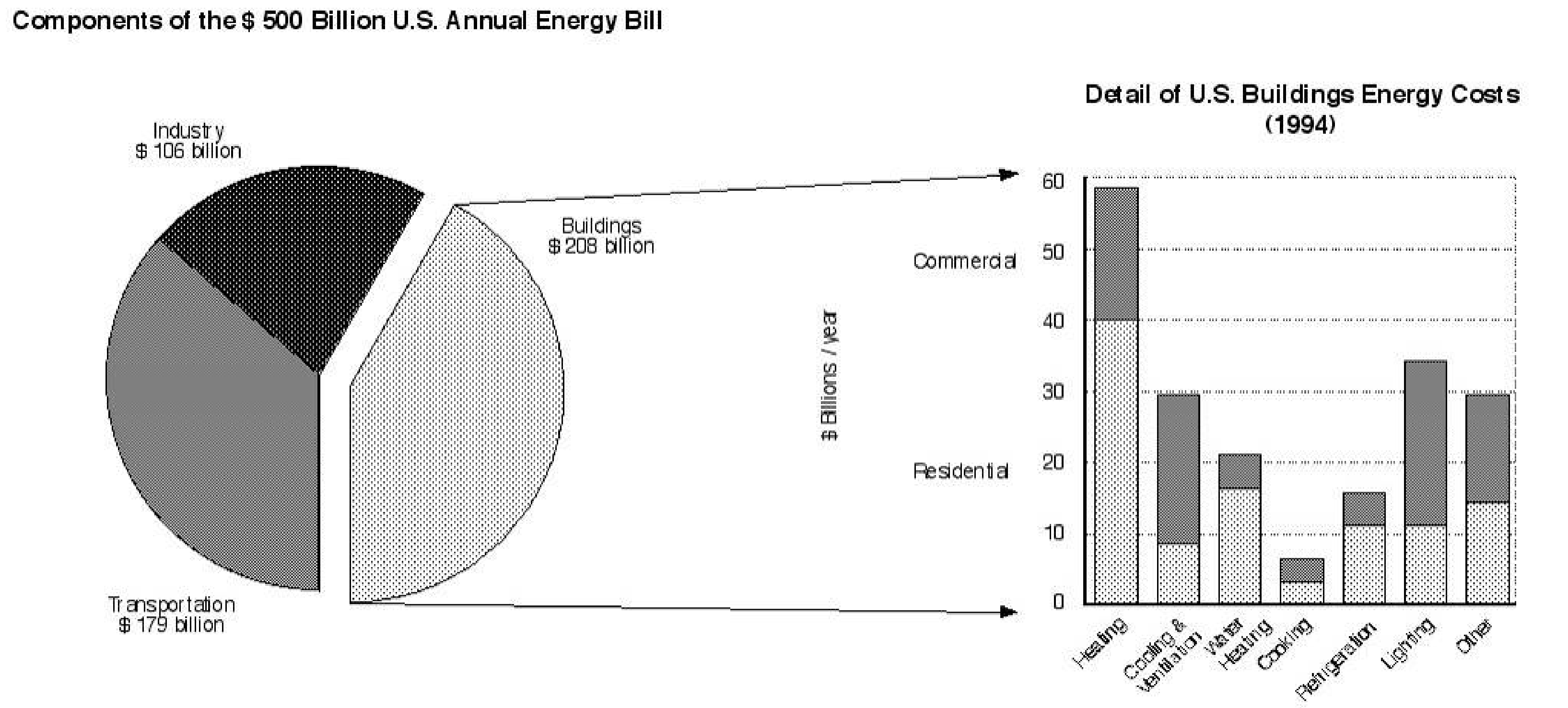
IPCC 2007 (SPM WG III, S. 25)



Conservation and renewables are the two most critical actions for energy and carbon savings

The Environmental Potential of Buildings & Communities

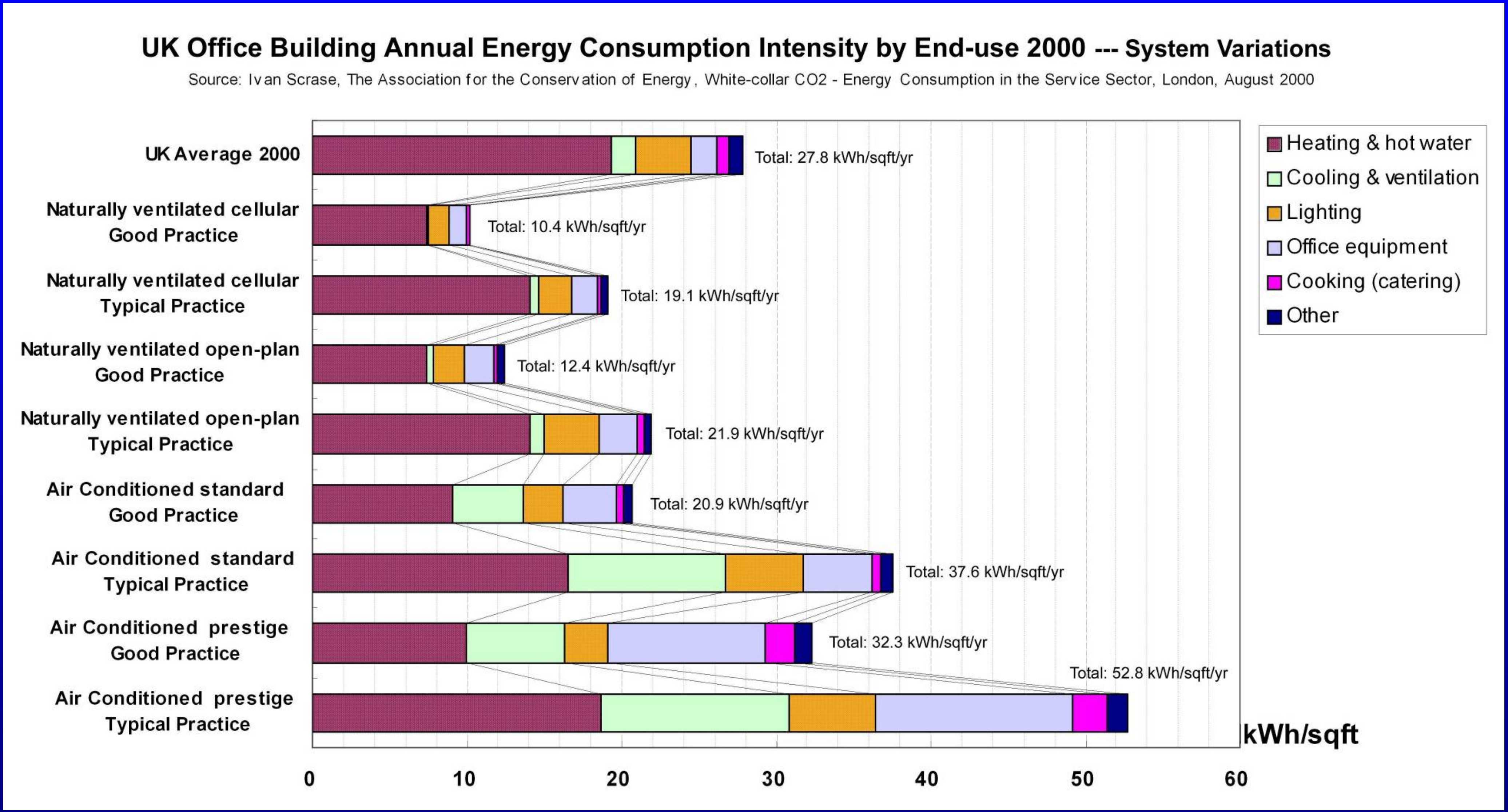
Pollution Reduction
Energy Reduction



LBNL

Buildings consume over 35% of US energy, and through sprawl, a significant proportion of transportation energy

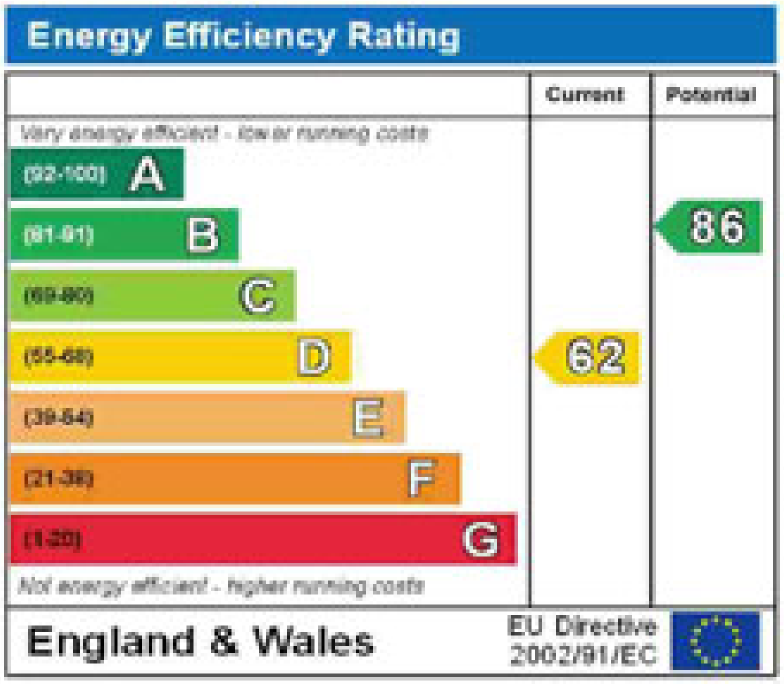
The True Cost of Least-cost Buildings: Annual Energy

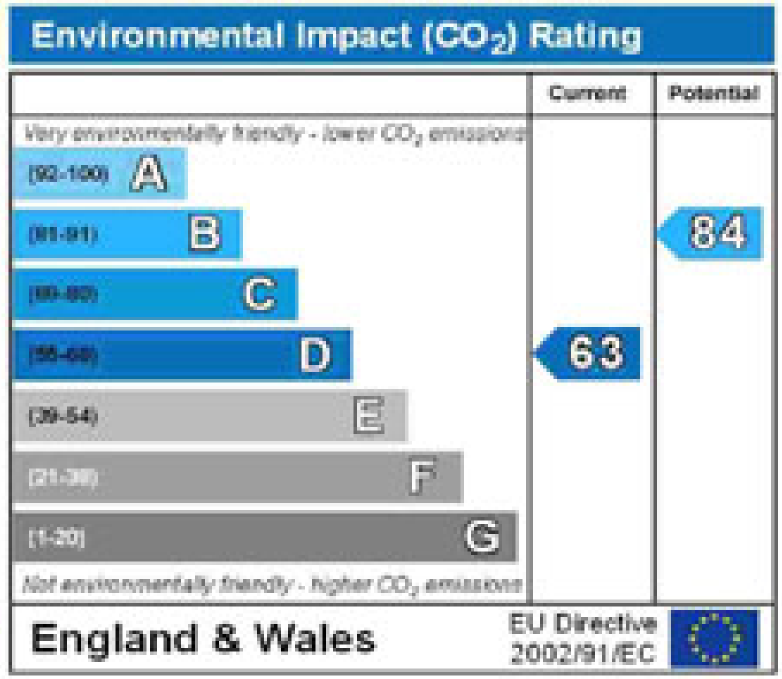


There is a five fold difference between the best and worst existing buildings.

Asset Ratings

Graphs showing energy rating of homes, which can be included in particulars

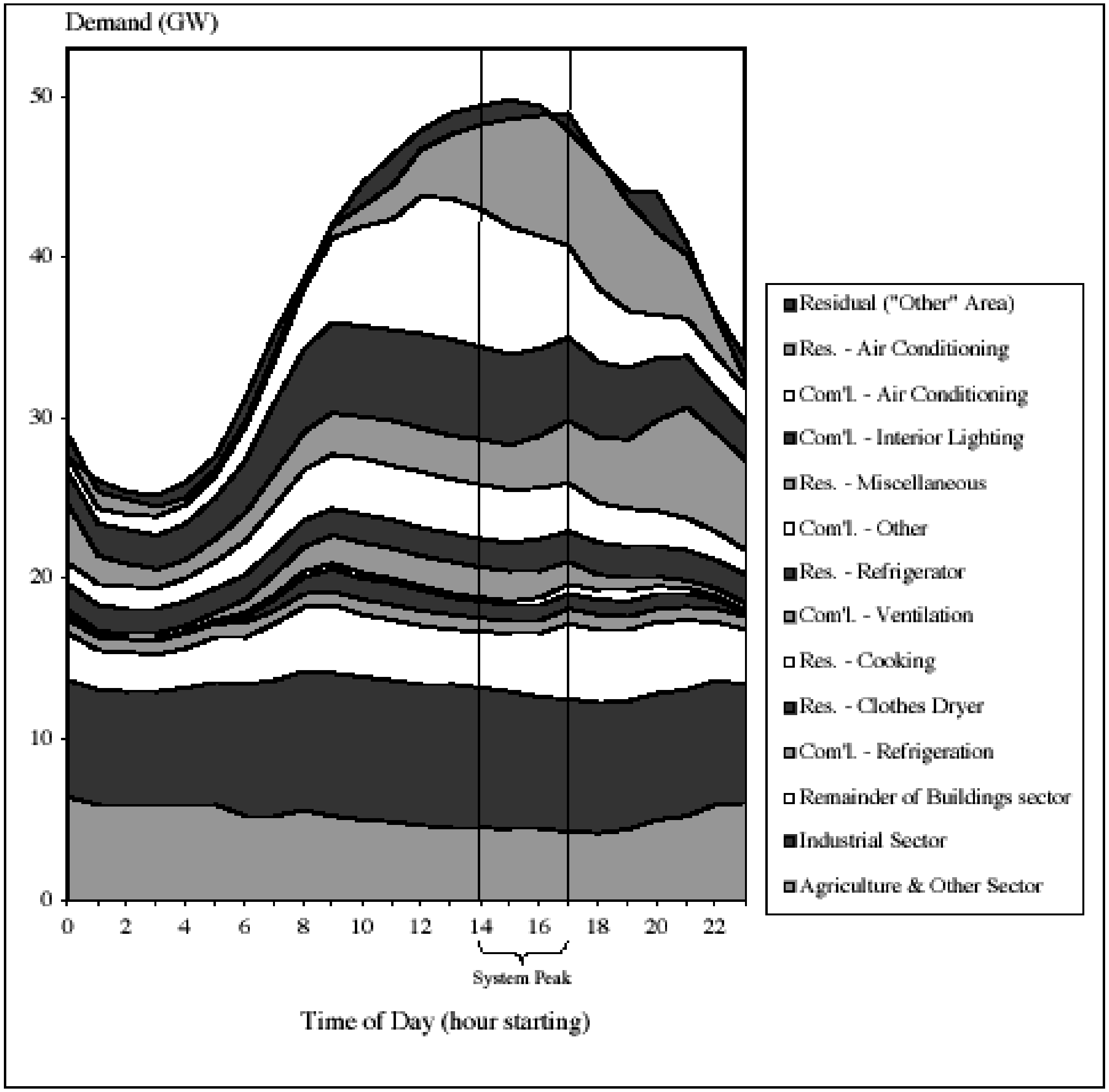




The energy efficiency rating is a measure of the overall efficiency of a home. The higher the rating the more energy efficient the home is and the lower the fuel bills will be.

The environmental impact rating is a measure of a home's impact on the environment in terms of carbon dioxide (CO_2) emissions. The higher the rating the less impact it has on the environment.

Figure 1: California 1999 Summer Peak-day End-use Load (GW): 10 largest coincident building-sector end-uses and non-building sectors



& Peak Energy Savings that = Energy Security

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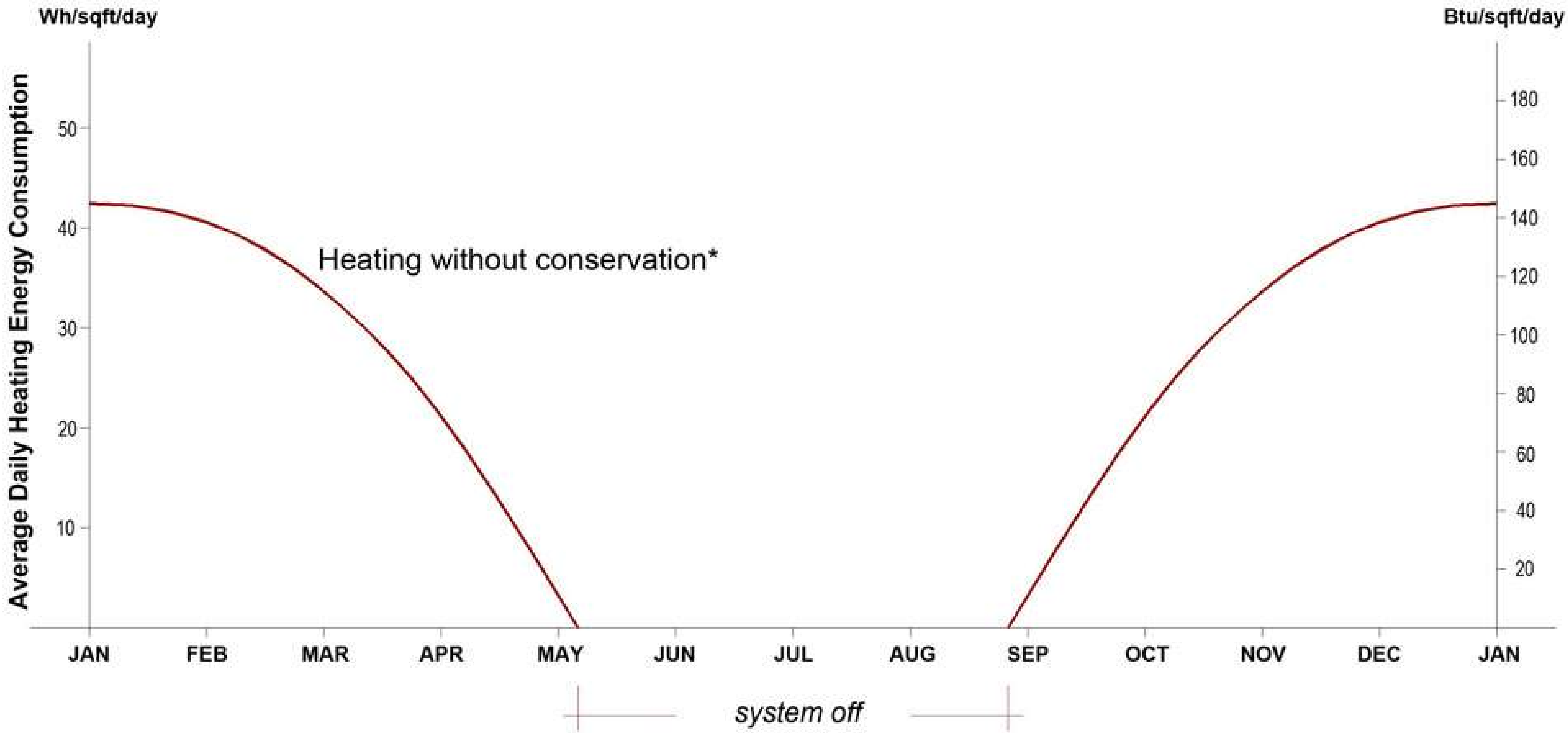

* Total annual heating energy consumption refers to EIA-CBECS 1995 &1999

But Zero Carbon?

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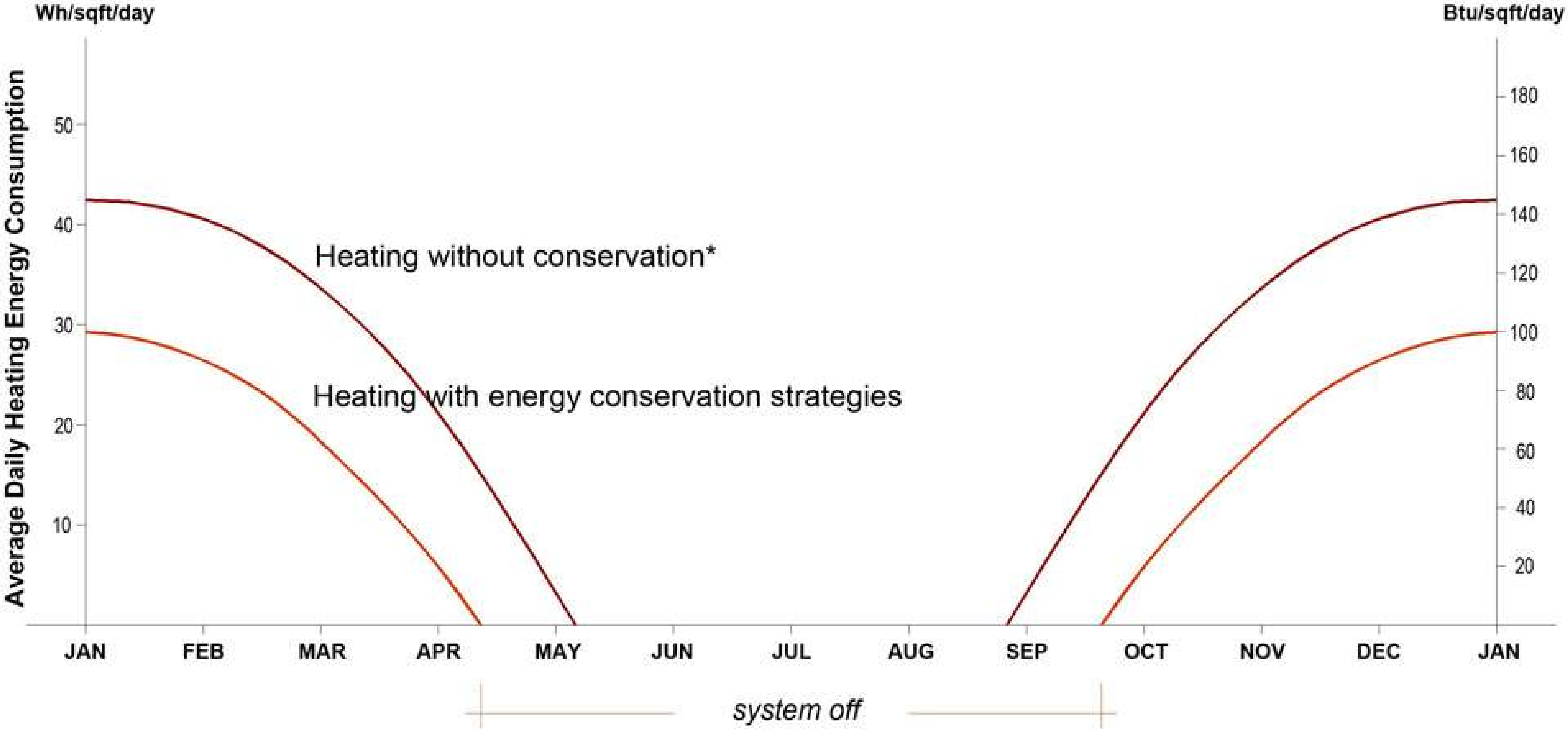

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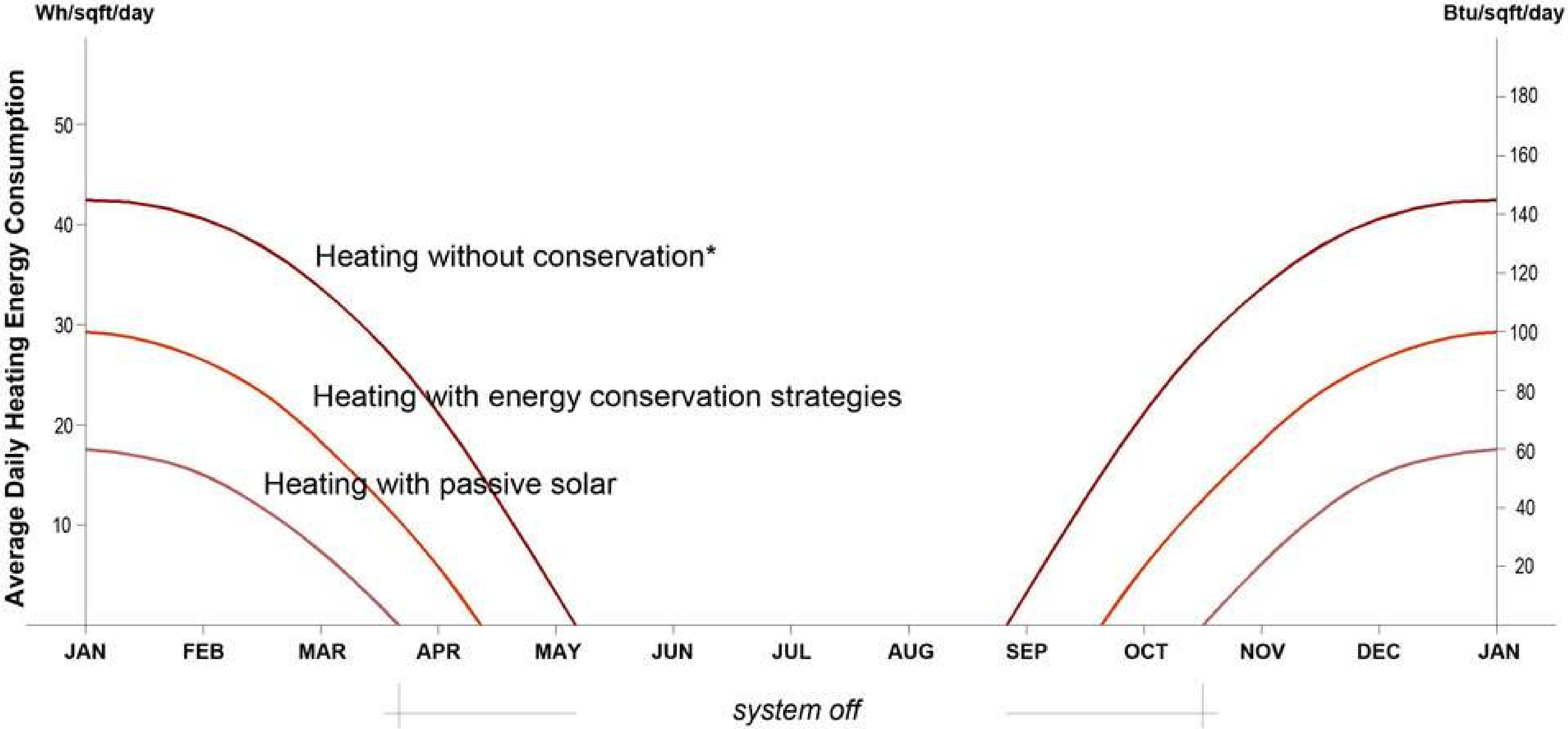

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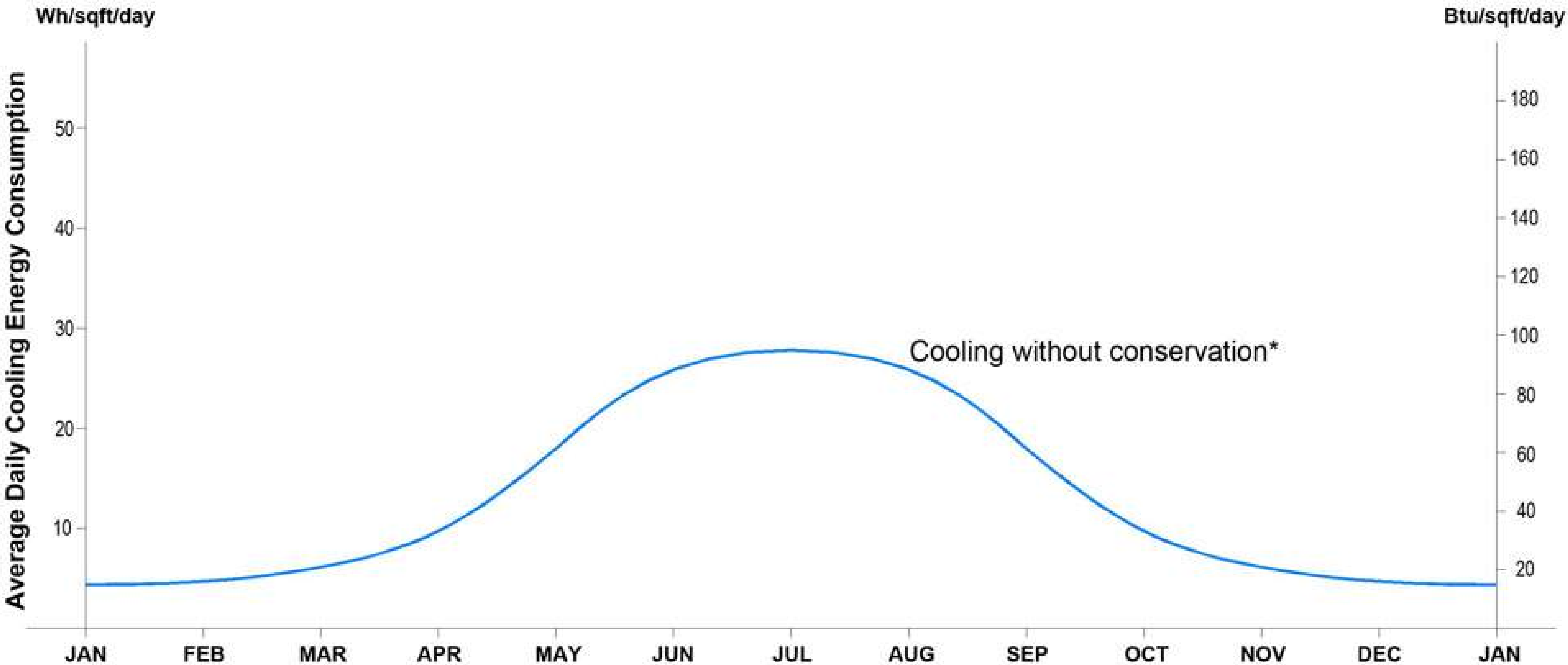
Loftness, V. & Hua, Y., Center for Building Performance & Diagnostics, Carnegie Mellon University



* Total annual cooling energy consumption refers to EIA-CBECS 1995 &1999

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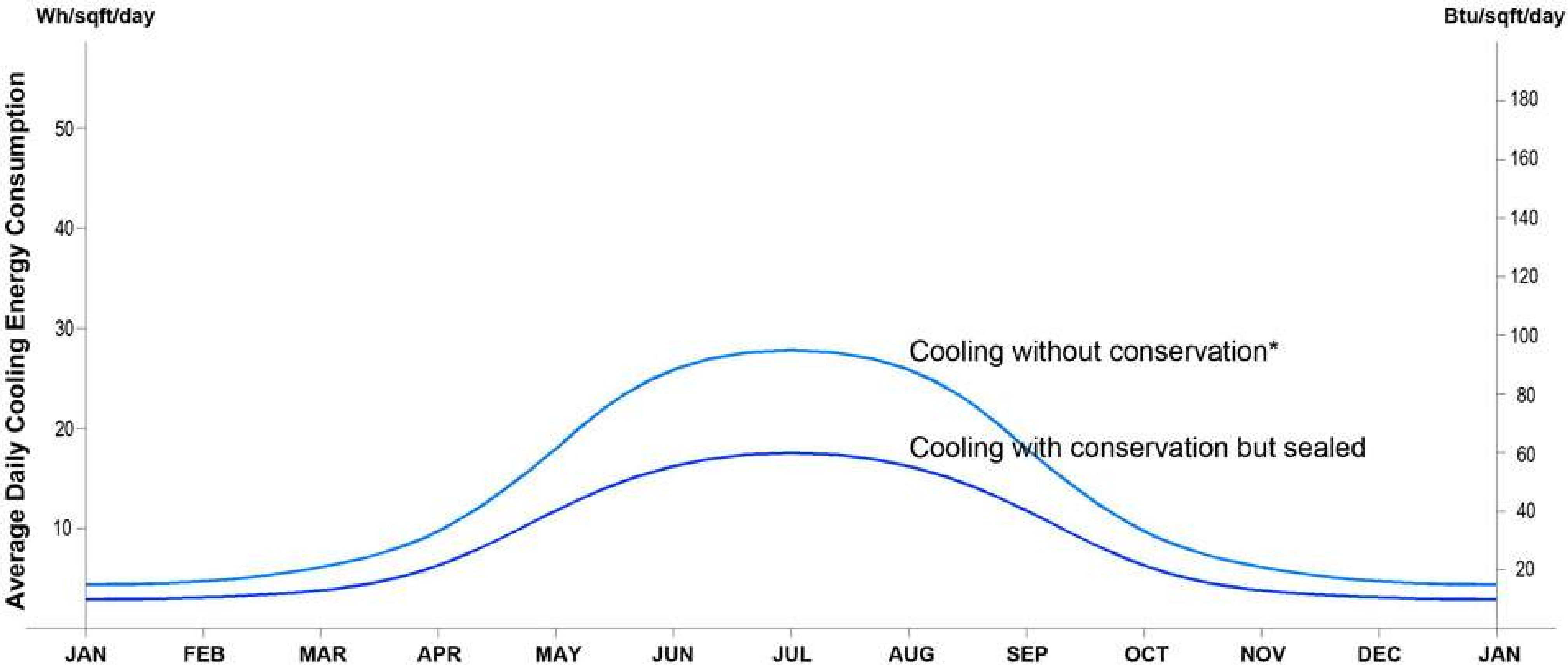

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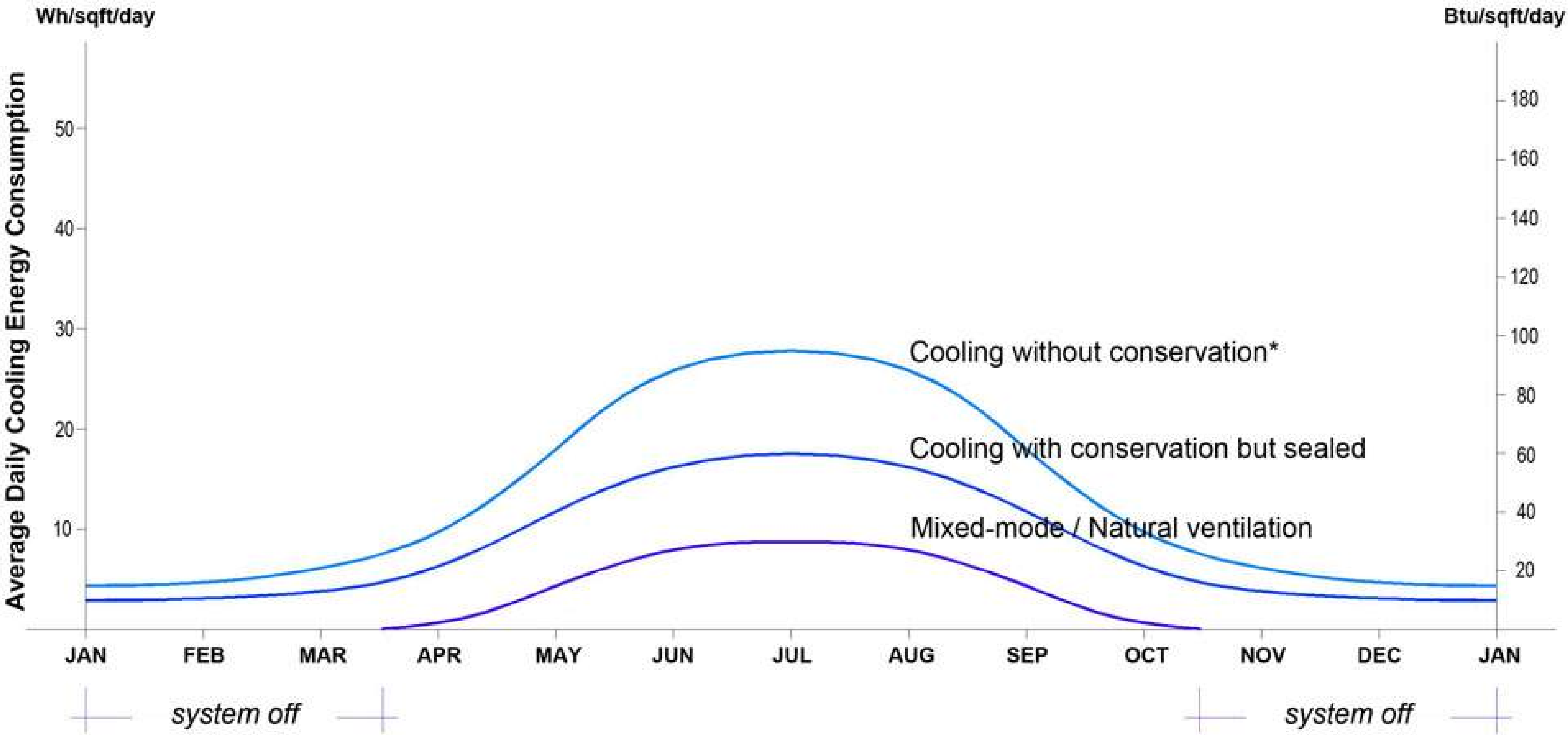

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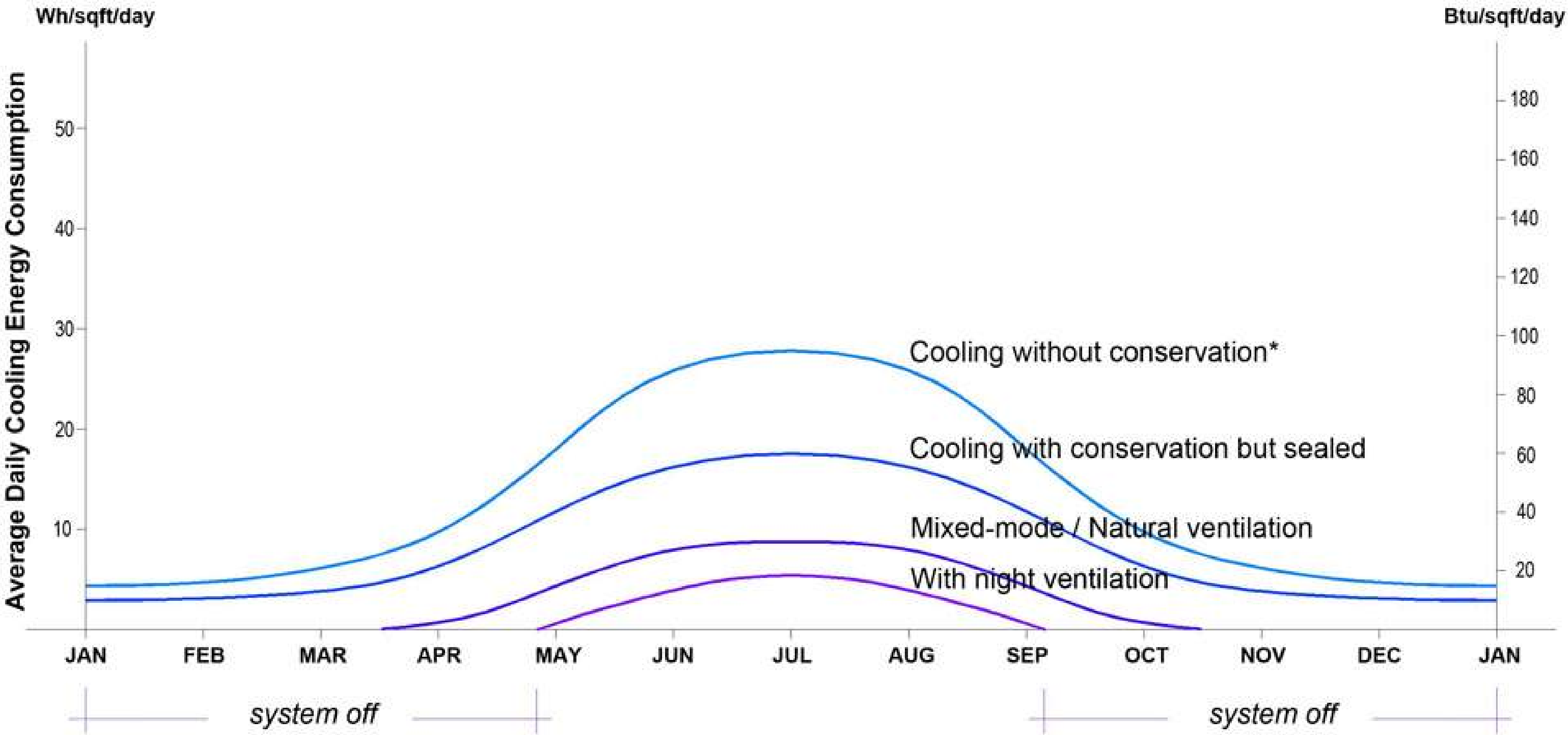

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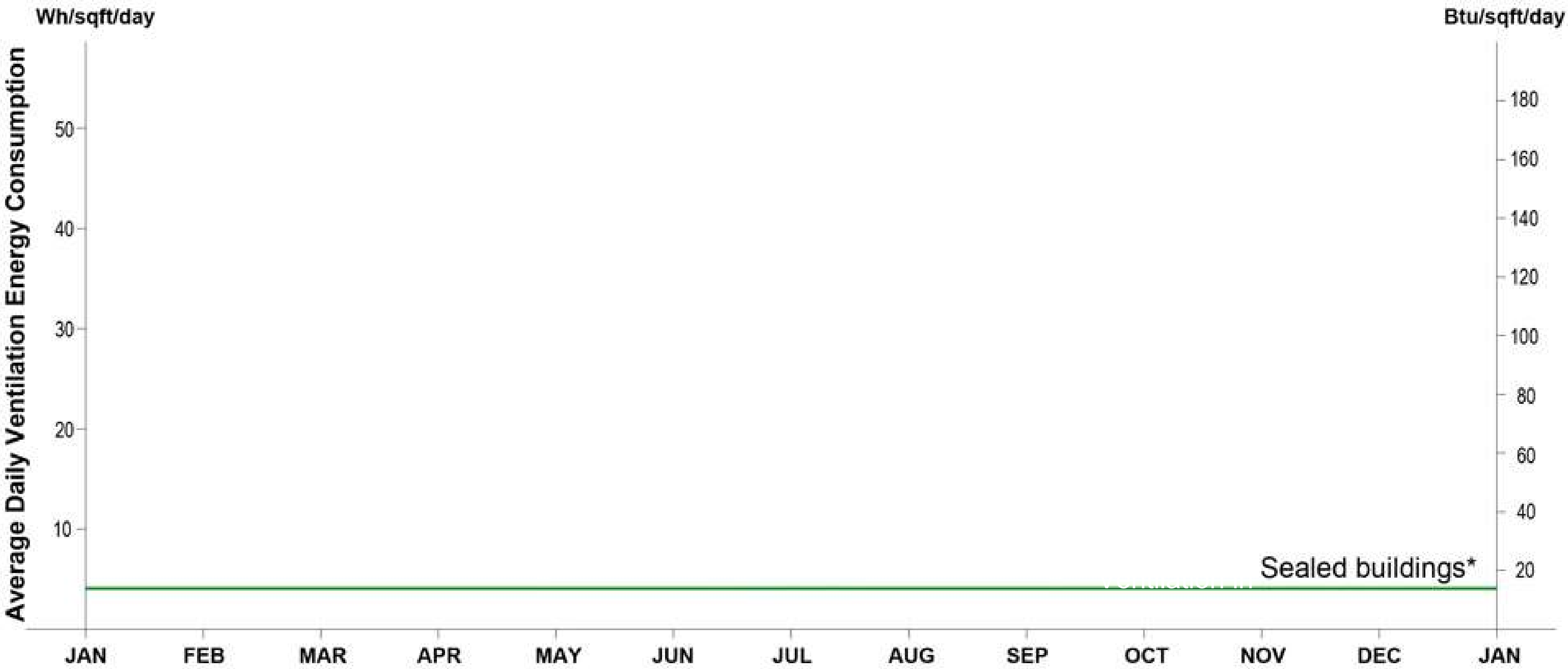

* Total annual ventilation energy consumption refers to EIA-CBECS 1995 &1999

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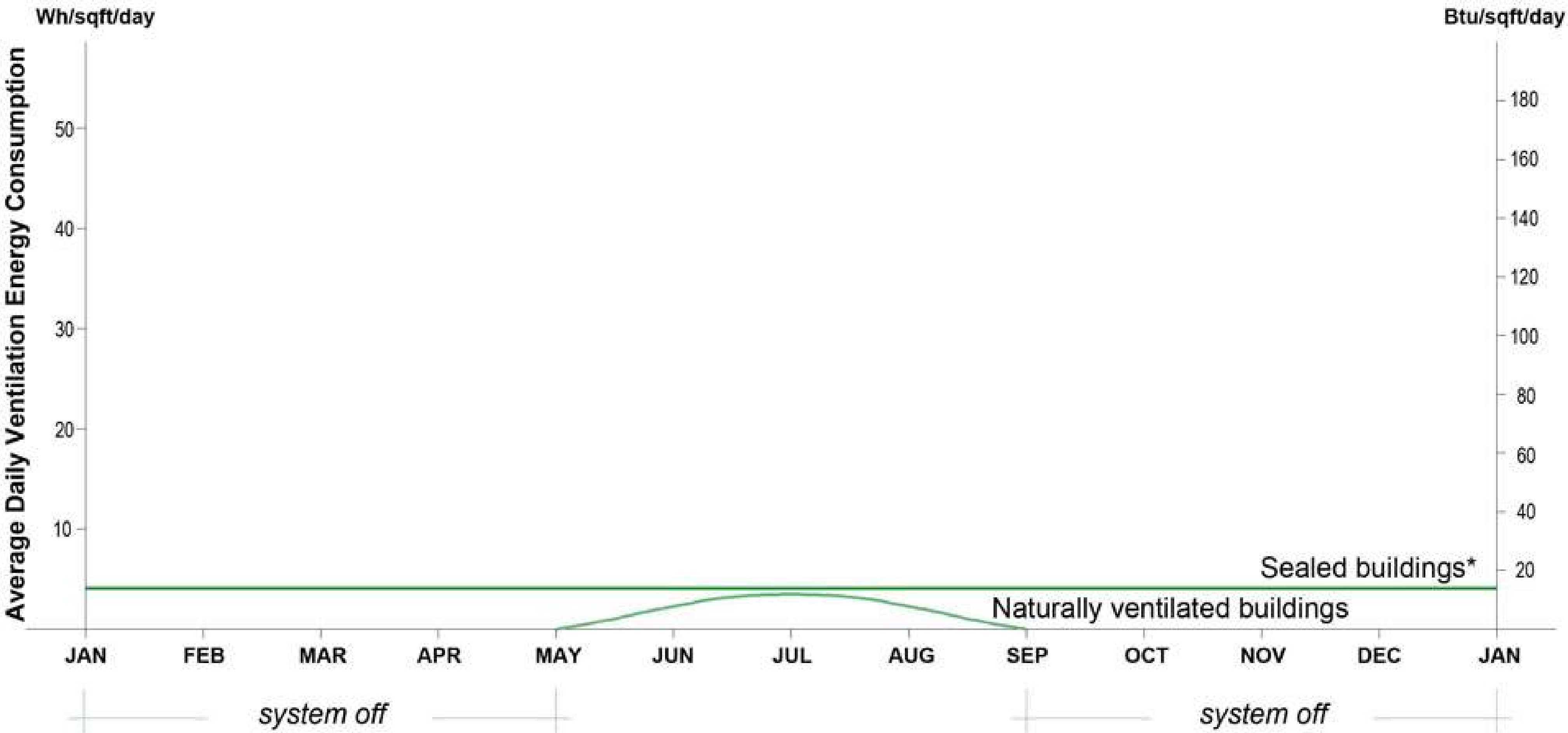

* Total annual ventilation energy consumption refers to EIA-CBECS 1995 &1999

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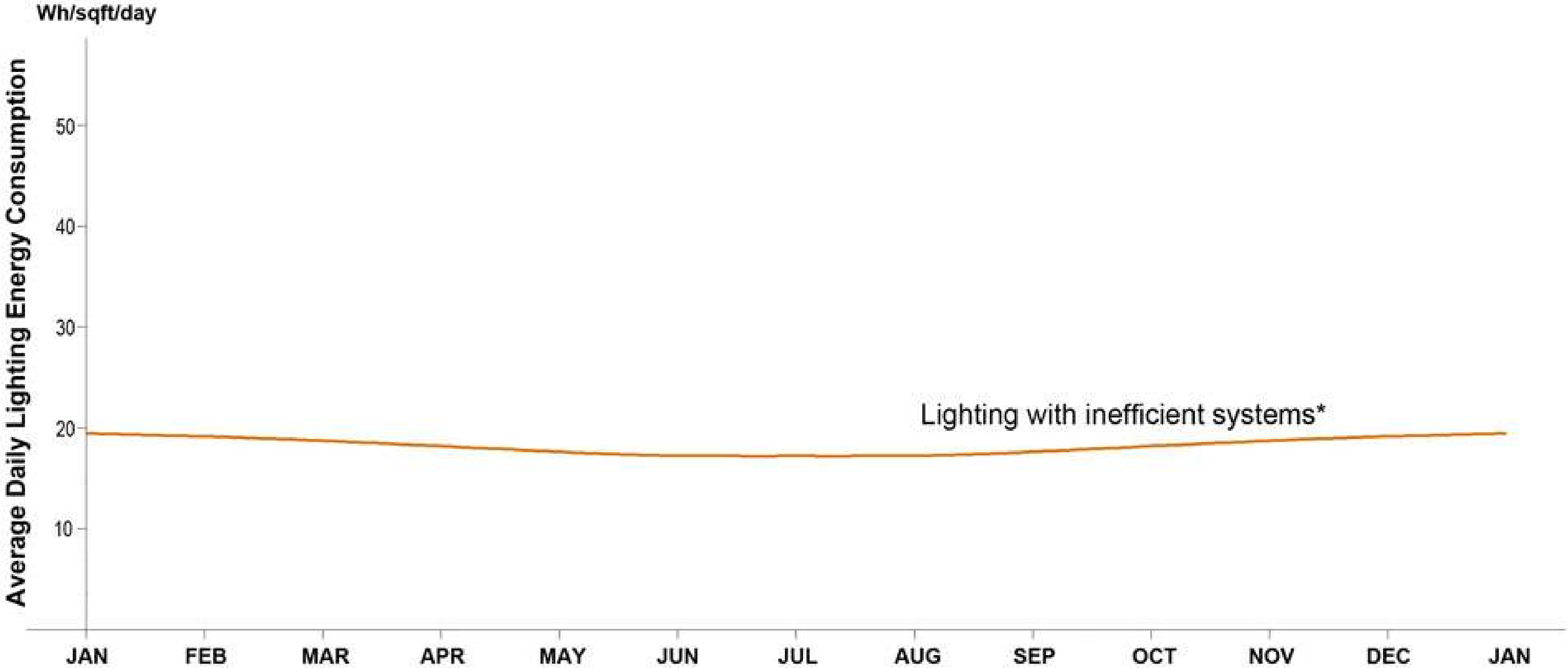

* Total annual lighting energy consumption refers to EIA-CBECS 1995 &1999

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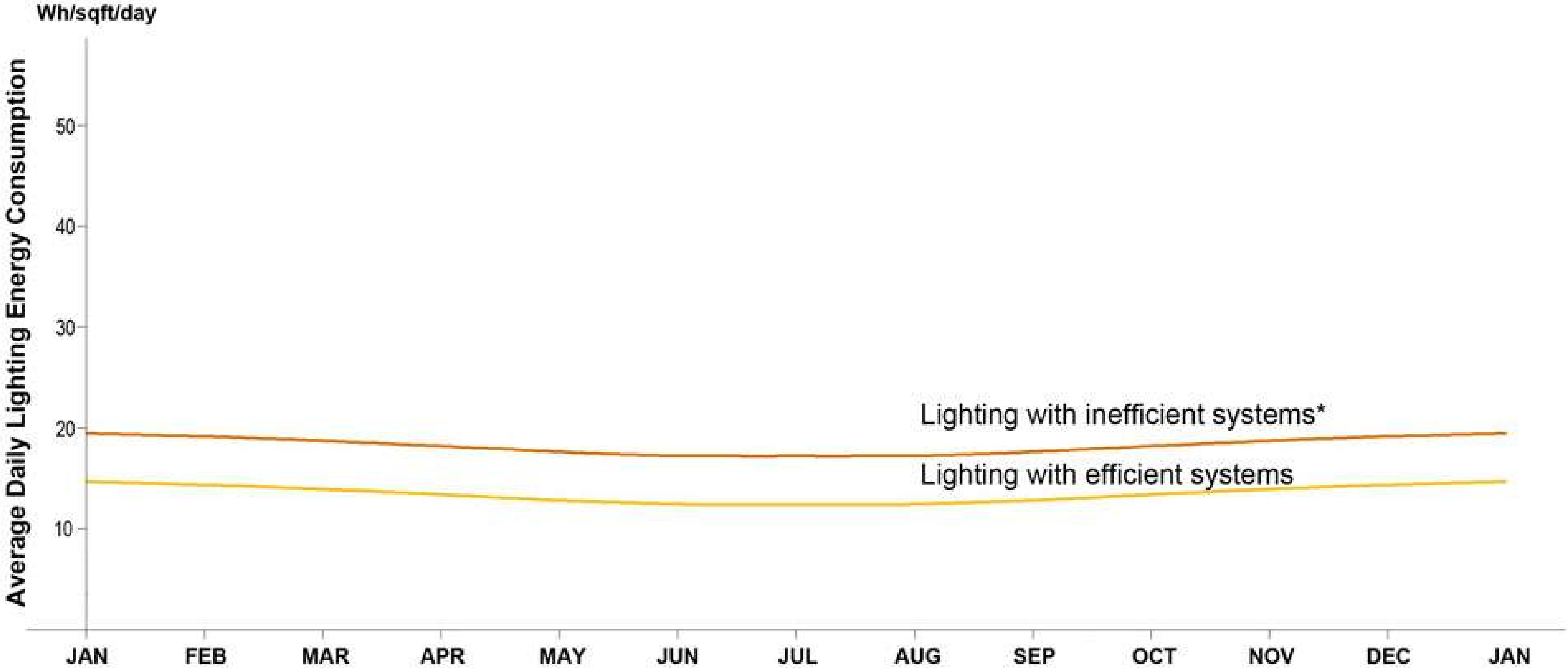

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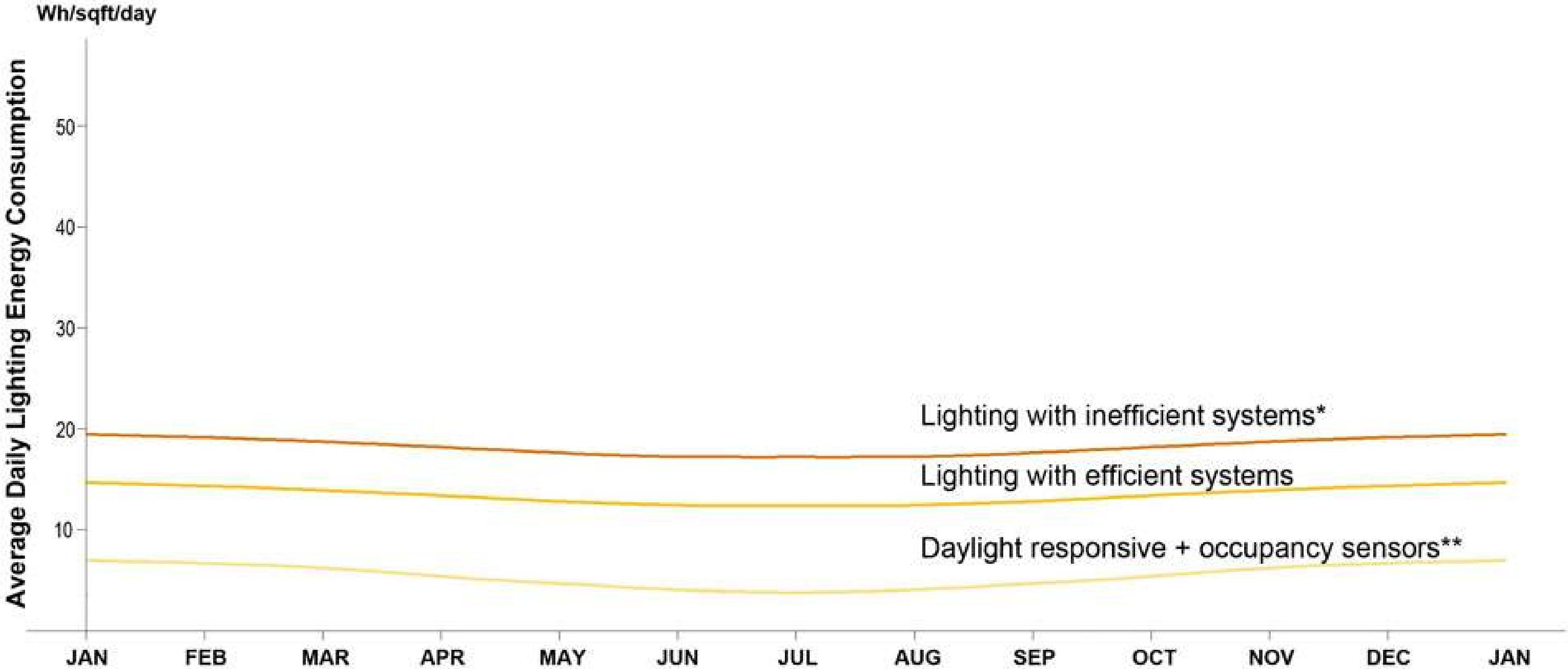
Loftness, V. & Hua, Y., Center for Building Performance & Diagnostics, Carnegie Mellon University



* Total annual lighting energy consumption refers to EIA-CBECS 1995 &1999

** Monthly lighting energy profile refers to McDougall, T., Nordmeyer, K. & Klaassen, C. J. (2006). Low-Energy building case study: IAMU office and training headquarters. ASHRAE Transactions, Vol.12, pp312-320

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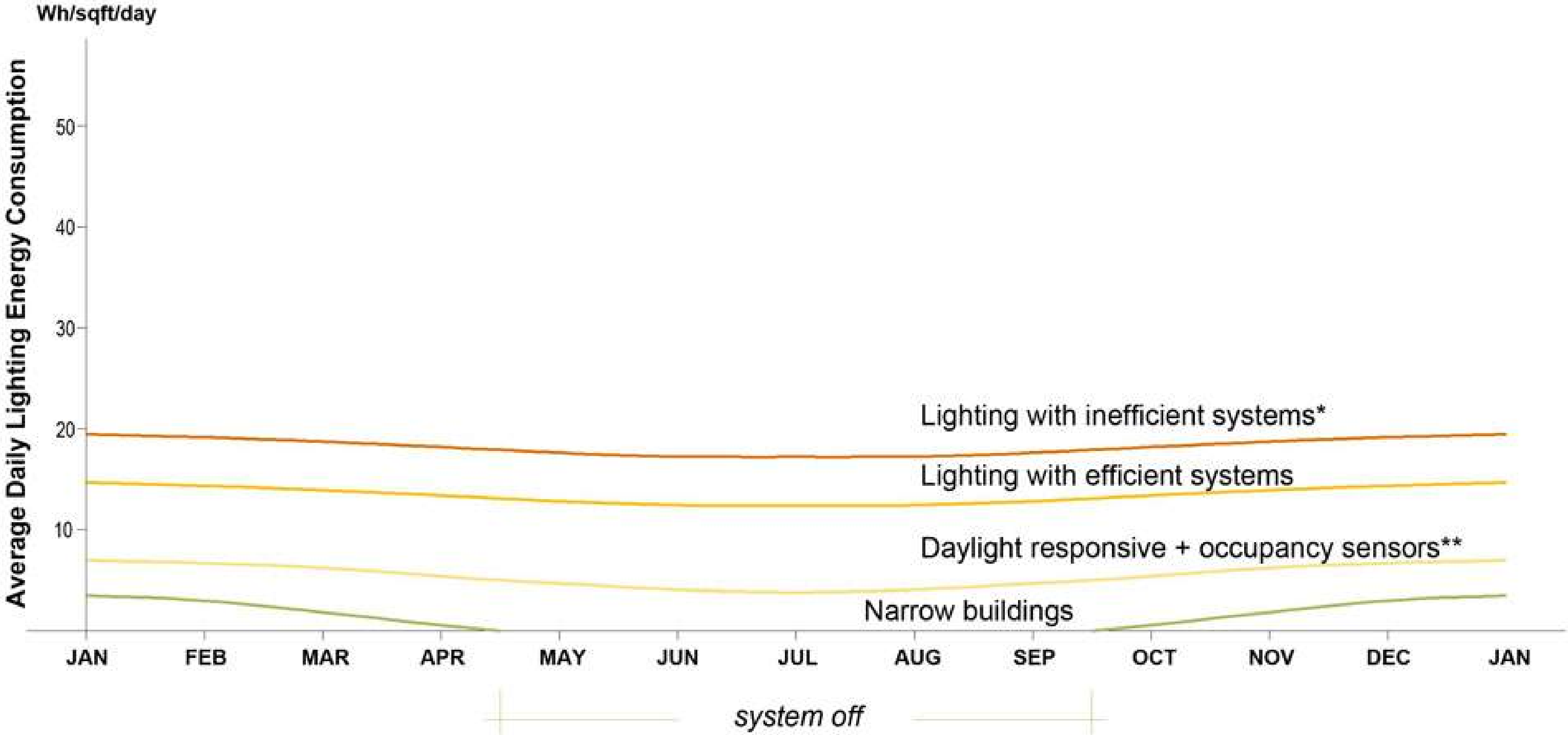

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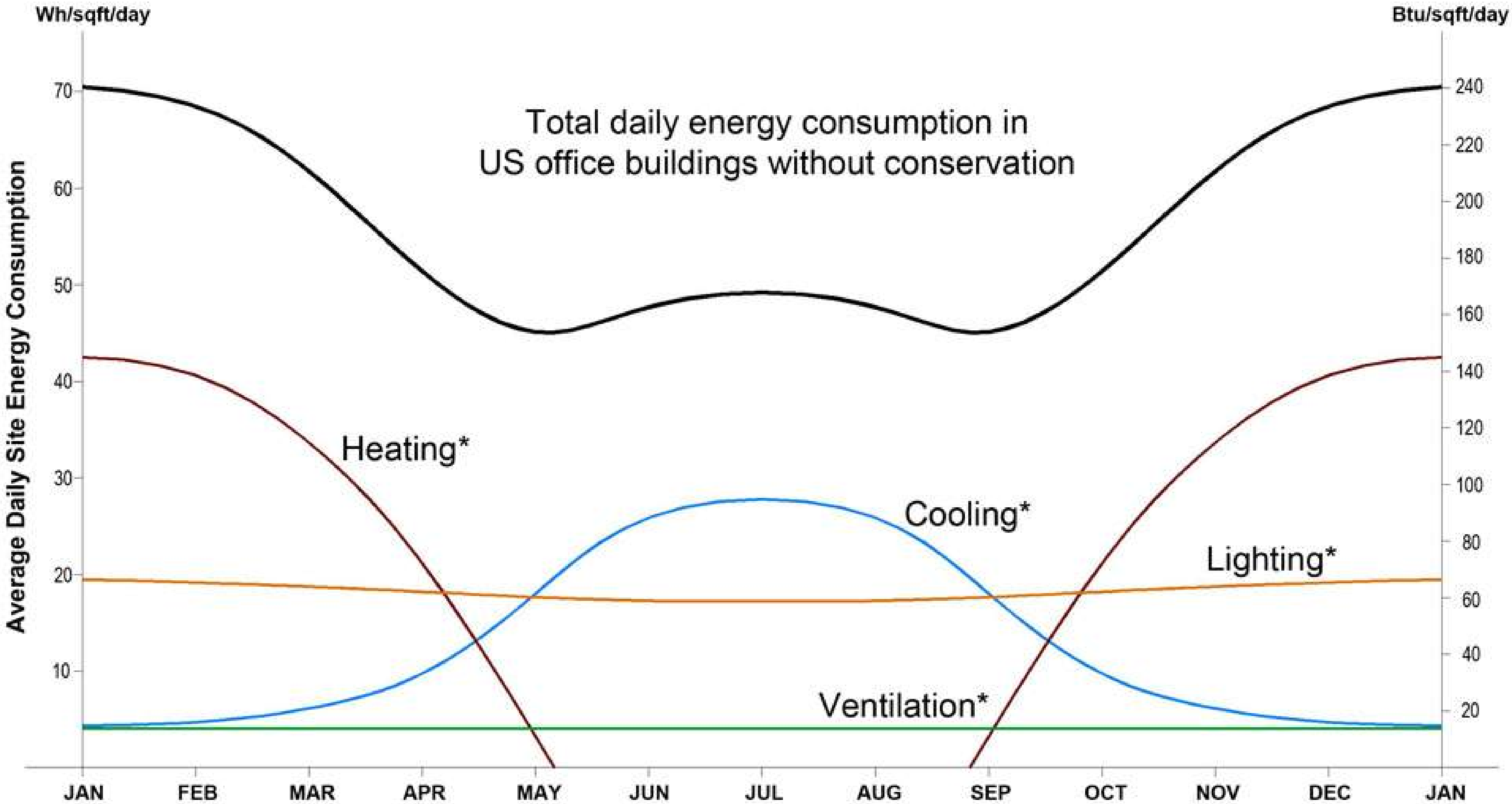
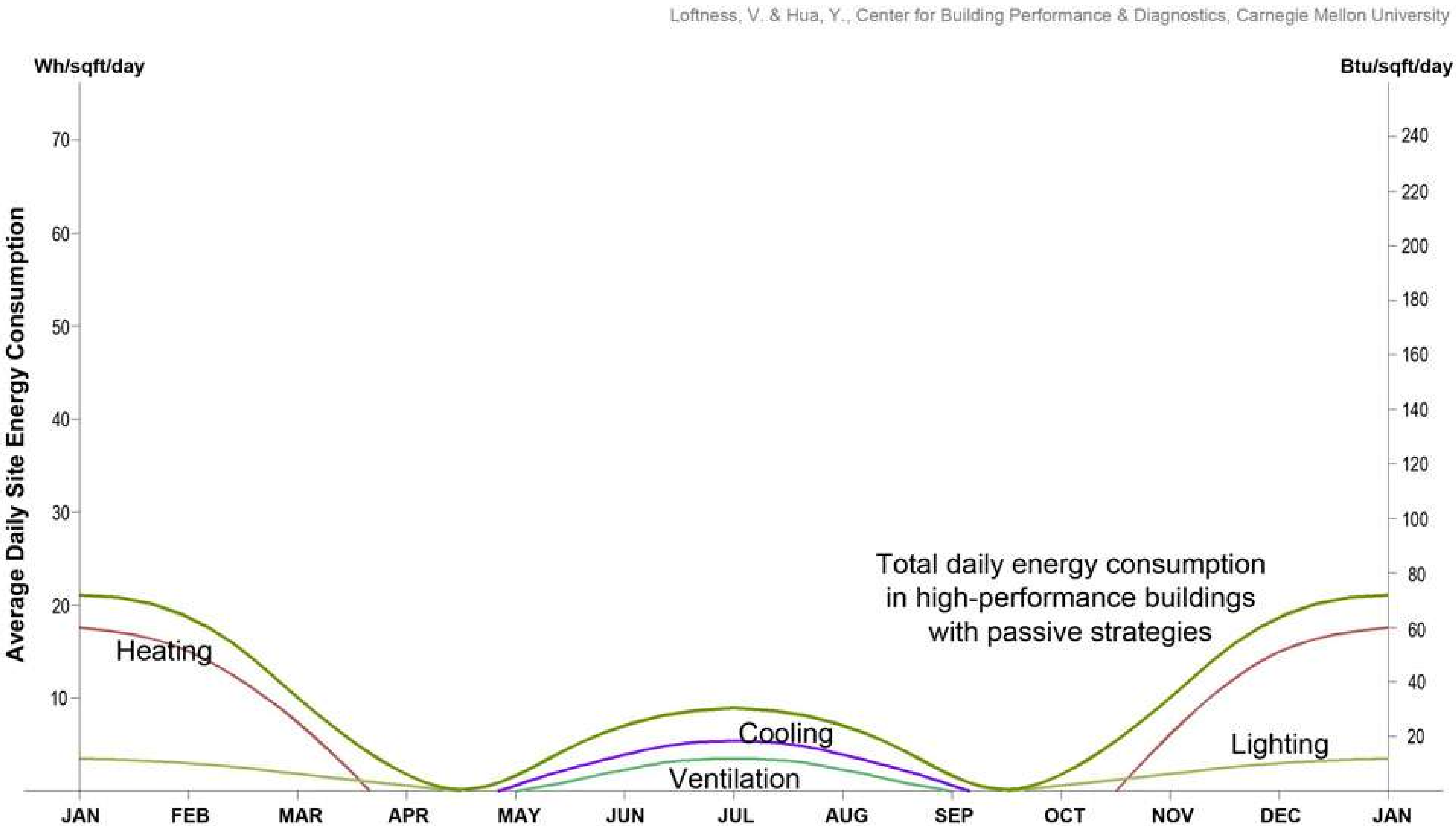
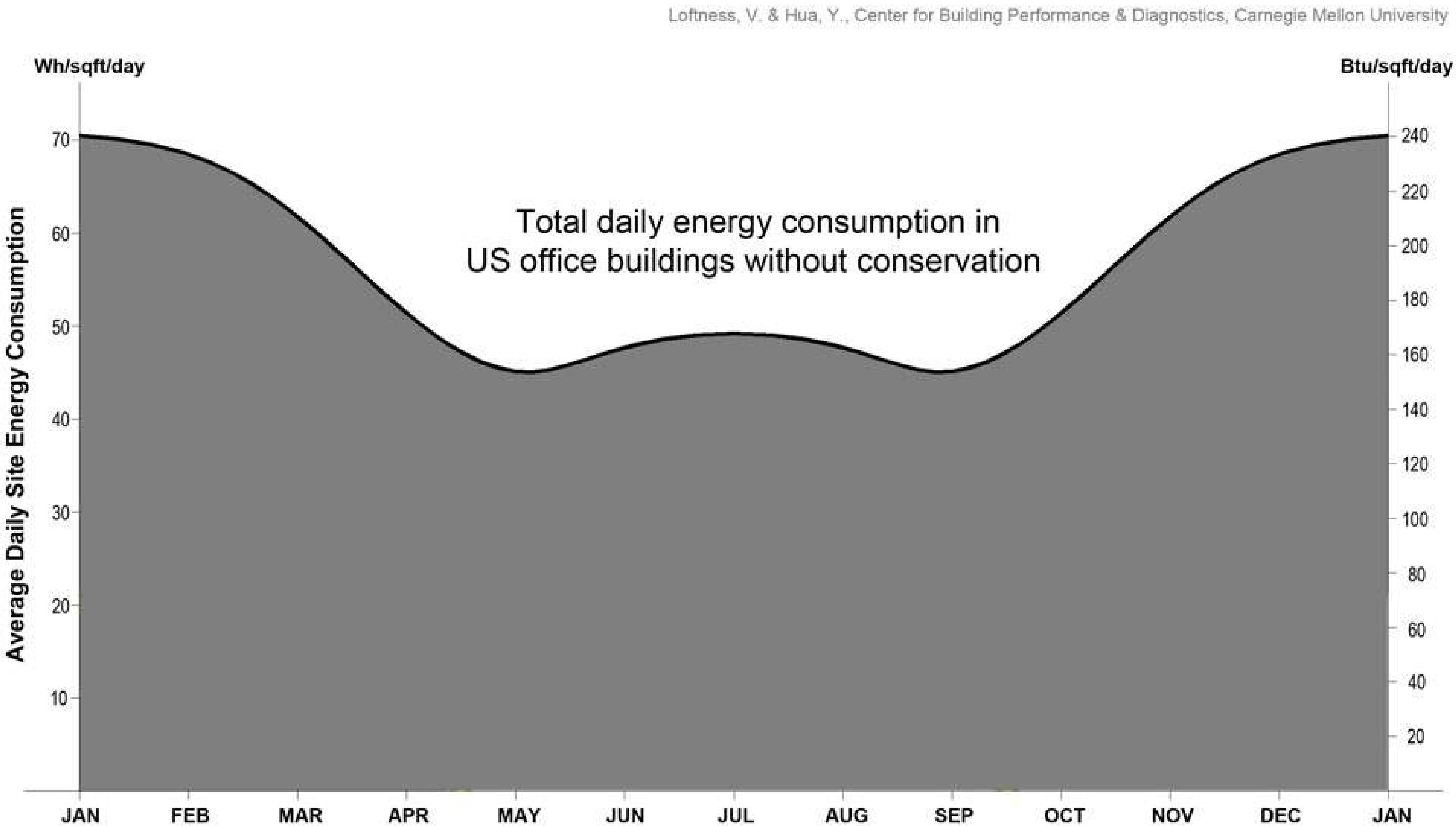


* Total annual heating, cooling, ventilation and lighting energy consumption refers to EIA-CBECS 1995 &1999


Loftness, V. & Hua, Y., Center for Building Performance & Diagnostics, Carnegie Mellon University
Wh/sqft/day
Btu/sqft/day
Average Daily Site Energy Consumption
70
60
50
40
30
20
10
240
220
200
180
160
140
120
100
80
60
40
20
Total daily energy consumption
in high-performance buildings
with passive strategies
Heating
Cooling
Ventilation
Lighting
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
JAN


Loftness, V. & Hua, Y., Center for Building Performance & Diagnostics, Carnegie Mellon University
Wh/sqft/day
Btu/sqft/day
Total daily energy consumption in
US office buildings without conservation
Average Daily Site Energy Consumption
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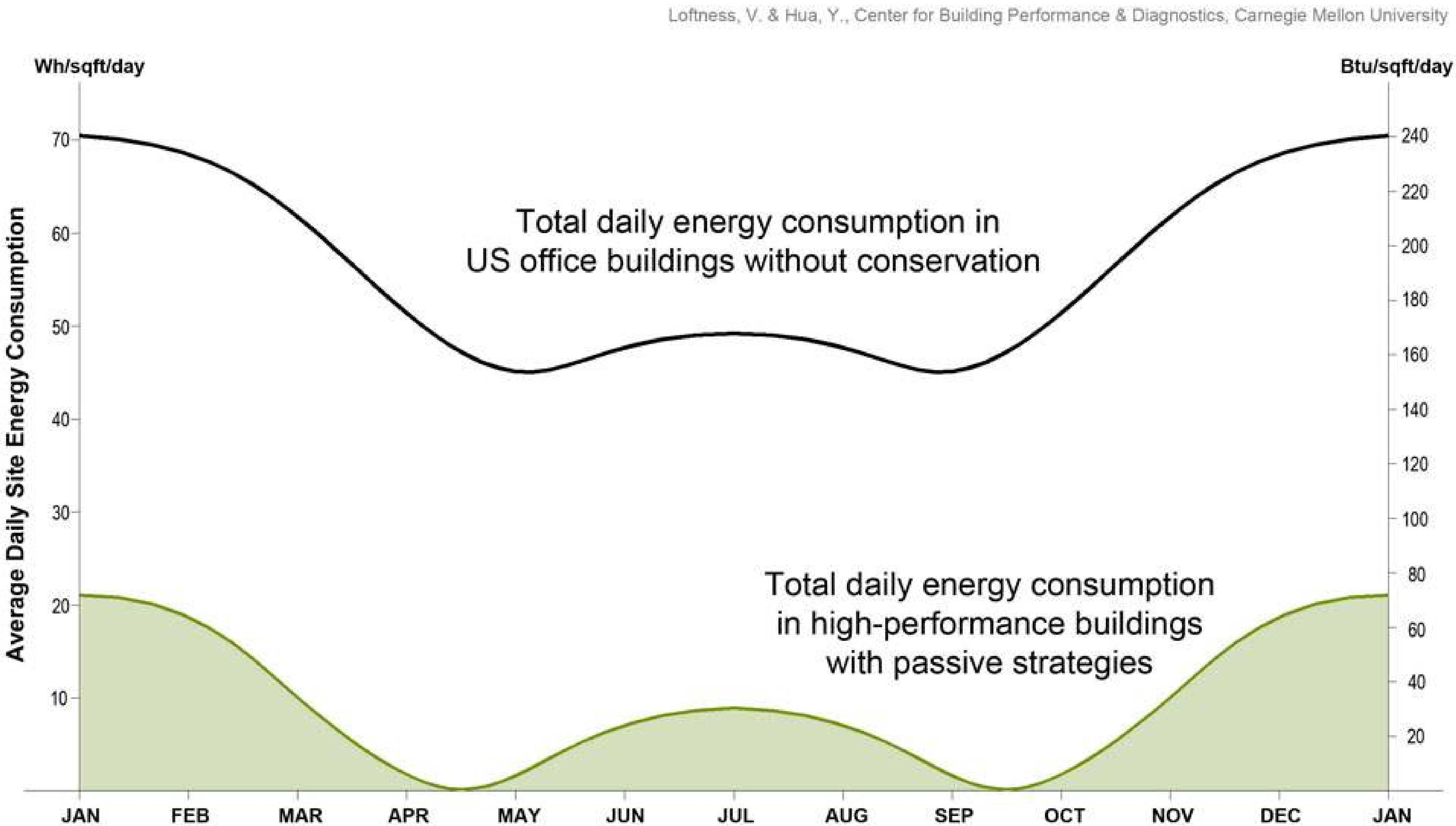
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with passive strategies
JAN
FEB
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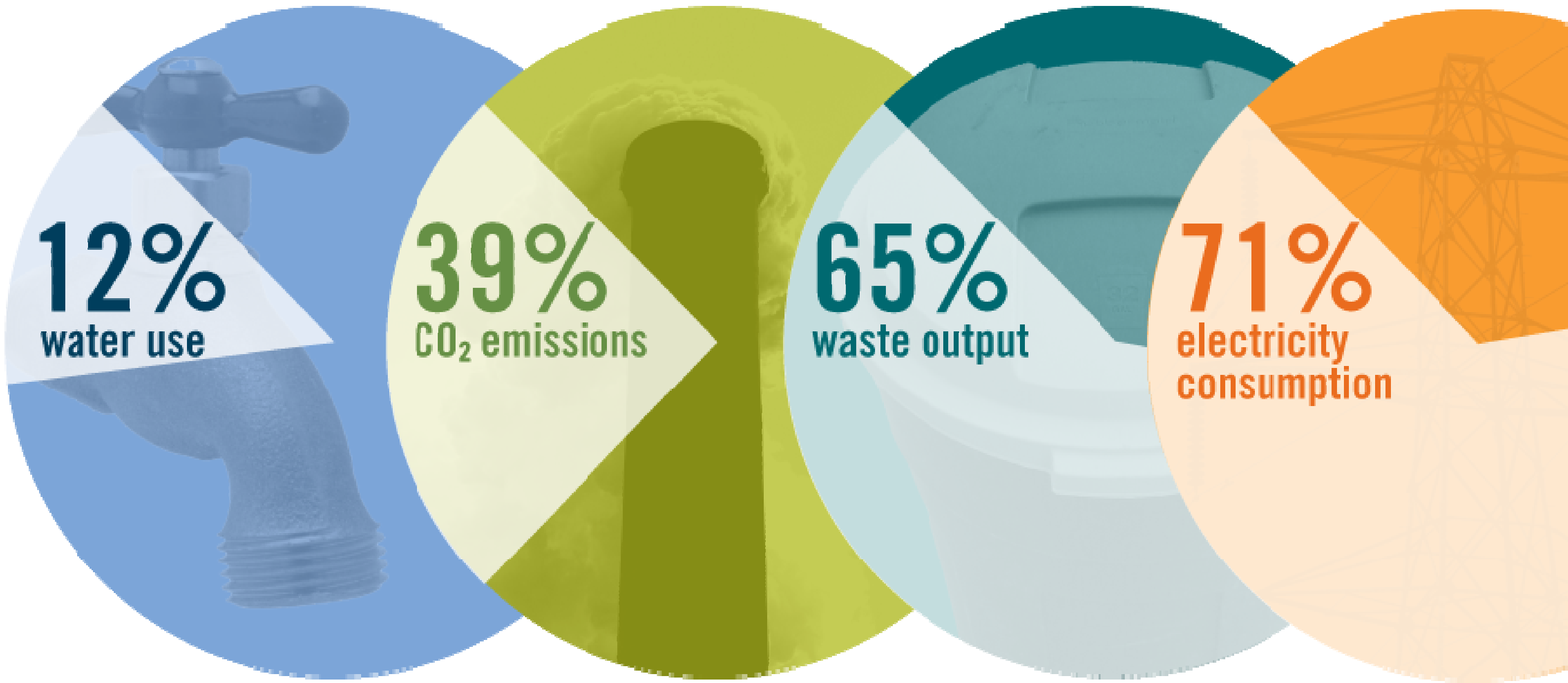
The scale of the challenge and the opportunity, with US buildings responsible for:



LEED

LEED-EB Certification Points ← **Potential Green Cleaning Points**

Plan for Green Site & Building Exterior Management
2 points

Innovation in Upgrades, Operation, and Maintenance
Per Case Basis

Sustainable Sites Maximum 14 Points	**Water Efficiency** Maximum 5 Points	**Innovation** Maximum 5 Points
Materials & Resources Maximum 16 Points	**Energy & Atmosphere** Maximum 23 Points	**Indoor Environmental Quality** Maximum 22 Points

85 Possible Points

Certified	32 to 39 points
Silver	40 to 47 points
Gold	48 to 63 points
Platinum	64 to 85 ponits

- Sustainable Cleaning Products & Materials 3 points
- Occupant Recycling 3 points

- Entryway Systems 1 point
- Isolation of Janitorial Closets 1 point
- Low Environmental Impact Cleaning Policy 1 point
- Low Environmental Impact Cleaning Equipment Policy 1 point

WORLD GREEN BUILDING COUNCIL

LEED
GreenStar
BREEAM
CASBEE

Australia

Canada

India
Japan

New Zealand
South Africa

United Arab Emirates
United Kingdom
United States

What building attributes matter the most?

Air

Light

Thermal Control

Privacy and Interaction

Ergonomics

Material Quality

Access to Nature

Land use and mobility

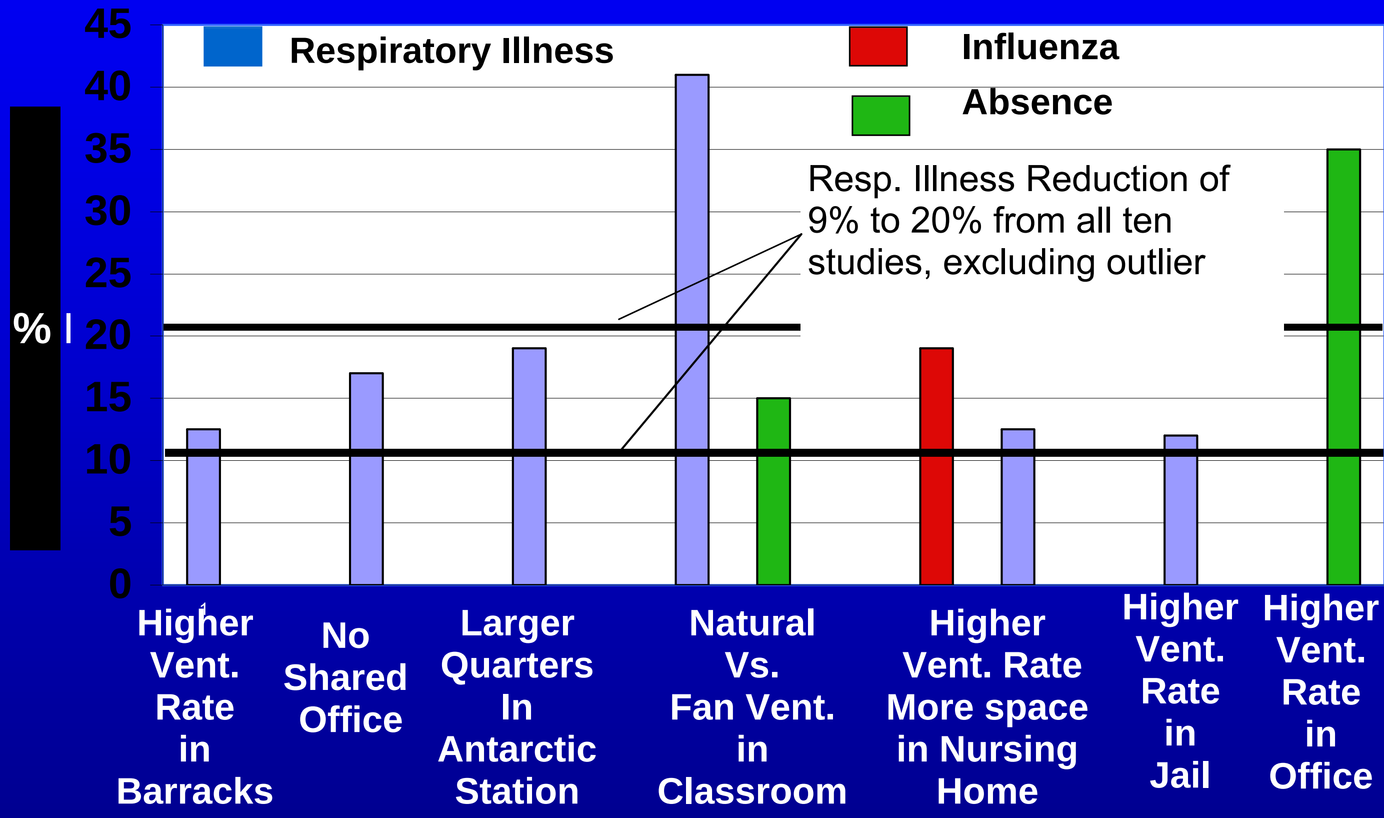
Wine Creek Residence, Siegel & Strain, CA

Healthy, Sustainable Air

Maximize natural ventilation with mixed-mode HVAC
Separate ventilation air from thermal conditioning
Provide task air for individual control
Pollution source control
Improve the quality and quantity of outside air

The Health Potential of Buildings and Communities

Sick Building Costs
Healthy Building Gains

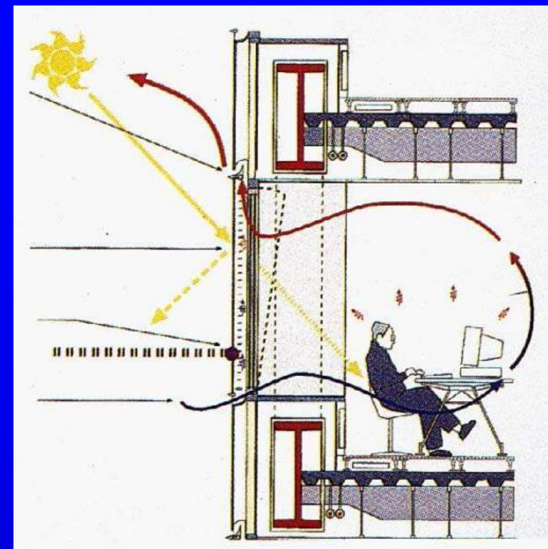


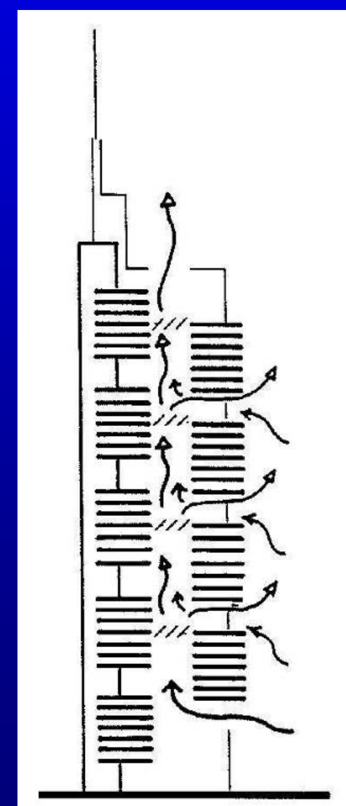
(Fisk/LBNL 2000)

Increased outdoor ventilation rates and natural ventilation significantly reduces respiratory illness, flus and absenteeism by 9-20%

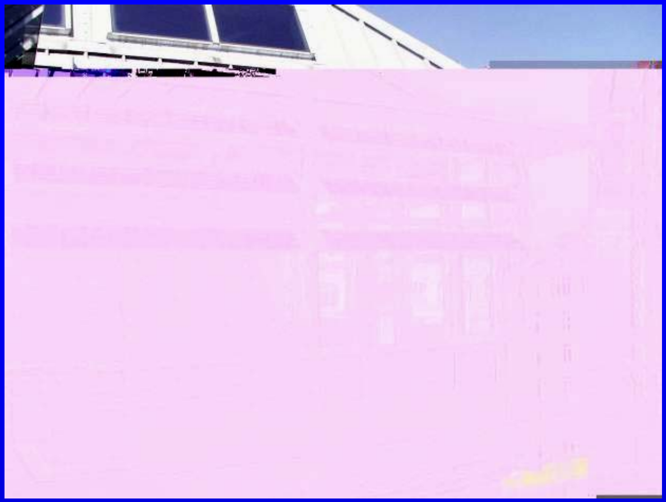
Access to operable windows reduces energy use, absenteeism, SBS symptoms, and improves productivity and test scores

Colonia Insurance

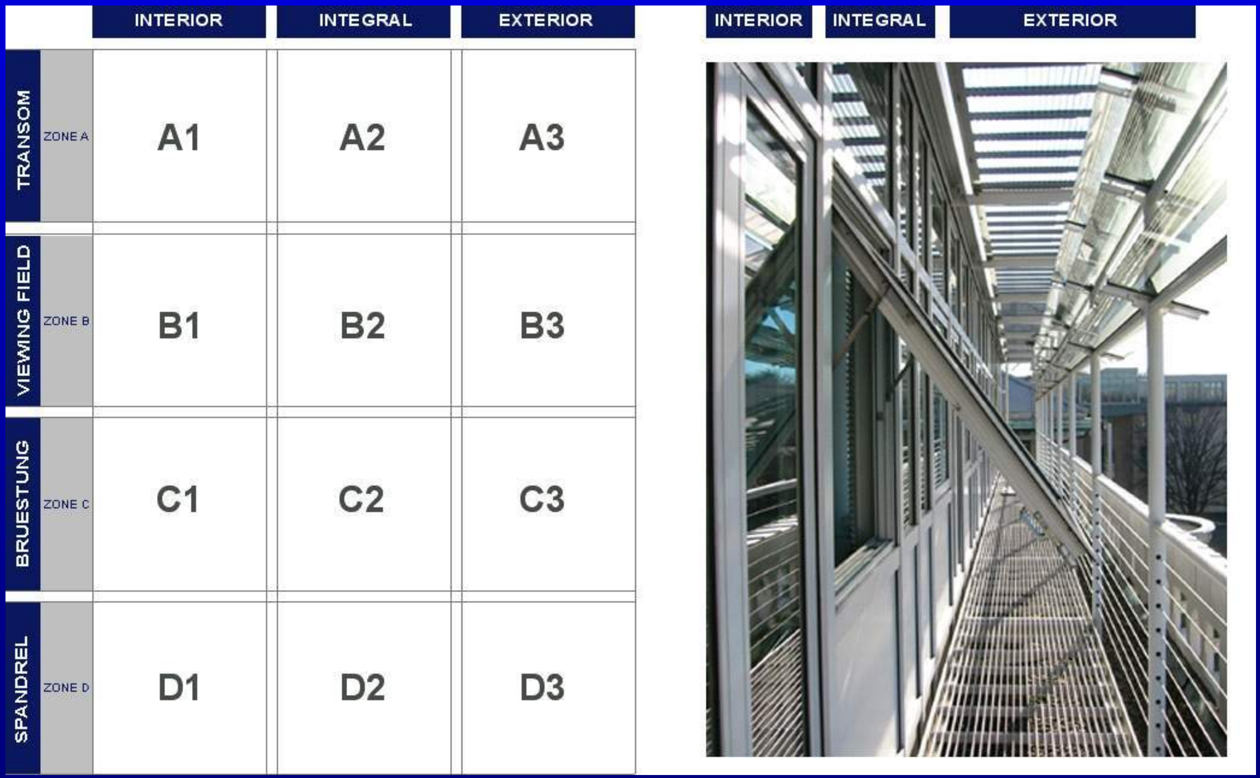




Even high rise offices can be naturally ventilated



Sustainable enclosures



Modular
prefabricated
designed for disassembly
100% recycled content
thermal excellence
daylight rich
natural ventilation
renewables

Sustainable Enclosures

Daylighting dominant

Natural ventilation dominant

Solar heat and glare control

Load balancing –
façade as circulatory system
Thermal Mass/ Flywheel effect

Solar heating, cooling, power

Material sustainability

Healthy, Sustainable Light

Maximize the use of Daylighting without glare
Select the highest quality lighting quality fixtures
Separate task and ambient light
Design Plug-and-play lighting and dynamic lighting zones

Shading alone passively reduces overheating, glare, and energy costs;

and can be combined with light redirection for effective daylighting

Sustainable, High Performance Lighting includes improvements in fixtures, ballasts, lamps, lenses; the separation of task and ambient lighting; with user responsive, innovative controls

Task light:
Split task-ambient lighting
task light with articulated arm
and relocatable on the desktop

Controls:
Individual control, continuous dimming to 0%, daylight dimming, occupancy sensors

Katzev 1992 | DeMarco and Lister 1987

Lighting Quality = Individual Productivity

In a 1992 controlled experiment, Katzev identifies a 26% improvement in reading comprehension in offices with direct/indirect luminaires, as compared to performance in offices with standard recessed troffers.

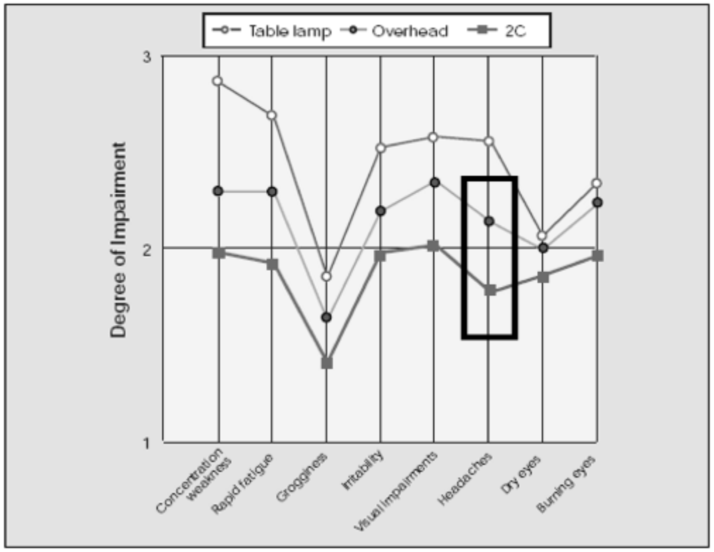
Katzev, R. (1992) The Impact of Energy-Efficient Office Lighting Strategies on Employee Satisfaction and Productivity. Environment and Behavior, 24:6, pp. 759-778.
DeMarco, T. and Lister, T. (1987) Peopleware: Productive Projects and Teams. Dorset House Publishing Co.

Lighting control = Individual productivity + Health

Cakir and Cakir 1998

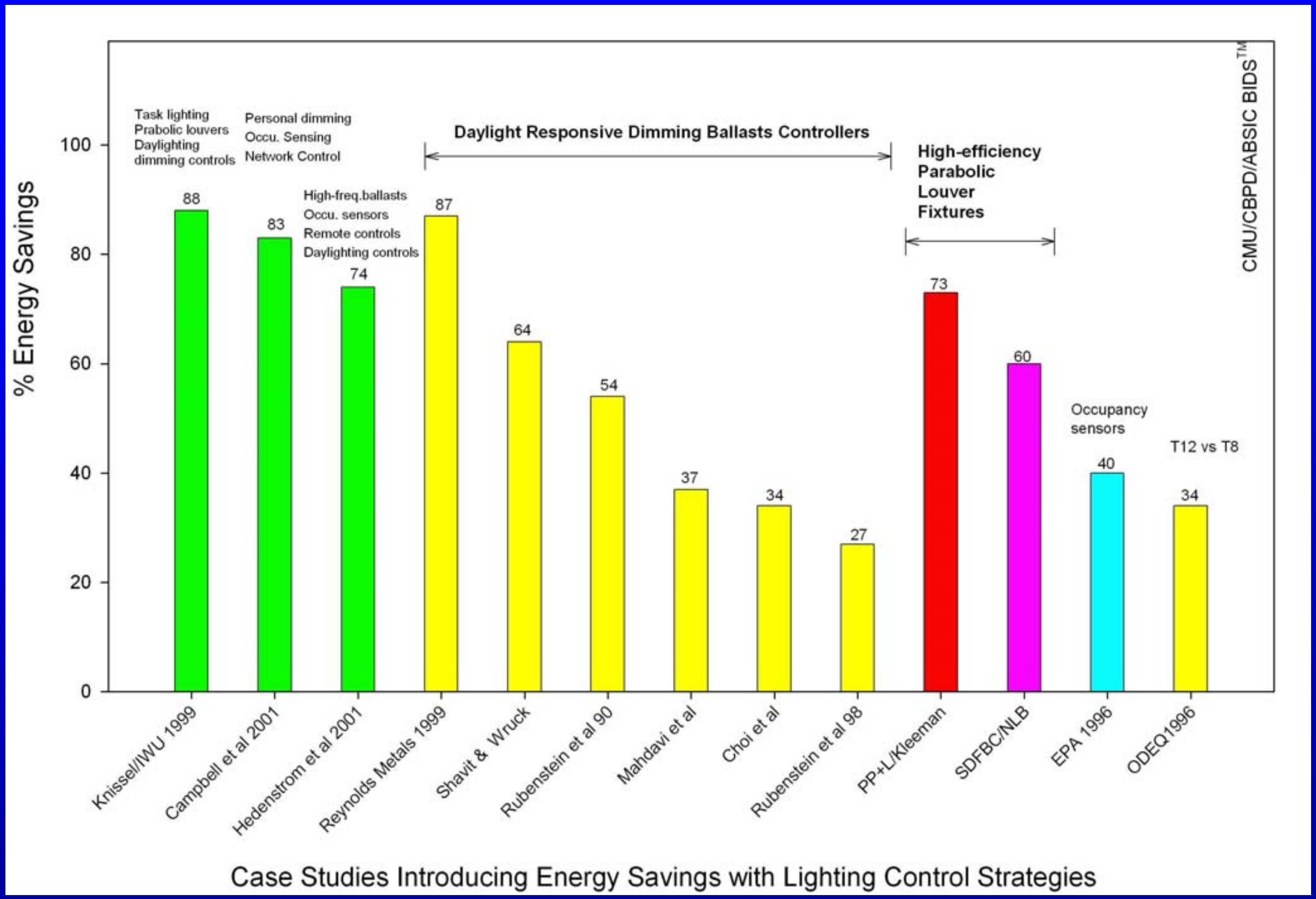
In a 1998 multiple building study in Germany, Çakir and Çakir identify a 19% reduction in headaches for workers with separate task and ambient lighting, as compared to workers with ceiling-only combined task and ambient lighting.

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



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

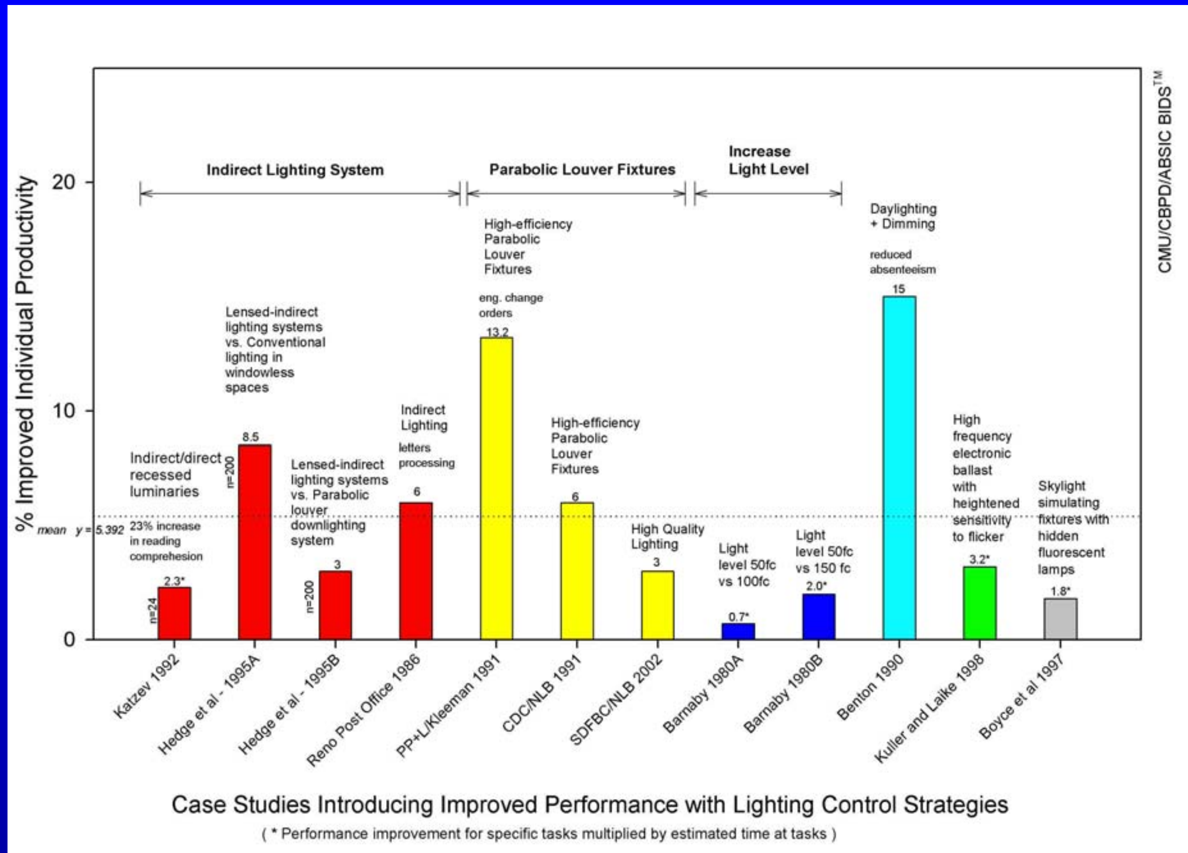
Lighting System Quality Reduces Energy Use



13 international case studies demonstrate that improved lighting design reduces annual energy loads by 27-88%.

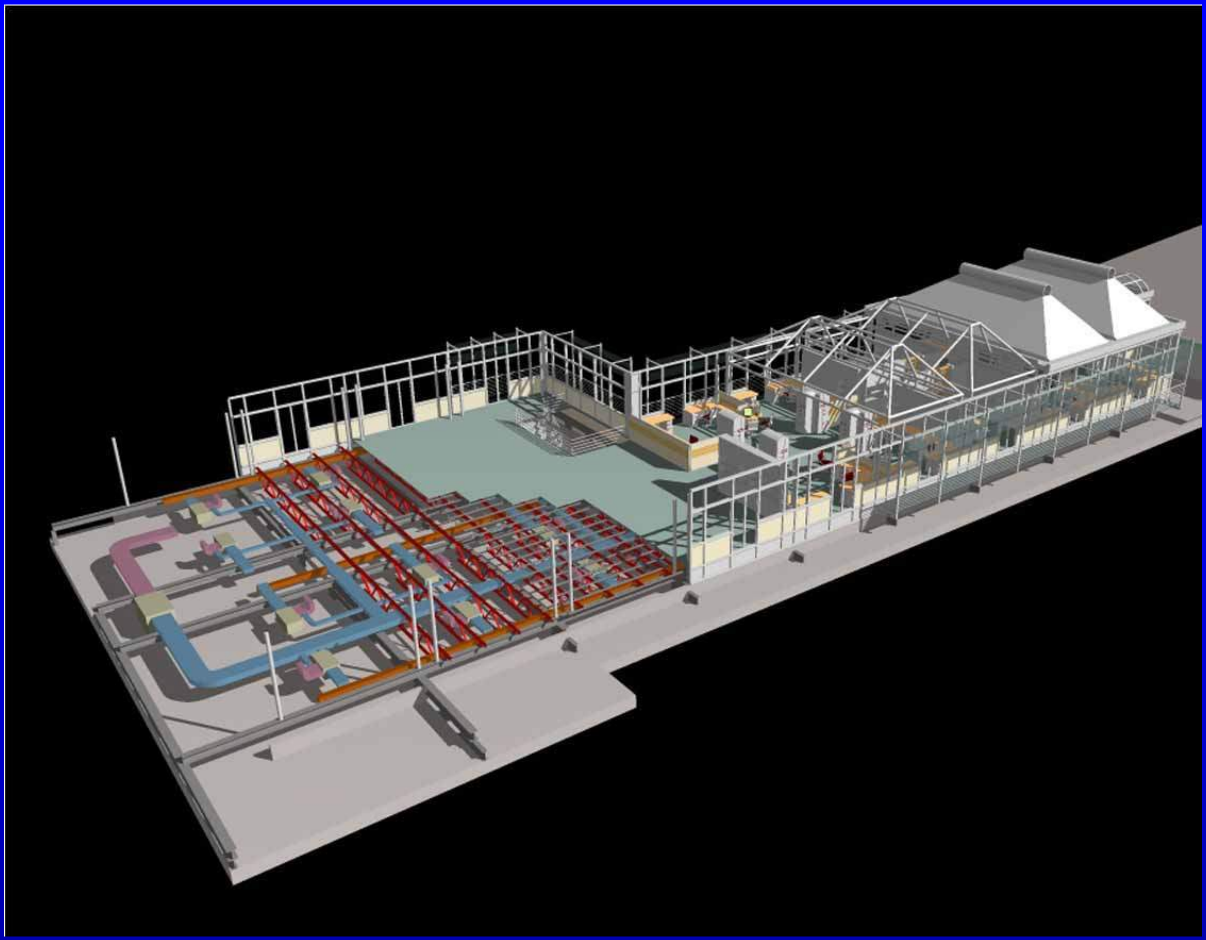
6 studies demonstrate 27-87% improved lighting design decisions
4 studies identify 40-88% energy savings through innovative control systems
3 studies illustrate 34-73% energy savings from higher quality fixtures

Lighting System Quality Increases Individual Productivity



12 international case studies demonstrate that improved lighting design increases individual productivity between 0.7-23%.

4 studies demonstrate 3-23% productivity gains with the introduction of indirect-direct lighting systems
4 studies demonstrate 3-13.2% productivity gains with the higher quality fixtures
4 studies demonstrate 0.7-2% productivity gains with higher daylighting levels & daylight simulating fixtures



Healthy, Sustainable Thermal Control

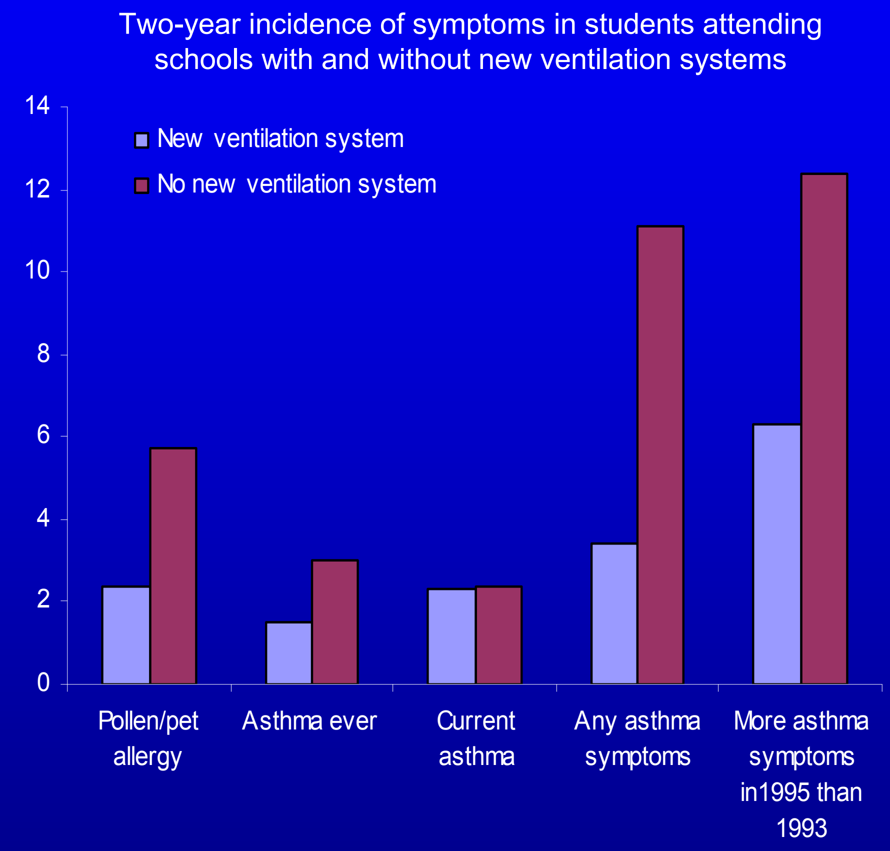
Separate ventilation air from thermal conditioning
Install integrated, prototyped, robust HVAC systems
Provide individual thermal controls
Design for dynamic thermal zone sizes
Design for building load balancing and radiant comfort

Floor-based ventilation + Increased outside air = Health

Smedje & Norback 2000 (School)

In a 2000 multiple building study of 39 schools in Sweden, Smedje and Norback identify a 69% reduction in the 2-year incidence of asthma among students in schools that received a new displacement ventilation system with increased fresh air supply rates, as compared to students in schools that did not receive a new ventilation system.

First cost increase:	$38 / student
Annual energy cost increase:	$2 / student
Annual health savings:	$36 / student
ROI:	**89%**



Reference: Smedje, G and Norback, D. (2000) New ventilation systems at select schools in Sweden—Effects on Asthma and Exposure. Archives of Environmental Health, 35(1), pp. 18-25.

Radiant Ceiling Panel System = Productivity + Energy Savings

Imanari et al 1999 (Office)

In a 1999 controlled field experiment and simulation study, Takehito et al identify a 23.8% improvement in measured work efficiency among women subjects and a simulated 10% HVAC energy savings in the Tokyo climate from providing cooling with a radiant ceiling panel system, as compared to a conventional air handling unit.

Results of work efficiency test with cooled ceiling and AHU

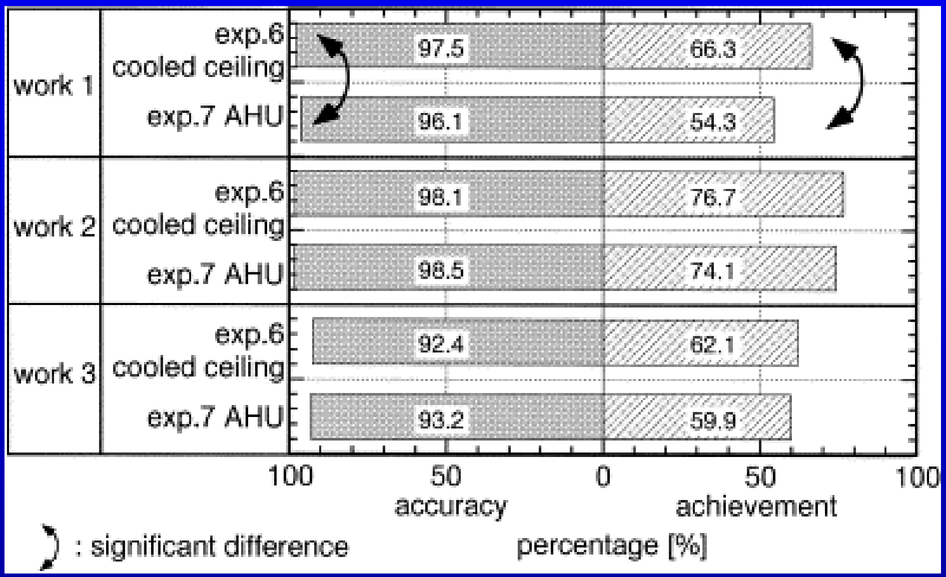
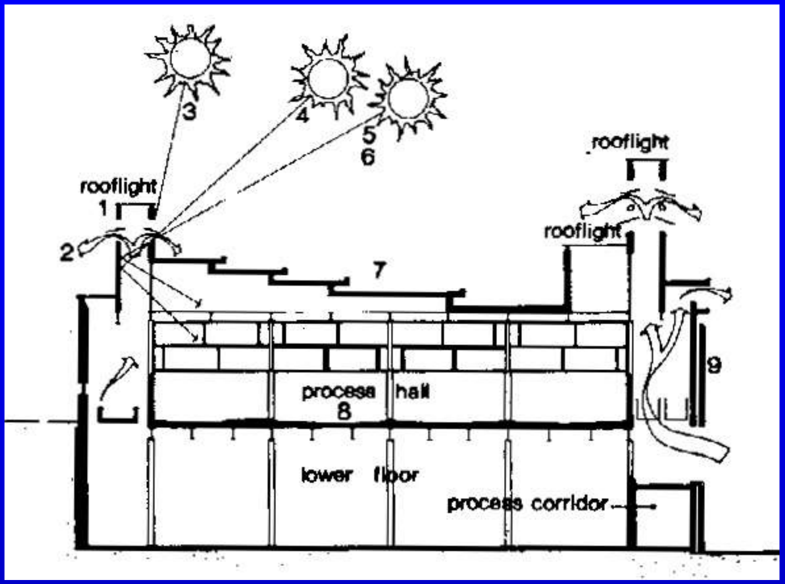


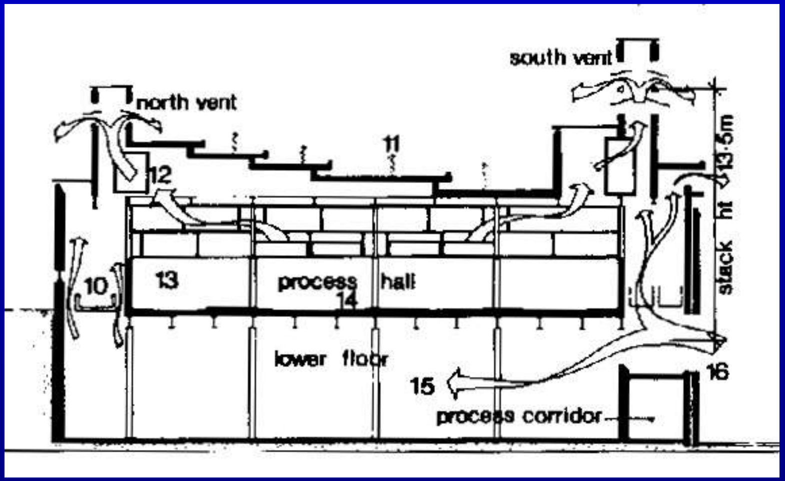
Chart: Imanari et al 1999

First cost increase:	$18 / employee
Annual health savings:	$18 / employee
Annual productivity savings:	$485 / employee
ROI:	**2,792%**

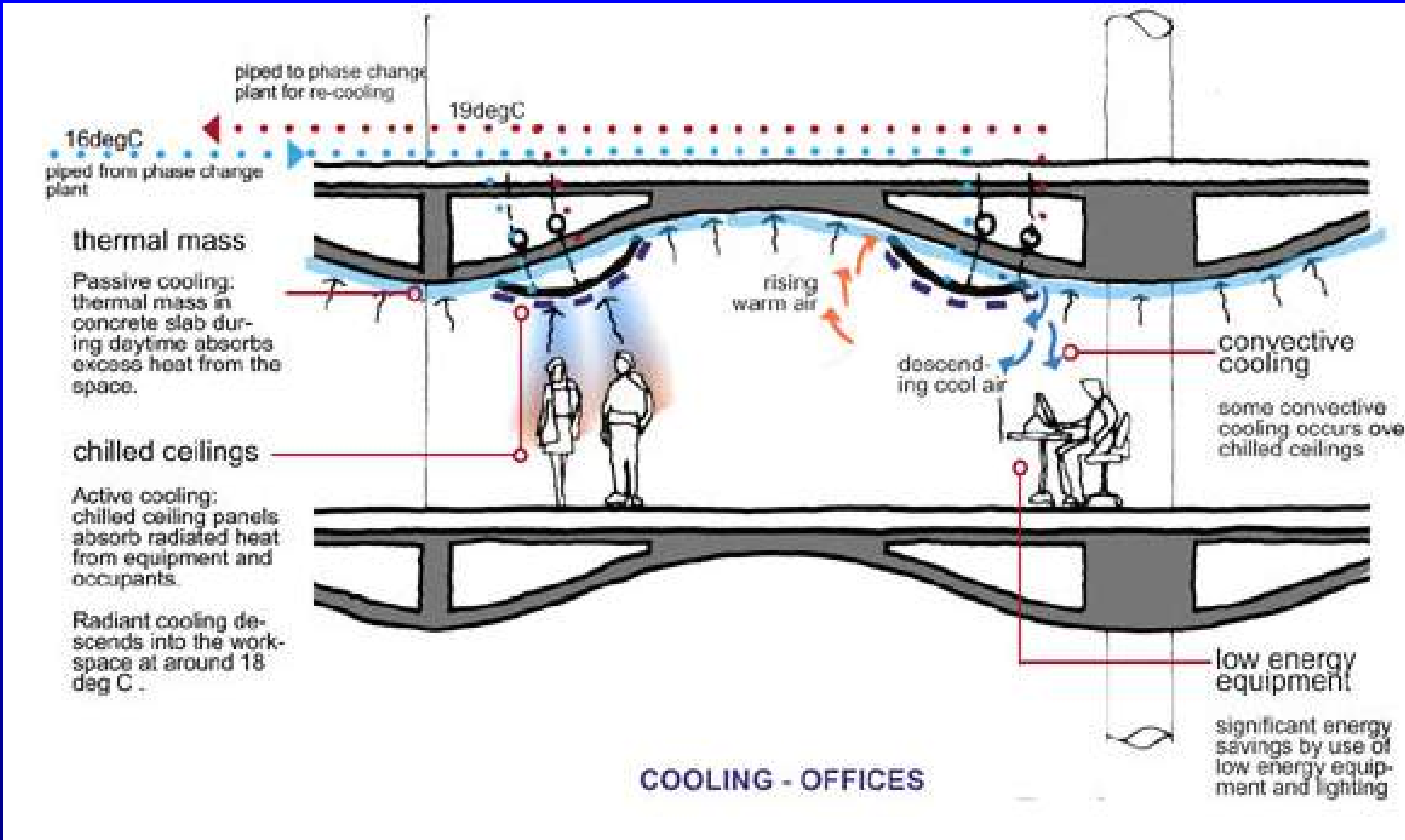
Reference: Imanari,T., T. Omori and K.Bogaki (1999) Thermal comfort and energy consumption of the radiant ceiling panel system. Comparison with the conventional all-air system. Energy and Buildings. Vol. 30, pp167-175.

6. Engineer load balancing and radiant temperatures

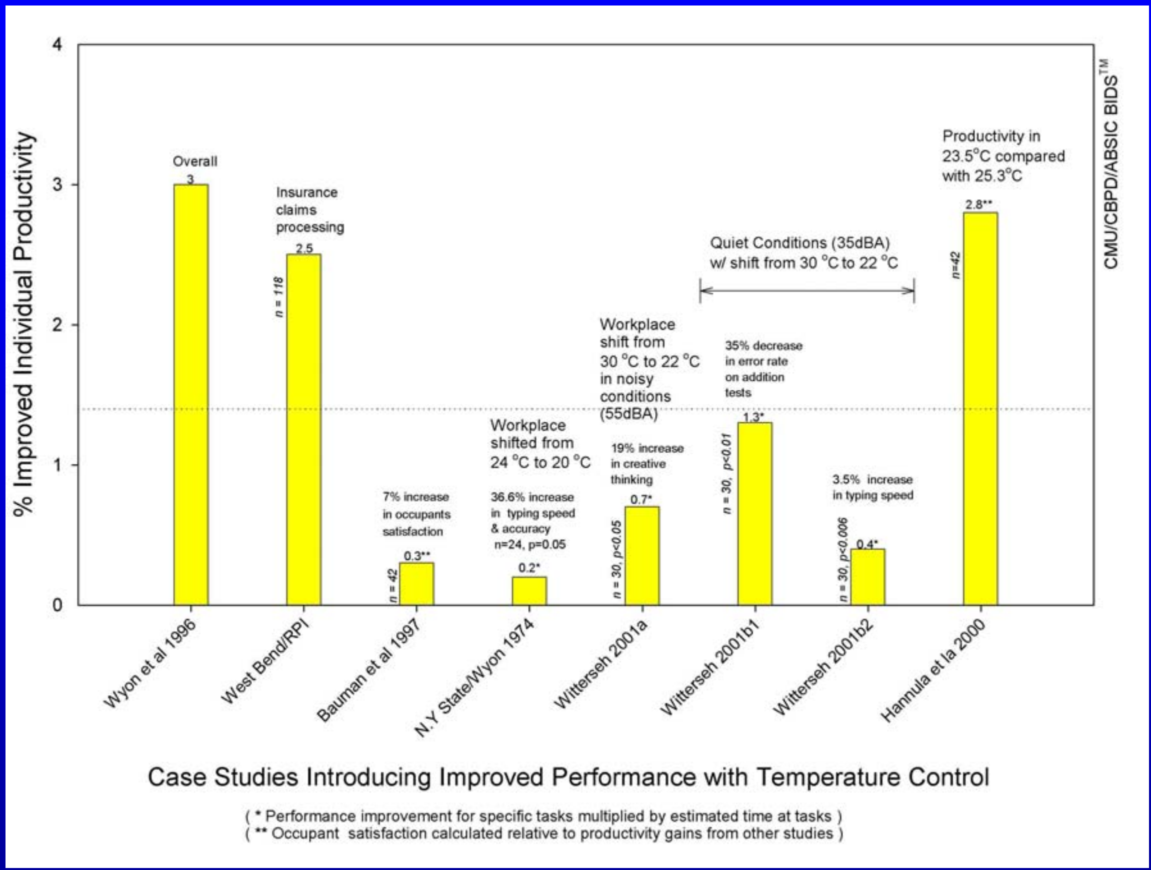




Advanced enclosure controls for night cooling of thermal mass without risk of condensation

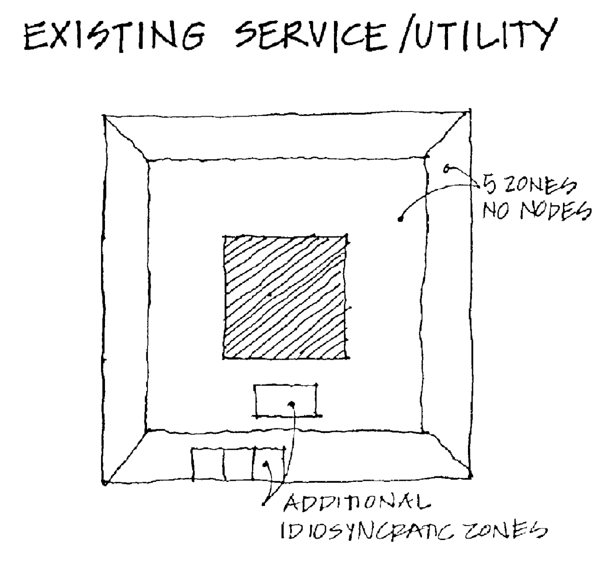

piped to phase change plant for re-cooling
19degC
16degC
piped from phase change plant
thermal mass
Passive cooling: thermal mass in concrete slab during daytime absorbs excess heat from the space.
chilled ceilings
Active cooling: chilled ceiling panels absorb radiated heat from equipment and occupants.
Radiant cooling descends into the workspace at around 18 deg C .
rising warm air
descending cool air
convective cooling
some convective cooling occurs over chilled ceilings
low energy equipment
significant energy savings by use of low energy equipment and lighting
COOLING - OFFICES

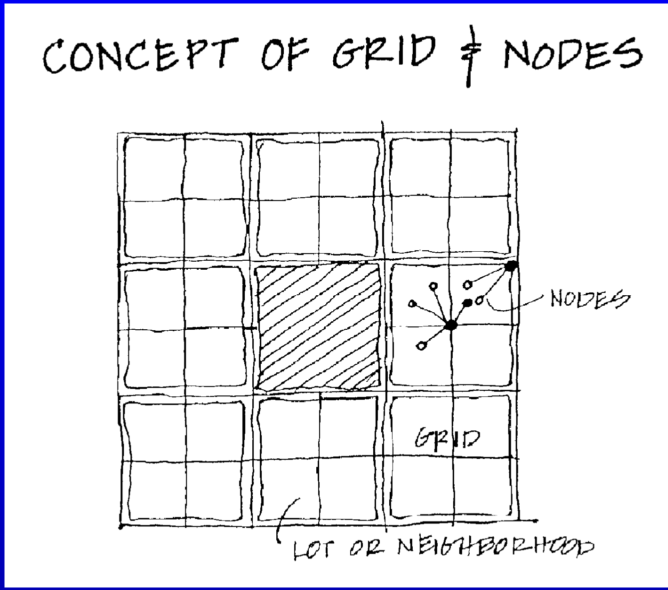
Temperature Control Increases Productivity and Reduces Energy Use



8 international case studies demonstrate that providing individual temperature control for each worker increases individual productivity by 0.2-3%.

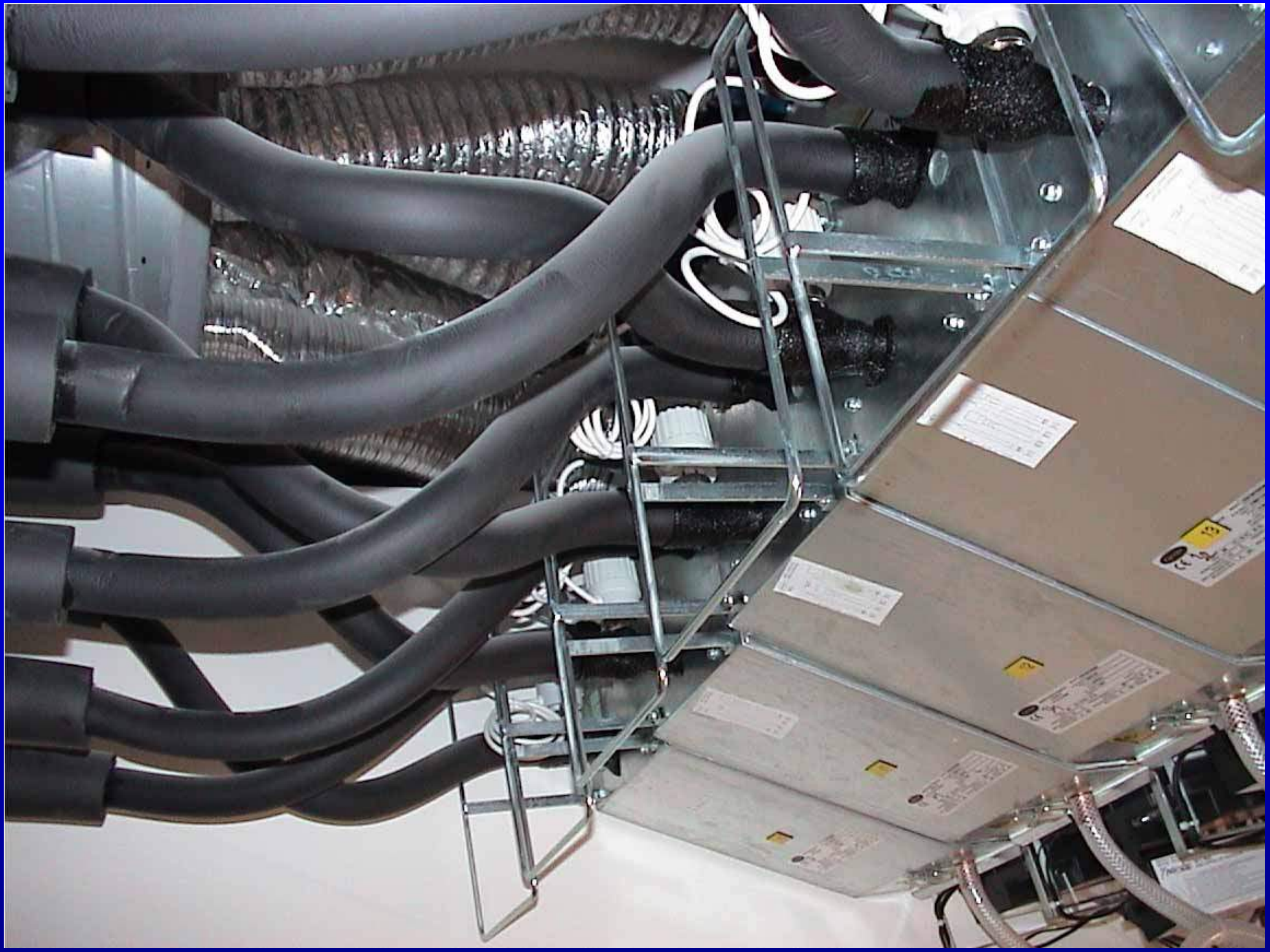
Sustainable design depends on the design of flexible, plug and play systems.



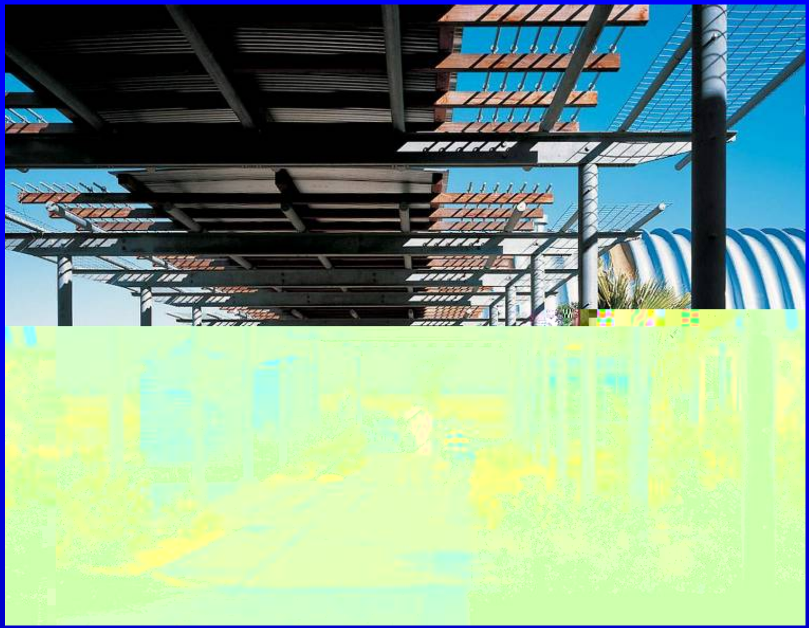


Flexible Grid - Flexible Density - Flexible Closure
Building Infrastructure Systems

are a constellation of building subsystems that permit each individual to set the location and density of HVAC, lighting, telecommunications, and furniture, and the level of workspace enclosure (ABSIC/CMU).



The best HVAC systems provide individual control, access for maintenance, and separate ventilation and thermal conditioning.



World Birding Center, Mission, Texas   Lake Flato Architects

Sustainable design depends on the use of materials and assemblies that ensure healthy environments

Mcdonough/Braungart

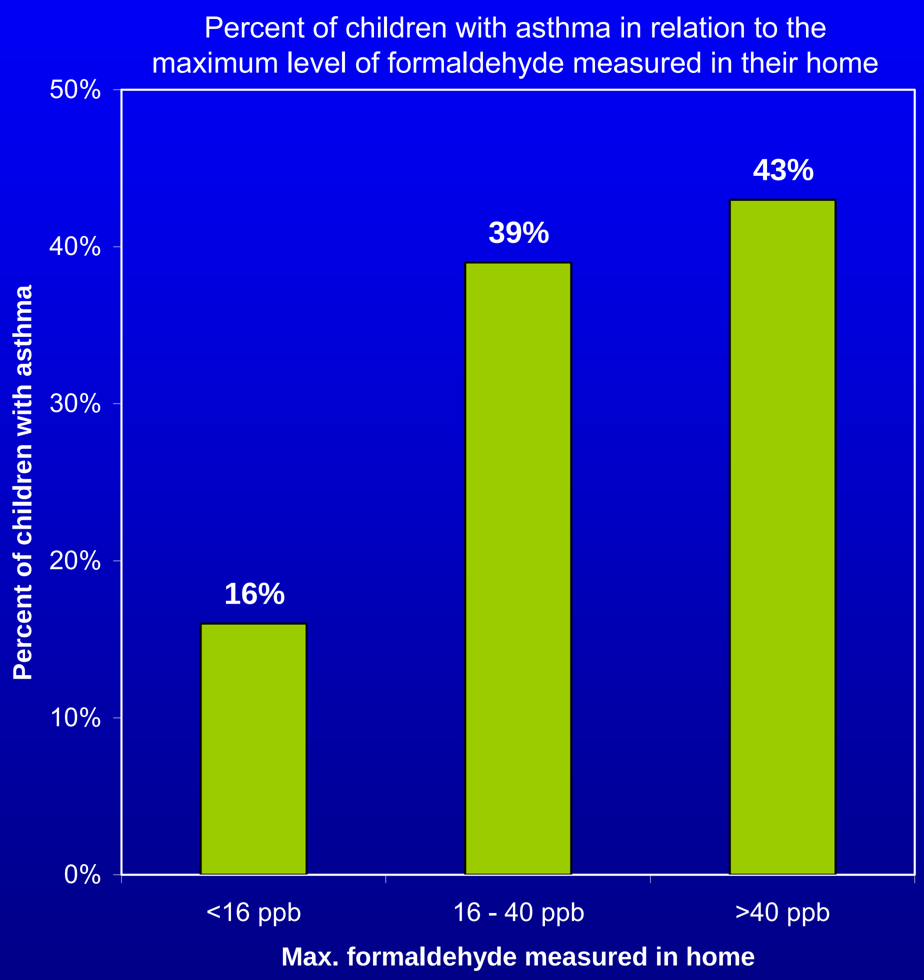
Material Selection is critical in relation to outgassing, toxicity in fires, radon, cancer causing fibers, and mold, impacting respiratory and digestive systems, eyes and skin.

Pollutant source control = Health + Individual productivity (hospital)

Garrett et al 1996

In a 1996 multiple building study of 80 homes Victoria, Australia, Garrett et al identify a 60% reduction in the prevalence of asthma and a 63% reduction in the prevalence of allergies among children whose homes contain formaldehyde-free composite wood products, as compared to those exposed to formaldehyde from furnishings and products in their home.

First cost increase:	$615 / household
Annual health savings:	$1,108 / household
ROI:	**180%**

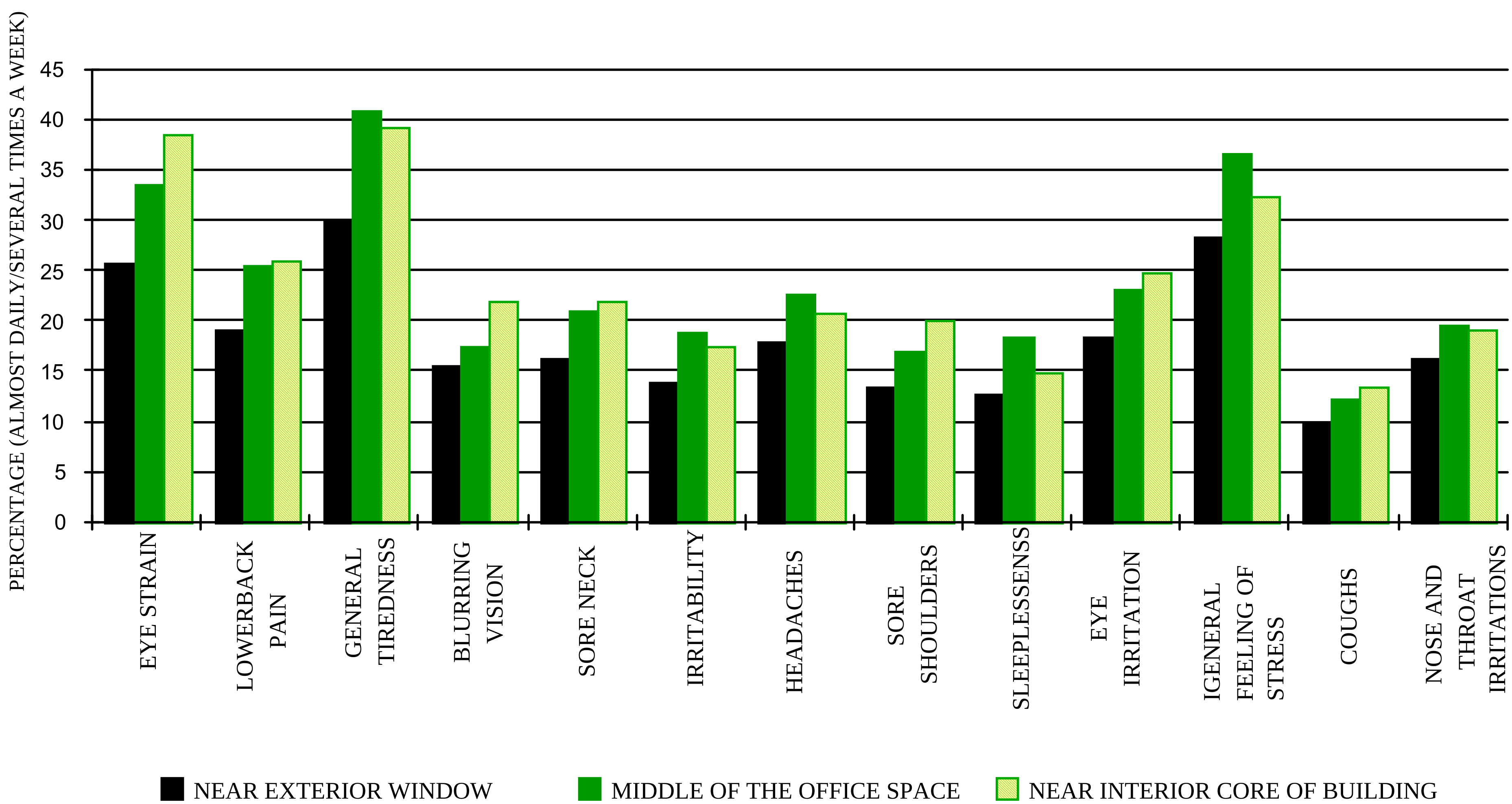


Garrett, MH, MA Hooper, and BM Hooper (1996) Low levels of formaldehyde in residential homes and a correlation with asthma and allergy in children. In Proceedings of Indoor Air 96, vol 1.

Comparative studies of daylit offices and classrooms demonstrate 10-25% performance gains, 5-10% reductions in SBS symptoms, and over 30% energy savings

Ove Arup offices

Comparison between Window Proximity and Health Complaints (Forrestal and Germantown)

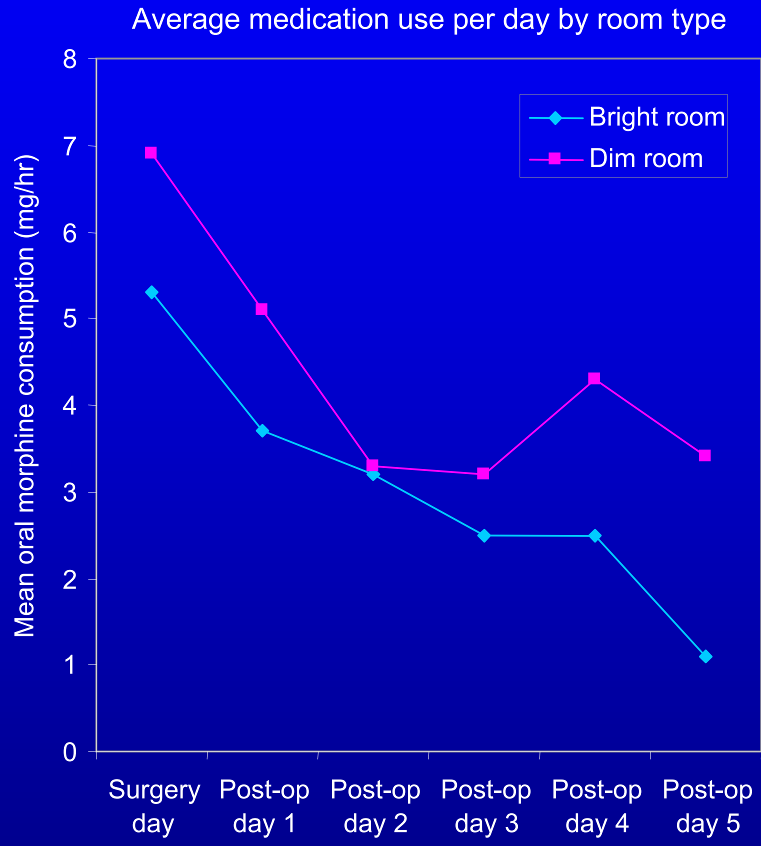


Sunlight = Health

Montefiore Hospital / Walch et al 2005

In a 2005 study of pain medication use among 89 patients undergoing elective cervical and lumbar spinal surgery at Montefiore Hospital in Pittsburgh, PA, Walch et al identify a 22% reduction in analgesic medication use among patients in bright rooms who were exposed to more natural sunlight after surgery, as compared to patients located in dim rooms after surgery.

First cost increase:	$1,000 / bed
Annual health savings:	$28 / bed
ROI:	**3%**



CMU Architecture Graduate: Walch, Jeffrey et al (2005) The effect of sunlight on postoperative analgesic medication use: a prospective study of patients undergoing spinal surgery. Journal of Psychosomatic Medicine, 67, pp. 156-163.

Seated Views = Individual productivity

SMUD Call Center /Heschong Mahone Group, Inc. 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%**

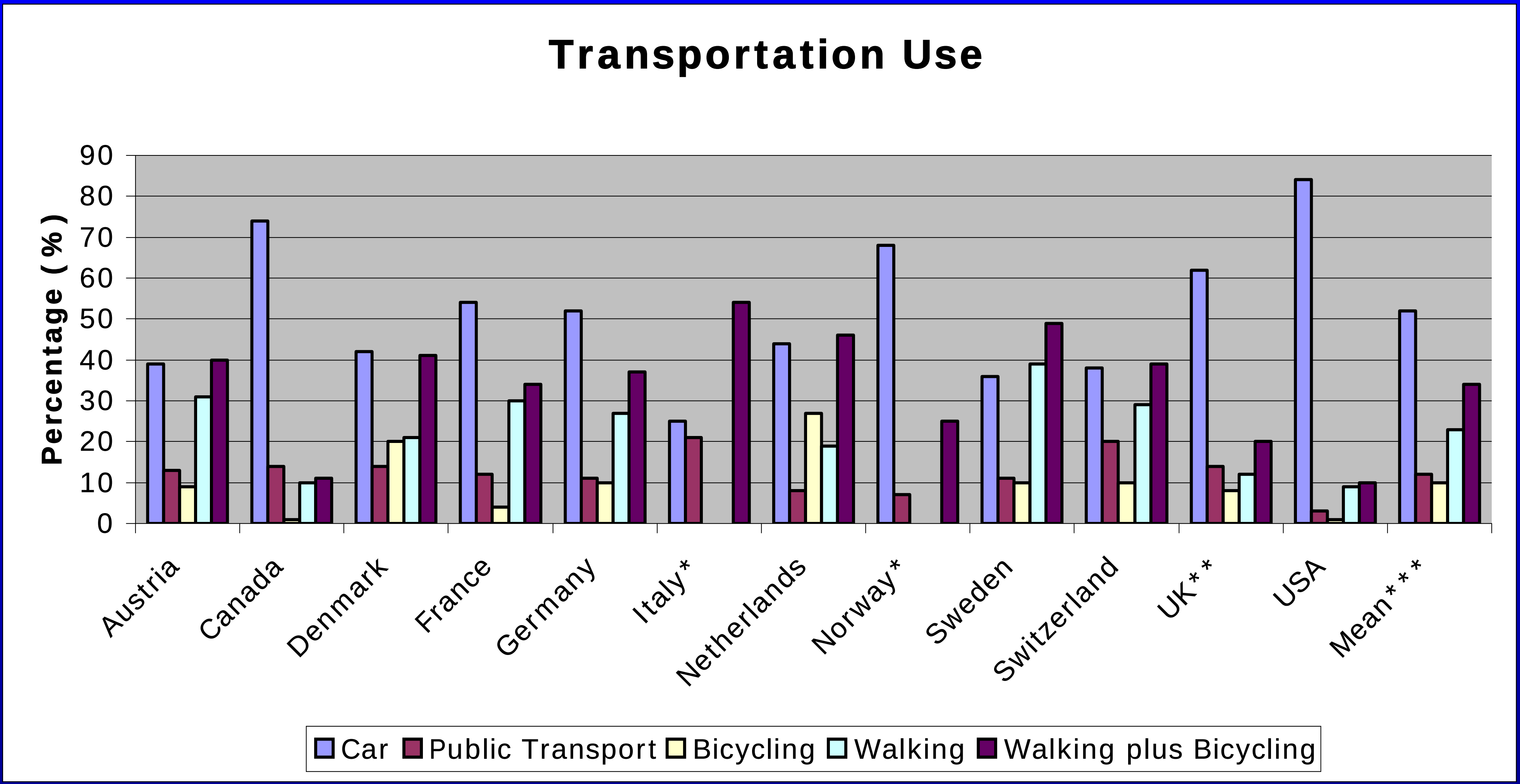
Healthy, Sustainable design depends on changing approaches to Land Use, Community Planning, and Regional Infrastructures

Design for live-work-walk - mixed use communities
Design for mobility- mixed mode transportation
The beauty of regenerative landscapes

www.pedbikeimages.org / Dan Burden

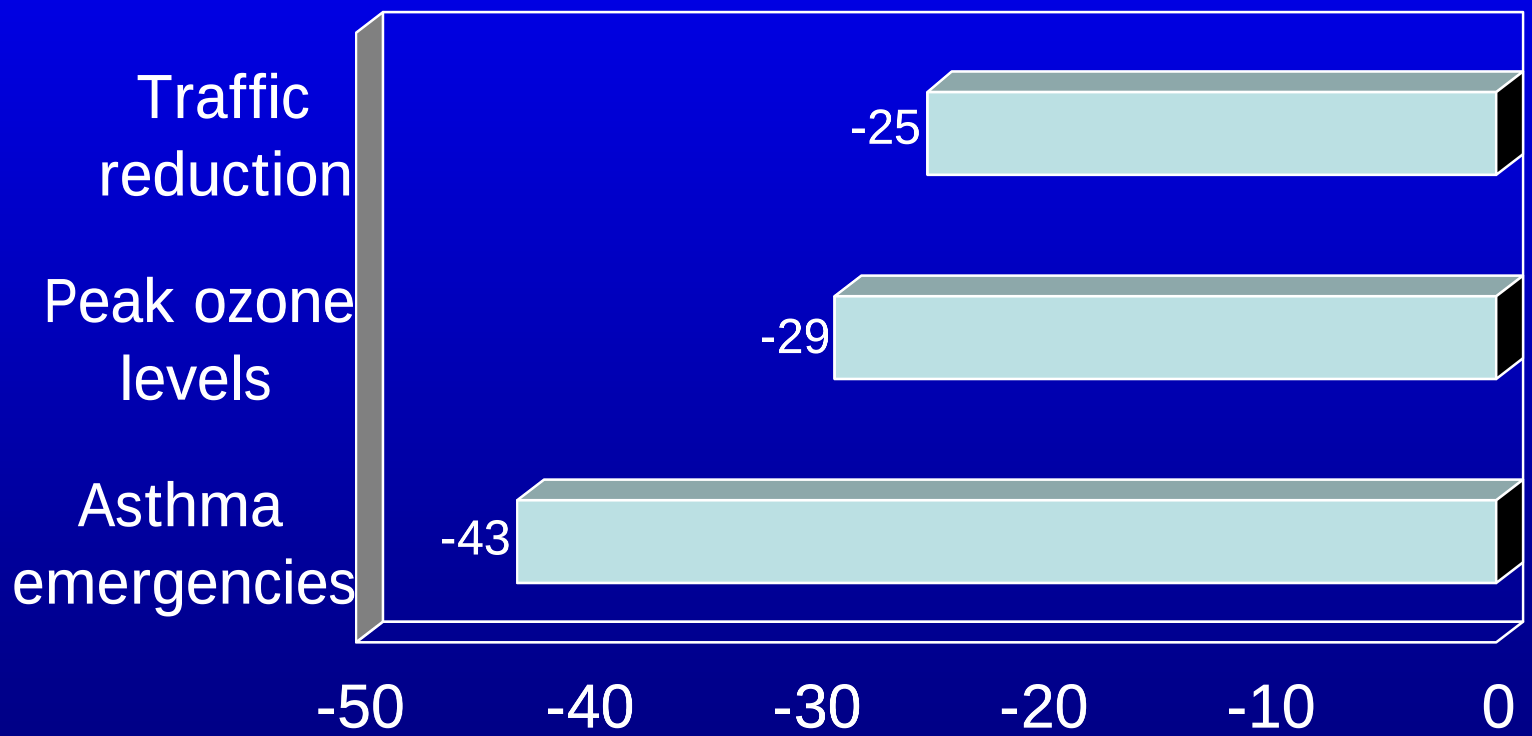
Which future?

Vehicle miles have risen by 80% from 1980 to 2000, while population rose only 21.5%, creating both energy and health consequences.

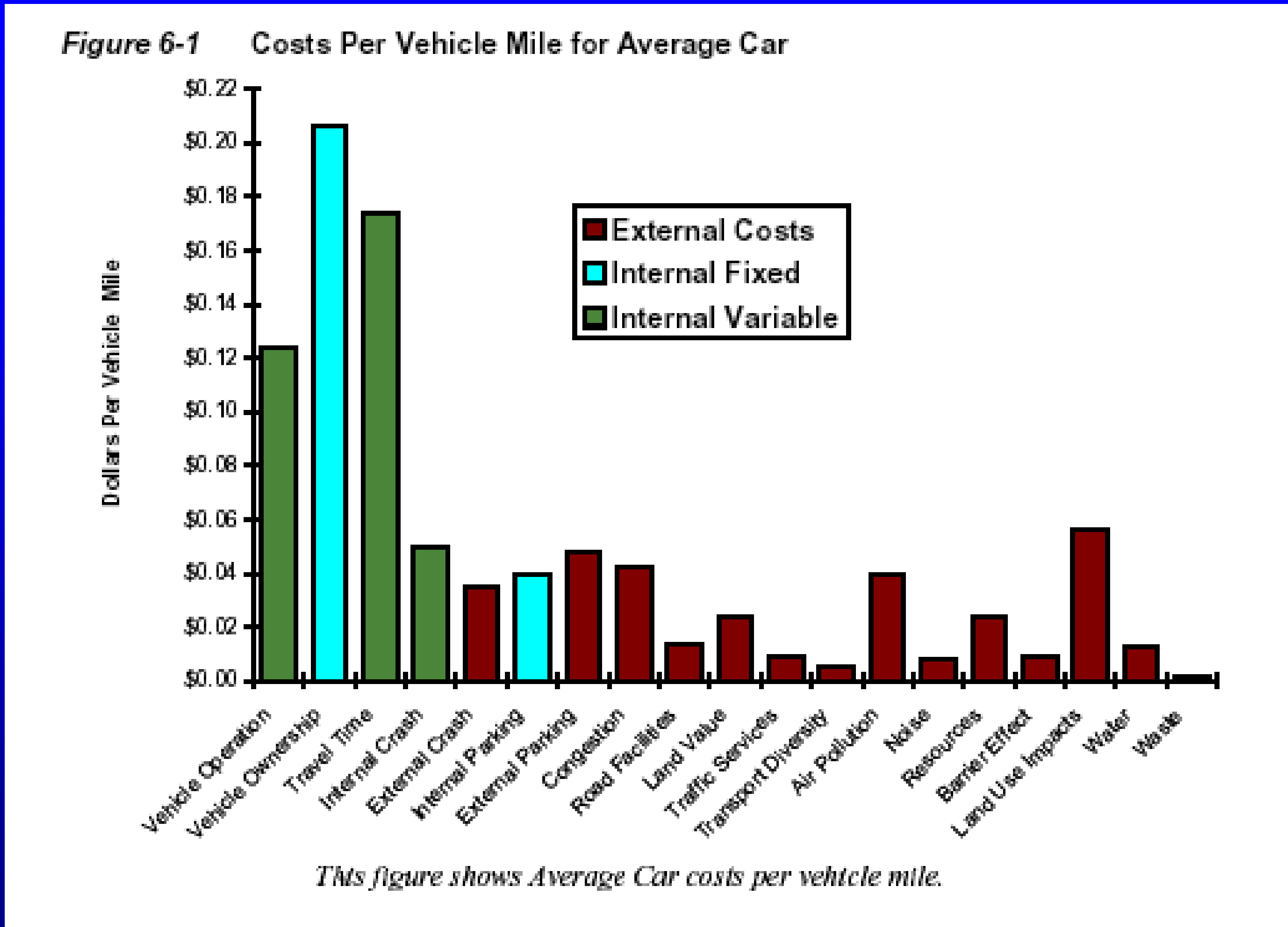


The CDC has identified that obesity is lowest in countries and neighborhoods with significant walking and biking.

During the 1996 Olympics in Atlanta, city officials reduced vehicle traffic by 22.5% and asthmas related emergencies decreased 41.6%



Source: Friedman et al., 2001 (CDC/*JAMA*)



2004 Transportation Cost and Benefit Analysis

Victoria Transport Policy Institute (www.vtpi.org)

Typical Strip Commercial Development
Pearl City, Hawaii

Courtesy Benjamin Lee, FAIA

Design alternatives
for strip commercial development

Courtesy Benjamin Lee, FAIA

Design alternatives for strip commercial development

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Design alternatives for strip commercial development

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Design alternatives for a "big box" development

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Design alternatives
for a “big box” development

Ecological footprints

pedestrian oriented development = transportation shed, watersheds, air sheds, energy sheds material sheds, food sheds, waste sheds

Sustainable design depends on the promotion of infrastructures to neighborhood amenities.

landscape for water management, mobility and energy sources

Cool Roofs and "Cool Community" developments reduce annual cooling loads by 10% and peak cooling by 5% with carbon sequestration, storm runoff management, and a 6-8% reduction in smog.

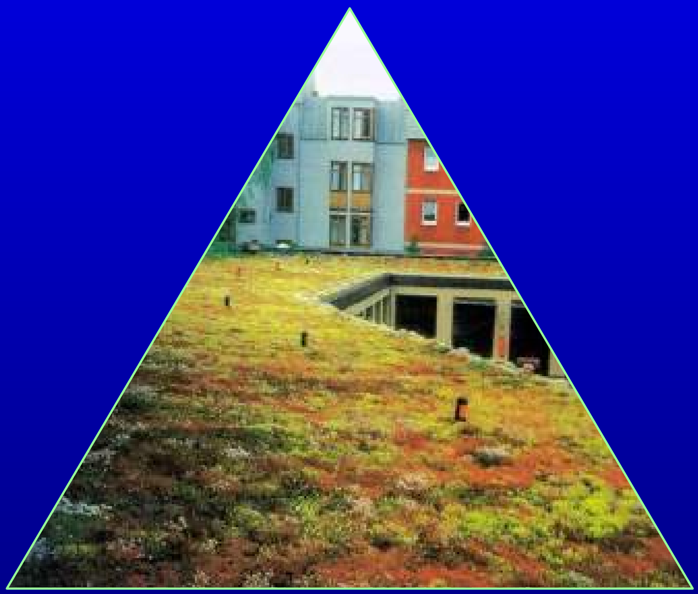
Green Roof Triple Bottom Line

Profit

Roof longevity

Energy conservation

Real estate value



People

Noise abatement

Occupant health, well-being, productivity

New industry/ job creation

Planet

Storm-water runoff benefits

Erosion reduction

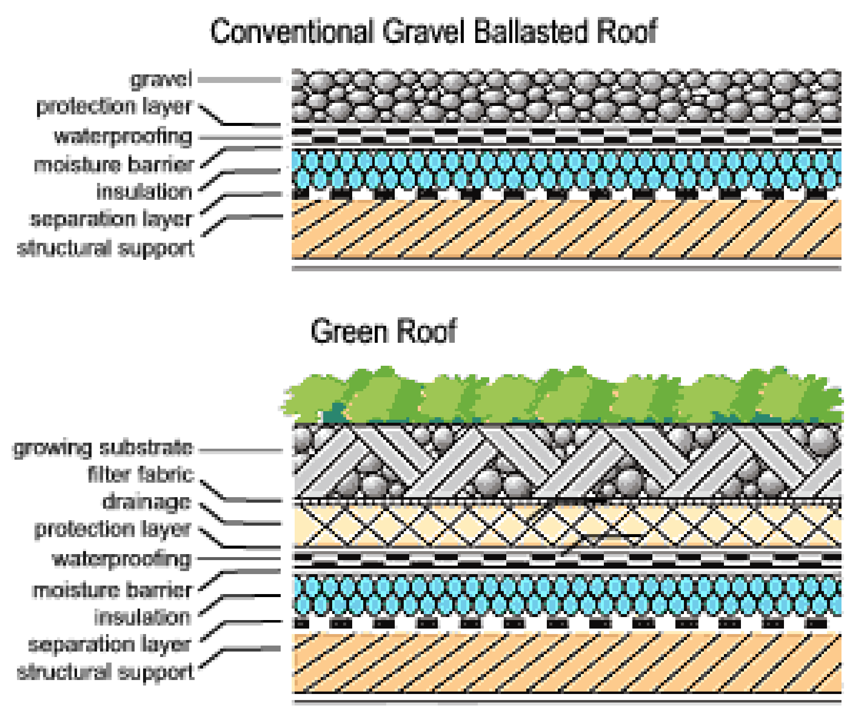
Urban heat island mitigation

Wildlife habitat creation

Improved outdoor air quality

Carbon sequestration

Green Roof Components



- Mix of vegetation
- Growing medium
- Layer for water storage, drainage, filtration, aeration
- Root barrier
- Waterproof membrane
- Insulation layer

Optional: Walkways, terraces and sitting areas
Curbs and railings
Lighting
Irrigation systems
Leak detection systems

Types of Green Roofs

Extensive

>6 inch growing medium
>35 pounds / ft^2
Sedums, herbs
Low maintenance
Lowest cost
Inaccessible

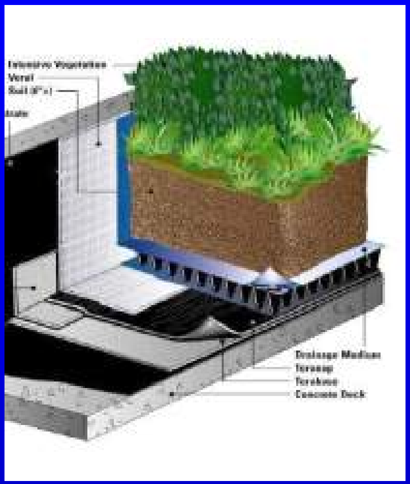
Semi-intensive

6-12 inch growing medium
35-50 pounds / ft^2
Height variation, meadow plants
Maintenance varies
Moderate cost
Partially accessible

Intensive

>12 inch growing medium
50-300 pounds / ft^2
Gardens, canopies
High maintenance
High cost
Accessible

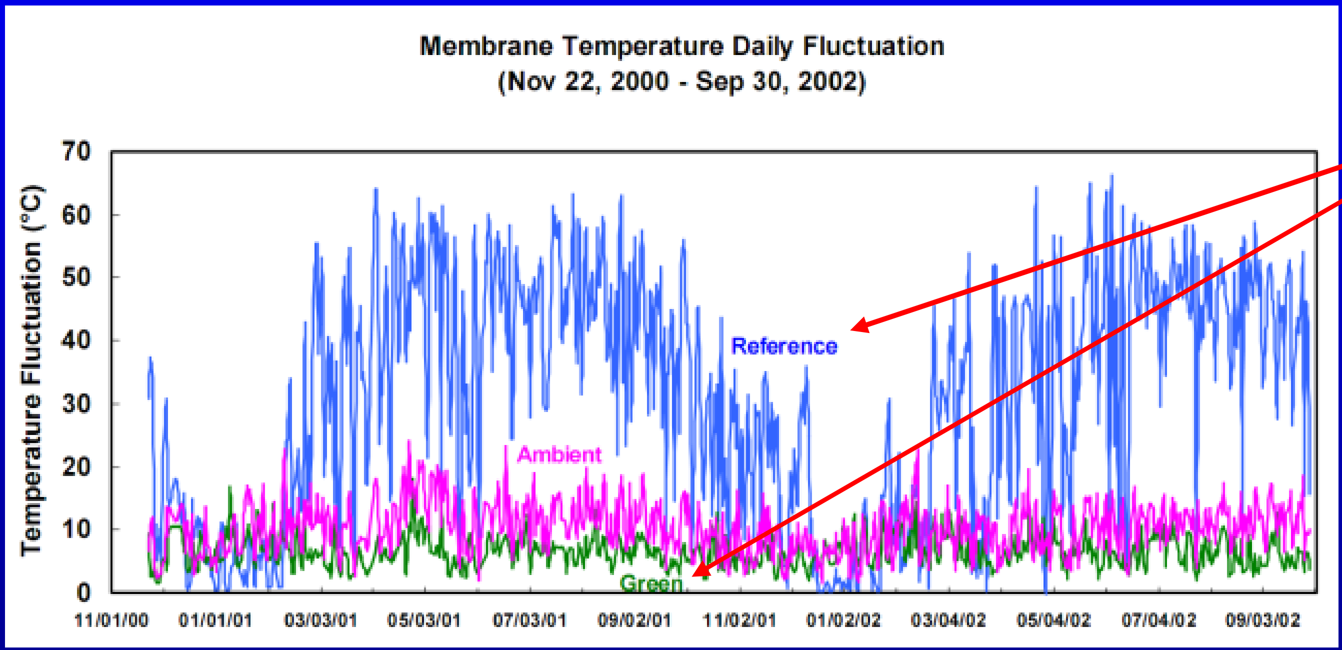
Ways to Install Green Roofs



Pre-vegetated mats	Pre-planted modular containers	Built-in-place systems
Extensive type only	All types	All types
Fast installation	Fast installation	Slow installation
Immediately green	Pre-"green" as desired	Up to 2 years for full coverage
Low flexibility for change	High flexibility for change	Low flexibility for change
Relatively lower cost	Relatively lower cost	Relatively higher cost

Profit: Roof longevity

Green roof shades membrane from UV and thermal stress



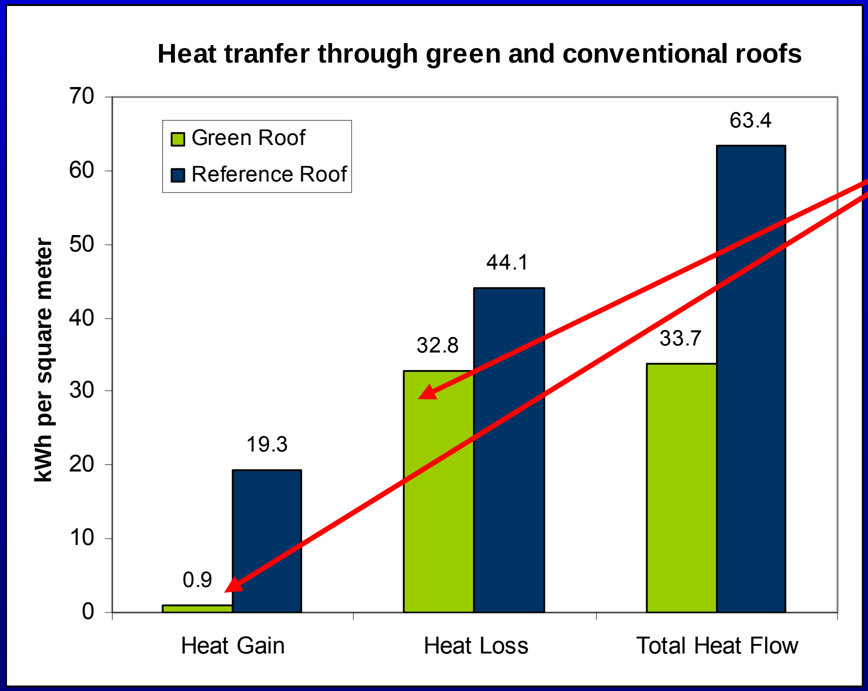
Median daily temperature swing of conventional dark-colored roof = 45ºC, compared to 6ºC for green roof[1]

Increases membrane life by 2-4X; up to 50 years[2]

1) Liu and Baskaran 2003
2) Kosareo and Ries 2007

Profit: Energy Conservation

- Direct roof shading
- Evaporative cooling from the plants and growing medium
- Additional thermal mass in the roof
- Additional insulation in the roof assembly



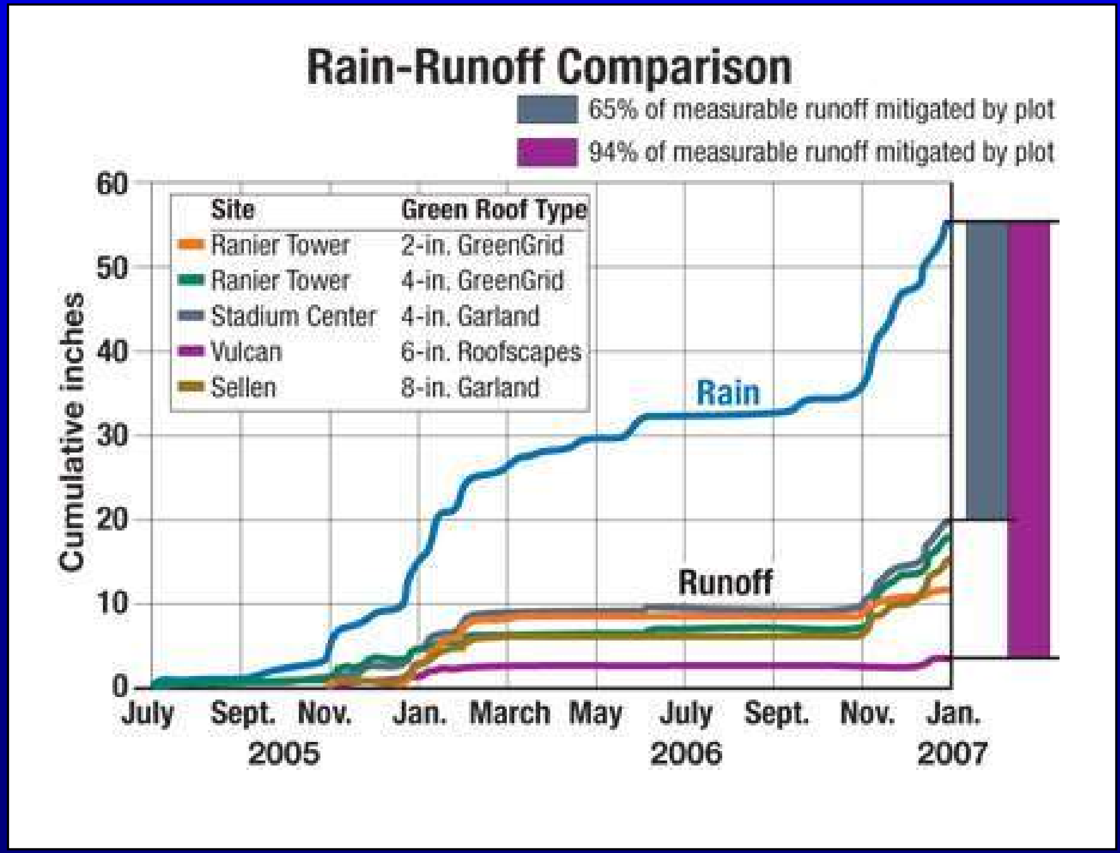
Green roof reduced summer heat gain through the roof by 95%, and reduced winter heat loss through the roof by approximately 26%[3]

3) Liu and Baskaran 2003

Profit or Planet? Stormwater Runoff & Erosion

Excessive runoff during rainstorms results in:

- Sewage overflow to the Potomac & Anacostia Rivers and Rock Creek (CSOs)
- Erosion of runoff paths and at downspout outlets

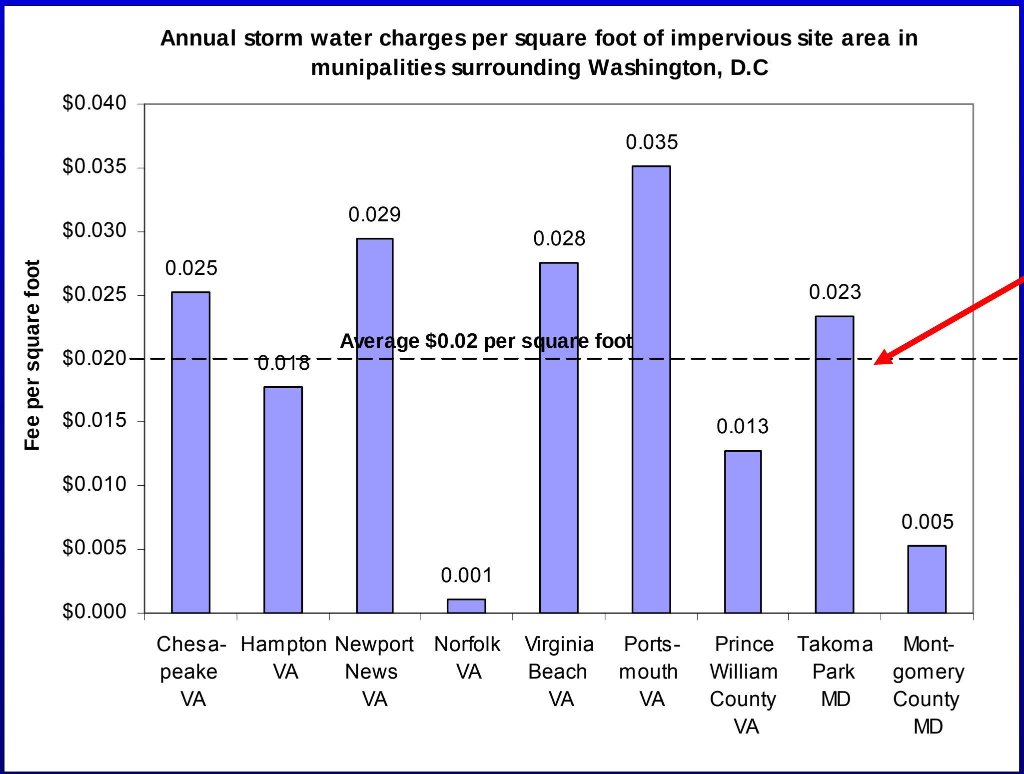


Green roofs retain more than 50% of the rainwater that falls on them.

Magnusson Klemencic 2007

Stormwater Fees & Savings

- Stormwater fee: individual building owners pay for storm water runoff that leaves their building site.
- Rates per impervious area of a parcel, including the roof surface
- DCWASA is planning to implement a similar fee system



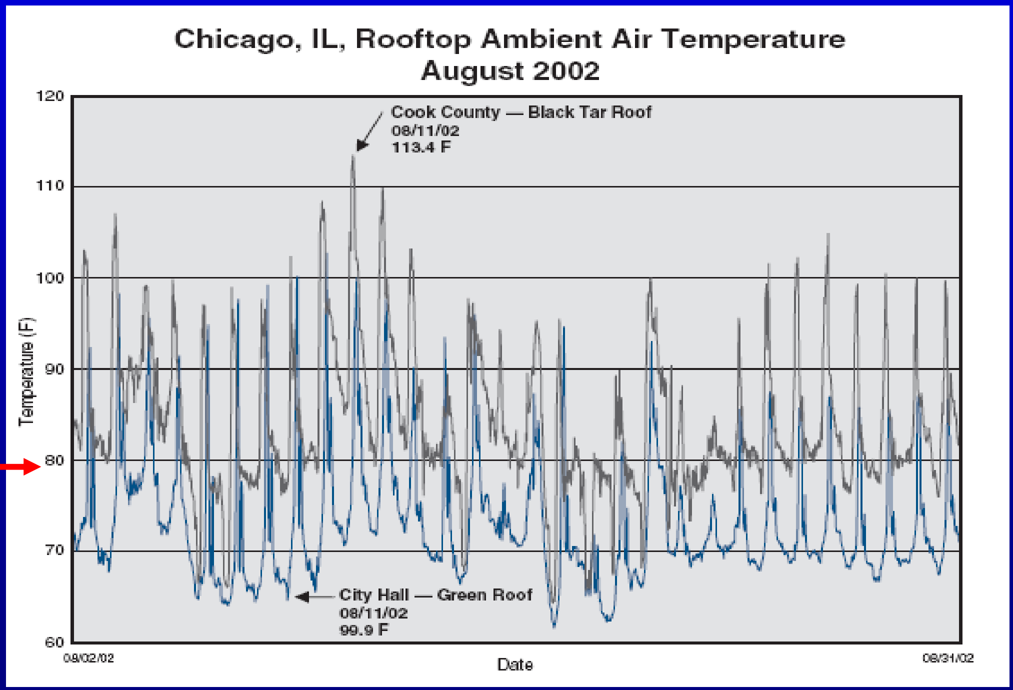
Given the average stormwater rate of surrounding municipalities, the Dirksen SOB green roof would avoid $11,900 in stormwater fees over a 25-year life cycle.

Planet: Urban Heat Island Mitigation

Urban heat island: can result in temperature differences of up to 10°F between rural and urban areas, which:

- Increases the use of air conditioning equipment
- Increases building cooling load
- Increases peak energy penalties

A green roof mitigates the heat island effect by cooling rooftop air through evapo-transpiration.



FEMP/DOE Federal Technology Alert DOE/EE-2098

Planet: Peak Load Reduction

- 0.334 kW - 0.359 kW peak load reduction per 1,000 ft^2 green (cool) roof area (pre-1980 building, Washington, D.C. climate)[5]
- $600 per kW to bring a new power plant online to supply additional load[6]

Peak capacity savings due to Dirksen SOB green roofs:

$5,900 - $6,900

5) Akbari et al 2005
6) Banting et al 2005

Planet: Habitat Creation

- Green roofs can attract migratory and other birds, insects, and invertebrate soil-dwelling organisms.
- May function as ecological corridors through developed areas, linking larger green spaces
- ‘Features’ known to attract wildlife[6]

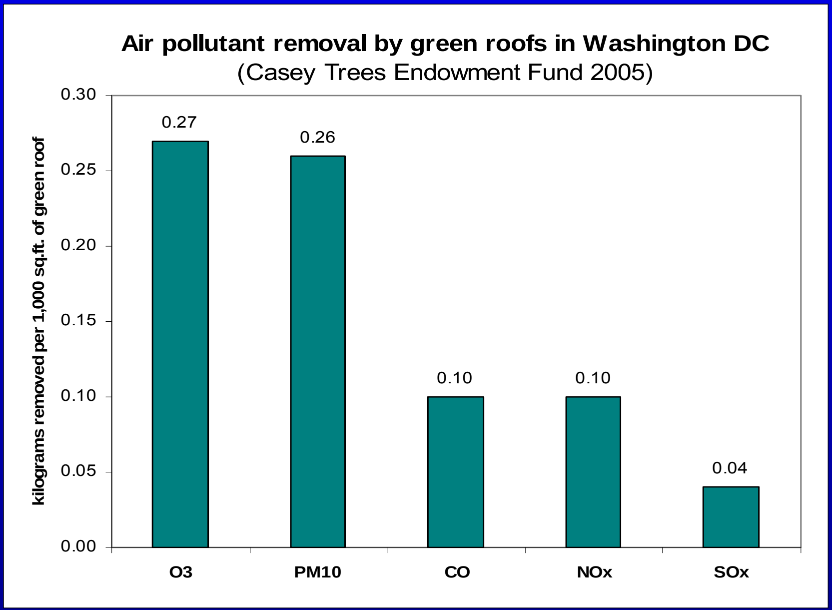
Variety in height and slope of soil
Sparsely and densely planted areas
Freely and poorly draining areas
Diverse plant population

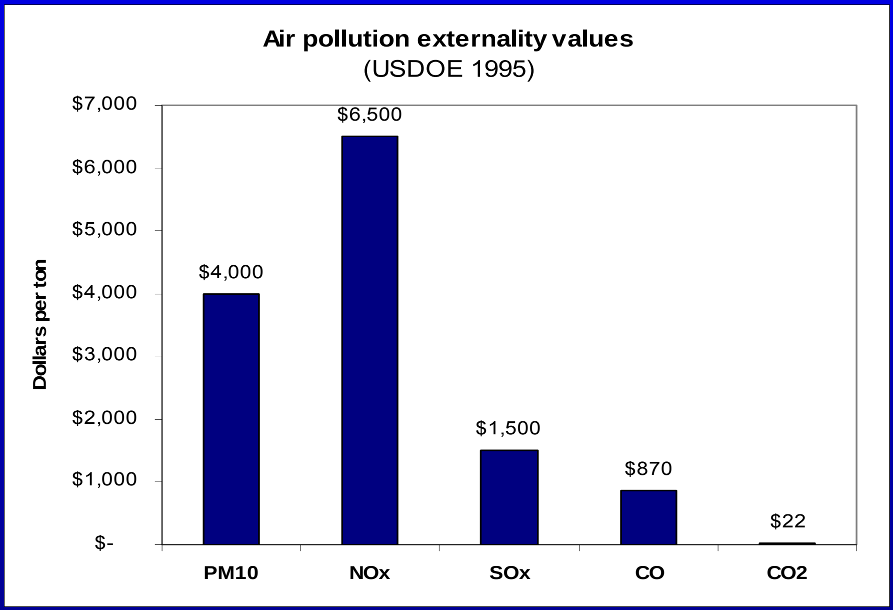
Northern lapwing on a Swiss green roof

6) Brenneisen 2003

Planet: Outdoor Air Quality

- Rooftop plants can trap particulates and sequester gaseous pollutants with their leaves
- Reduced power plant emissions due to energy savings





25-year life cycle emissions savings for Dirksen SOB green roof: $56,400 - $56,900

People: Noise abatement

Unlike hard surface roofs,
green roofs absorb sound rather than reflect it.

- Green roof with 4-inch growing medium reduces transmission of airport noise into building by at least 5 decibels.[7]
- GAP Inc. headquarters green roof attenuates airplane sound to 50dB
- Many airport authorities offer cash to improve building enclosures; In 2004, the average noise mitigation paid by airport authorities to qualifying households was $12,500 ($5 per square foot)[9]

Noise abatement value of
Dirksen SOB green roof: $34,000

7) Dunnett and Kingsbury 2004
9) Landrum & Brown 2005

People: Productivity Benefits

A 2003 study by the Heschong-Mahone Group found a 6% improvement in call center average handling time for workers with the highest rated views, as compared to workers with no view at all.

Range of improvement from 0.5 percent to 1.4 percent per one point increase in view rating

In the Dirksen SOB, the productivity gain for staffers who will now have a view of a vegetated roof, is estimated at 2.9% and valued at $65,000 per year.

People: New Industry & Job Creation

Emerging US industry?

Germany's green roof industry growing 15-20% a year
10% of all flat roofed buildings in Germany now green
over 500 million square feet of roof spurred by taxes and incentives:

fees for storm water management

subsidies to avoid infrastructure replacement

indirect subsidies to substitute green roofs as open space

Local job development?

design/engineering
manufacturing
installation

Green Roof Triple Bottom Line

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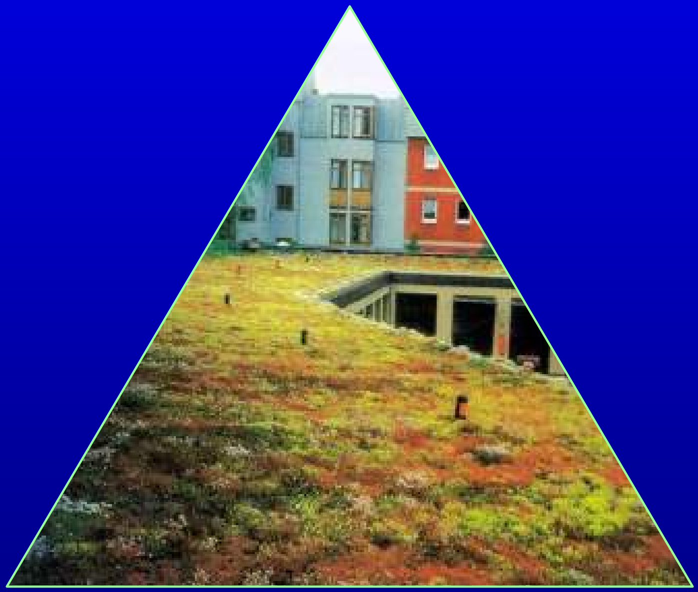
Roof longevity

Energy conservation

Real estate value



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QuickTime™ and a TIFF (Uncompressed) decompressor are needed to see this picture.

Environmental sciences

Environmental engineering

Environmental policy

Environmental business

Environmental art

Hands-on learning dramatically outperforms book learning

The Intelligent Workplace… and next

Carnegie Mellon University

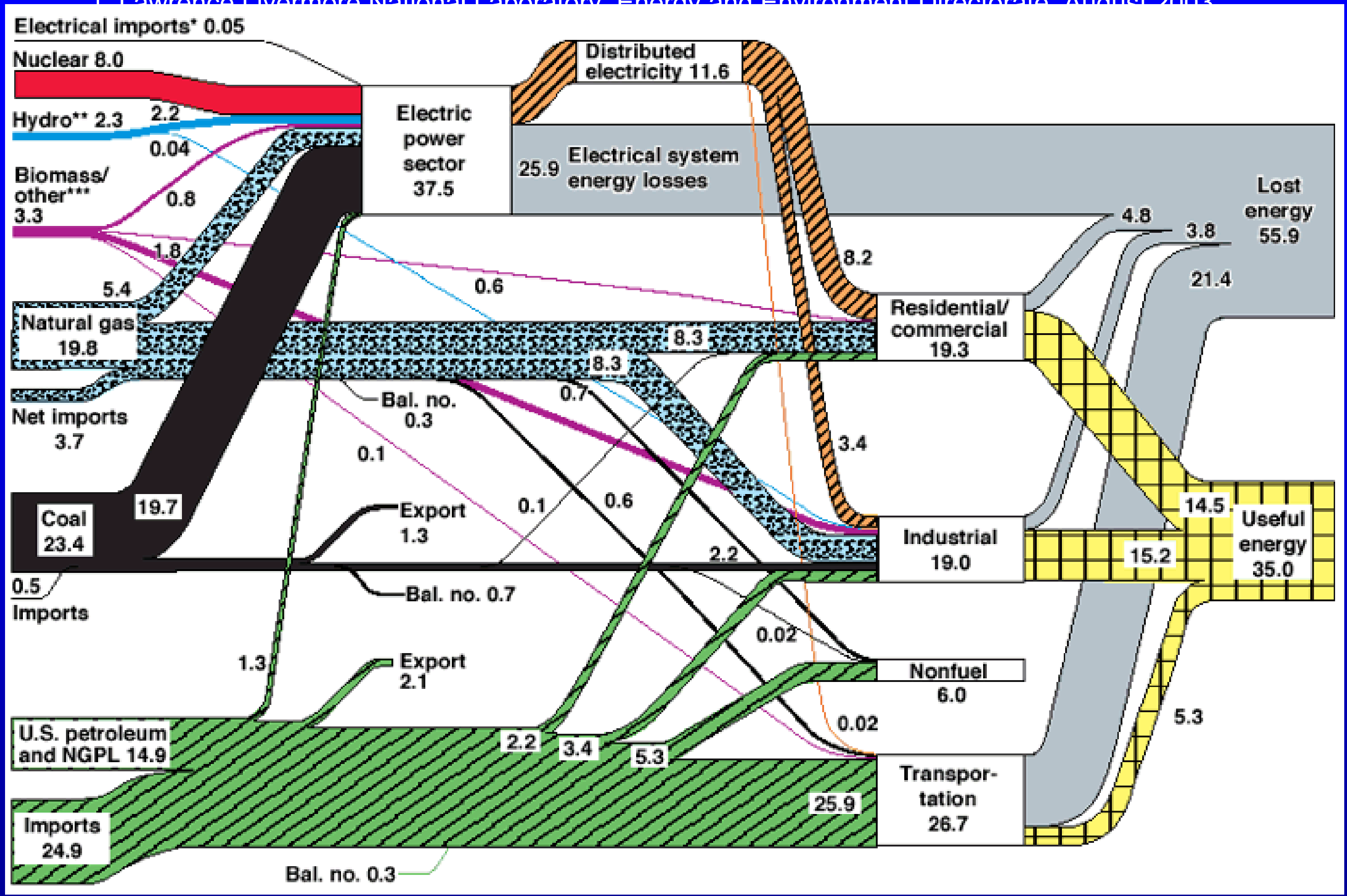
A Living Laboratory for Building Environmental Research

Carnegie Mellon's Building as Power Plant:
merging ascending and cascading energy systems

On-site generation and energy cascades
can shift generation efficiencies from 30% to 70%.

Add renewable sources and buildings can generate more power than they use.

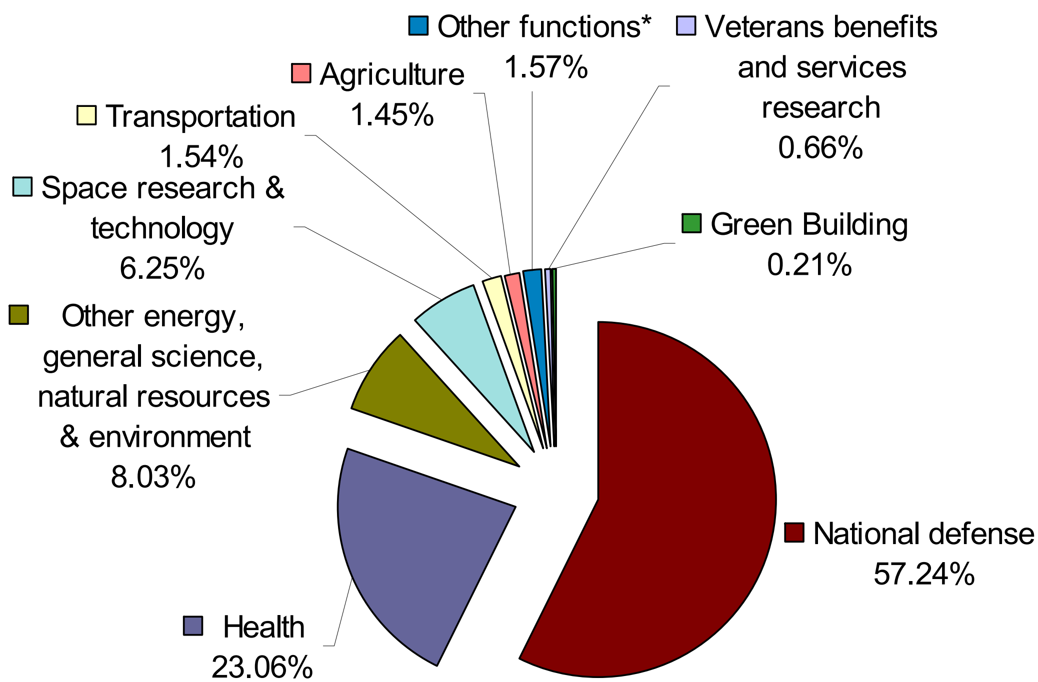
1. Lawrence Livermore National Laboratory, Energy and Environment Directorate, August 2003



In 2003, the US wasted 60% more energy than it consumed, due to generation and transmission losses - losses that Distributed Gen & CHP can dramatically reduce.


RECYCLE
Sustainable Workplaces for
Human Health and Productivity
Vivian Loftness, FAIA

Toward a Green Building Research Agenda



research

40% of the energy challenge
yet 0.2% of federal research dollars!

Starving the national labs

Starving the universities

Starving inventions

Starving technology transfer and investment

Nano, bio, info national research priorities   eco?