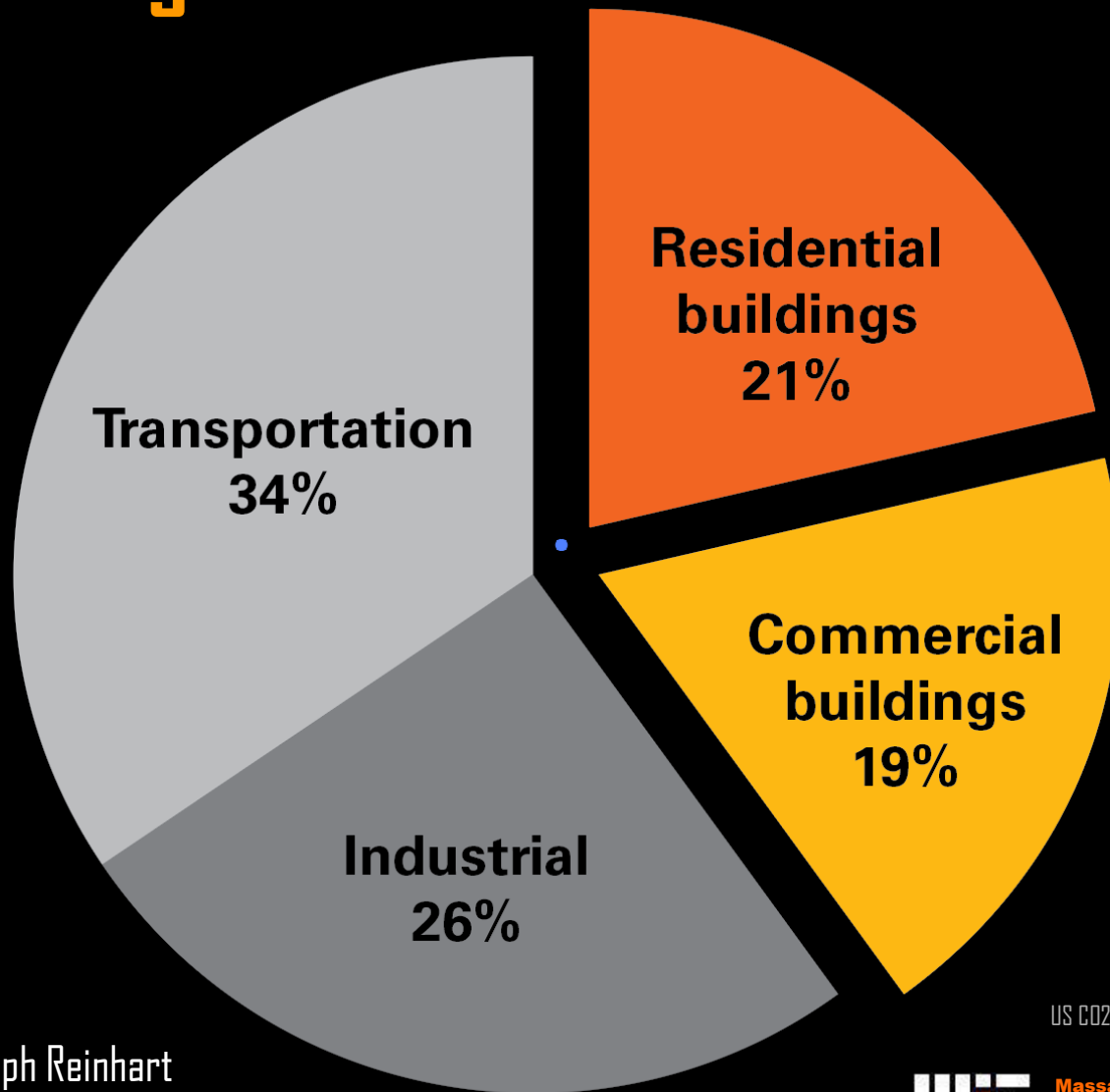


# 4.401/4.464 Environmental Technologies in Buildings



US CO2 emission by sector

# Environmental Technologies

---

*Why comfortable?*

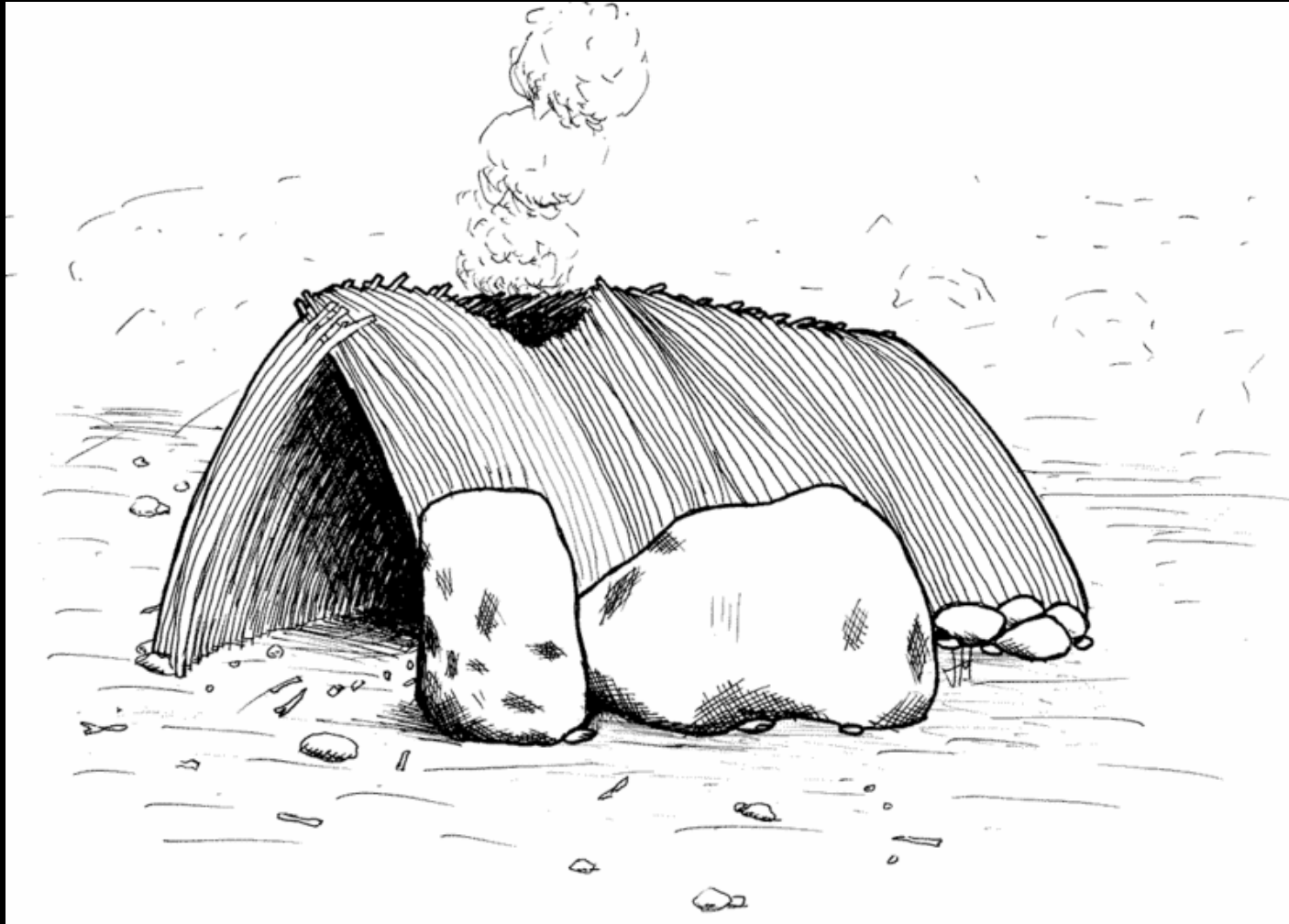
# Why comfortable?



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If you watched *Alpha* you may agree that nobody was ever comfortable in today's sense during the ice age.

# First Shelters



Protect from wind and rain and trap the heat.

Public domain image courtesy of José-Manuel Benito on Wikipedia

# Roman *Domus*



Central heating, warm water, adequate rain protection.  
Life was getting better, if you could afford it.

Photo by [Mary Harrsch](#) on Flickr. License: CC BY-NC-SA.

# Medieval Living



Photo by [Dunnoch D](#) on Flickr. License CC BY-NC.

You need a lot of wood to keep that space somewhat comfortable during winter.

# 18<sup>th</sup> Century Colonial Housing



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Building adapts to local climate. Deciduous trees on the south side for shading, small rooms to keep warm during winter.



# Full Climate Control



Photo by Lynn Betts, USDA Natural Resources Conservation Service. This image is in the public domain.

We can now separate building interiors from ambient climatic conditions. This photo could have been taken anywhere in the US and elsewhere.

*Why resource-efficient?*

# Why Resource-Efficiency?

- Population Growth—see Thomas Malthus's *An Essay on the Principle of Population* (1798)
- Environmental Damage—see Rachel Carson's *Silent Spring* (1962)
- Limited Resources—see Meadows et al.'s *Limits to Growth* (1972)

# Remaining Oil

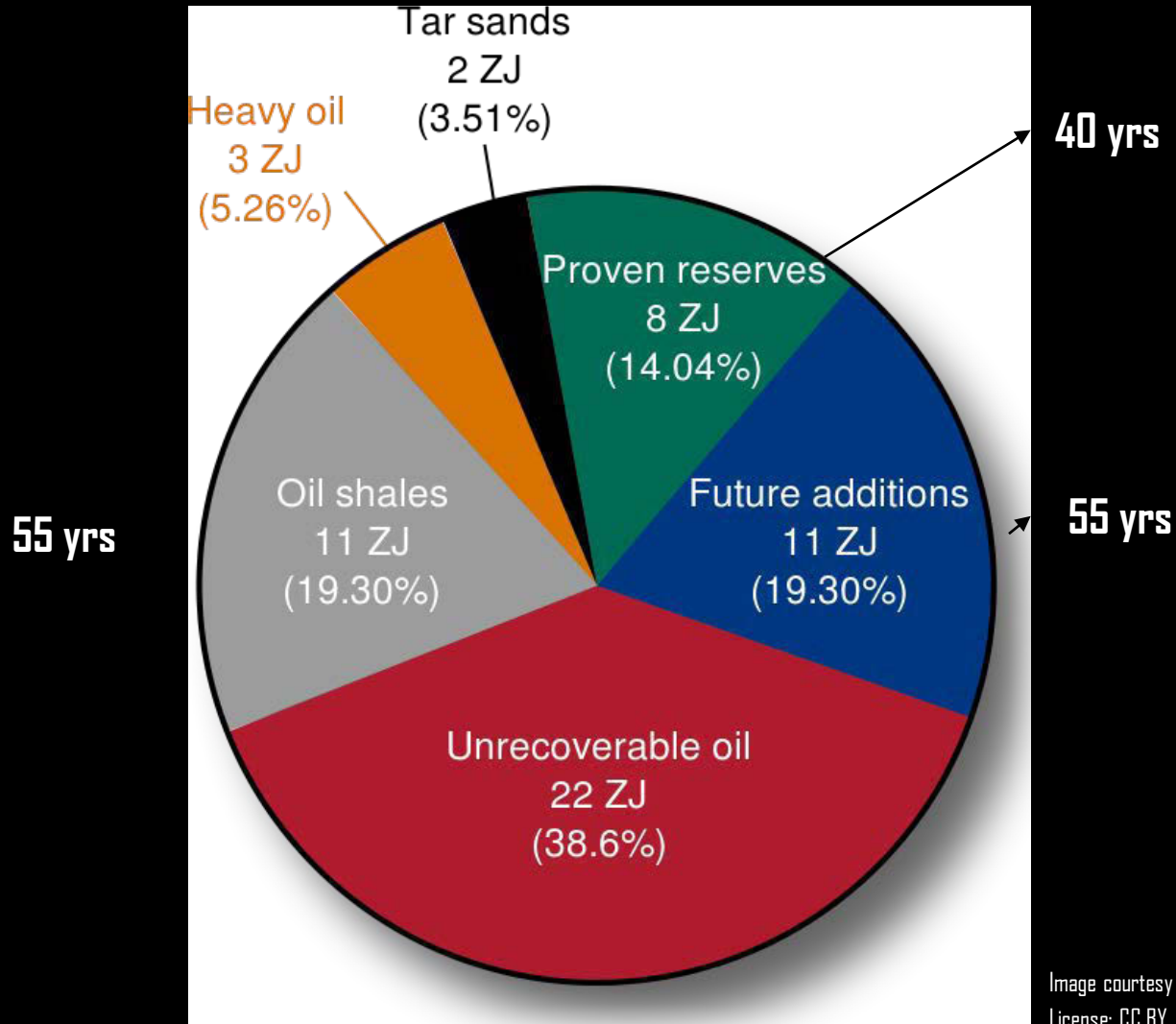


Image courtesy of Scott Nazelrod at Wikipedia.  
License: CC BY.

□ ~0.2 ZJ per year (32 billion barrels)

We are looking at 100 to 150 years of supply if demand stays stable.

# Climate Change Milestones

## 1992 IPCC Report

Global mean surface air temperature has increased by 0.3 to 0.6°C over the last 100 years.... The size of this warming is ... the same magnitude as natural climate variability. Thus the observed **increase could be largely due to this natural variability**; alternatively this variability and other human factors could have offset a still larger human-induced greenhouse warming.

## 2007 IPCC Report

Warming of the climate system is **unequivocal**. Most of the observed increase in global average temperatures since the mid-20th century is **very likely** due to the observed increase in **anthropogenic** greenhouse gas concentrations.

## 2014 IPCC Report

Global warming is **here**, human-caused, and probably already dangerous — and it's increasingly likely that the heating trend **could be irreversible**, a draft of a new international science report says.

## 2016 Paris Agreement (UNFCCC)

195 countries agreed to seek to limit global temperature increases in the 21st century to below **2 Degrees Celsius**.



# SUSTAINABLE DEVELOPMENT GOALS

1 NO POVERTY



2 ZERO HUNGER



3 GOOD HEALTH AND WELL-BEING



4 QUALITY EDUCATION



5 GENDER EQUALITY



6 CLEAN WATER AND SANITATION



7 AFFORDABLE AND CLEAN ENERGY



8 DECENT WORK AND ECONOMIC GROWTH



9 INDUSTRY, INNOVATION AND INFRASTRUCTURE



10 REDUCED INEQUALITIES



11 SUSTAINABLE CITIES AND COMMUNITIES



12 RESPONSIBLE CONSUMPTION AND PRODUCTION



13 CLIMATE ACTION



14 LIFE BELOW WATER



15 LIFE ON LAND



16 PEACE, JUSTICE AND STRONG INSTITUTIONS



17 PARTNERSHIPS FOR THE GOALS



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# Energy Use in Buildings

# What is Energy?

- The ability to do work.
- One cannot see energy.
- Energy manifests itself in different forms: Kinetic, thermal, gravitational, sound energy, light energy, elastic, electromagnetic, chemical, nuclear, and mass.



# Energy Units for Electricity Use

□ 1 joule [J]: energy as work

□ 1 kilowatt hour = kWh                      with 1 watt = 1 J /s  
= 1000 x J/s x 3600s = 3.600.000 J

## Cell phone:

Battery size = 2900 mAh at ~3.8 V

$$= 2.9 \text{ Ah} \times 3.8 \text{ V}$$

$$= 0.011 \text{ kWh}$$

Annual energy use = 0.011 kWh x 365 d/yr

$$= 4 \text{ kWh/yr}$$

## Energy-Efficient Refrigerator:

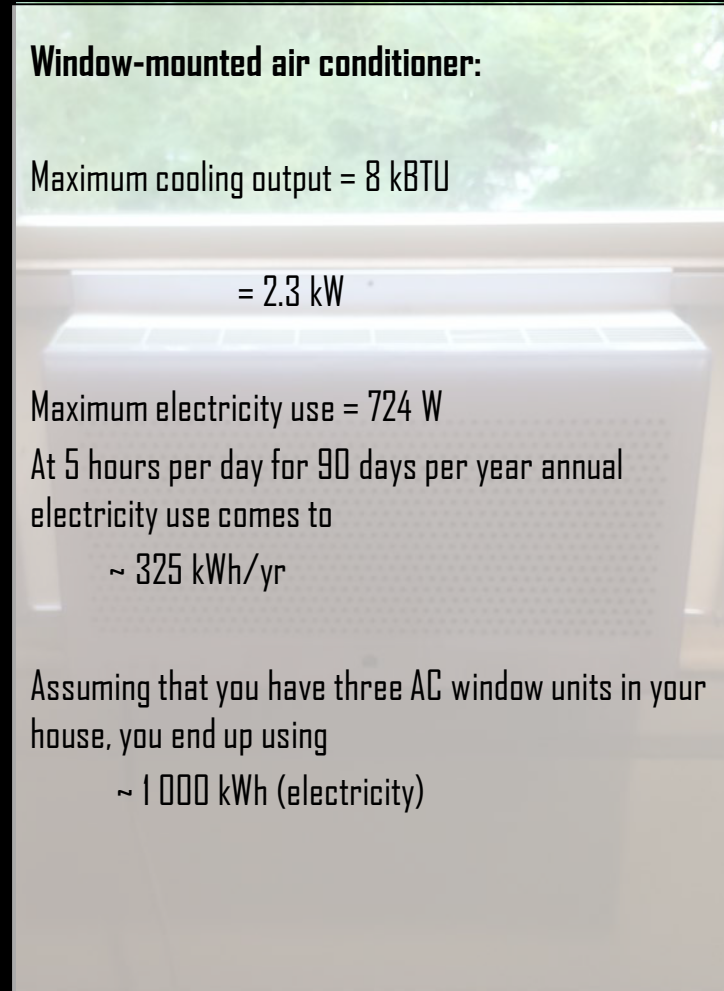
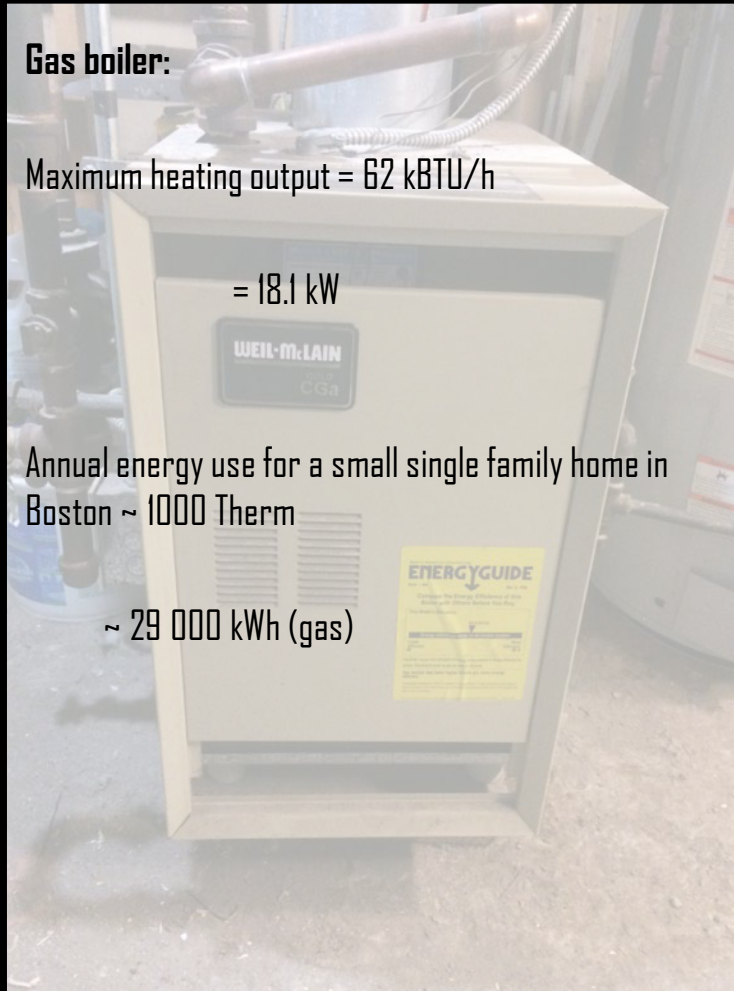
Annual energy use = 150 kWh/yr

□ A fridge constitutes one of the main energy uses in a living unit.

□ However, electronic equipment adds up quickly. A heavily used laptop uses 150 kWh/yr. A desktop may use 600 kWh/yr.

# Energy Units for Heating/Cooling

- 1 British Thermal Unit (BTU) = imperial unit, energy needed to cool or heat one pound of water by one degree Fahrenheit = 1 kBTU = 0.293 Wh
- 1 Therm = 100 000 BTU



# Energy Units for Heating/Cooling

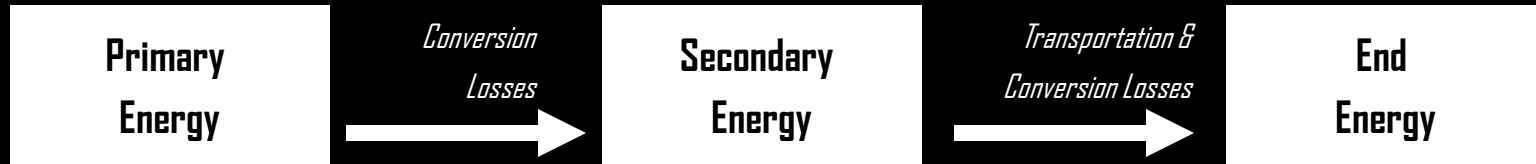
☐ Rule of thumb: The size of a heating and cooling unit depends on the size of the space to be cooled and very roughly corresponds to the following:

☐ Heating unit capacity (mild climate) = 30 BTU x floor area in feet

☐ Heating unit capacity (cold climate) = 60 BTU x floor area in feet

☐ Cooling unit capacity = 20 BTU x floor area in feet

# Energy Conversion



- ❑ **Primary energy** is energy that has not been subjected to any conversion or transformation process. Primary energy is energy contained in raw fuels and any other forms of energy received by a system as input to the system.
- ❑ **Secondary energy** is energy being converted into more convenient forms of energy, such as electrical energy and cleaner fuels.
- ❑ **End Energy** is the energy delivered to a site to carry out work such as heating a house, running a fan, or lighting a room.

**Table 7.5.3-1 CO<sub>2</sub>e Emission Factors**

<b><i>Building Project Energy Source</i></b>	<b>CO<sub>2</sub>e lb/kWh (kg/kWh)</b>
Grid delivered electricity and other fuels not specified in this table	1.670 (0.758)
LPG or propane	0.602 (0.274)
Fuel oil (residual)	0.686 (0.312)
Fuel oil (distillate)	0.614 (0.279)
Coal (except lignite )	0.822 (0.373)
Coal (lignite)	1.287 (0.583)
Gasoline	0.681 (0.309)
Natural gas	0.510 (0.232)

❑ 10 000 kWh electricity = 7.6 ton CO<sub>2</sub>e

❑ 29 000 kWh natural gas = 6.7 ton CO<sub>2</sub>e

❑ Gas and electricity use have comparable environmental impact.

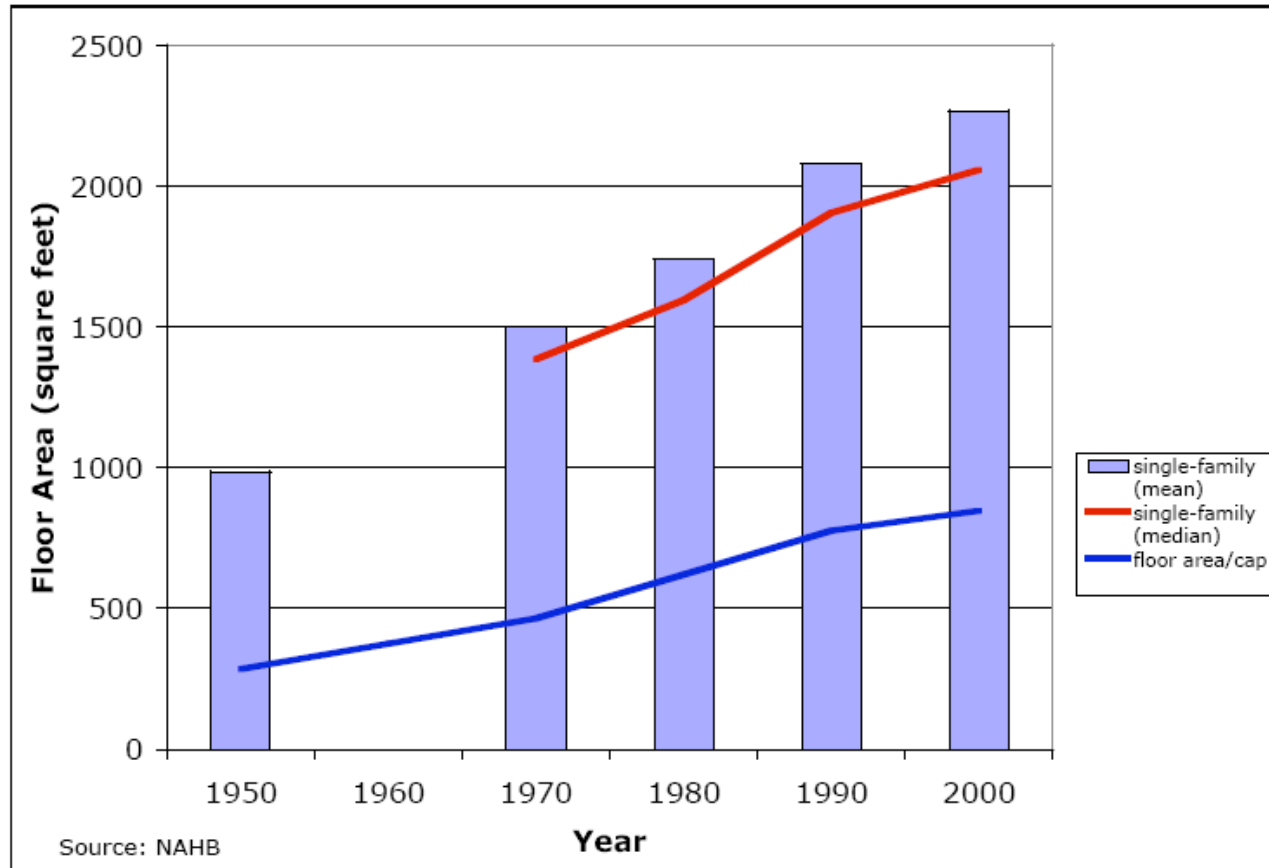
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# Energy Use Intensity (EUI)

- ❑ Is a widely used performance metric to describe the energy performance of a building. It is defined as the annual site energy use of a building divided by its floor area. It is expressed in kWh/m<sup>2</sup>yr or kBTU/ft<sup>2</sup>yr with 1 kWh/m<sup>2</sup>yr = 317 BTU/ft<sup>2</sup>yr
- ❑ When applied to a building that uses electricity and gas, adding energy use for gas and electricity is literally mixing “apples and oranges.”
- ❑ By normalizing energy use by building size, the goal is to compare the energy performance of different buildings. This **works best for buildings of comparable size, with similar programs and in related climates.**
- ❑ EUI is a measure of how efficiently a space is thermally conditioned (heated and cooled) and lit. It is not a **measure of the efficiency of the building program.** In fact, having a spatially inefficient program with occupants and equipment spread over a larger area can reduce the EUI of a building.

# Floor Area of US Residential Buildings

**Figure 3. US New Single-Family Housing Floor Area (Square Feet)  
Mean, Median and Per Capita**

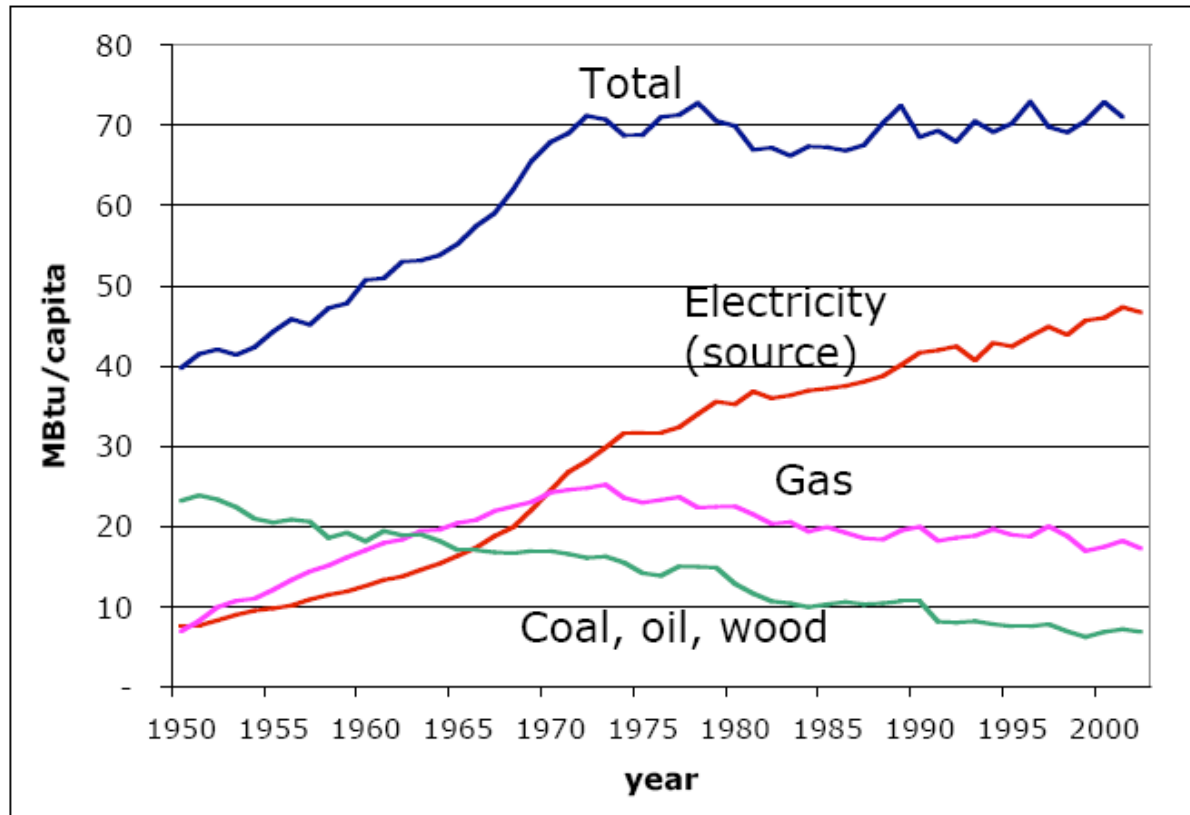


Source: NAHB

Source: NAHB, US Census

# Energy Use per Capita

Figure 2. US Residential Energy Use Per Capita, Total, Electricity [Source], Gas and Other (MBtu/cap)

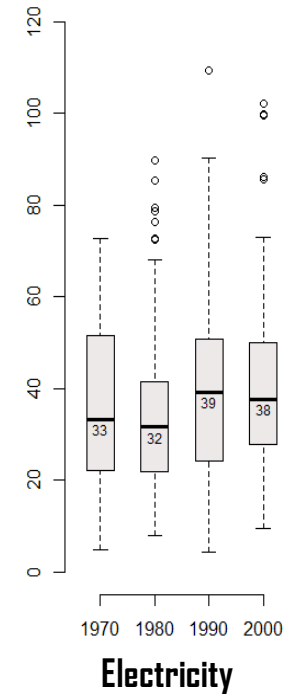
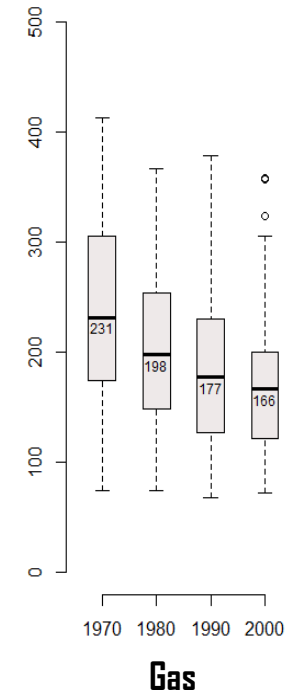


Source: EIA 2003

This image is in the public domain. Source: <https://homes.lbl.gov/sites/all/files/lbnl-55011.pdf>



# Building Energy Use by Age



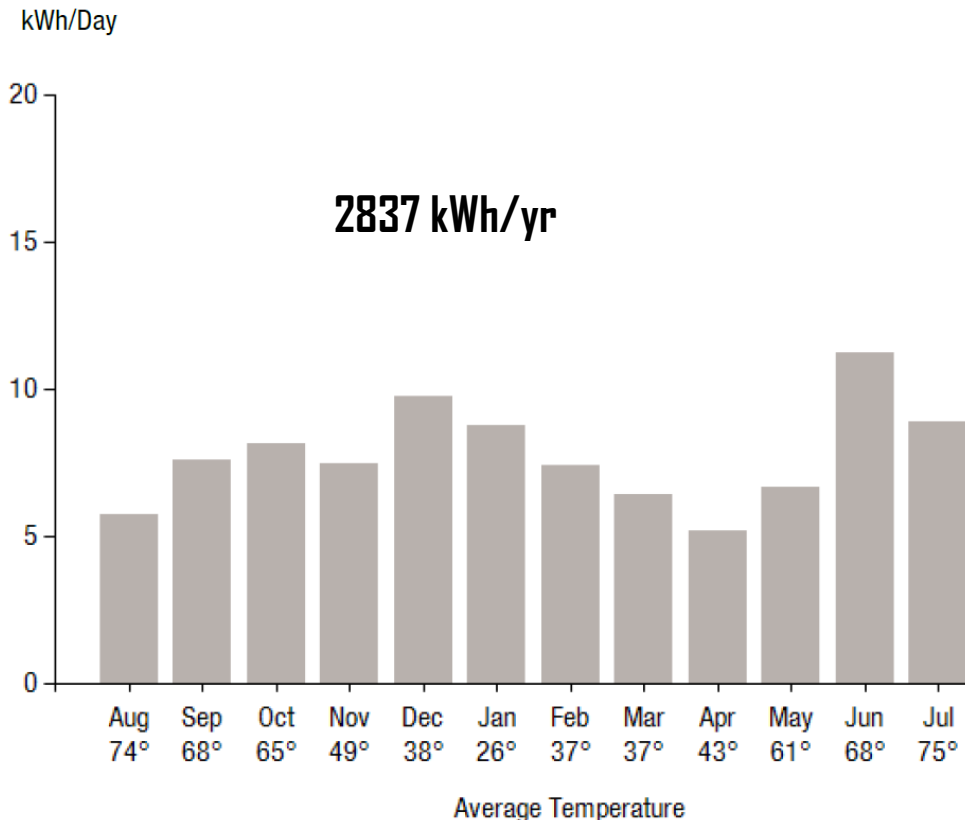
Source: J Sokol, C Cerezo and C F Reinhart, "Validation of a Bayesian-Based Method for Defining Archetypes in Urban Building Energy Models," Energy and Buildings, 134, pp. 11-24, 2017 . @ Elsevier B.V. All rights reserved. This content is excluded from our Creative Commons license. For more information, see <https://ocw.mit.edu/help/faq-fair-use/>.

# Beyond Energy Use Intensity

- ❑ For day-to-day decisions owners favor **costs** and/or maintenance costs per floor area to analyze buildings.
- ❑ To overcome some of the limitations of EUI, annual energy use for a space can be **normalized by person hours** used. This metric interprets a building as a service provider for comfortable space conditions (adequate temperature and lighting).
- ❑ The drawback of this metric is that it largely lies out of the control of the architect how a building is being used. Is a building design “bad” because occupants behave inefficiently?
- ❑ On the other side, is a high EUI for an office building that is being used 24/7 an indication of poor performance?

# Assignment 1: Your Past Energy Use

## Electric Usage History - Kilowatt Hours (kWh)

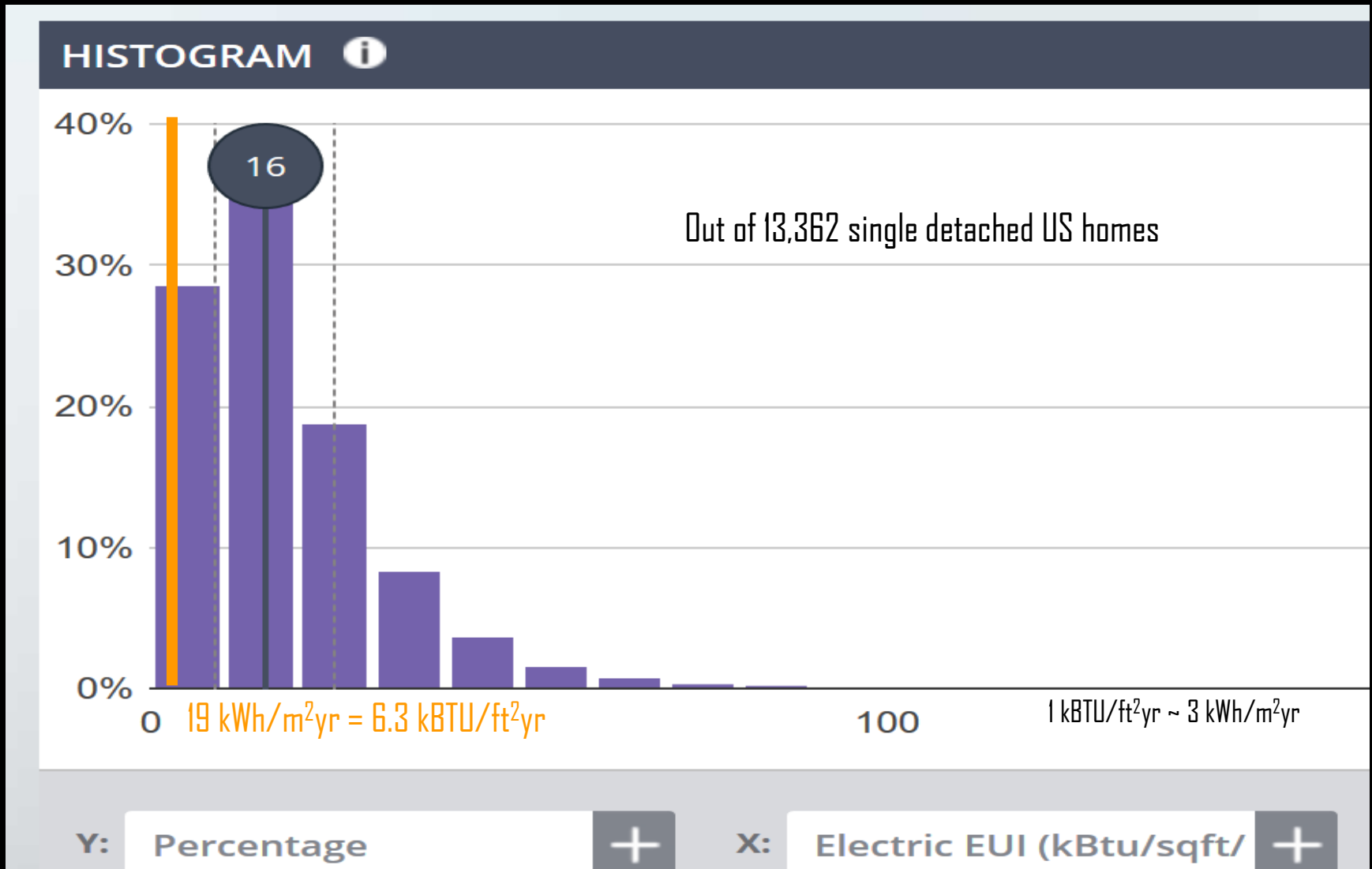


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□ 2837 kWh/yr / 150 m<sup>2</sup> ~ 18.9 kWh/m<sup>2</sup> yr

□ 2837 kWh/ yr / 4 person ~ 709 kWh/person year


# Buildings Performance Database



Source: <http://energy.gov/eere/buildings/building-performance-database>. This image is in the public domain.


# Handy Online Energy Converter


**Welcome to OnlineConversion.com**  
Energy Conversion

Convert what quantity?  

From: To:

<ul style="list-style-type: none"><li>attojoule</li><li>Board of Trade unit</li><li>Btu</li><li>Btu [thermochemical]</li><li>calorie [I.T.]</li><li>calorie [15° C]</li><li>Calorie [nutritional]</li><li>calorie [thermochemical]</li><li>celsius heat unit</li><li>centijoule</li></ul>	<ul style="list-style-type: none"><li>attojoule</li><li>Board of Trade unit</li><li>Btu</li><li>Btu [thermochemical]</li><li>calorie [I.T.]</li><li>calorie [15° C]</li><li>Calorie [nutritional]</li><li>calorie [thermochemical]</li><li>celsius heat unit</li><li>centijoule</li></ul>
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Result: 

Source: <http://www.onlineconversion.com/energy.htm>. © Robert Fogt. All rights reserved. This content is excluded from our Creative Commons license. For more information, see <https://ocw.mit.edu/help/faq-fair-use/>.

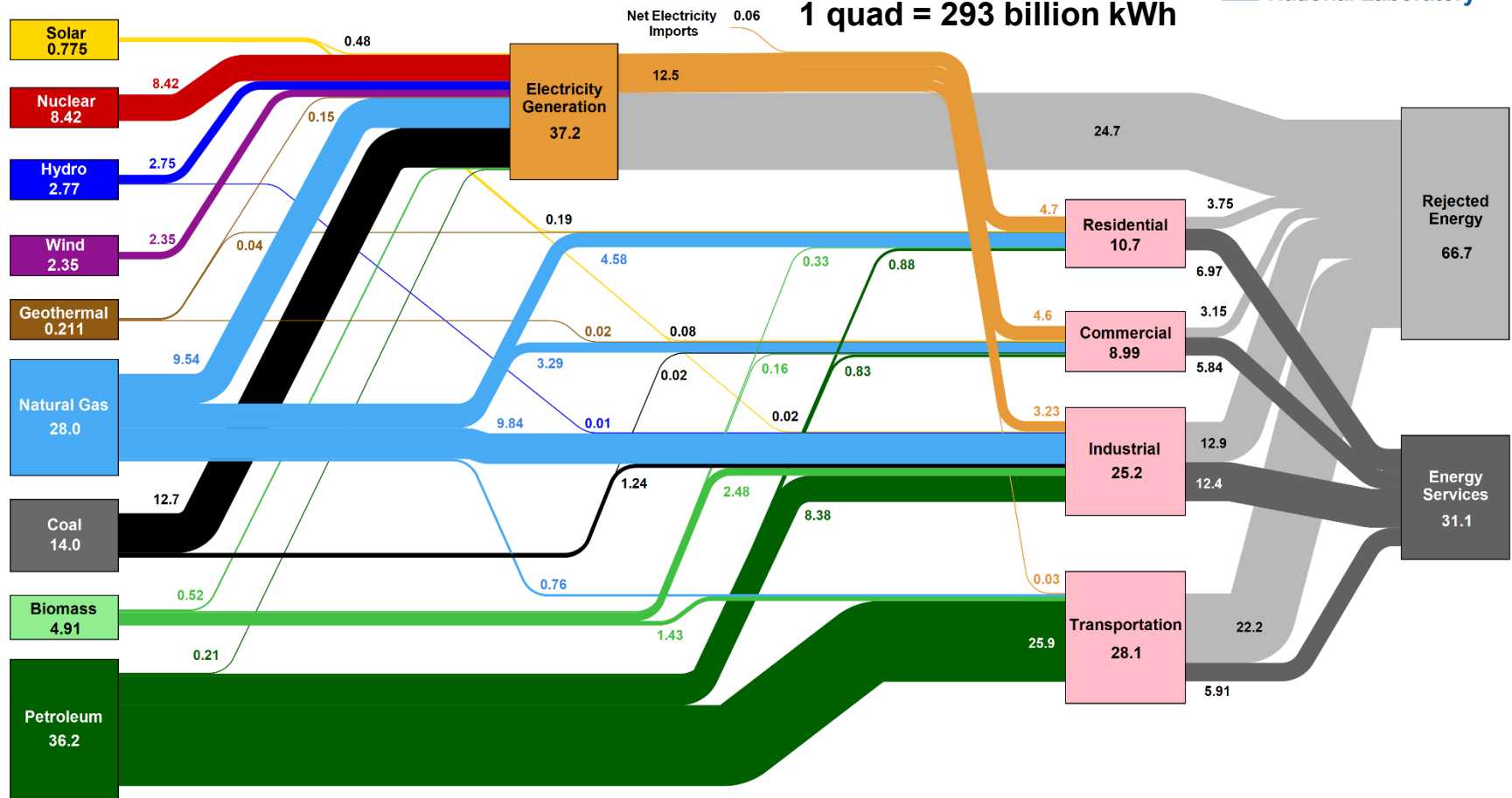
*How does building energy use fit in the overall US energy infrastructure?*

# US Energy Flows 2017

Estimated U.S. Energy Consumption in 2017: 97.7 Quads



1 quad = 293 billion kWh

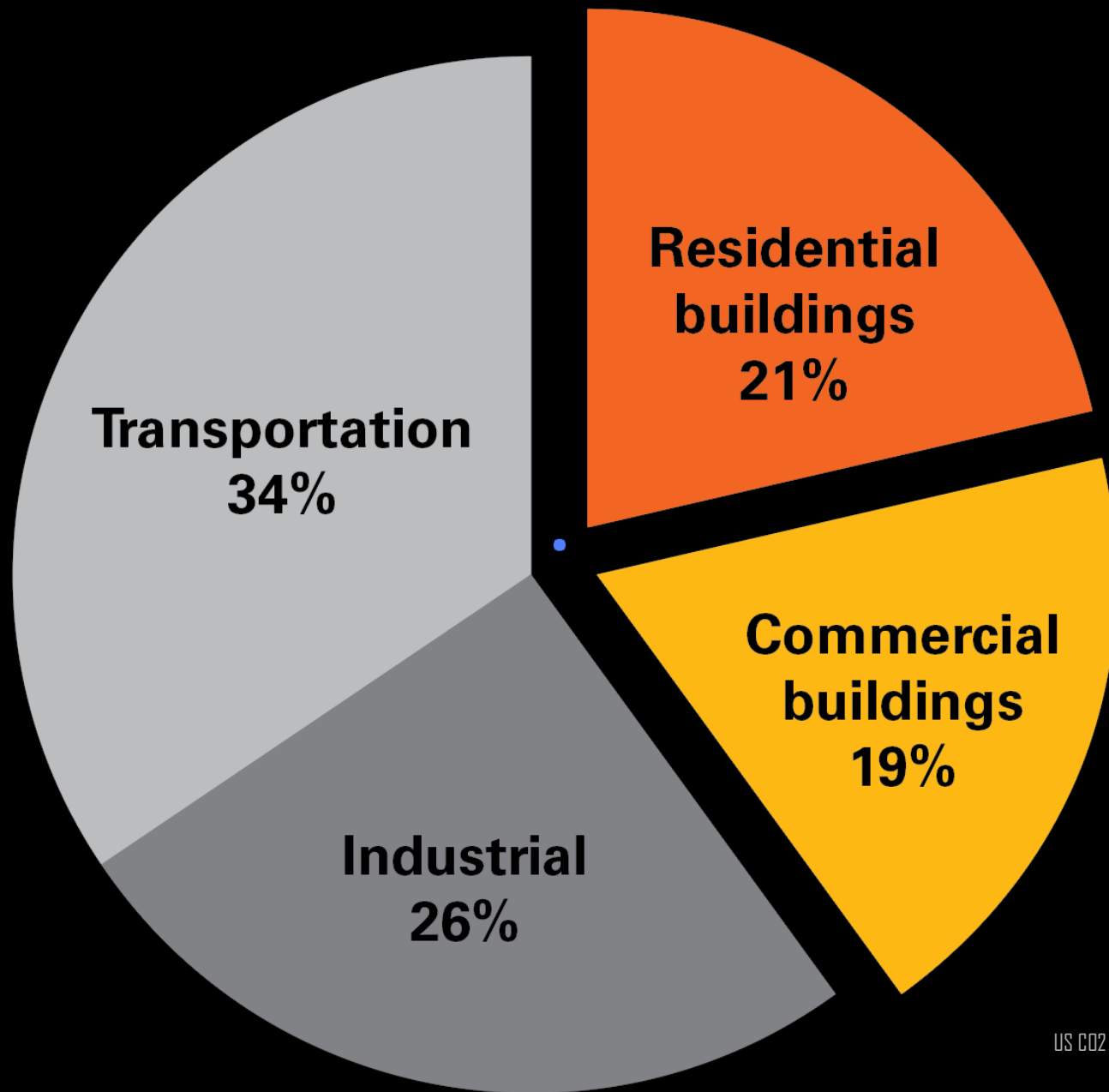


Source: LLNL April, 2018. Data is based on DOE/EIA MER (2017). If this information or a reproduction of it is used, credit must be given to the Lawrence Livermore National Laboratory and the Department of Energy, under whose auspices the work was performed. This chart was revised in 2017 to reflect changes made in mid-2016 to the Energy Information Administration's analysis methodology and reporting. The efficiency of electricity production is calculated as the total retail electricity delivered divided by the primary energy input into electricity generation. End use efficiency is estimated as 65% for the residential sector, 65% for the commercial sector, 21% for the transportation sector, and 49% for the industrial sector which was updated in 2017 to reflect DOE's analysis of manufacturing. Totals may not equal sum of components due to independent rounding. LLNL-MI-410527

Source: [https://flowcharts.llnl.gov/content/assets/images/energy/us/Energy\\_US\\_2017.png](https://flowcharts.llnl.gov/content/assets/images/energy/us/Energy_US_2017.png). This image is in the public domain.

Electricity Use: 1/3 Industrial, 1/3 Residential, 1/3 Commercial

End Energy Use: 1/3 Transportation, 1/3 Industrial, 1/3 Buildings

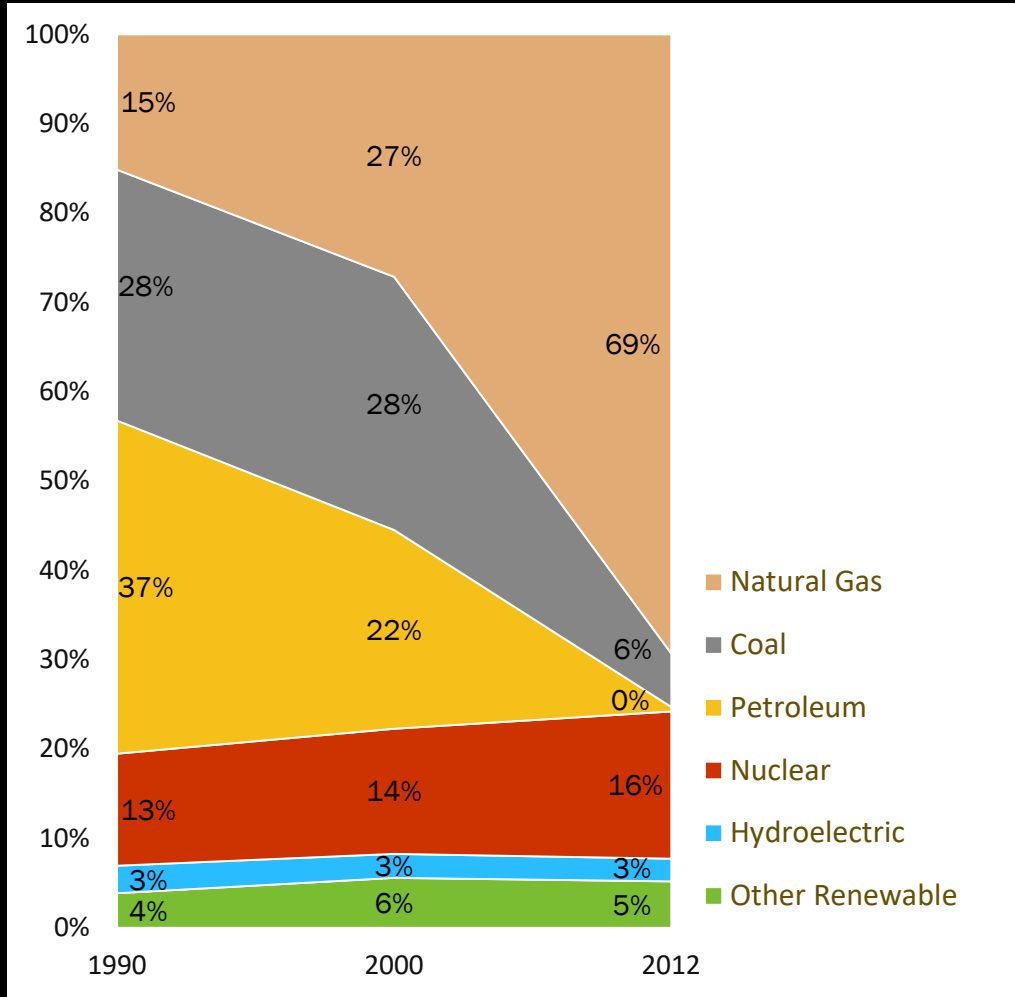


US CO2 emission by sector



# Decarbonization of the Electric Grid

Massachusetts Historical Electricity Generation by Source (%) (1990-2012)



Graph based on data from <http://www.eia.gov/state/?sid=MA>.

*How do we compare to the rest of the world?*

# World Energy Use and Population

**7.6 x 10<sup>9</sup> People** (2015)

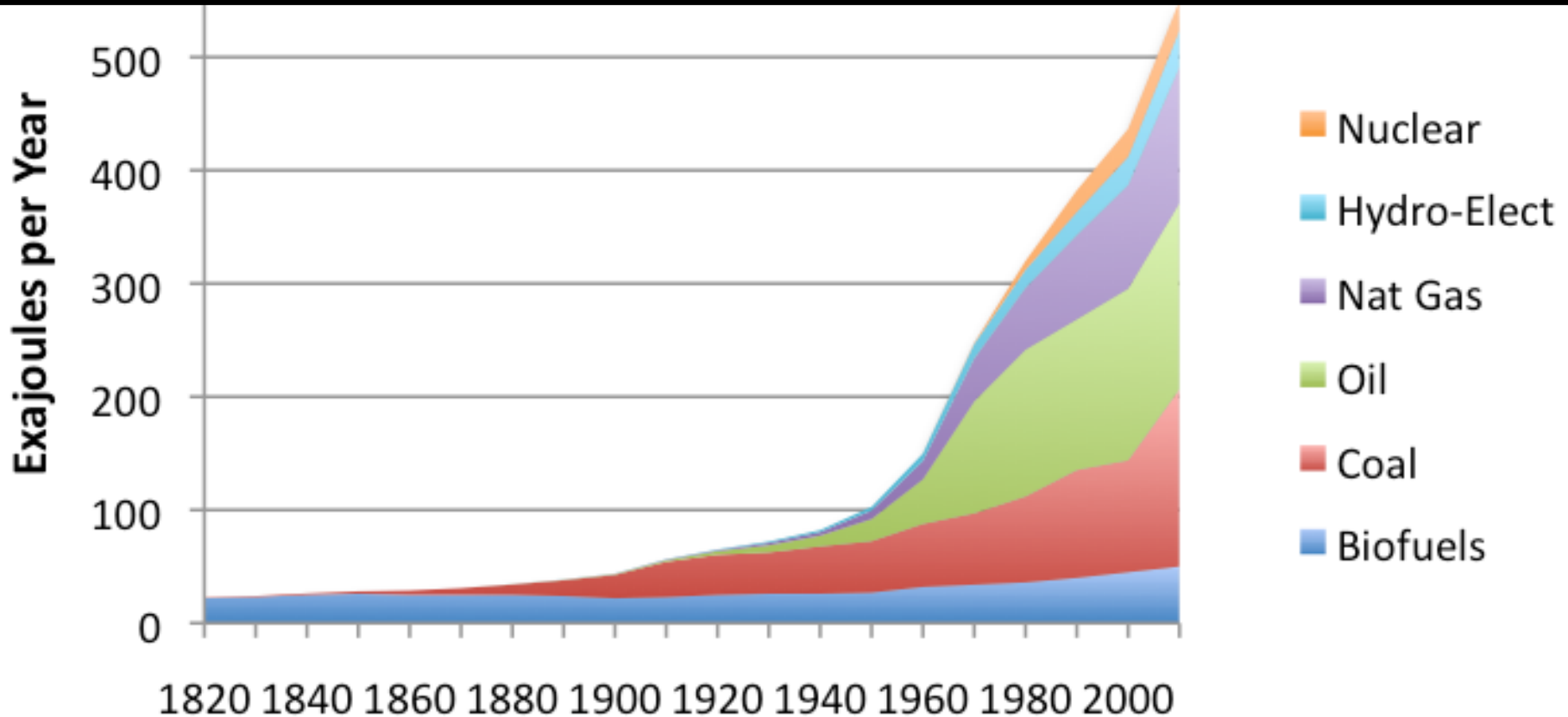
using

**10<sup>14</sup> kWh** (2013)

**13000 kWh/person**

**(10% of average American)**

# Where does our energy come from?



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# High Performance Buildings

# Terminology

## Sustainable – Green – Net Zero

□ These are related but different terms to characterize the environmental performance of a building. When developing an environmental concept for a building, the design team should early on agree upon what type of building they aim to design.

- o **Sustainable:** most comprehensive as it addresses societal, economic, and environmental concerns.
- o **Green:** includes operational energy use, embodied energy use, on site resource management, and occupancy well-being
- o **Net zero energy:** concentrates on balanced use and generation of energy (differences exist as to whether energy has to be generated on-site or off-site and whether the cost for energy or primary energy should be considered. Embodied energy of the building structure is sometimes considered as well.)

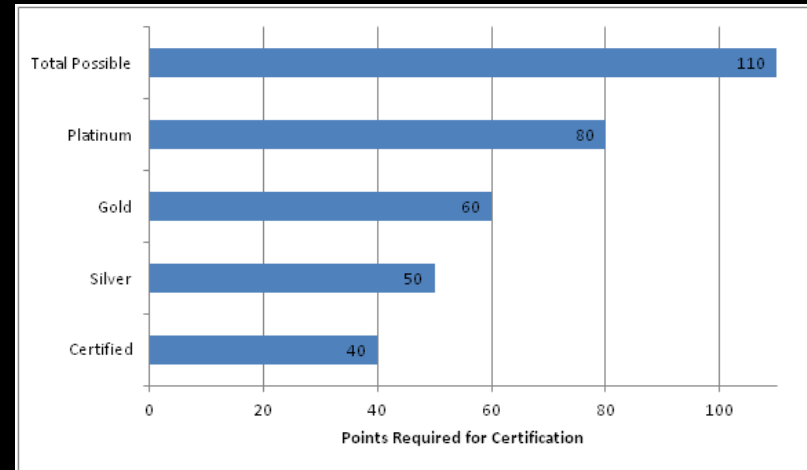
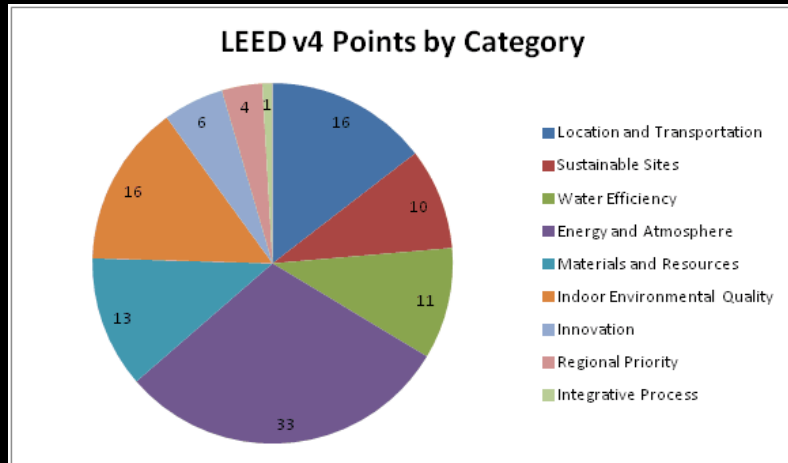
# 'Green' Building Design



Greenbuild 2011

□ The 'green' building market has become a mass movement (Greenbuild ~30,000 visitors, Light+Building 180,000 visitors).

# LEED – A Market Transformation Tool



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❑ LEED is a green building rating system.

❑ LEED stands for Leadership in Energy and Environmental Design.

❑ LEED operates at the building levels and addresses: Sustainable Sites, Water Efficiency, Energy & Atmosphere, Materials and Resources, and Indoor Environmental Quality.

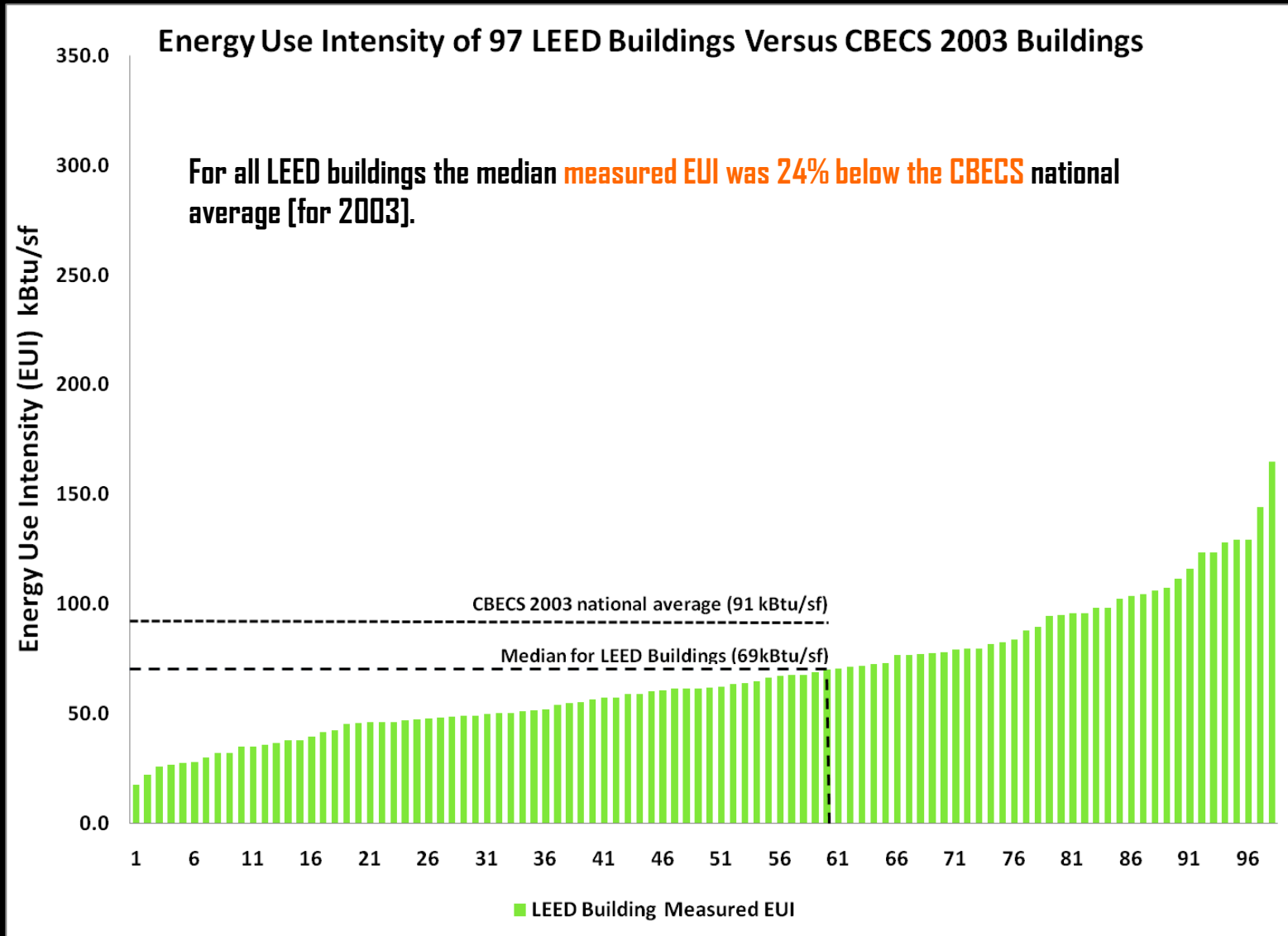
❑ As of fall 2016, ~150,000 buildings were LEED registered and certified (106,000 homes, 33,500 commercial projects).

❑ LEED ratings come in Certified, Silver, Gold and Platinum.



# Energy Performance of LEED Buildings

New Buildings Institute (NBI) Study (2008)



# Energy Star Target Finder

- ❑ A useful first step is to establish a meaningful baseline for energy use.
- ❑ The Energy Star Target Finder is based on the US Energy Information Administration's Commercial Building Energy Consumption Survey (CBECS).
- ❑ CBECS 2003: ~5000 commercial buildings across the US

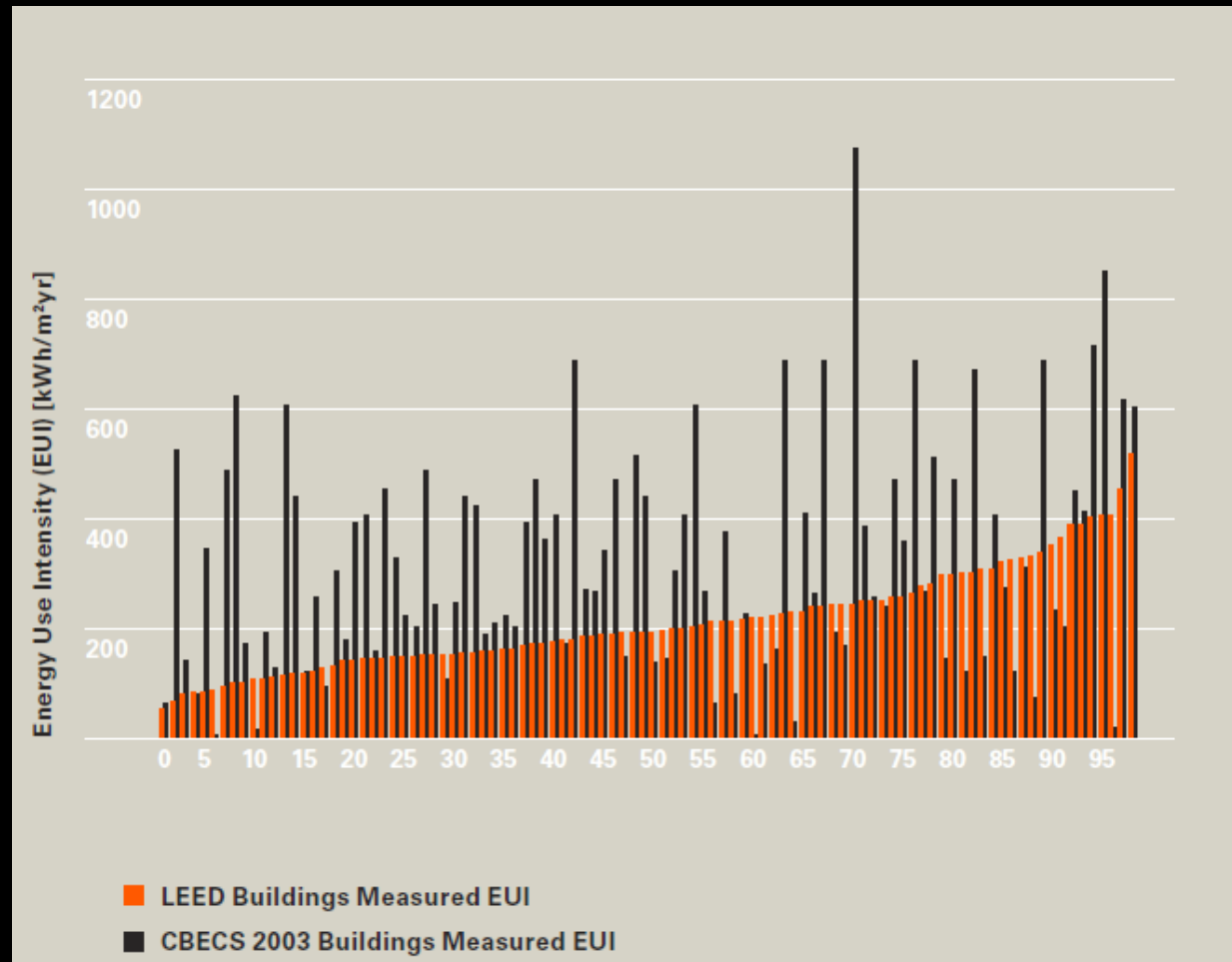
<http://www.energystar.gov/buildings/service-providers/design/step-step-process/evaluate-target/epa%20%80%99s-target-finder-calculator>

The screenshot shows the Energy Star Target Finder interface. At the top, there is a navigation bar with the Energy Star logo, the text 'TARGET FINDER', and links for 'PRINT', 'FAQ FREQUENTLY ASKED QUESTIONS', 'CONTACT US', and 'HELP'. Below the navigation bar, a breadcrumb trail reads 'Return to ENERGY STAR Web site > Target Energy Performance Results'. The main heading is 'Target Energy Performance Results'. To the right of this heading, a note states: 'The design **must** achieve a rating of 75 or higher to be eligible for "Designed to Earn the ENERGY STAR".' Below this note is a button labeled 'View Statement of Energy Design Intent'. A note below the button explains the assumptions: 'NOTE: Assumptions are 74% Electricity - Grid Purchase and 26% Natural Gas. The Target & Average Building energy use for this facility are calculated based on the typical fuel mix in the zip code specified.' The core of the screenshot is a table titled 'Target Energy Performance Results (estimated)'. The table has four columns: 'Energy', 'Design', 'Target', and 'Average Building'. The rows include various energy metrics, with 'Total Annual Site Energy (kBtu)' highlighted by a yellow border. The 'Total Annual Site Energy (kBtu)' row shows a Design value of N/A, a Target of 13,582,210, and an Average Building value of 19,403,157. Other rows include Energy Performance Rating (1-100), Energy Reduction (%), Source Energy Use Intensity (kBtu/Sq. Ft./yr), Site Energy Use Intensity (kBtu/Sq. Ft./yr), Total Annual Source Energy (kBtu), Total Annual Energy Cost (\$), Pollution Emissions, CO2-eq Emissions (metric tons/year), and CO2-eq Emissions Reduction (%).

Target Energy Performance Results (estimated)			
Energy	Design	Target	Average Building
<a href="#">Energy Performance Rating (1-100)</a>	N/A	78	50
<a href="#">Energy Reduction (%)</a>	N/A	30	0
<a href="#">Source Energy Use Intensity (kBtu/Sq. Ft./yr)</a>	N/A	186	265
<a href="#">Site Energy Use Intensity (kBtu/Sq. Ft./yr)</a>	N/A	68	97
<a href="#">Total Annual Source Energy (kBtu)</a>	N/A	37,142,563	53,060,804
<a href="#">Total Annual Site Energy (kBtu)</a>	N/A	13,582,210	19,403,157
<a href="#">Total Annual Energy Cost (\$)</a>	N/A	\$ 400,552	\$ 572,216
Pollution Emissions			
<a href="#">CO2-eq Emissions (metric tons/year)</a>	N/A	1,713	2,447
<a href="#">CO2-eq Emissions Reduction (%)</a>	N/A	30%	0%

This image is in the public domain.

# Performance of LEED Buildings

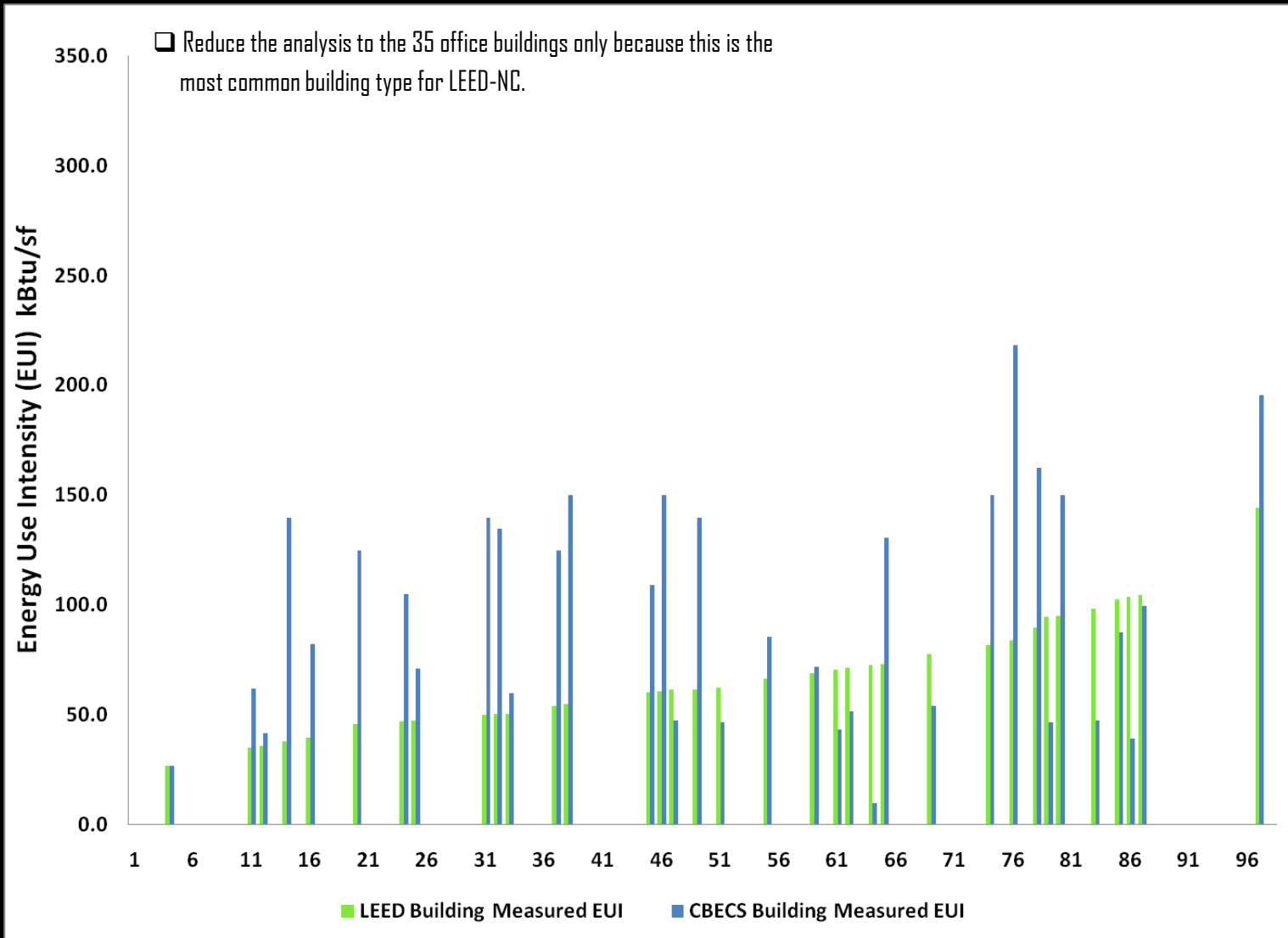


Graph based on LEED-NBI data, CBECs matching by Newsham et al, 2009

- ❑ LEED buildings have on average a 30% lower EUI (Energy Use Intensity).
- ❑ A third of LEED buildings had a higher EUI than their matched CBEC counterpart.

# Energy Performance of LEED Buildings

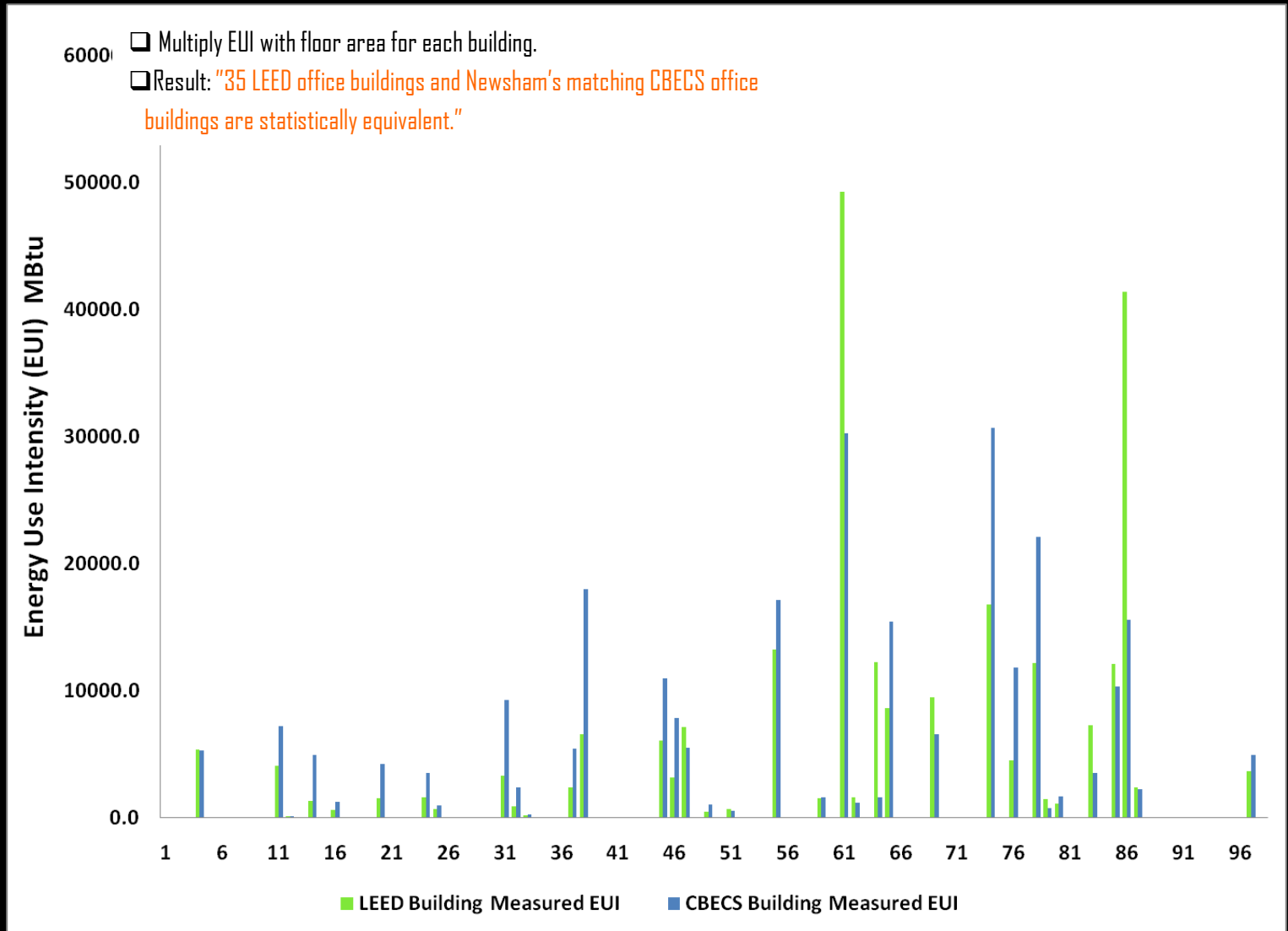
DO LEED buildings save energy? Not Really ...



Paper: J H Scofield, "Do LEED-certified buildings save energy? Not really..." *Energy and Buildings*, Volume 41, Issue 12, December 2009, Pages 1386-1390

# Energy Performance of LEED Buildings

DO LEED buildings save energy? Not Really ...

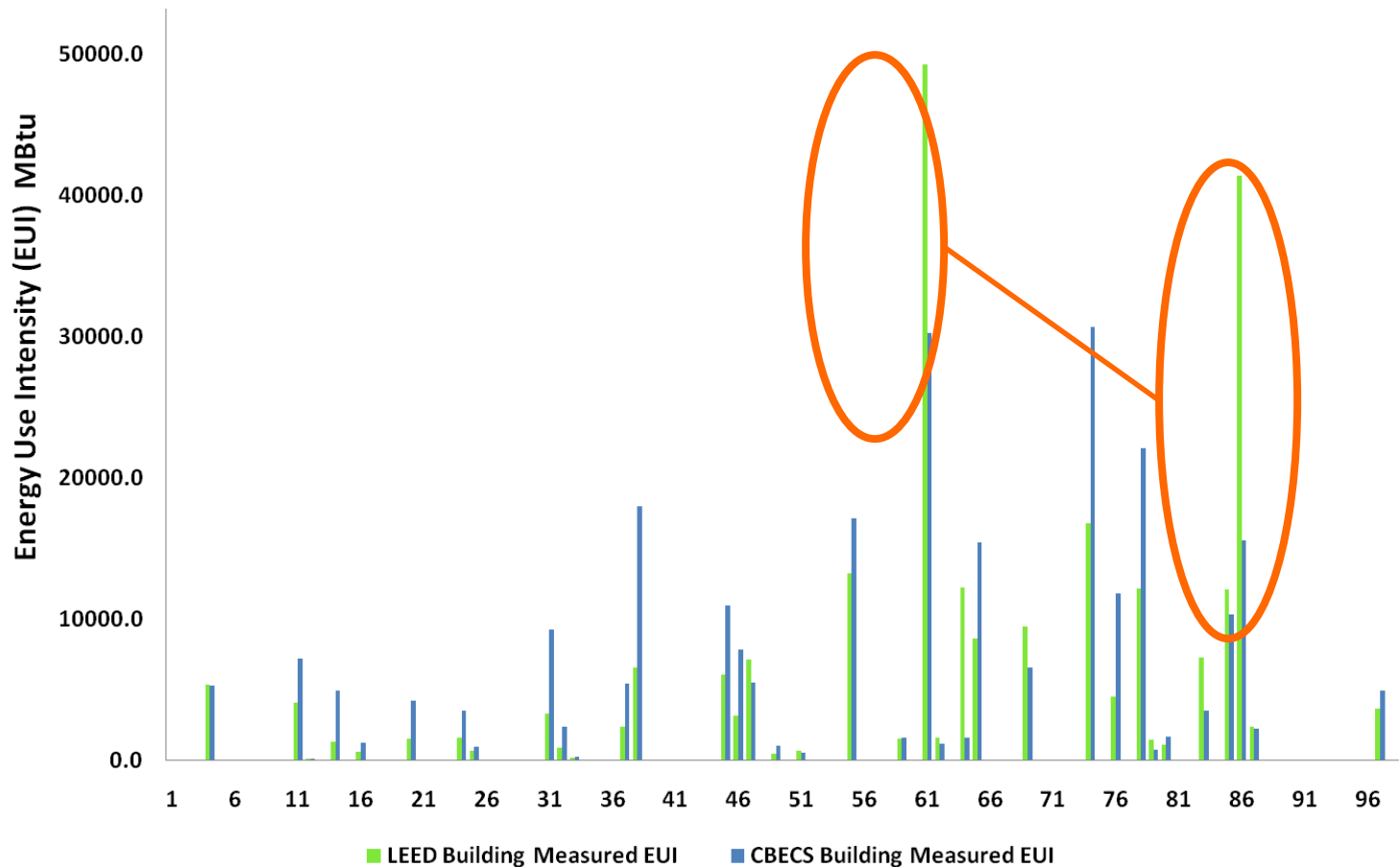


Paper: J H Scofield, "Do LEED-certified buildings save energy? Not really..." *Energy and Buildings*, Volume 41, Issue 12, December 2009, Pages 1386-1390

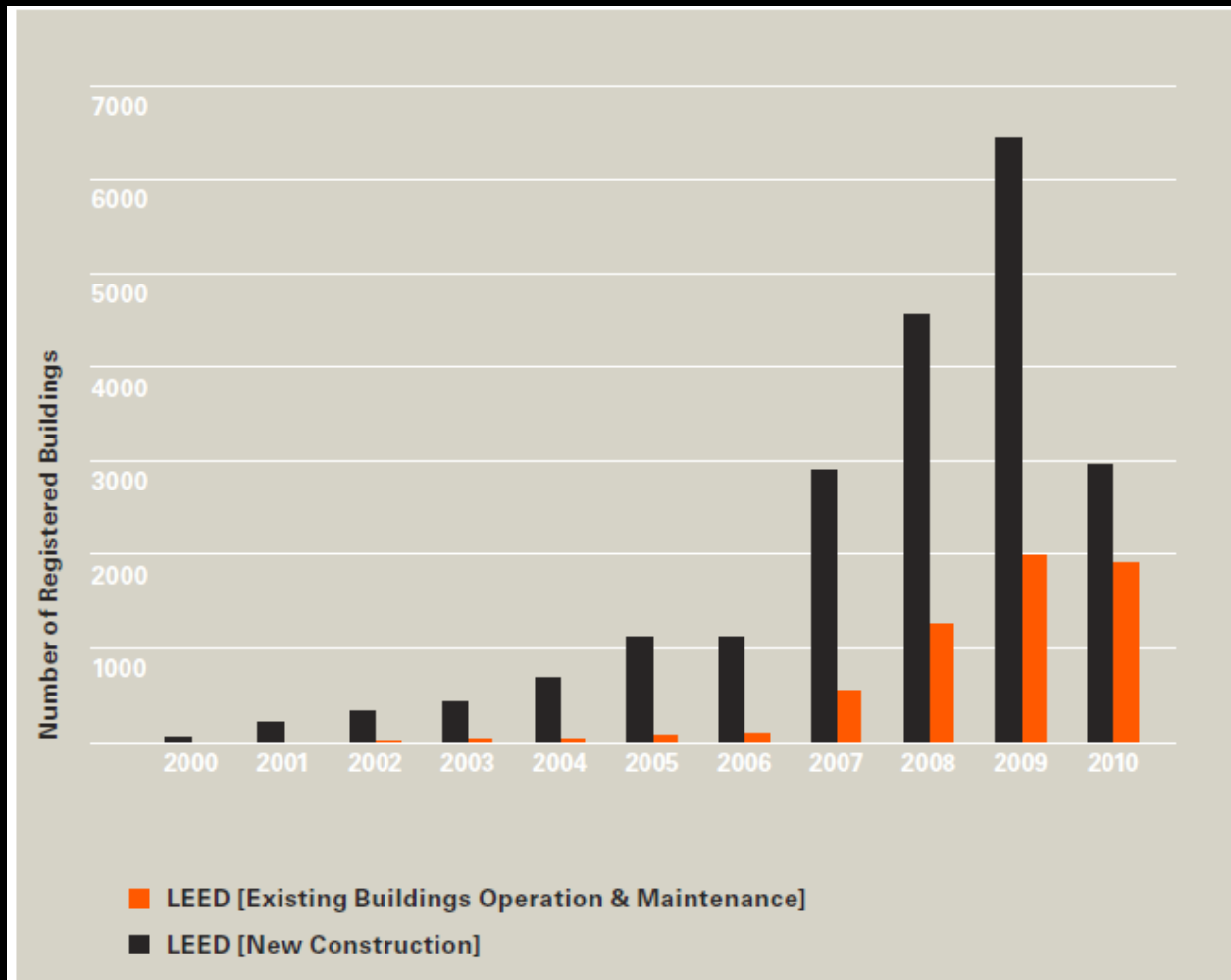
# Energy Performance of LEED Buildings

DO LEED buildings save energy? Not really ...

- 6
- Notice significance of two large buildings (700000 ft<sup>2</sup> and 400000 ft<sup>2</sup>).
  - Are smaller LEED office buildings generally more energy-efficient than larger buildings? (Argument on the 'over-use' of PV in smaller buildings.)



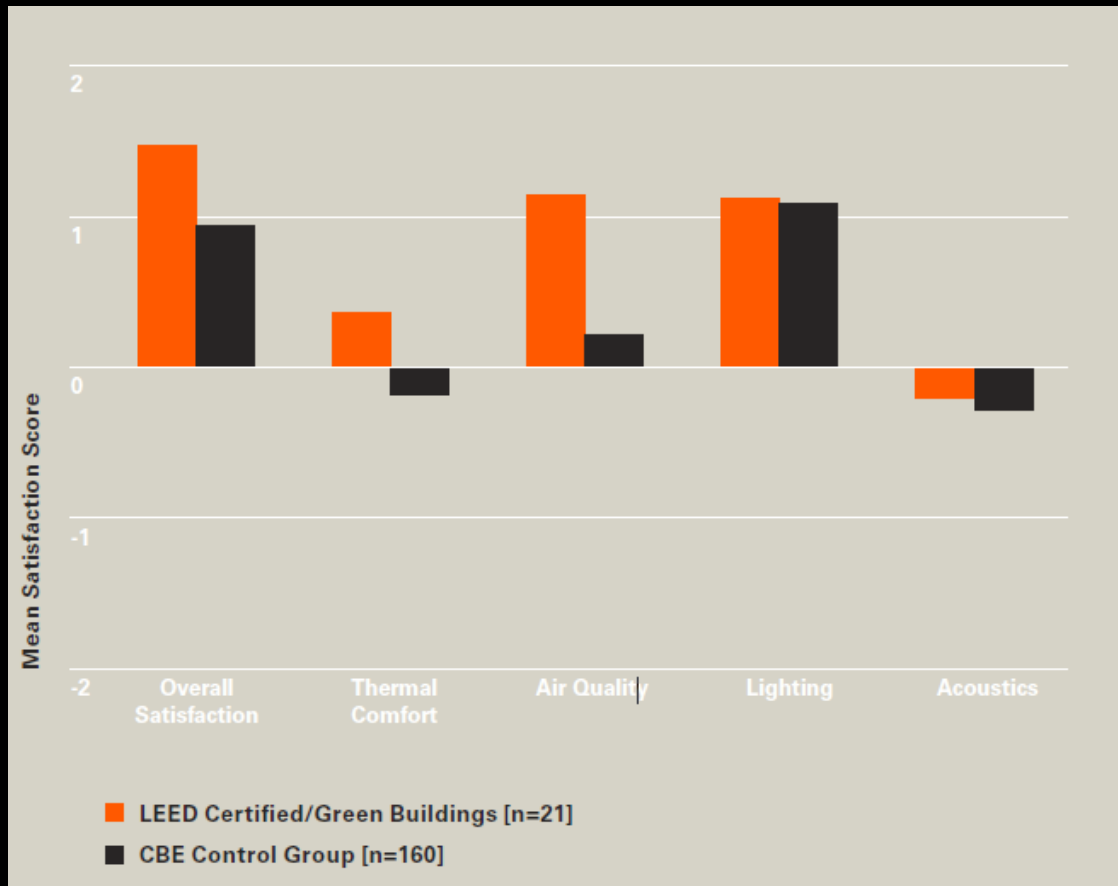
# Trend for LEED-NC and LEED-EBOM



Graph based on USGBC data.

□ Owners are learning that commissioning is key.

# Environmental Satisfaction in LEED Buildings (2006)

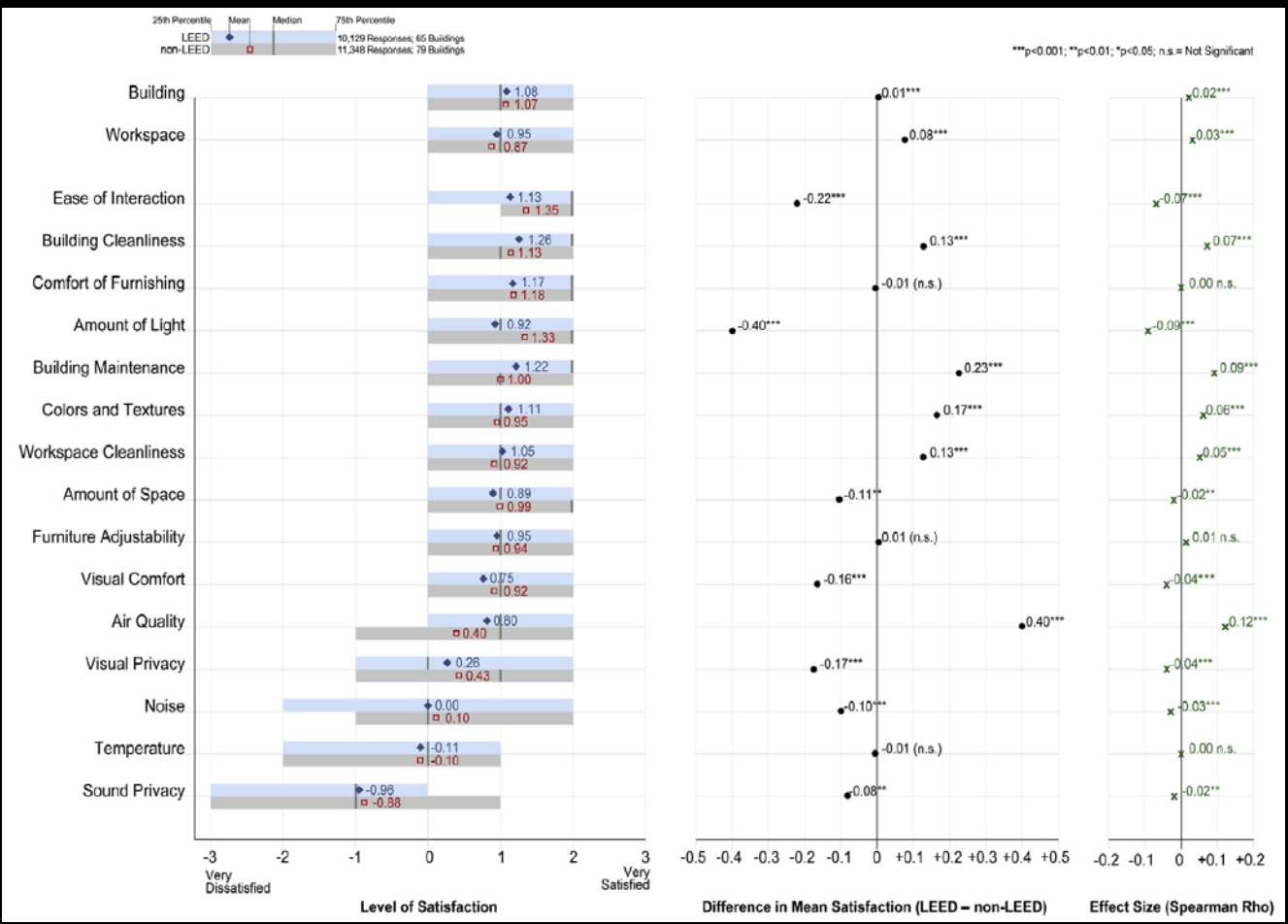


Graph based on data from S. Abbaszadeh et al., 2006.

- ❑ Environmental satisfaction with lighting and acoustics in LEED buildings the same as in conventional buildings. Main complaint: "not enough daylight."
- ❑ In 2009, out of over 1200 buildings that were certified under LEED, 43% and 66% were awarded the daylighting and view credits, respectively.



# Environmental Satisfaction in LEED Buildings (2013)

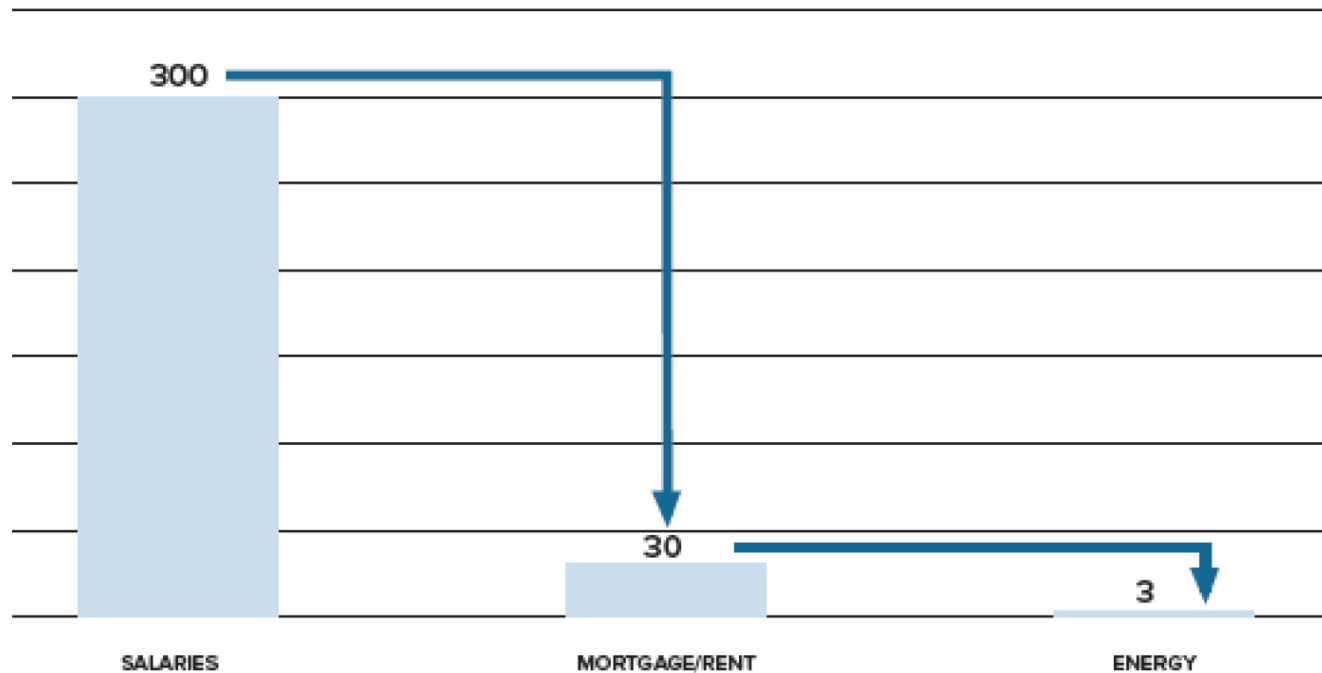


S. Altomonte, S. Schiavon, 2013, "Occupant satisfaction in LEED and non-LEED certified buildings." *Building and Environment* 68, pp. 66-76. Courtesy of Elsevier, Inc., <https://www.sciencedirect.com>. Used with permission.

- Occupants of LEED certified buildings are **equally satisfied** with the building overall and with the workspace as occupants of non-LEED buildings are.
- Occupants of LEED buildings tend to be slightly **more satisfied** with the air quality and workspace cleanliness and **less satisfied** with the amount of light, visual privacy and amount of space than occupants of non-LEED buildings.

# This is important because ...

ANNUAL ORGANIZATION ENERGY AND OTHER COSTS  
(USD per square foot)



Source: [https://rmi.org/wp-content/uploads/2017/04/Pathways-to-Zero\\_Bldg-Case-for-Deep-Retrofits\\_Report\\_2012.pdf](https://rmi.org/wp-content/uploads/2017/04/Pathways-to-Zero_Bldg-Case-for-Deep-Retrofits_Report_2012.pdf). © Rocky mountain Institute.  
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# Financial Performance of LEED & Energy Star Buildings

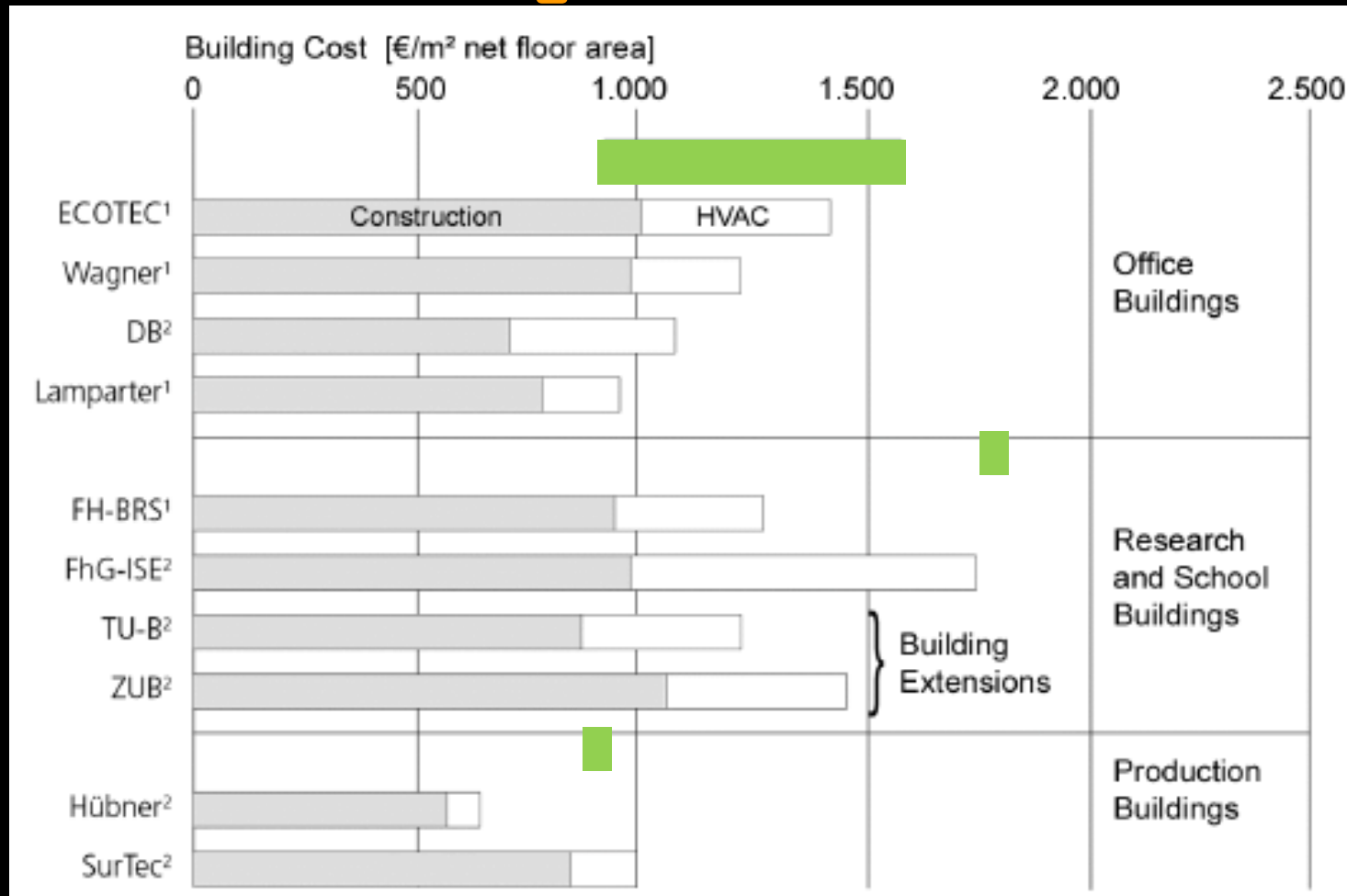
“We find that buildings with a 'green rating' command rental rates that are roughly 3 percent higher per square foot than otherwise identical buildings – controlling for the quality and the specific location of office buildings. *Ceteris paribus*, premiums in effective rents are even higher – above 6 percent. Selling prices of green buildings are higher by about 16 percent.

Our analysis establishes that variations in the premium for green office buildings are systematically related to their energy-saving characteristics. For example, calculations show that a one dollar saving in energy costs from increased thermal efficiency yields roughly 18 dollars in the increased valuation of an Energy-Star certified building.”

Eichholtz, Kok, Quigley 2009

<http://www.ucei.berkeley.edu/PDF/csemwp192.pdf>

# Construction Costs for High Performance German Buildings

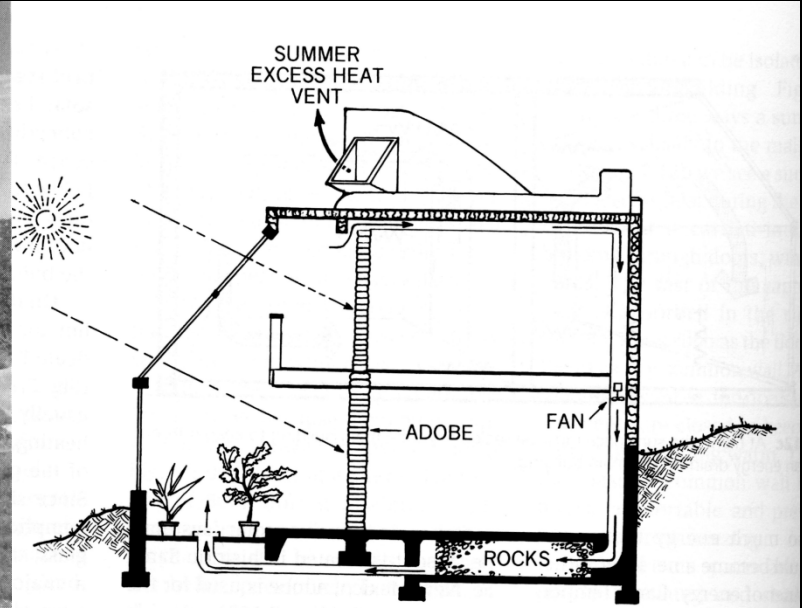


## Costs for German reference buildings in 2000

Paper: Reinhart C F, Voss K, Wagner A, Löhnert G, "Lean buildings: Energy-efficient commercial buildings in Germany." Proceedings of the ACE<sup>3</sup> 2000 Summer Study on Energy Efficiency in Buildings 3 pp.

# Selected Examples

# Solar Architecture (1978)



Balcomb Residence, Santa Fe, NM (around 1978) Photo from Lechner, *Heating, Cooling, Lighting* © John Wiley & Sons. All rights reserved. This content is excluded from our Creative Commons license. For more information, see <https://ocw.mit.edu/help/faq-fair-use/>.

Two-story sunspace, thermal mass, Trombe wall, active air circulation system for thermal comfort, 83% solar heated.

# Self-Sufficient Solar House Freiburg

South-exposed half cylinder  
Air-to-ground heat exchanger  
Ventilation-heat-recovery  
Solar hot water  
Photovoltaics 4.2 kW<sub>peak</sub>  
Transparent insulating panels  
Fuel cells and hydrogen tanks

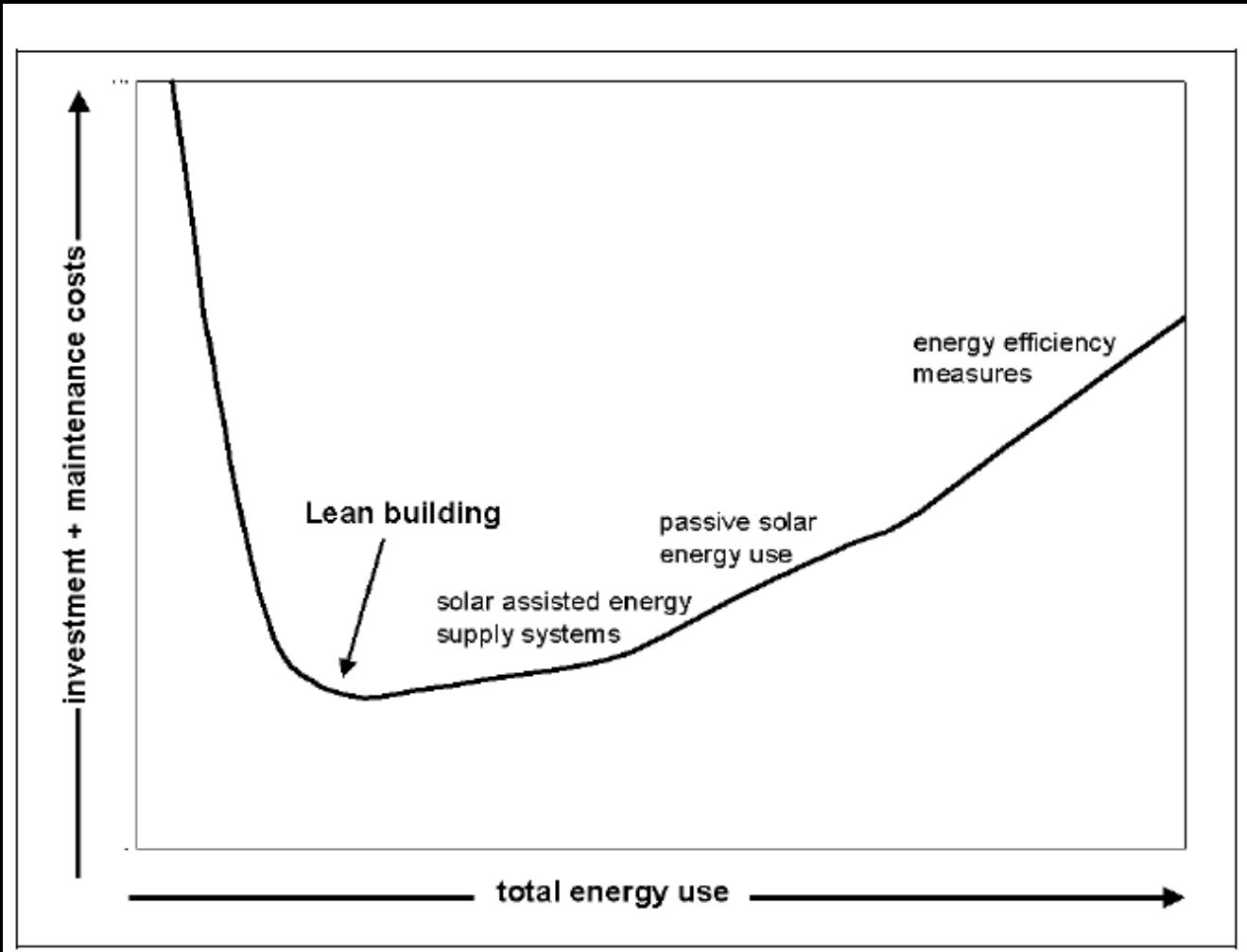


Self-sufficient solar house Freiburg, 1991  
Architecture: Planerwerkstatt Hölken & Berghoff

Mixed reactions in the architectural community:  
the building of the future ... a building in the emergency room

# Lean Building ('Schlankes Gebäude')

Reinhart, Voss, Wagner 2000)

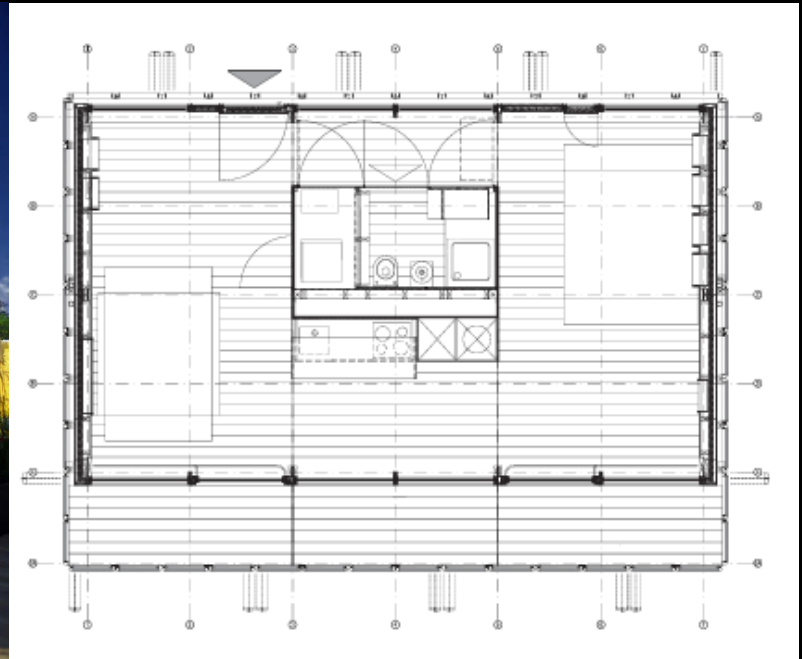


Using the electric grid for energy storage.

Finding the 'sweet spot'.



# Selected Solar Home (2007)



Solar Decathlon Winner 2007 (Team Germany)

“Made in Germany.” Triple glazing, thermal mass through PCM, exterior wooden shutters, PV on the roof, integrated lighting system, clear architectural forms

Left: public domain image courtesy of [Dirk Davidson](#) on Flickr.

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# Passive House

Photo: Mark Peterson/Redux Pictures. © Politico Magazine. All rights reserved. This content is excluded from our Creative Commons license. For more information, see <https://ocw.mit.edu/help/faq-fair-use/>.



- ❑ Reduced heating demand 15 kWh/m<sup>2</sup> per year
- ❑ Tight building envelope (blower door  $n_{50} < 0.6 \text{ hr}^{-1}$ ).
- ❑ Energy-efficient appliances and domestic hot water heating (total primary energy use for heating, hot water and electricity less than 120 kWh/m<sup>2</sup> per year.

# Zero Net Energy Buildings

# This is a Zero Net Energy Building



The New Monte Rosa Hut, Zermatt, CH, 2009

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# What does that mean?

## ZEB

A ZEB is a non grid connected, energy efficient building matching its energy needs by on-site generation fully based on renewables.

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## Net ZEB

A Net ZEB is a grid connected, energy efficient building that balances its total annual energy needs by on-site or near-by generation and associated feed-in credits.

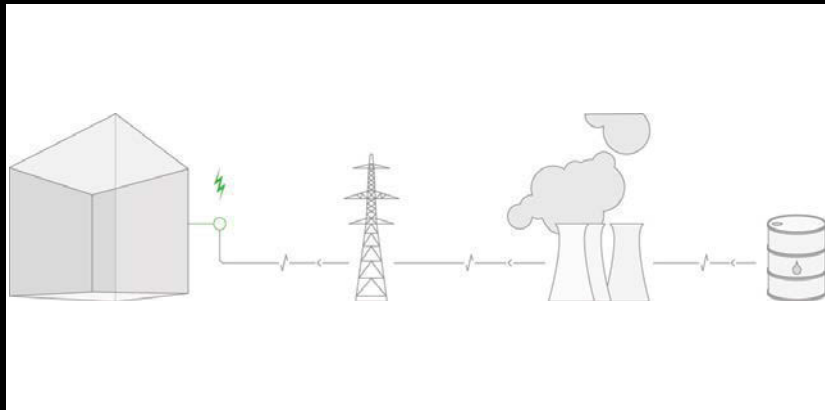
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## Net ZEC

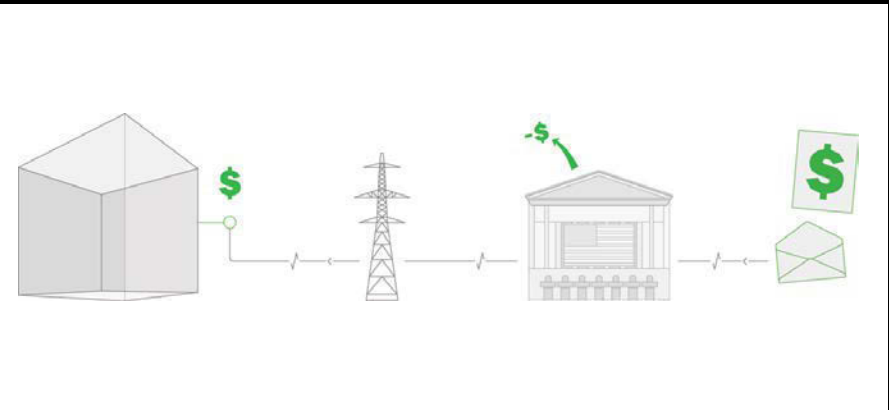
A Net ZEC is a cluster of buildings fulfilling the net zero balance in total using the identical, local energy infrastructure. The cluster uses benefits from the economy of scale and levelling out the load and generation profiles of each building.

# Zero Net Energy Building Definition

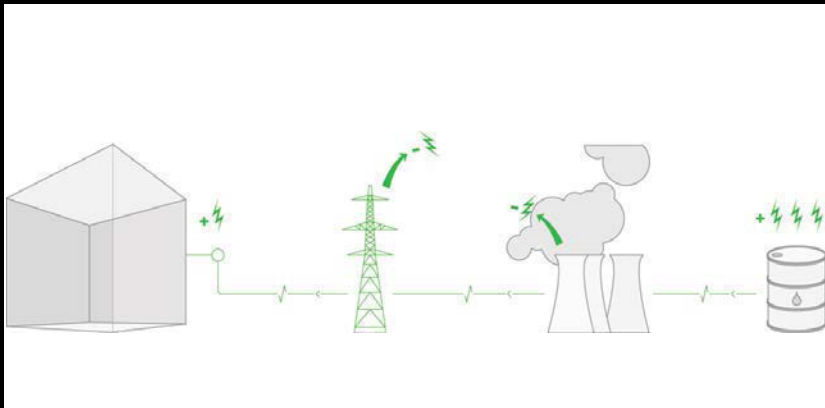
Net Zero Site Energy: produces as much as it uses



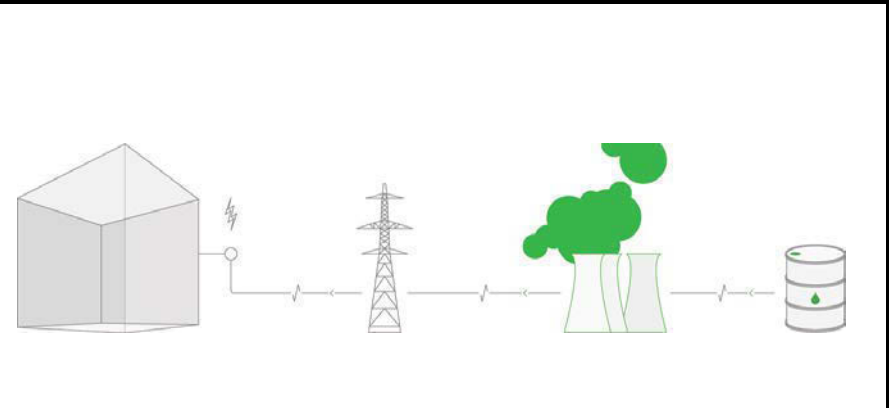
Net Zero Energy Costs: aims for an annual energy bill of \$0



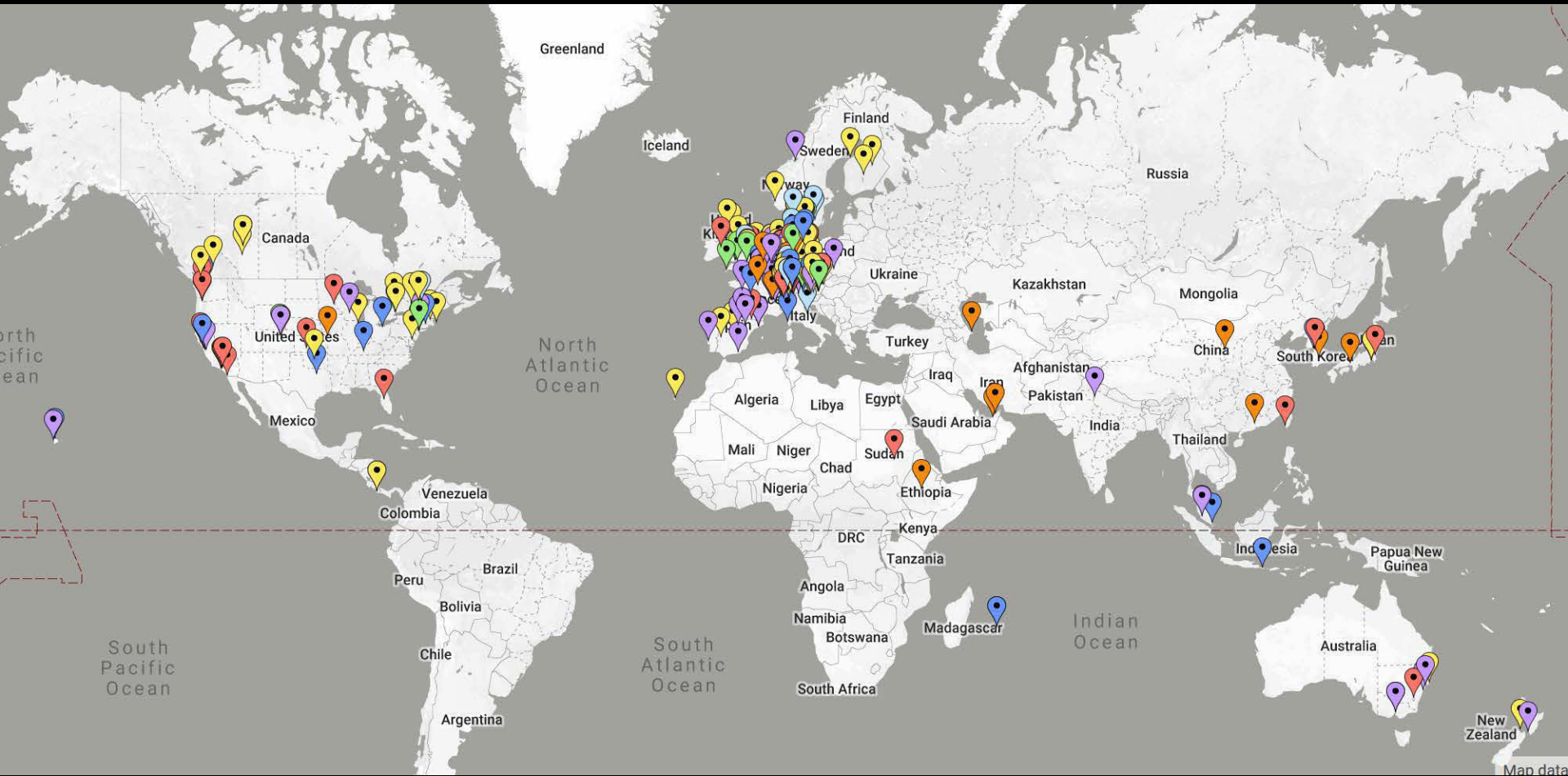
Net Zero Source Energy: produces as much as it uses at sources



Net Zero Energy Emission: aims for carbon neutral



# Net ZEBs in the world



<http://batchgeo.com/map/net-zero-energy-buildings>, © Eike Musall. All rights reserved. This content is excluded from our Creative Commons license.

For more information, see <https://ocw.mit.edu/help/faq-fair-use/>.

Database maintained until 2013

# Examples



Energy Flex House, Denmark



Home for Life, Denmark



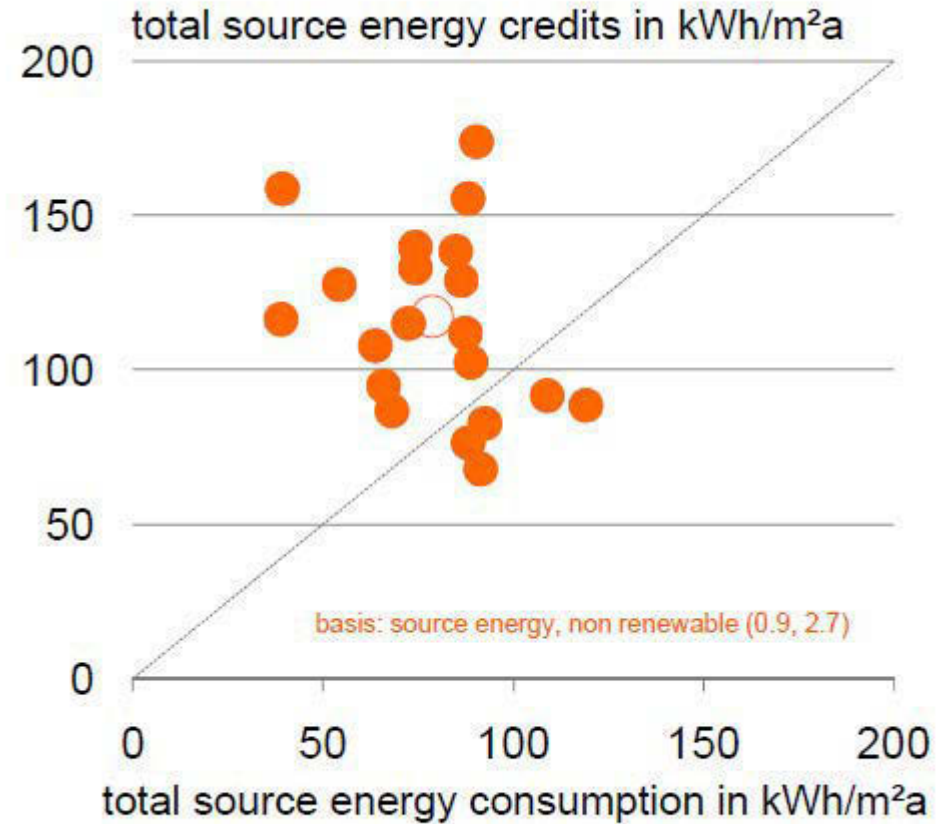
Truro Residence, MA



Aldo Leopold Legacy Center, Fairfield, WI



# Plus Energy Houses



Quelle: Universität Wuppertal, b+tga

Slide courtesy of Karsten Voss. Used with permission.

# Larger Examples



„The first Swiss Zero Energy Office Building“  
Support Office Marché International, Kemtthal, 2008

Architecture and concept: Beat Kämpfen

# Highest Net ZEB in the world?

**HHS** HEGGER · HEGGER · SCHLEIFF  
ARCHITECTEN

**Source: HHS, Kassel**

Aktiv-Stadthaus Frankfurt	
Typologie	Wohnhaus
Ort	Frankfurt am Main
Land	Deutschland
Planungs-Risiko	2012 - 2014
Auftraggeber	WZB
Auftraggeber	AGB PRODUKTIV HOLZING, Wohnungsbau- und Betriebsgesellschaft mbH, Frankfurt am Main
Projektziele	Forschung, TU Darmstadt, Lehrstuhl Energieeffizientes Bauen Prof. Manfred Hegger, Carin Stadl, Sebastian Toppert, Team Energie- Gebäude- und Solartechnik, Stuttgart Technische Gebäudeausrüstung, CO2-Plan, Energieausweisform für Energie-Gebäude und Gebäudetechnik, Stuttgart Trassenführung, Bedienung und Gefahren- Instandhaltung für Fassadenplanung Gesamtschulung, in Frankfurt, Frankfurt am Main Projektbau, Höger, Vermeier, Bauarchitektur & Co. KG
Leibnizpreis 2016	Architektur
Bruttogeschossfläche (BGF)	117000 m <sup>2</sup>
Bruttobaufläche (BR)	38000 m <sup>2</sup>

Die AGB Holding Frankfurt präsentiert 41 Eigentumswohnungen in zeitgemäßem, Mehrgeschossbau in einer Energieeffizienzklasse von Plusenergiehaus bis zu Plusenergiehaus (DIN EN 15603) zu realisieren.

Das Objekt steht bei Beginn der Bauarbeiten im Zentrum der Stadt, die sich durch die Dichte der Bebauung auszeichnet. Die Dichte der Bebauung ist ein zentraler Bestandteil des Projekts. Die Dichte der Bebauung ist ein zentraler Bestandteil des Projekts. Die Dichte der Bebauung ist ein zentraler Bestandteil des Projekts.

Das Aktiv-Stadthaus Frankfurt ist ein Plusenergiehaus mit einer Net Zero Energy Balance (Net ZEB). Das Aktiv-Stadthaus Frankfurt ist ein Plusenergiehaus mit einer Net Zero Energy Balance (Net ZEB).

Informationen  
Aktiv-Stadthaus Frankfurt

[www.hhs.ag/projekte--aktiv-stadthaus-frankfurt.de.html?image=0](http://www.hhs.ag/projekte--aktiv-stadthaus-frankfurt.de.html?image=0)

## Net Zero Energy in Downtown Urban Districts?

Density and shading are unfavourable circumstances for individual buildings with equalized annual energy balance. Initial projects try to overcome the barriers with extreme building and solar module efficiency.

# A vision for future cities

## On-Site Measures versus Energy Landscaping

### Status Quo

fossil resources



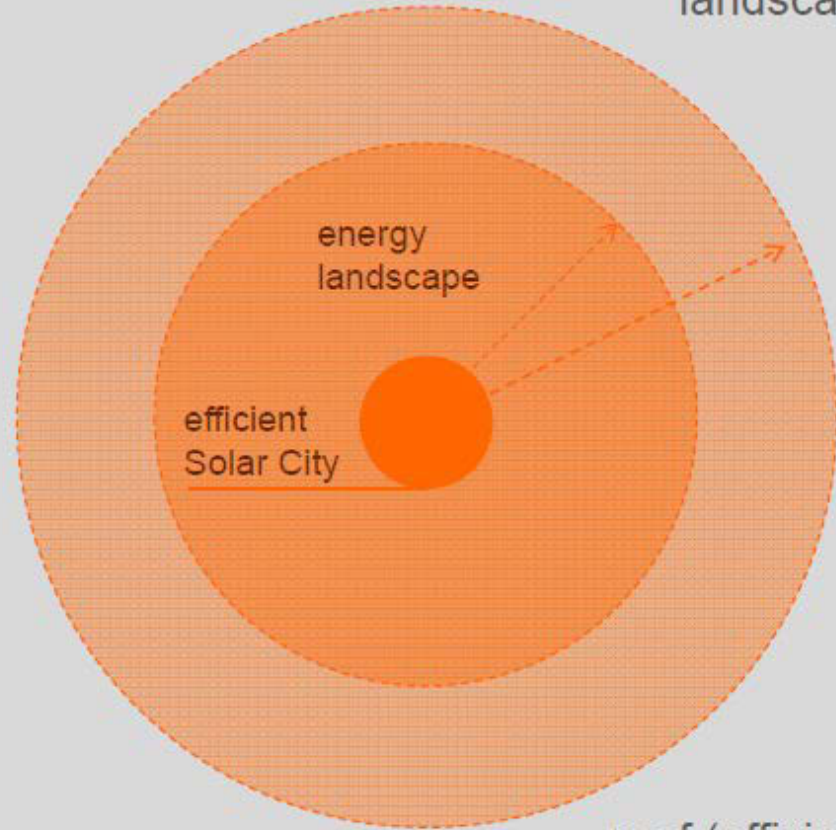
landscape

city



### City of Tomorrow

landscape

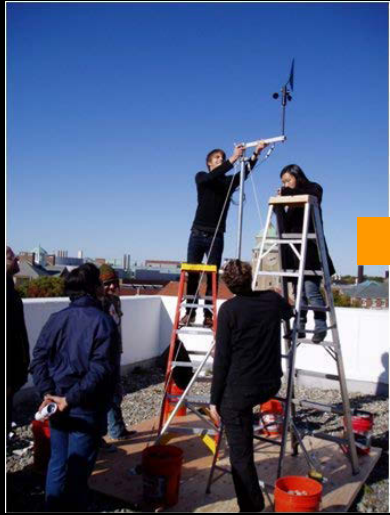


$$r = f(\text{efficiency})$$

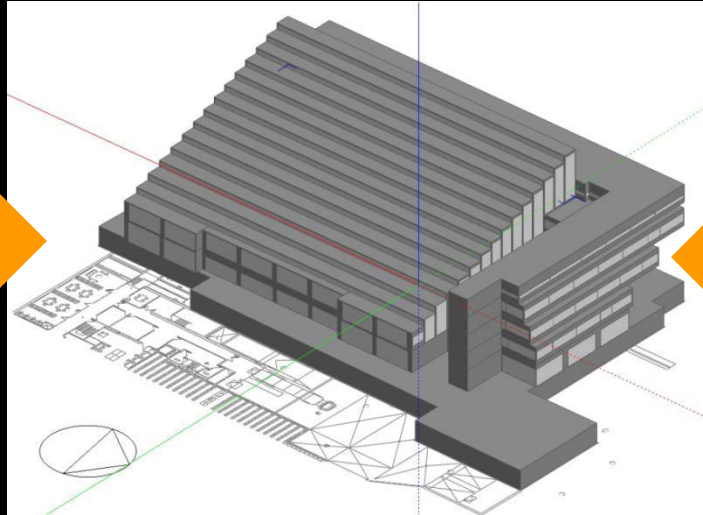
Slide courtesy of Karsten Voss. Used with permission.

# Case Study Gund Hall

# Case Study - Gund Hall



*Collect weather data*



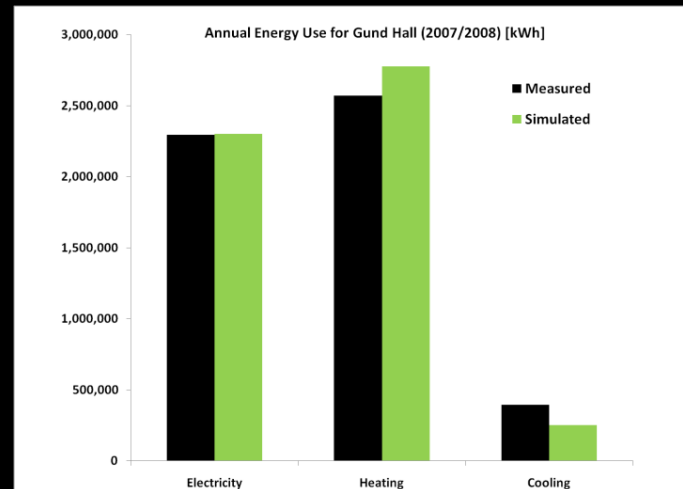
*Build an energy model*



*Survey occupant behavior*



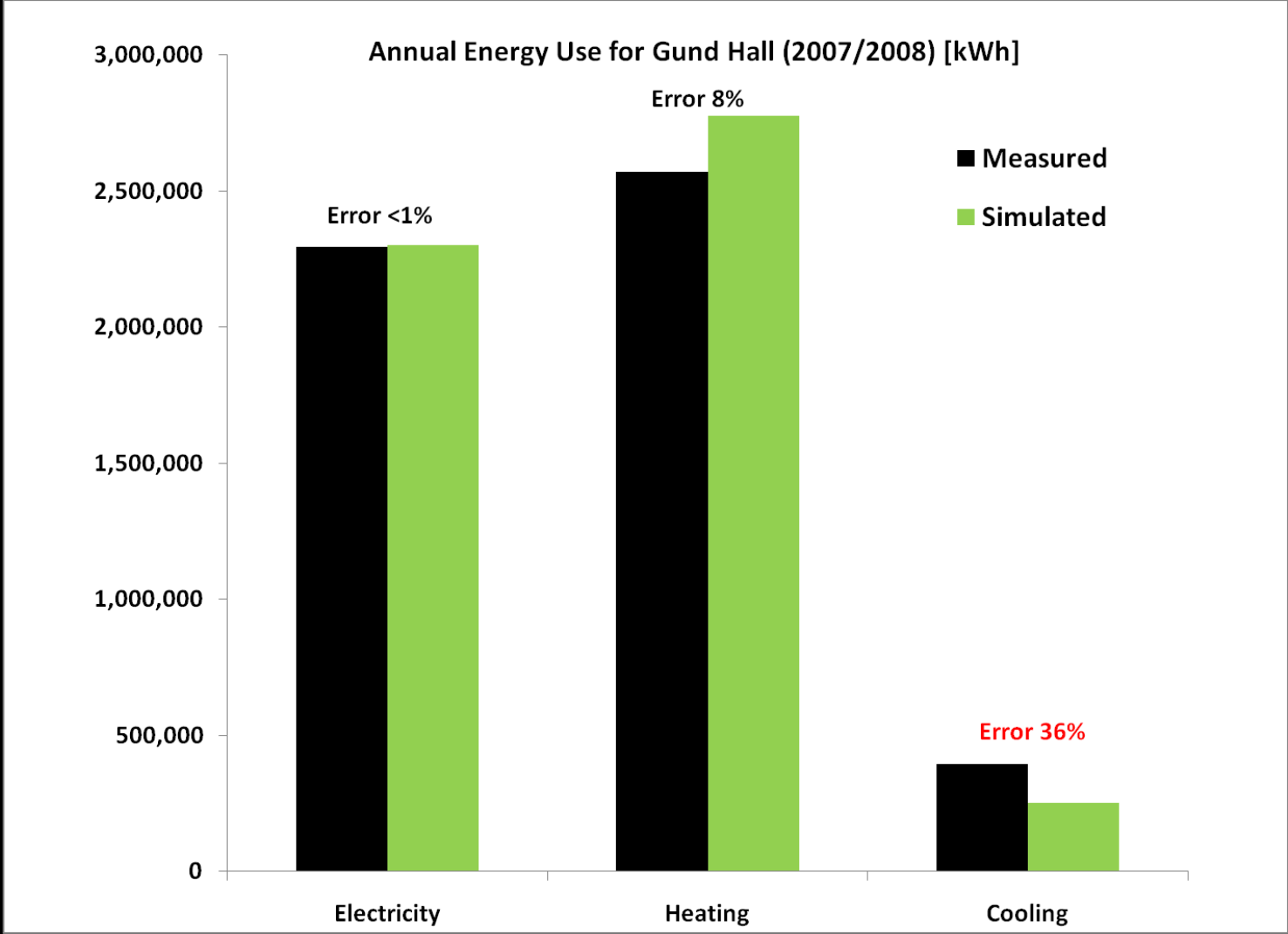
*Measure Energy Use*



*Predicted versus measured energy use*

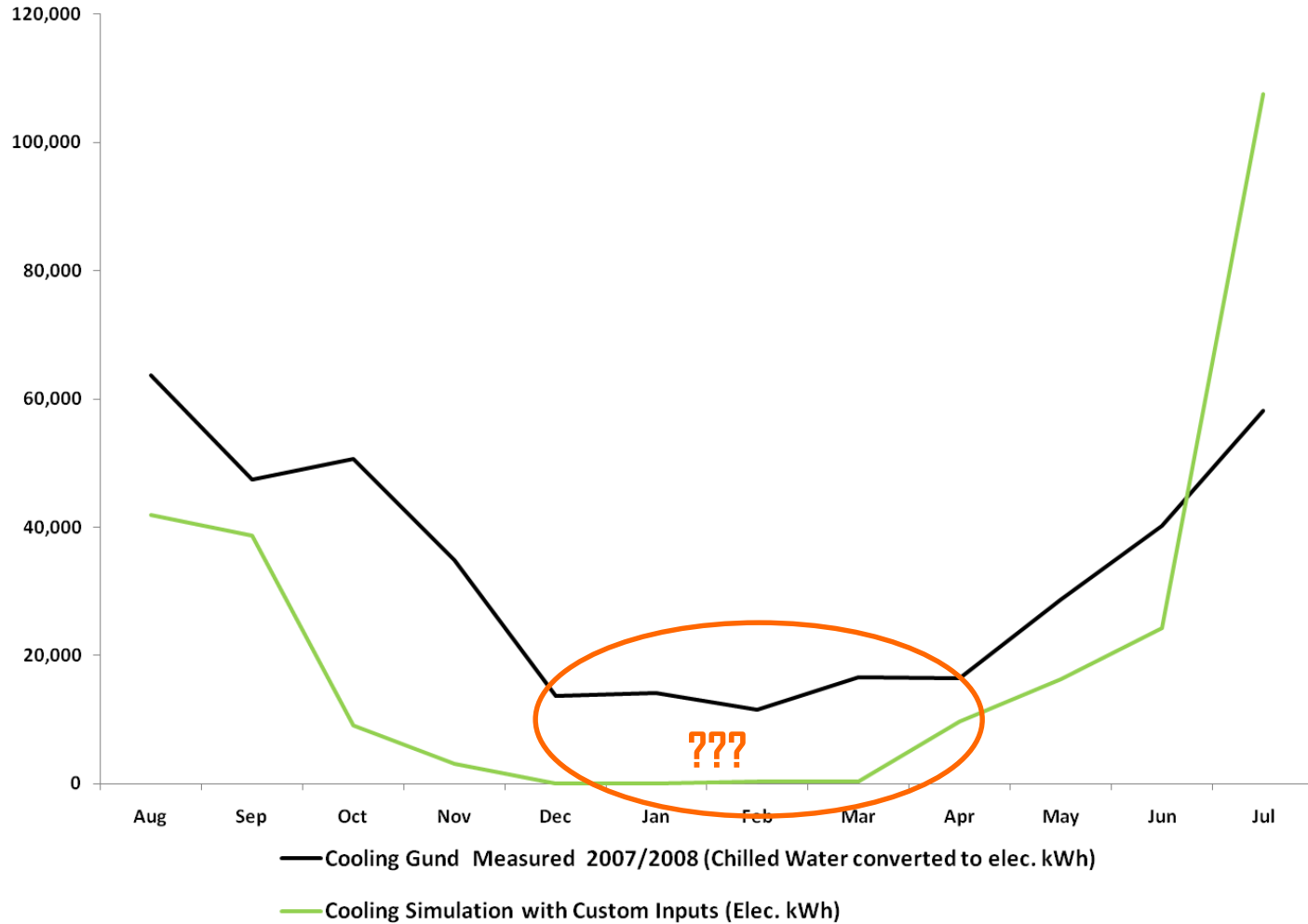
Paper: Wasilowski H A, Reinhart C F, "Modeling an existing building using customized weather data and internal load schedules as opposed to default assumptions - A Case Study," Proceedings of Building Simulation 2009, Glasgow, July 2009

# Energy Use of Gund Hall: Measurement vs. Simulation



# Monthly Energy Use for Cooling

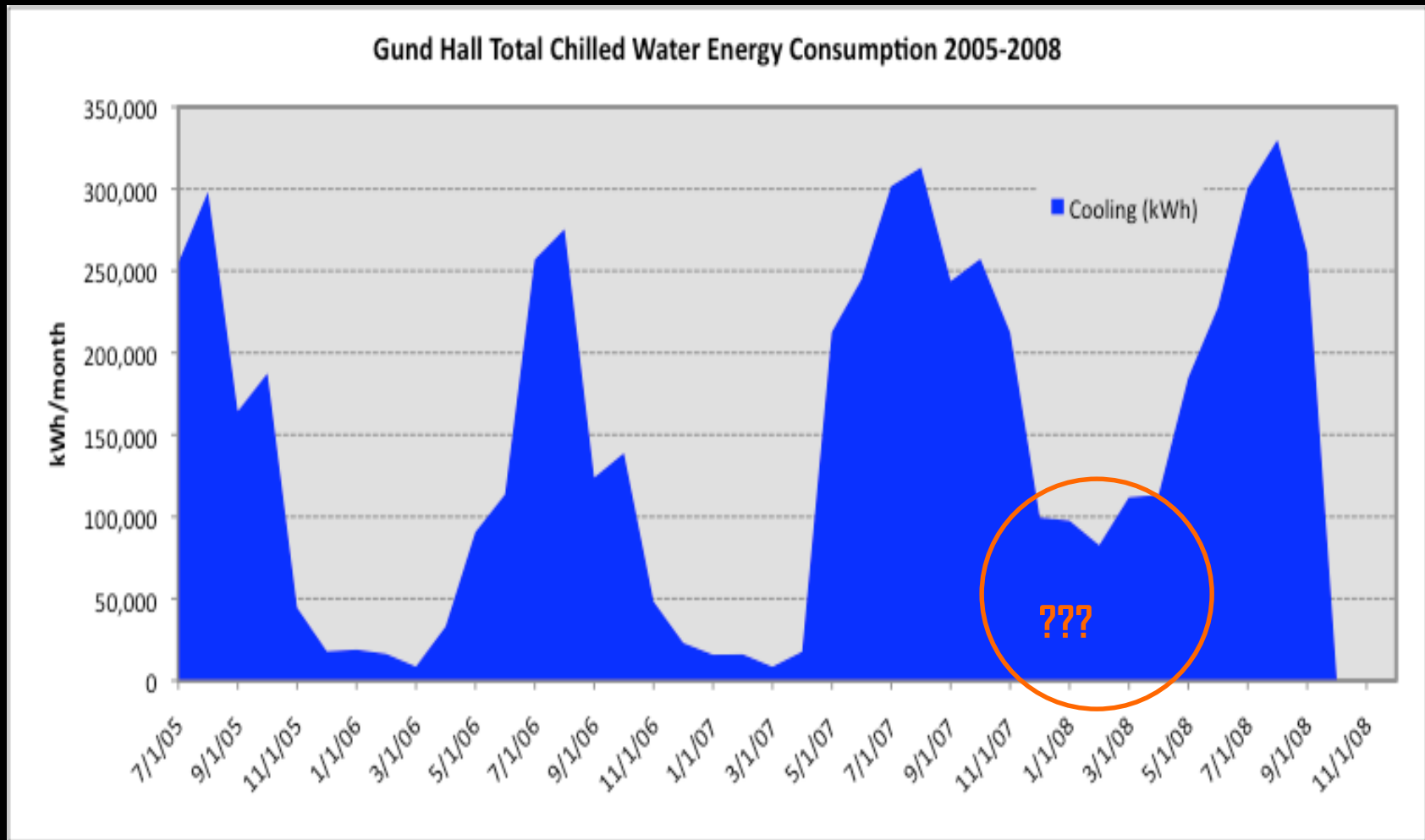
Monthly Energy Use for Cooling for Gund Hall (2007/2008) [kWh]



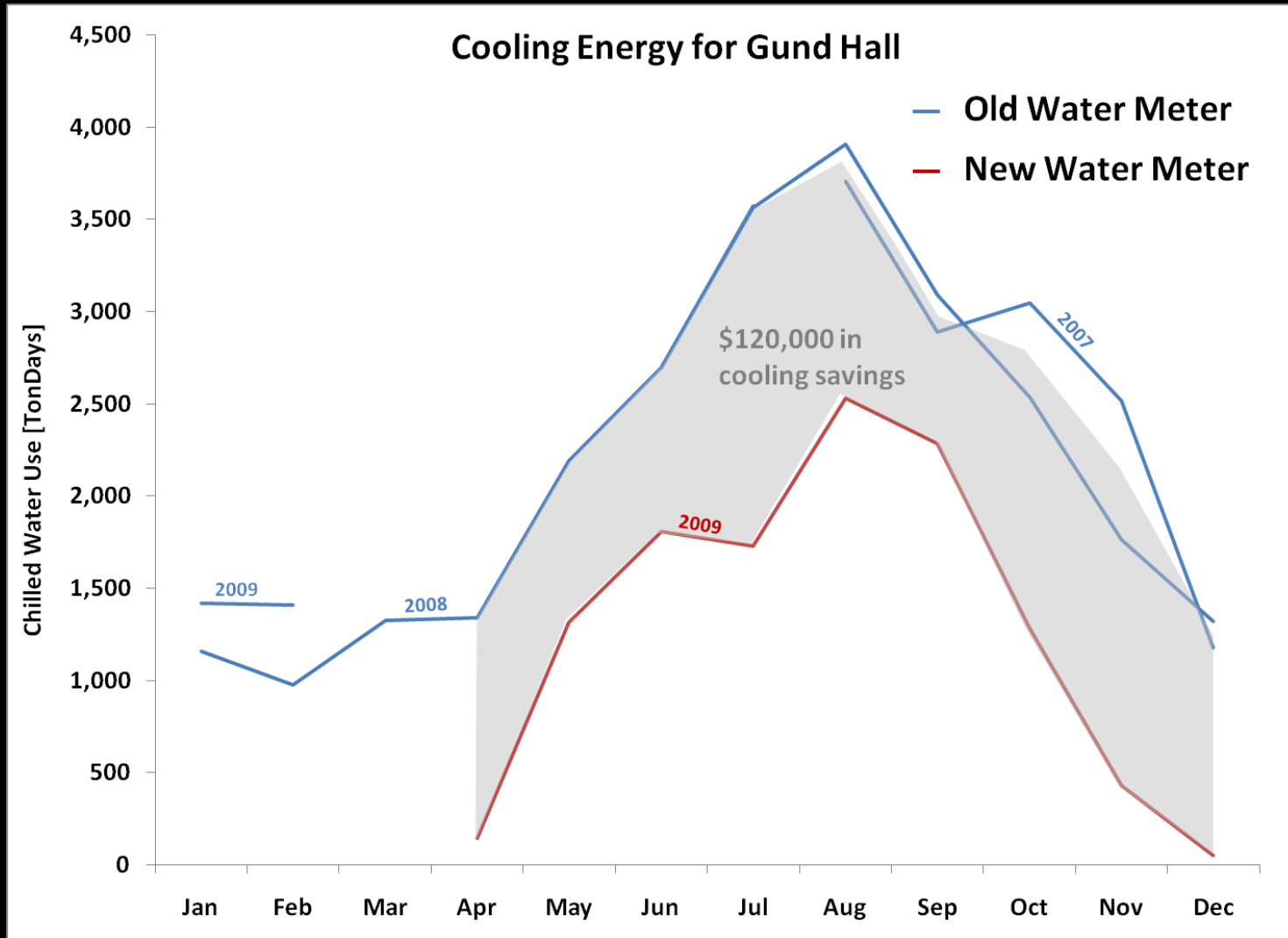
❑ Cooling use in winter?



# Historic Cooling Data for Gund Hall



# Monthly Energy Use for Cooling

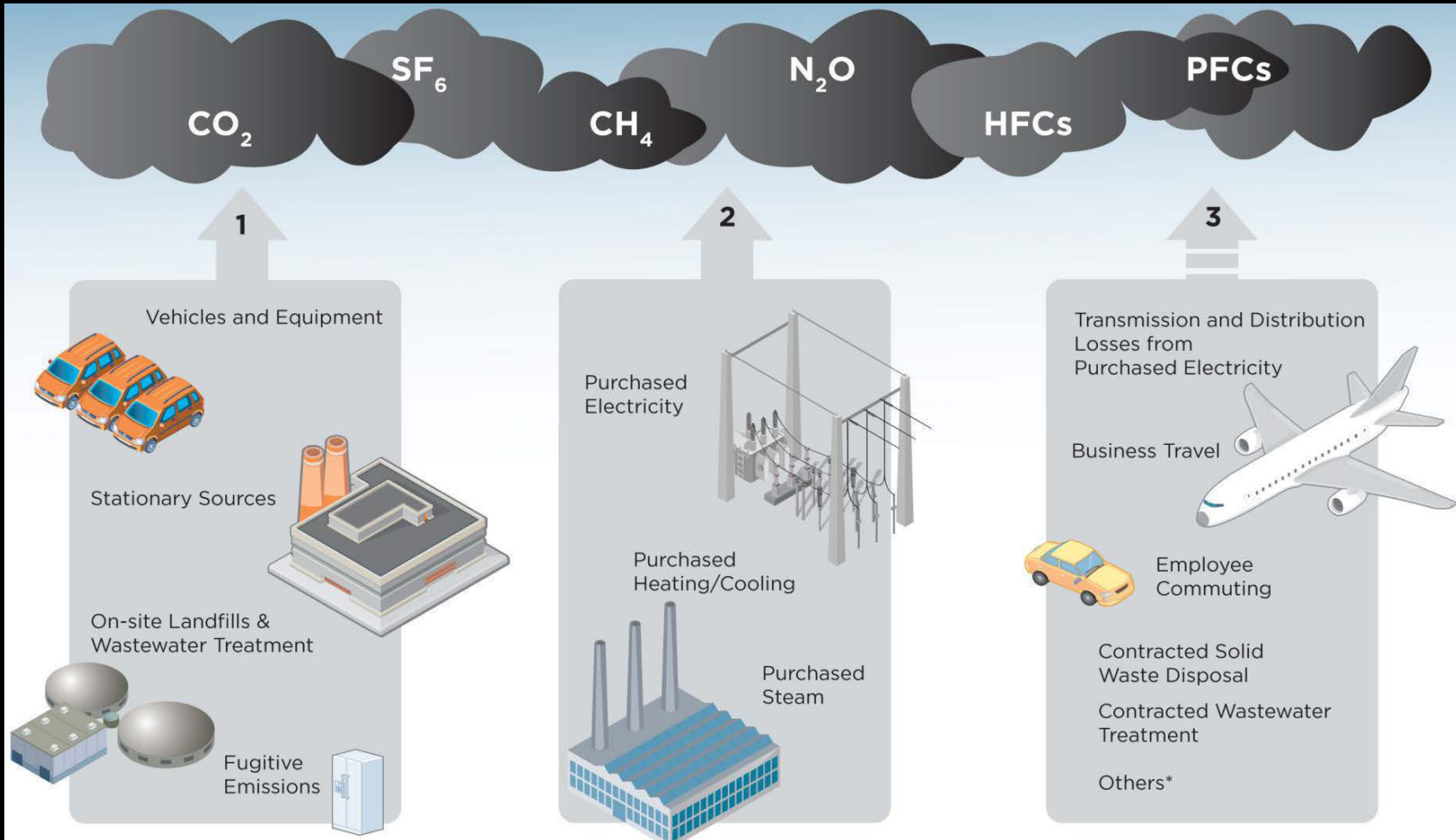


□ Chilled water flow meter was replaced in March 2009.

# MIT Campus Study

# Scope and Carbon Emissions

Public domain image courtesy of US EPA.



## Scope 1:

Greenhouse gas emissions from sources that are owned or controlled by Institute

## Scope 2:

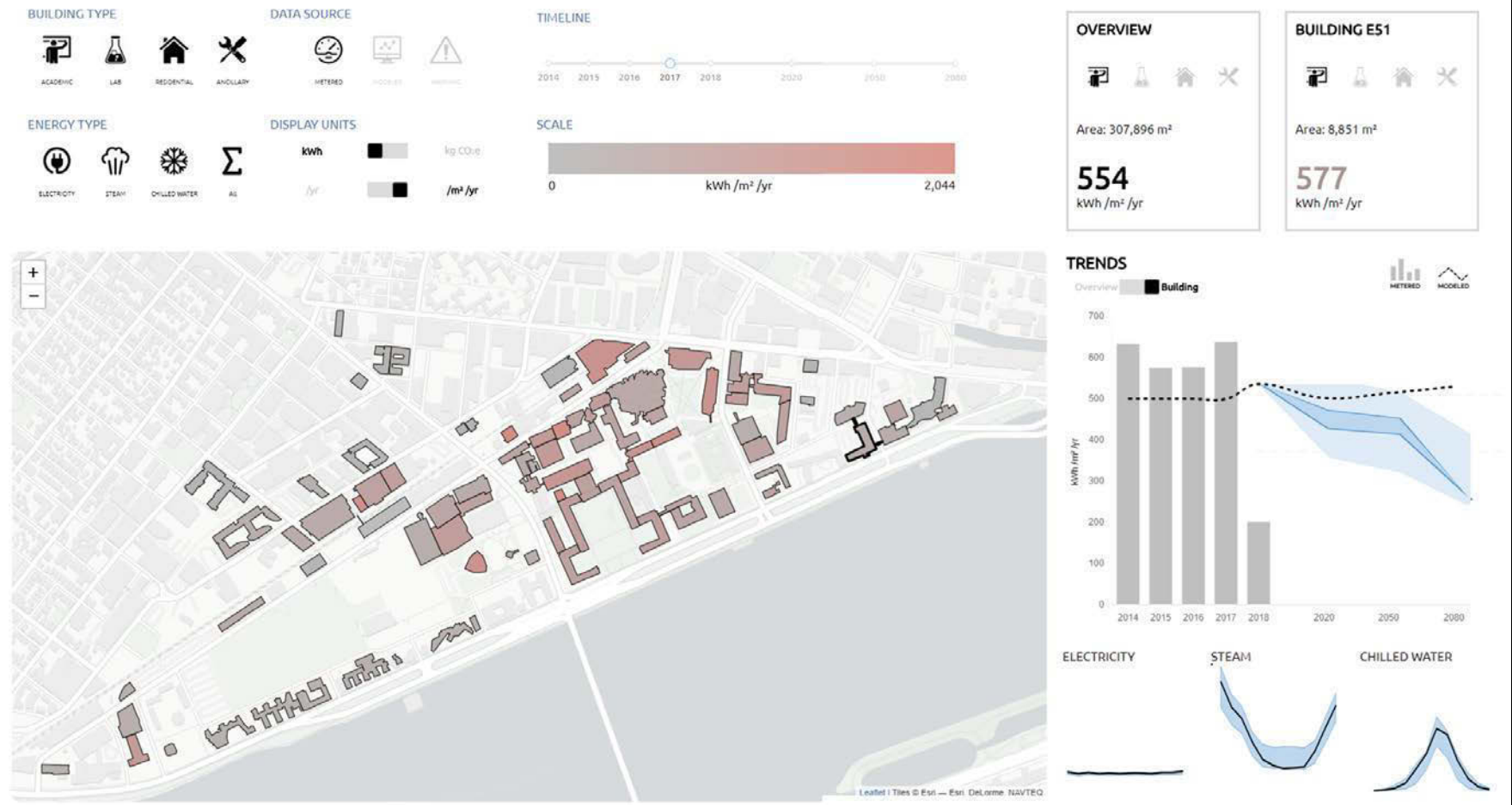
Greenhouse gas emissions resulting from the generation of electricity, heat, or steam purchased by the Institute

## Scope 3:

Greenhouse gas emissions from sources not owned or directly controlled by the Institute but related to Institute activities

# MIT Live Campus Model

## MIT GHG EMISSIONS MANAGEMENT



<https://web.mit.edu/CampusEnergyModel/www/>

Paper: S Nagpal, J T Hanson, K Spencer, N Bhatia, C F Reinhart, "Auto-Calibrated Urban Building Energy Models as Continuous Commissioning and Planning Tools," submitted to *Applied Energy*

# Questions?

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4.401/4.464 Environmental Technologies in Buildings Fall 2018

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