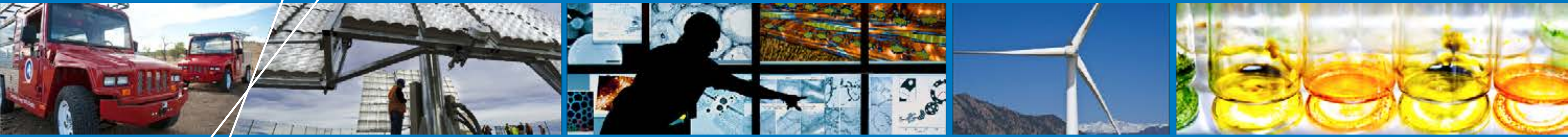
The Pathway to Zero Energy Buildings



ASHRAE New Mexico Chapter

December 18, 2017

Paul A. Torcellini, Ph.D., P.E.

Principal Engineer, National Renewable Energy Laboratory

Associate Professor, Eastern Connecticut State University

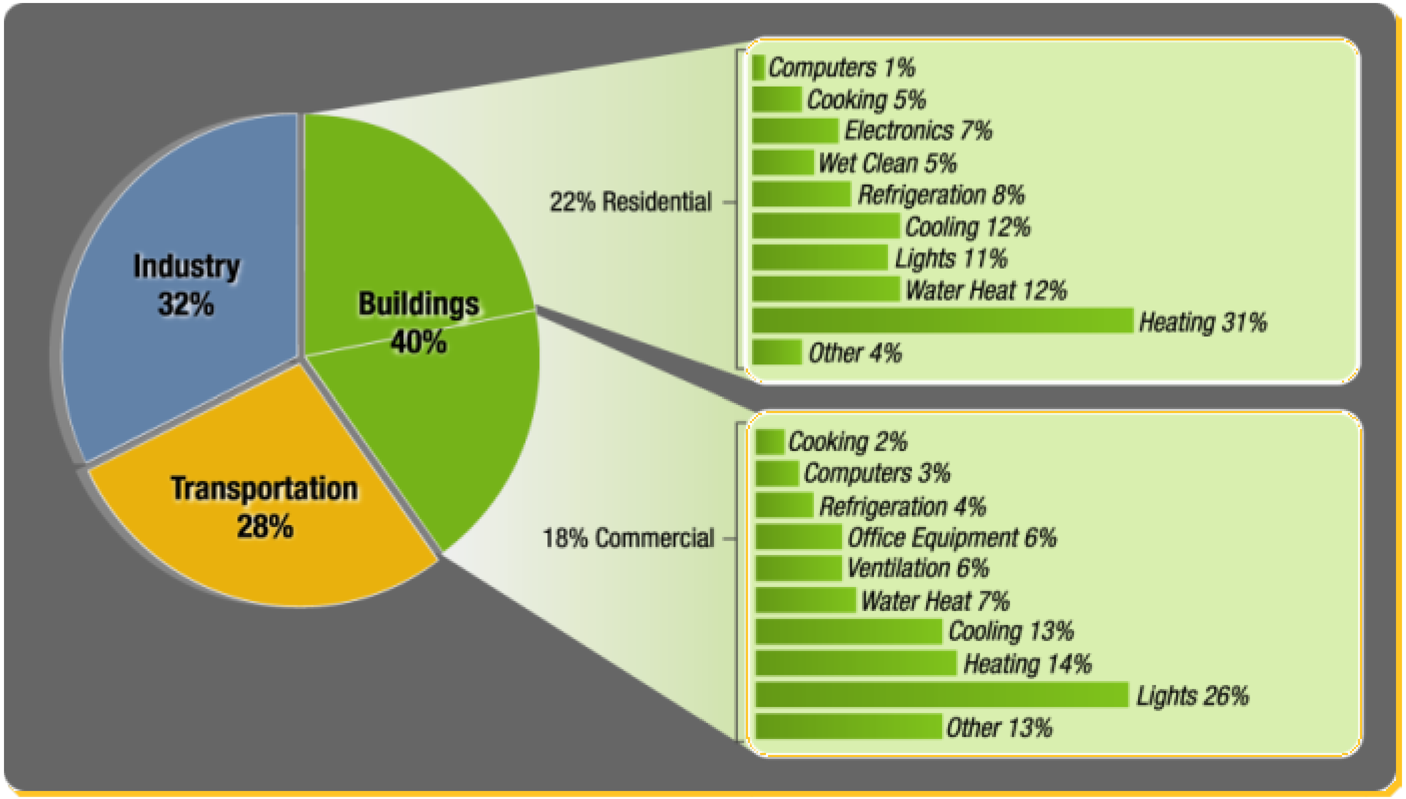
NREL is a national laboratory of the U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, operated by the Alliance for Sustainable Energy, LLC.

- RSF uses 50% less energy than if it were built to current commercial codes at no extra capital cost
- RSF increases space at NREL by 60% but only increases energy use by 6%

NREL/17833

Why Buildings' Energy Use is Important

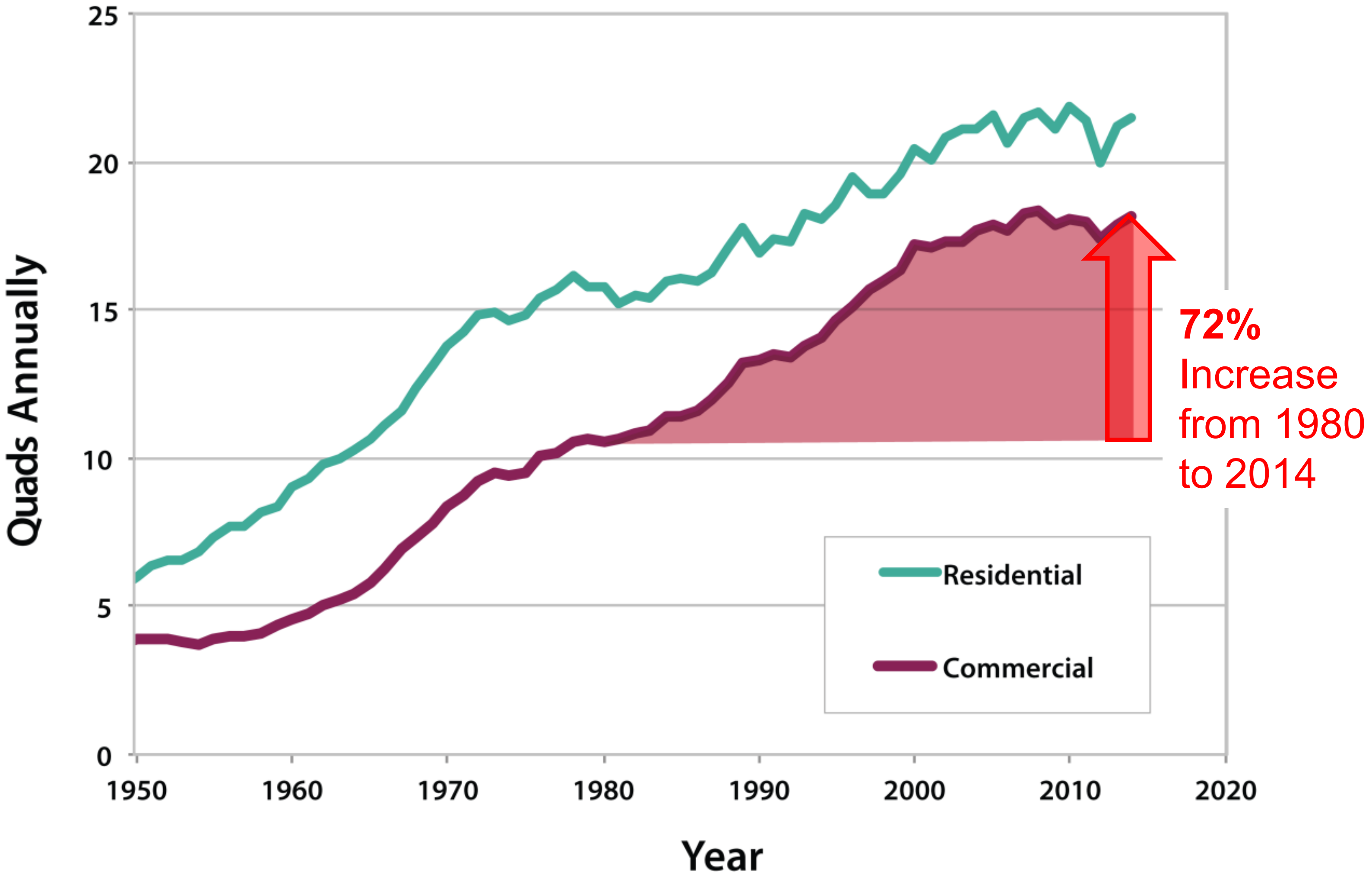
- Largest energy consumer in U.S.
- 40% of U.S. Primary Energy Consumption
- 72% of U.S. Electricity
- 55% of U.S. Natural Gas



Trends of Commercial Sector

- Growth is faster than energy efficiency measures

U.S. Building Energy Consumption



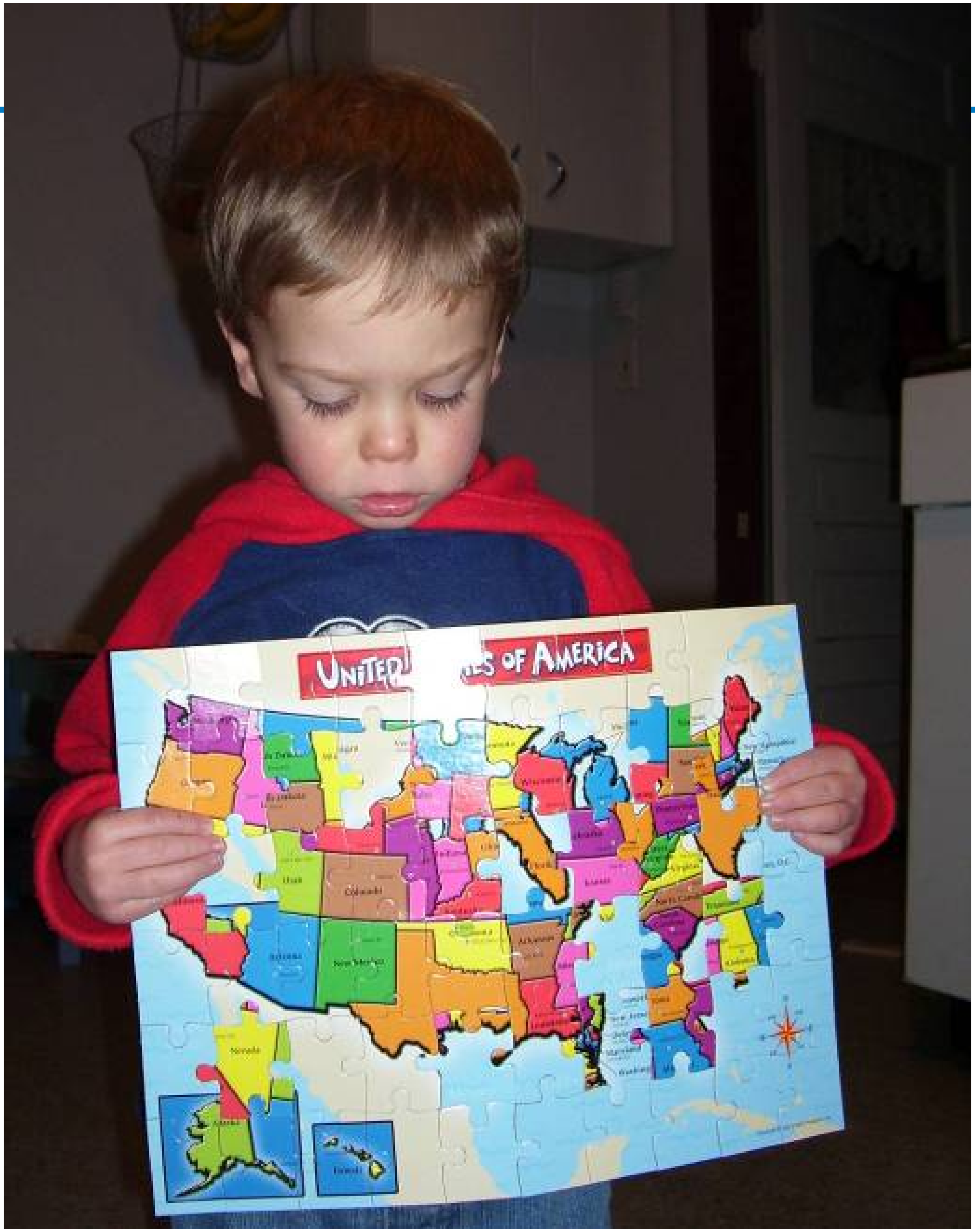
72%
Increase
from 1980
to 2014

Trends of Commercial Sector

- Growth is faster than energy efficiency measures
- Every decision has an energy and environmental impact
- Buildings mortgage the energy futures of the world

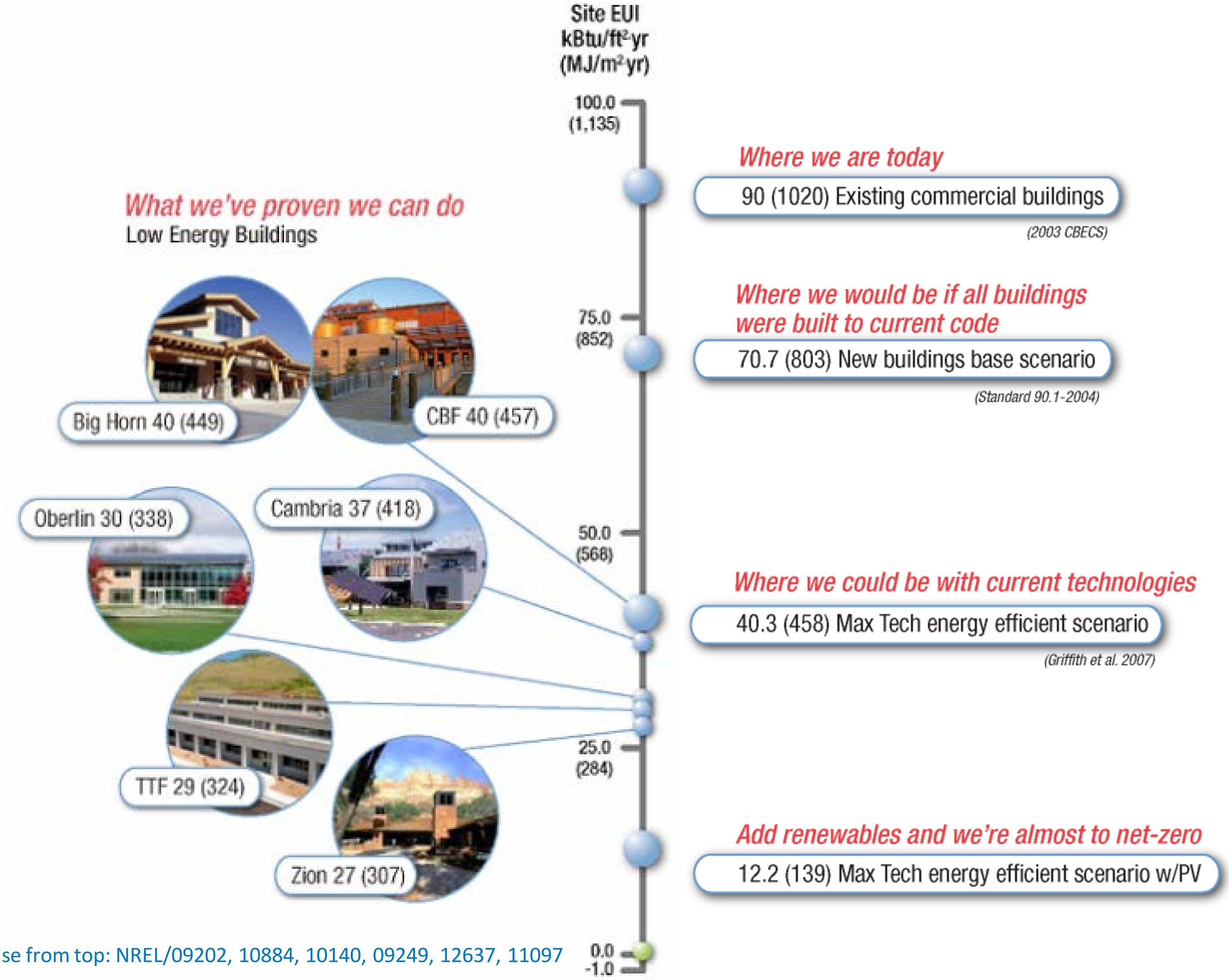
Many Pieces

- So many ways to assemble the pieces
- Design is about making decisions – need motivation to make the right decisions
- Who are the decision makers?



Used by permission: Paul Torcellini/NREL

Great Potential in Commercial Buildings



What we've proven we can do

Low Energy Buildings

Where we are today

90 (1020) Existing commercial buildings

(2003 CBECS)

Where we would be if all buildings were built to current code

70.7 (803) New buildings base scenario

(Standard 90.1-2004)

Where we could be with current technologies

40.3 (458) Max Tech energy efficient scenario

(Griffith et al. 2007)

Add renewables and we're almost to net-zero

12.2 (139) Max Tech energy efficient scenario w/PV

Clockwise from top: NREL/09202, 10884, 10140, 09249, 12637, 11097

Setting Goals

- **Measurable goals are better**
- **From bad to good…**
  - I want a green building
  - Design a LEED <rating> building
  - Design a building to use 30% less energy than ASHRAE 90.1-2013
  - Design a building to use less than 25,000 BTU/sqft
  - Design a ZERO ENERGY BUILDING

- **Influencing purchasing decision—the owner**

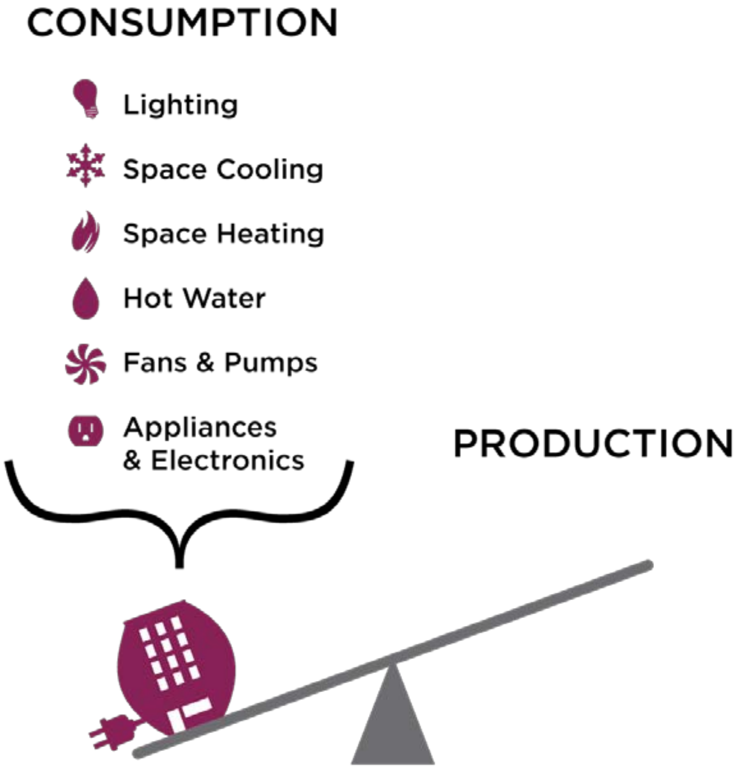
What are Zero Energy Buildings?

- Conceptually, a building that has no adverse energy [or environmental] impact [because of its operation]

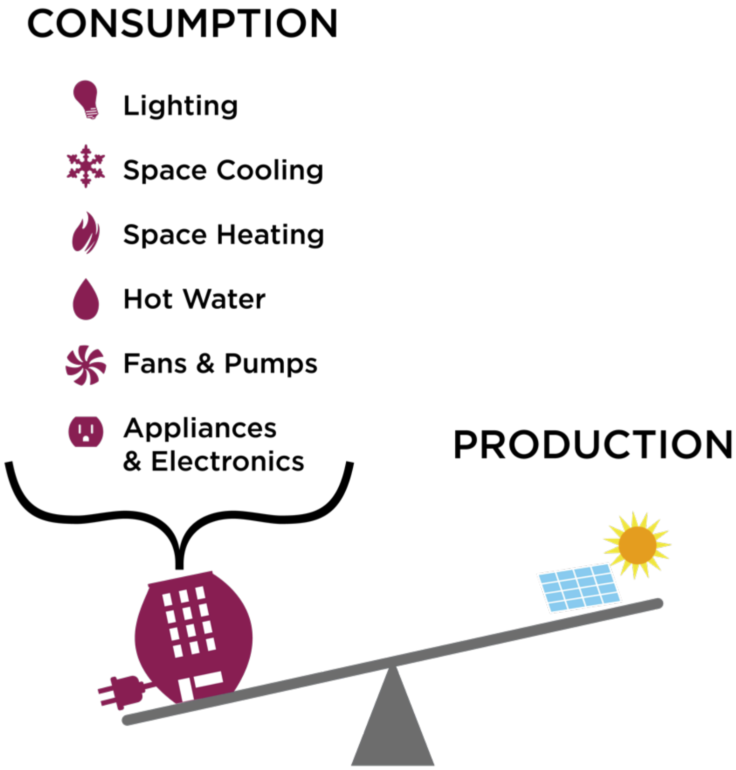
- Energy consumption has been a long-term surrogate for environmental impact

- Boundaries and metrics
- What energy flows to measure

Zero Energy Building



Adding Renewables

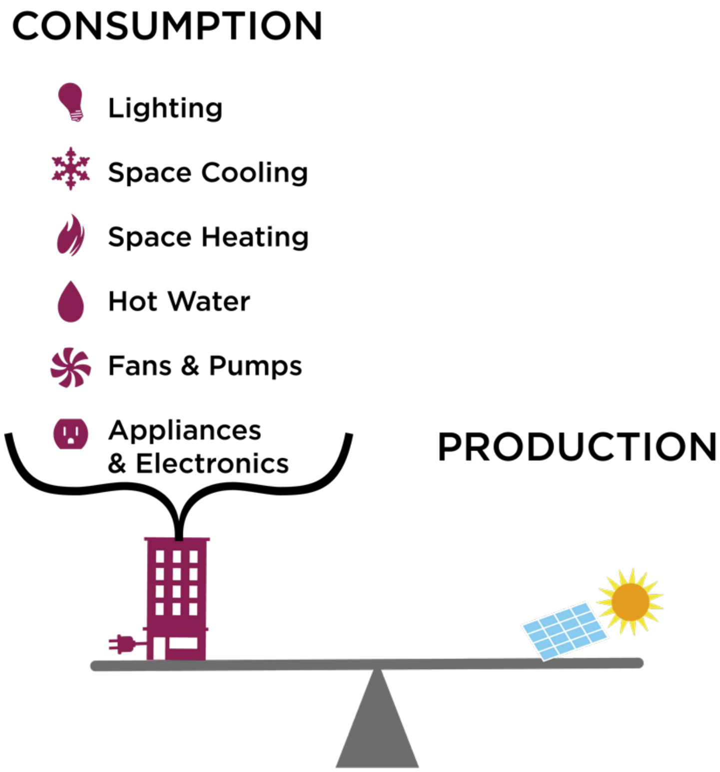


CONSUMPTION

- Lighting
- Space Cooling
- Space Heating
- Hot Water
- Fans & Pumps
- Appliances & Electronics

PRODUCTION

Building on a Diet



CONSUMPTION

- Lighting
- Space Cooling
- Space Heating
- Hot Water
- Fans & Pumps
- Appliances & Electronics

PRODUCTION

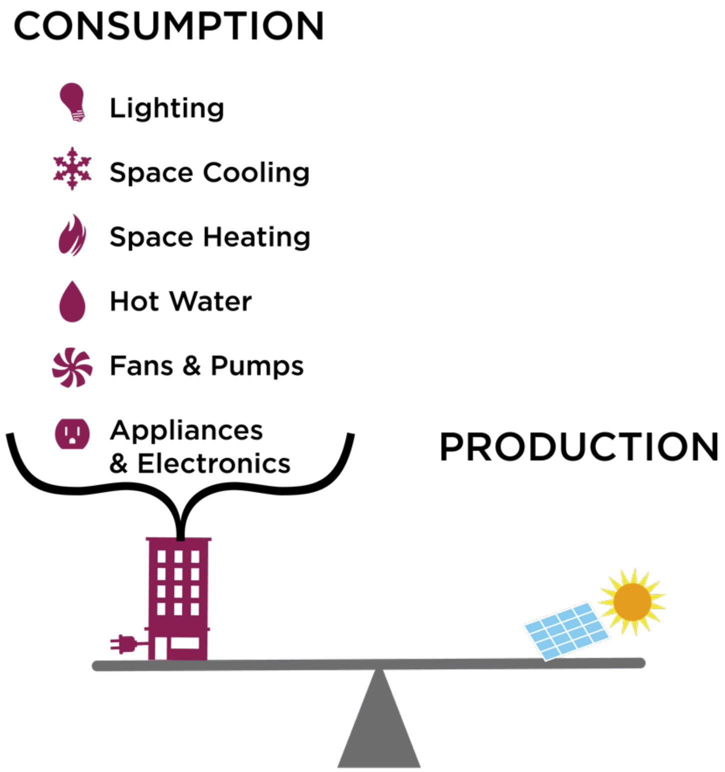
ZEB Concept

Goal 1:
Reduce Consumption

Goal 2:

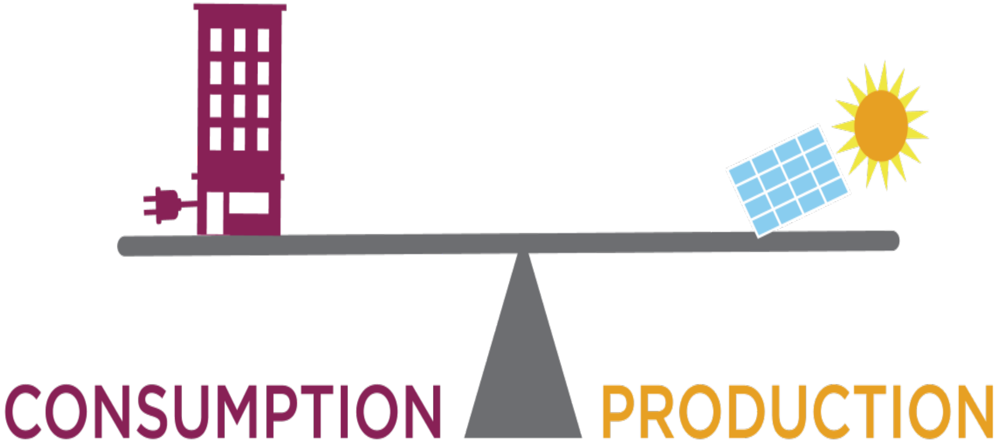
Apply On-site Renewable Energy

BALANCE!



Zero Energy Building (ZEB) Definition

An **energy-efficient building**, where on a source energy basis, the actual annual delivered energy is less than or equal to the on-site renewable exported energy.

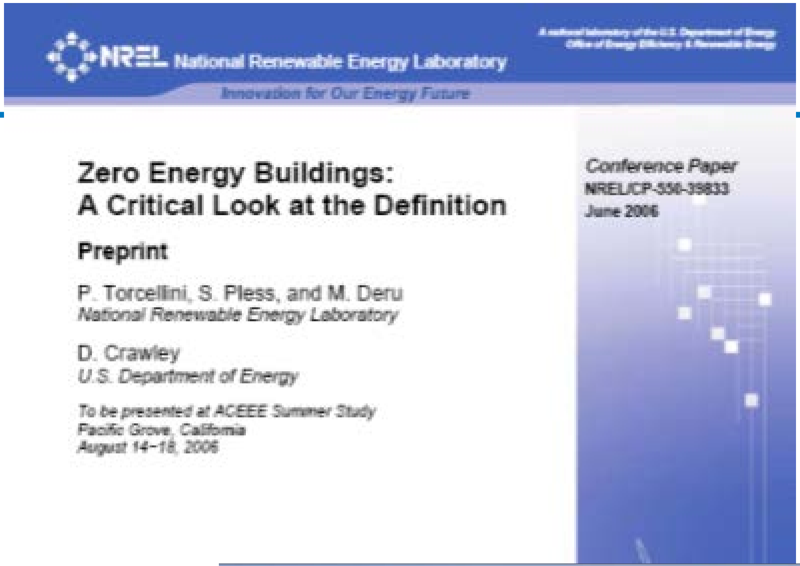


Definitions of ZEB's

- Zero Site Energy
- Zero Source Energy
- Zero Emissions
- Zero Energy Cost

- Boundaries and metrics

The Definition used WILL impact the ZEB design strategies!



NREL National Renewable Energy Laboratory

Innovation for Our Energy Future

A national laboratory of the U.S. Department of Energy
Office of Energy Efficiency & Renewable Energy

Zero Energy Buildings: A Critical Look at the Definition

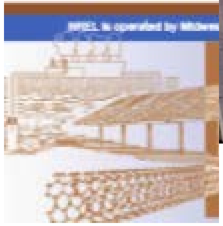
Preprint

P. Torcellini, S. Pless, and M. Deru
National Renewable Energy Laboratory

D. Crawley
U.S. Department of Energy

To be presented at ACEEE Summer Study
Pacific Grove, California
August 14–18, 2006

Conference Paper
NREL/CP-550-39833
June 2006



NREL is operated by Midwe

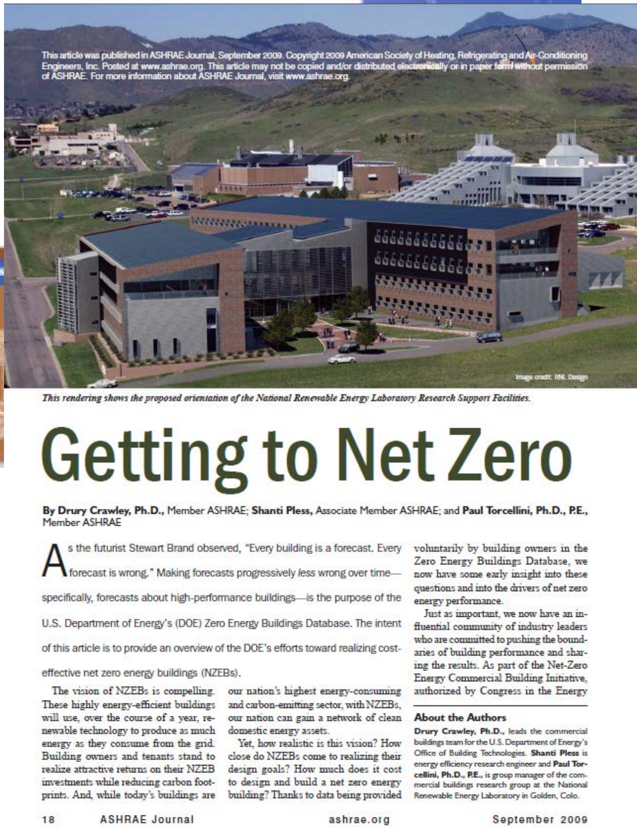


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Image credit: RNL Design

This rendering shows the proposed orientation of the National Renewable Energy Laboratory Research Support Facilities.

Getting to Net Zero

By **Drury Crawley, Ph.D.,** Member ASHRAE; **Shanti Pless,** Associate Member ASHRAE; and **Paul Torcellini, Ph.D., P.E.,** Member ASHRAE

As the futurist Stewart Brand observed, "Every building is a forecast. Every forecast is wrong." Making forecasts progressively *less* wrong over time—specifically, forecasts about high-performance buildings—is the purpose of the U.S. Department of Energy's (DOE) Zero Energy Buildings Database. The intent of this article is to provide an overview of the DOE's efforts toward realizing cost-effective net zero energy buildings (NZEBs).

The vision of NZEBs is compelling. These highly energy-efficient buildings will use, over the course of a year, renewable technology to produce as much energy as they consume from the grid. Building owners and tenants stand to realize attractive returns on their NZEB investments while reducing carbon footprints. And, while today's buildings are our nation's highest energy-consuming and carbon-emitting sector, with NZEBs, our nation can gain a network of clean domestic energy assets.

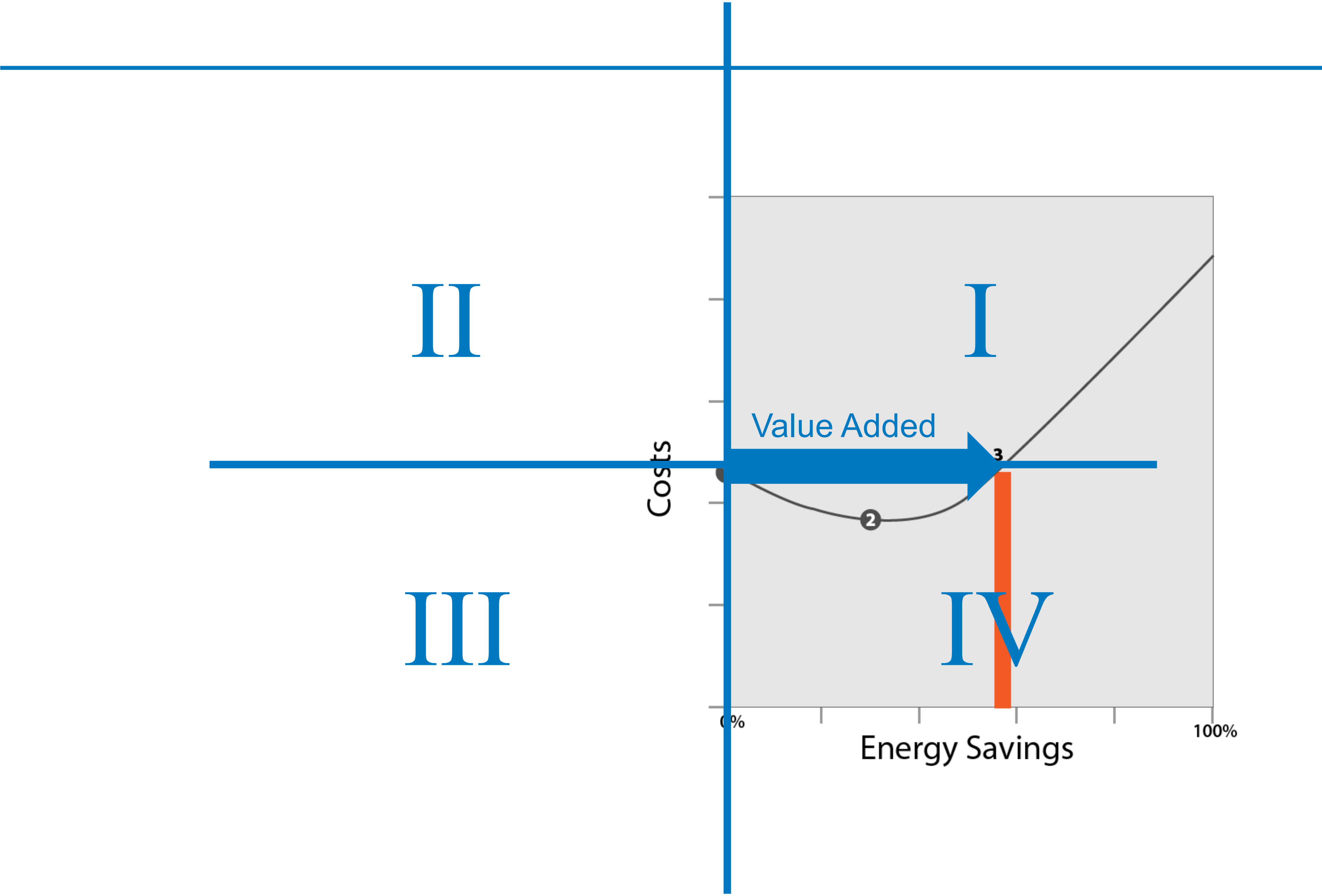
Yet, how realistic is this vision? How close do NZEBs come to realizing their design goals? How much does it cost to design and build a net zero energy building? Thanks to data being provided voluntarily by building owners in the Zero Energy Buildings Database, we now have some early insight into these questions and into the drivers of net zero energy performance.

Just as important, we now have an influential community of industry leaders who are committed to pushing the boundaries of building performance and sharing the results. As part of the Net-Zero Energy Commercial Building Initiative, authorized by Congress in the Energy

About the Authors

Drury Crawley, Ph.D., leads the commercial buildings team for the U.S. Department of Energy's Office of Building Technologies. **Shanti Pless** is energy efficiency research engineer and **Paul Torcellini, Ph.D., P.E.,** is group manager of the commercial buildings research group at the National Renewable Energy Laboratory in Golden, Colo.

18 ASHRAE Journal ashrae.org September 2009


II
I
Value Added
3
Costs
2
III
IV
0%
100%
Energy Savings

Problem Definition: RFP Objectives

MISSION CRITICAL

Attain safe work performance/Safe Design Practices

LEED Platinum

Energy Star "Plus"

HIGHLY DESIRABLE

800 staff Capacity

25 kBTU/sf/year

Architectural integrity

Honor future staff needs

Measurable ASHRAE 90.1

Support culture and amenities

Expandable building

Ergonomics

Flexible workspace

Support future technologies

Documentation to produce a "How to" manual

"PR" campaign implemented in real-time

Allow secure collaboration with outsiders

Building information modeling

Substantial Completion by 2010

IF POSSIBLE

Zero energy design approach

Most energy efficient building in the world

LEED Platinum Plus

ASHRAE 90.1 + 50%

Visual displays of current energy efficiency

Support public tours

Achieve national and global recognition and awards

Support personnel turnover

RFP also required maximum use of natural ventilation and 90% of floor space fully daylit

The Process

- **Owner made tough decisions up-front**
  - Set budget
  - Sought maximum value for that budget
  - Prioritized goals
- **Design-Build procurement process**
  - Managed the team to the RFP and its substantiation criteria
  - Rewards
- **Allowed design-build team to use creativity to maximize value--innovation**
- **Owner did not solve the problem (but knew the solution existed)**

Guidance for Unknowns

NREL/15884

- **Benchmarked current plug loads and data center load**
  - – Provided peak uses and occupancy schedule by plug load type
    - Laptops, monitors, copiers, kitchen equipment, task lights, etc.
    - 65 Watts/occupant 24/7 for datacenter
  - – Allowed design-build team to make recommendations on plug load reductions.

Owner Role

- **Spend the time to get RFP right**
  - Design/build team will study to pass the test
- **Set up acquisition process to "force" integrated design**
  - Energy modeling guides conceptual design decisions
  - Architecture and envelope are also efficiency measures

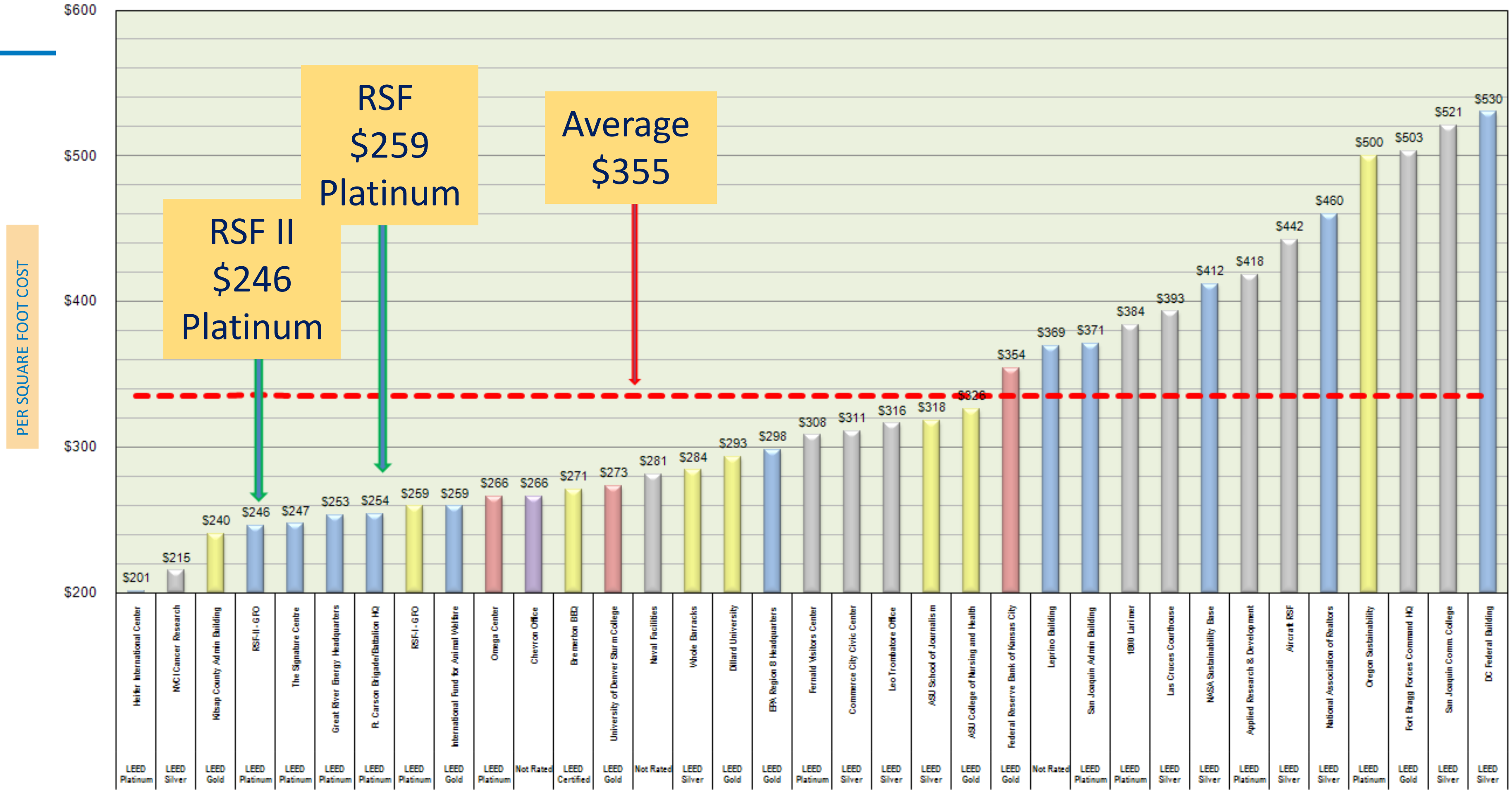
NREL/17833

Owner Role

- **Unwavering commitment to problem statement**
  - Unleash power of design/build team of experts to meet owner needs
    - true value engineering
  - Commit to your objectives and the prioritization and don’t adjust

Clockwise from top:
NREL/18784, 24690, 17823

COMMERCIAL BUILDING CONSTRUCTION COST



LEGEND:

- NOT RATED
- LEED CERTIFIED
- LEED GOLD
- LEED SILVER
- LEED PLATINUM

PROJECTS AND LEED CERTIFICATION

SOURCES:
www.fayobserver.com
www.dbia.com
www.nasa.gov
www.eomega.org
www.oregonsustainabilitycenter.org
www.americas.rlb.com
http://greensource.construction.com
www.1800larimer.com
www.usgbc.org
www.smithgroup.com
www.cronkite.asu.edu

Measured Versus Modeled Monthly and Cumulative EUI

The PV system is sized for an annual EUI of 35.1 kBtu/ft².

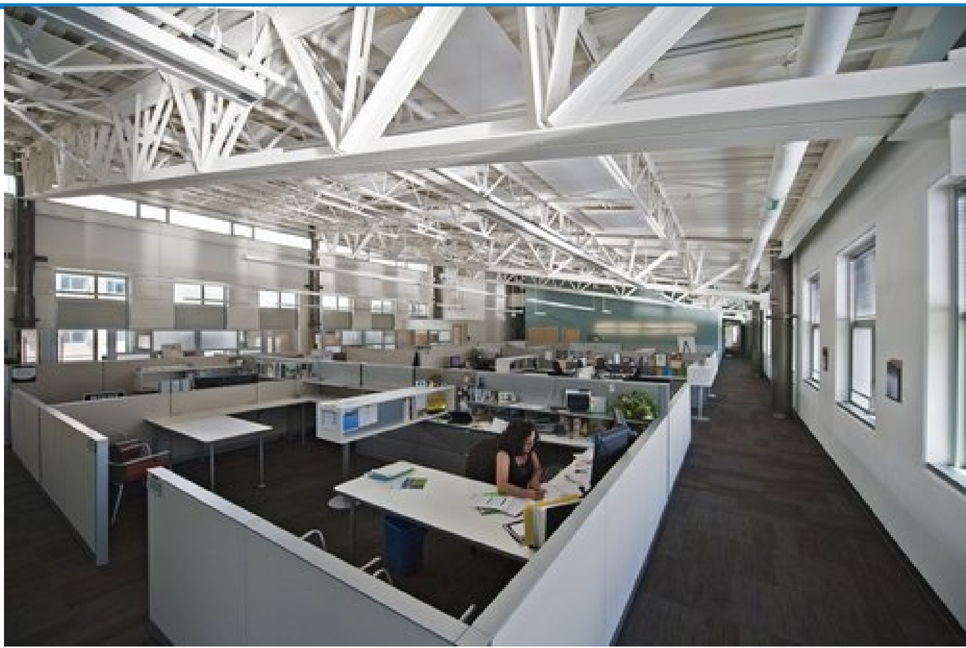
Credit: Chad Lobato/NREL

Note: The annual EUI values are demand side values and do not include the

Research Support Facility

- 800 people
- 220,000 ft^2
- 25 kBtu/ft^2
- 50% energy savings
- \$259/ft^2
- LEED Platinum
- Replicable
  - process
  - technologies
  - cost
- Site, source, carbon, cost ZEB
  - Includes plugs loads and datacenter

- Design/Build Process with required energy goals



Credit: Frank Rukavina- NREL

Credit: NREL PIX

Is this photo significant?

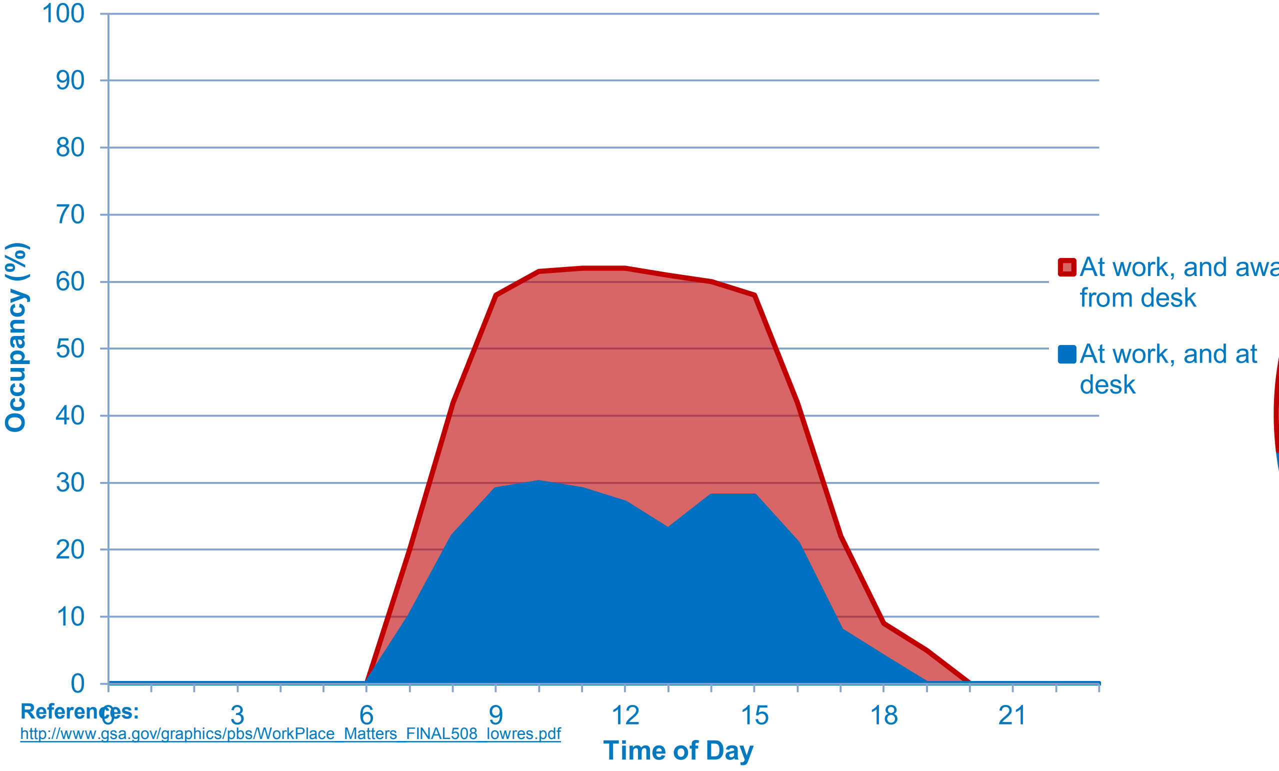
Credit: Jennifer Scheib/NREL

Buildings Are For Occupants!

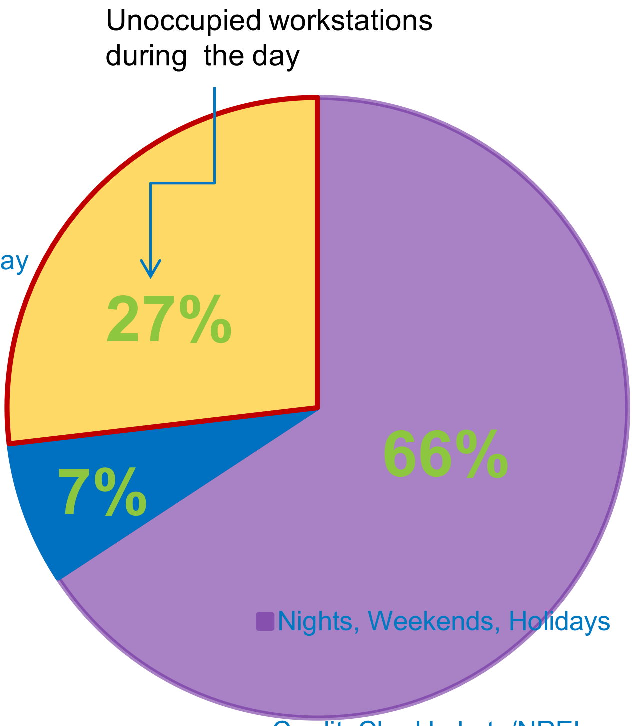
- Occupants and Operators ultimately control *all* the energy loads
- Frustration when Occupants are expected to "perform" but have no levers to control
- Plug loads
- Design elements for the Occupants
- Occupant training

Annual Occupied Hours

- Nights, weekends, and holidays account for 66% of the year
  - A typical office building is unoccupied during this time
- During a typical work day, building occupants are only at their desk less than 30% of the time
  - Workstations are vacant and should be powered down during more than 70% of business hours
- Workstations should only be powered 7% of the year!



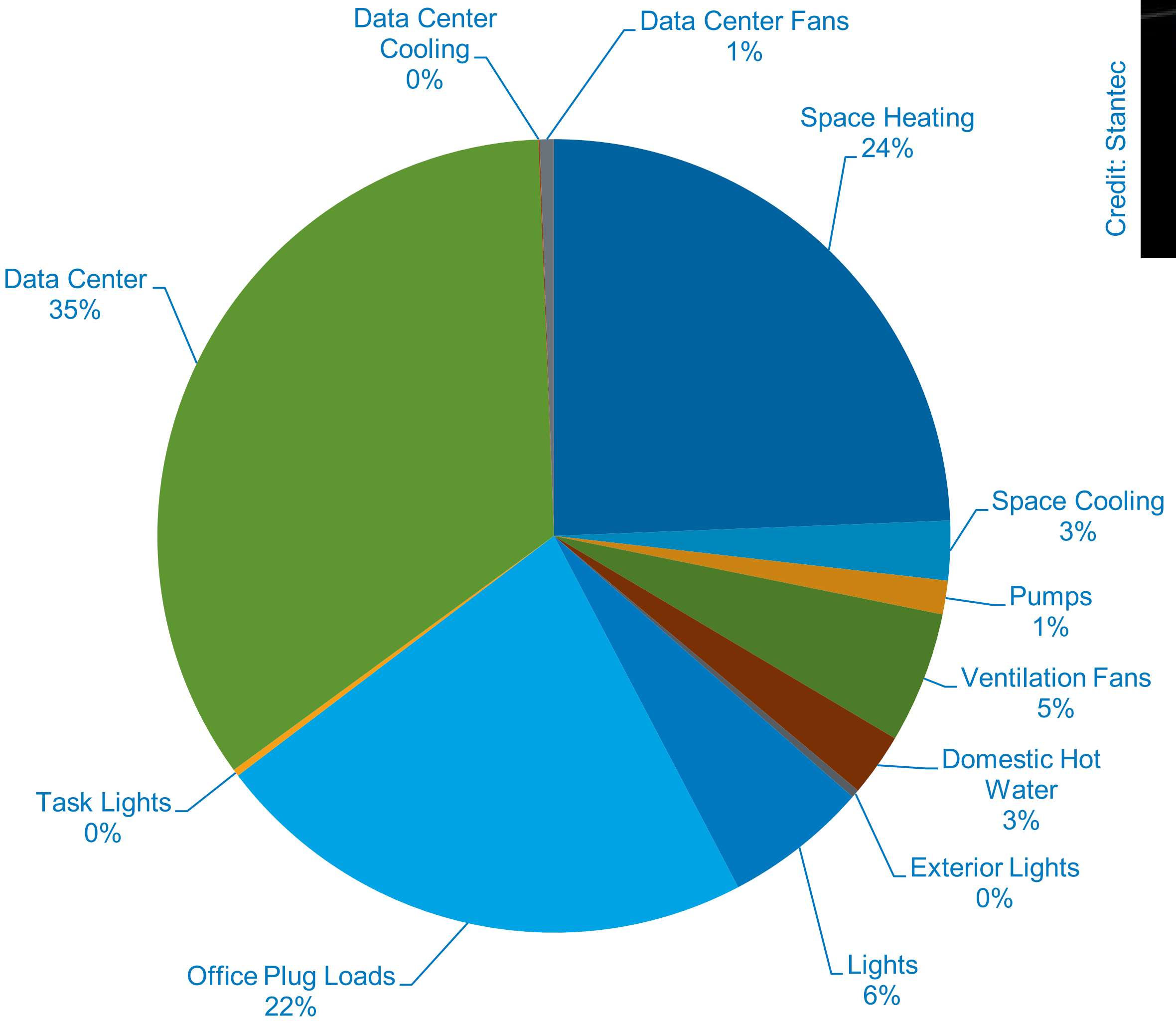
References:
http://www.gsa.gov/graphics/pbs/WorkPlace_Matters_FINAL508_lowres.pdf



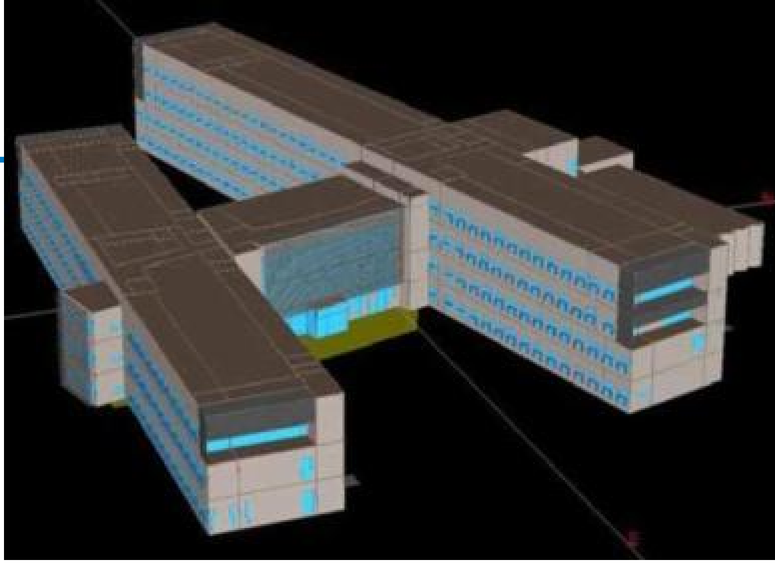
Credit: Chad Lobato/NREL

RSF Energy Modeling

NREL RSF Energy Use Breakdown



Credit: Chad Lobato/NREL



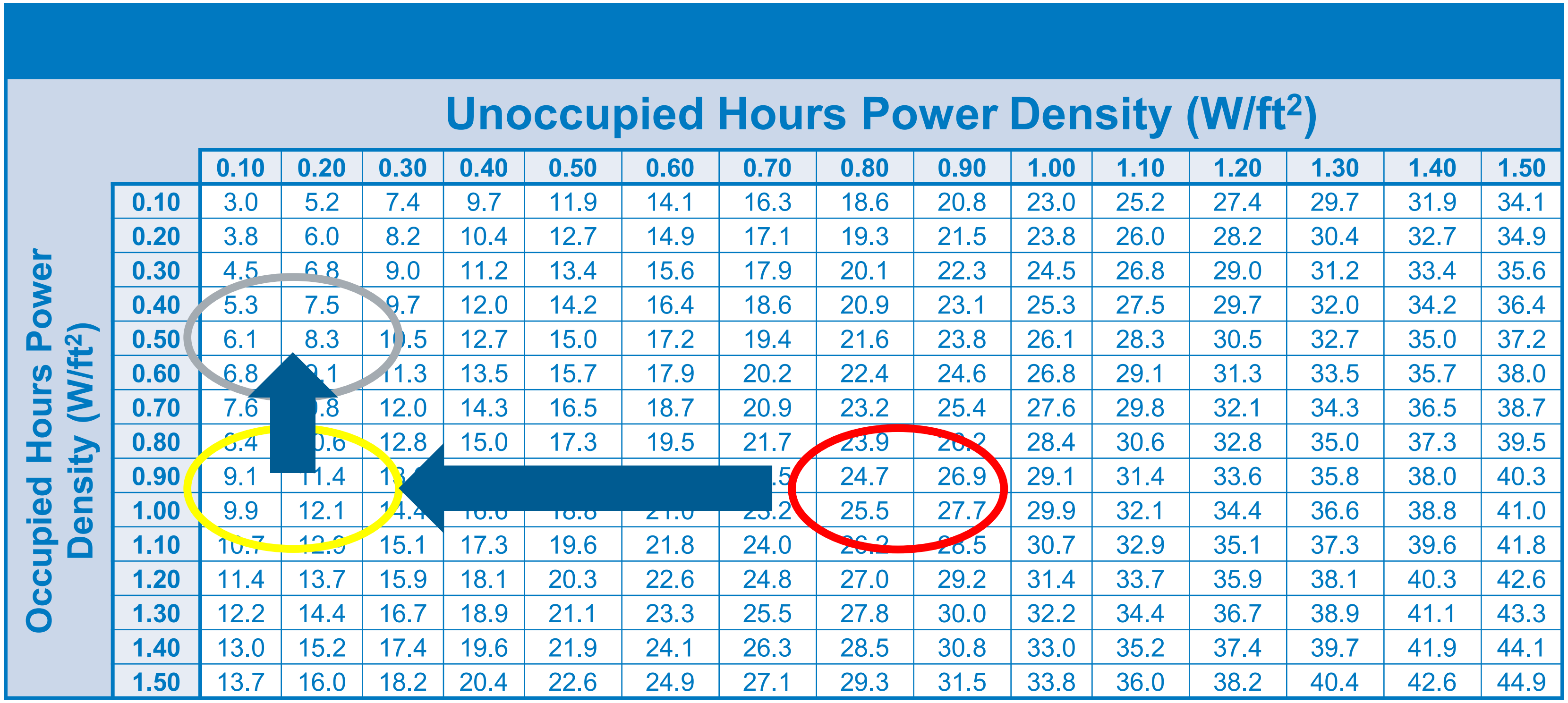
Credit: Stantec

End Use	**kBtu/ft²**
Space Heating	8.58
Space Cooling	0.85
Pumps	0.48
Ventilation Fans	1.88
Domestic Hot Water	0.90
Exterior Lights	0.12
Lights	2.07
Office Plug Loads	7.87
Task Lights	0.10
Data Center	12.11
Data Center Cooling	0.02
Data Center Fans	0.20

Day vs. Night Plug and Process Loads

Only occupied about ⅓ of the time

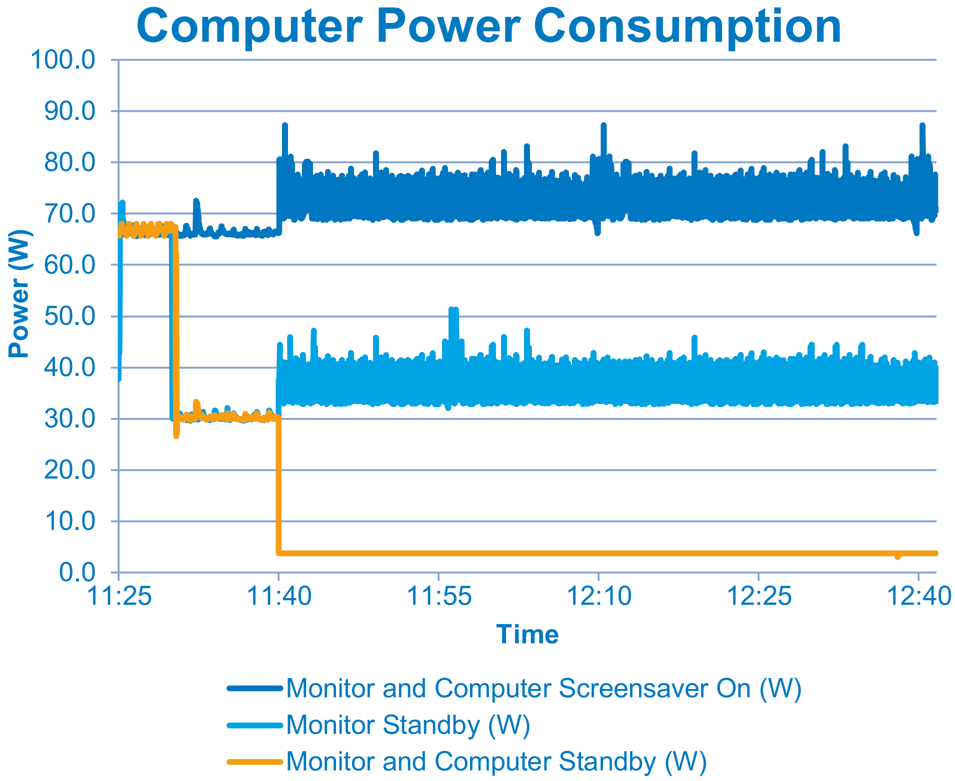
- -Nights Unoccupied
- -Weekends Unoccupied
- -Holidays Unoccupied



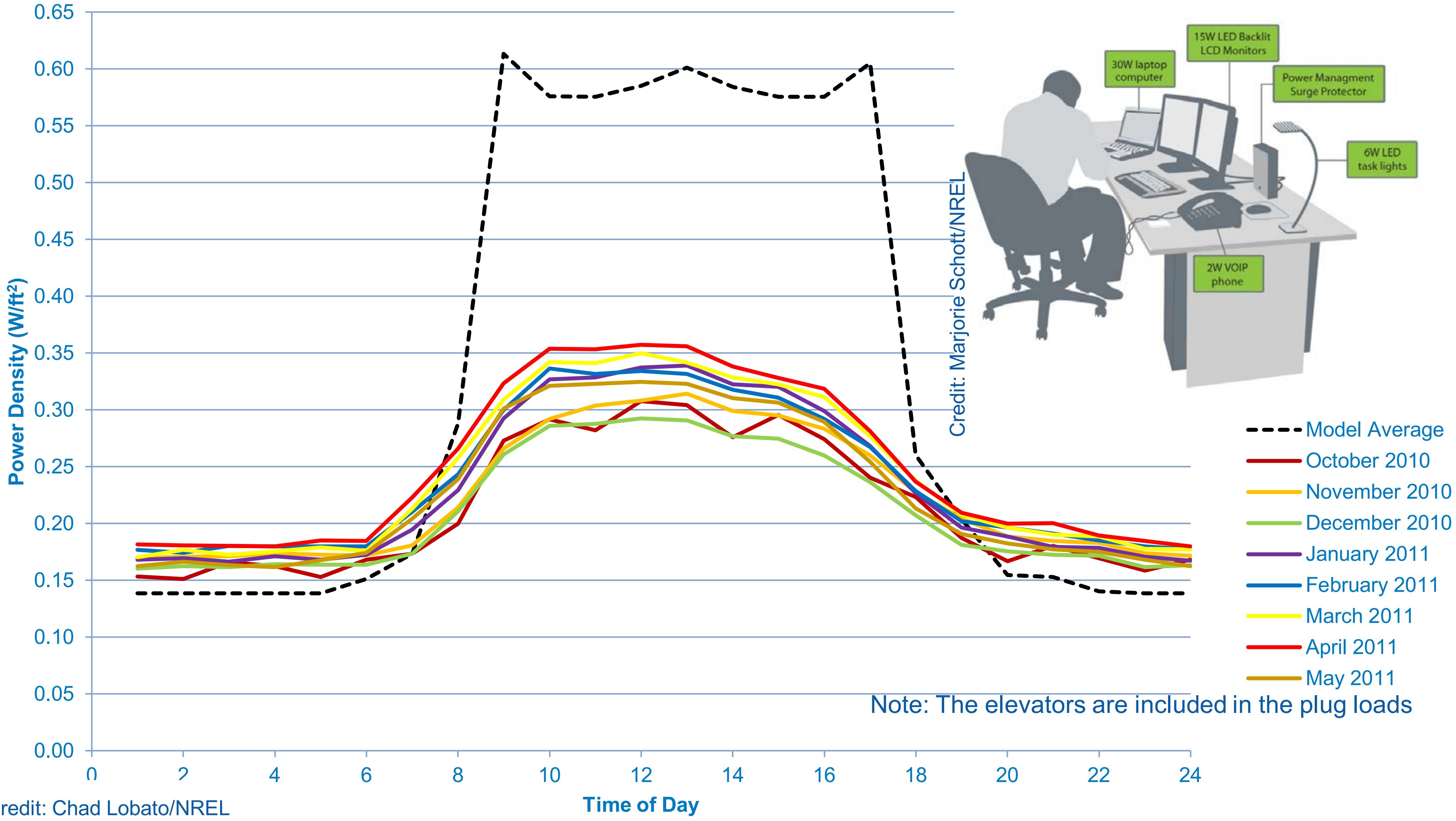
Occupied Hours Power Density (W/ft²)	Unoccupied Hours Power Density (W/ft²)														
	0.10	0.20	0.30	0.40	0.50	0.60	0.70	0.80	0.90	1.00	1.10	1.20	1.30	1.40	1.50
0.10	3.0	5.2	7.4	9.7	11.9	14.1	16.3	18.6	20.8	23.0	25.2	27.4	29.7	31.9	34.1
0.20	3.8	6.0	8.2	10.4	12.7	14.9	17.1	19.3	21.5	23.8	26.0	28.2	30.4	32.7	34.9
0.30	4.5	6.8	9.0	11.2	13.4	15.6	17.9	20.1	22.3	24.5	26.8	29.0	31.2	33.4	35.6
0.40	5.3	7.5	9.7	12.0	14.2	16.4	18.6	20.9	23.1	25.3	27.5	29.7	32.0	34.2	36.4
0.50	6.1	8.3	10.5	12.7	15.0	17.2	19.4	21.6	23.8	26.1	28.3	30.5	32.7	35.0	37.2
0.60	6.8	9.1	11.3	13.5	15.7	17.9	20.2	22.4	24.6	26.8	29.1	31.3	33.5	35.7	38.0
0.70	7.6	9.8	12.0	14.3	16.5	18.7	20.9	23.2	25.4	27.6	29.8	32.1	34.3	36.5	38.7
0.80	8.4	10.6	12.8	15.0	17.3	19.5	21.7	23.9	26.2	28.4	30.6	32.8	35.0	37.3	39.5
0.90	9.1	11.4	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	24.7	26.9	29.1	31.4	33.6	35.8	38.0	40.3
1.00	9.9	12.1	14.4	16.6	18.8	21.0	23.2	25.5	27.7	29.9	32.1	34.4	36.6	38.8	41.0
1.10	10.7	12.9	15.1	17.3	19.6	21.8	24.0	26.2	28.5	30.7	32.9	35.1	37.3	39.6	41.8
1.20	11.4	13.7	15.9	18.1	20.3	22.6	24.8	27.0	29.2	31.4	33.7	35.9	38.1	40.3	42.6
1.30	12.2	14.4	16.7	18.9	21.1	23.3	25.5	27.8	30.0	32.2	34.4	36.7	38.9	41.1	43.3
1.40	13.0	15.2	17.4	19.6	21.9	24.1	26.3	28.5	30.8	33.0	35.2	37.4	39.7	41.9	44.1
1.50	13.7	16.0	18.2	20.4	22.6	24.9	27.1	29.3	31.5	33.8	36.0	38.2	40.4	42.6	44.9

Cyber-Security Policy

- **Evaluate policies and operations to ensure effectiveness**
  - NREL used a screensaver to lock unused computers
    - The screensaver consumes on average 5W more than an idle computer
  - Instead of a screensaver, if the monitors and computers went into standby there would be a savings of 70W per person
  - ~$500,000 of PV saved
  - Anything multiplied by 800 is a lot!



October 2010 – May 2011 Plug Load Power Density



Credit: Marjorie Schott/NREL

Note: The elevators are included in the plug loads

Credit: Chad Lobato/NREL

Climate Sensitive Design

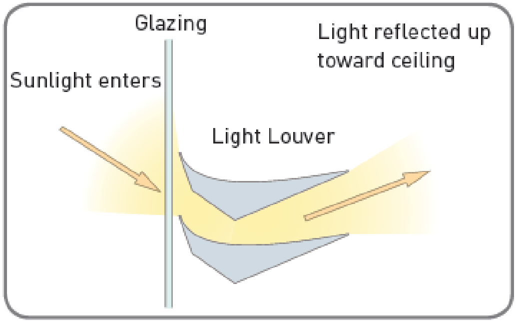
- Design buildings to the climate
- Required creative thinking by design team, contractor, trades, and manufacturers

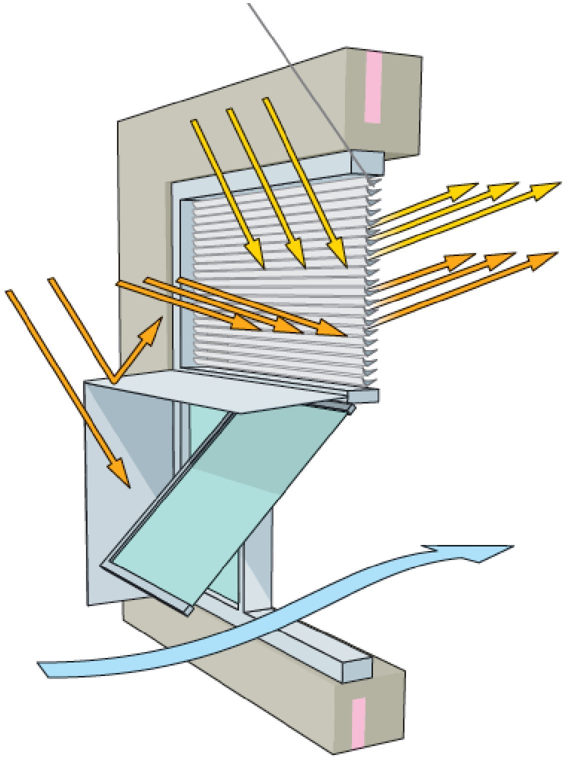
Window Design

NREL/17900

A light redirecting device reflects sunlight to the ceiling, creating an indirect lighting effect.

Fixed sunshades limit excess light and glare.

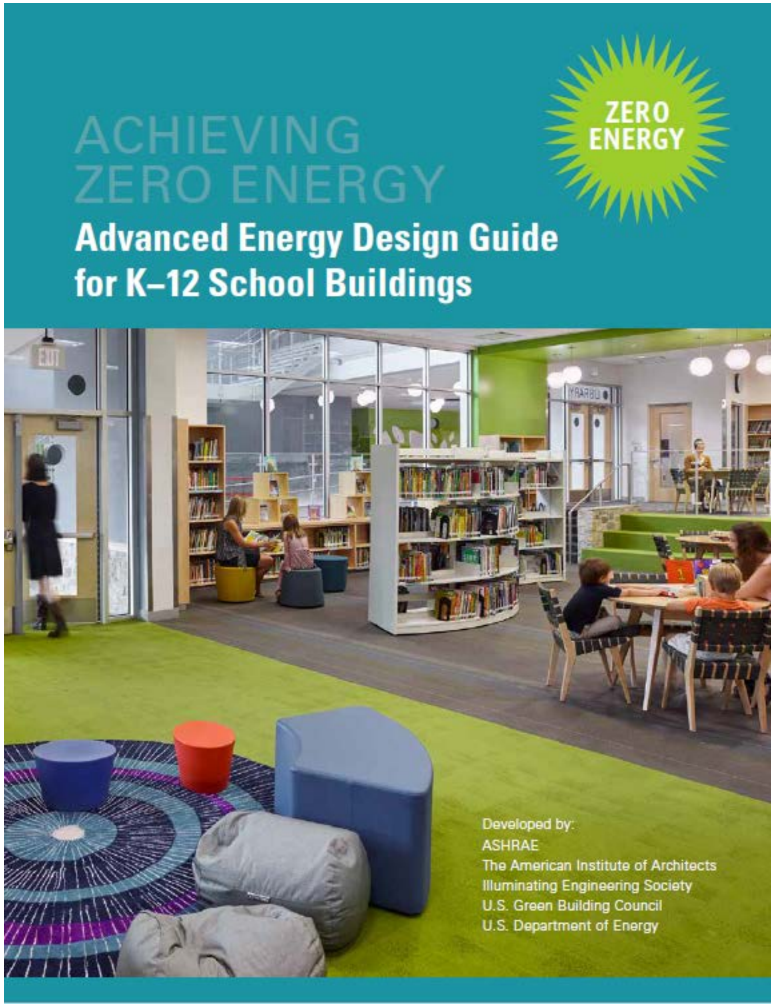




Credit: RNL

Resources

- Feasibility Studies
- Technical Support Documents
- Working with ASHRAE/AIA/IES/USGBC on Advanced Energy Design Guides for Zero Energy
- Modeling Tools and Validation
- Sector Accelerators (K-12 and Districts)
- Up next--Office Buildings



ZERO ENERGY

ACHIEVING ZERO ENERGY

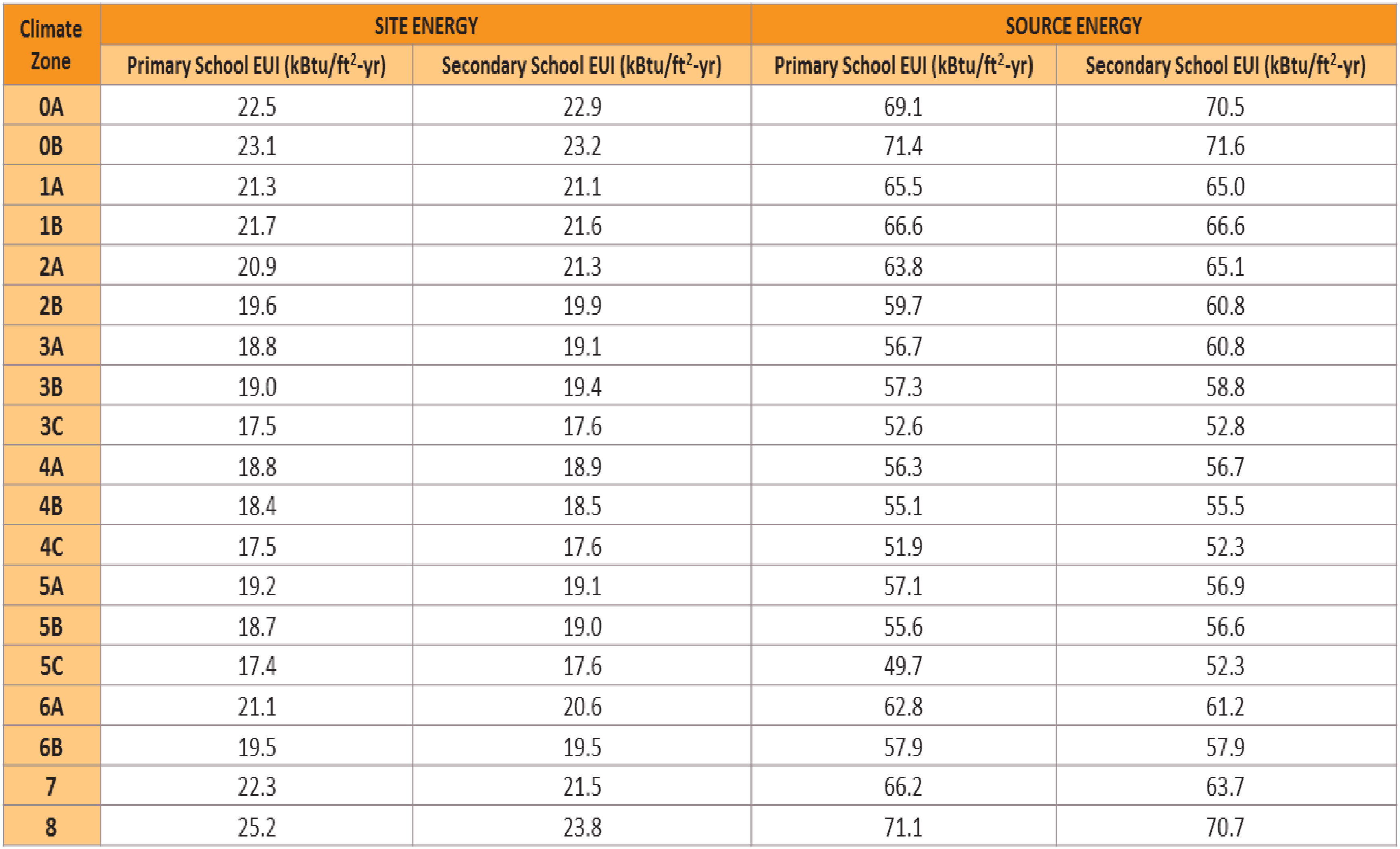
Advanced Energy Design Guide for K–12 School Buildings

Developed by:
ASHRAE
The American Institute of Architects
Illuminating Engineering Society
U.S. Green Building Council
U.S. Department of Energy

Energy Use Intensity Targets

- **NREL did exhaustive simulations to determine energy use intensity targets**
    - Can show that zero is possible and the types of strategies that can be used to get there
- **Set of design decisions that can achieve the targets**
    - Zero Energy Ready Buildings—buildings so efficient that on-site renewables can offset the energy needs

Energy Use Intensity Targets for Schools



Climate Zone	SITE ENERGY		SOURCE ENERGY	
	Primary School EUI (kBtu/ft^2-yr)	Secondary School EUI (kBtu/ft^2-yr)	Primary School EUI (kBtu/ft^2-yr)	Secondary School EUI (kBtu/ft^2-yr)
0A	22.5	22.9	69.1	70.5
0B	23.1	23.2	71.4	71.6
1A	21.3	21.1	65.5	65.0
1B	21.7	21.6	66.6	66.6
2A	20.9	21.3	63.8	65.1
2B	19.6	19.9	59.7	60.8
3A	18.8	19.1	56.7	60.8
3B	19.0	19.4	57.3	58.8
3C	17.5	17.6	52.6	52.8
4A	18.8	18.9	56.3	56.7
4B	18.4	18.5	55.1	55.5
4C	17.5	17.6	51.9	52.3
5A	19.2	19.1	57.1	56.9
5B	18.7	19.0	55.6	56.6
5C	17.4	17.6	49.7	52.3
6A	21.1	20.6	62.8	61.2
6B	19.5	19.5	57.9	57.9
7	22.3	21.5	66.2	63.7
8	25.2	23.8	71.1	70.7

Case Studies

Discovery Elem. School EUI=15.8

Dearing Elem. School EUI=23.5

Friends School EUI=11.7

- Need to unleash the creativity of design and construction professionals
- Incentivize the process, not the products
- We can create zero energy buildings today at little or no incremental cost

www.nrel.gov/rsf

Buildingdata.energy.gov/cbrd

Paul A. Torcellini

Paul.Torcellini@nrel.gov