National Institute of Building Sciences

Provider Number: G168

Whole Building Energy Performance: Driving Towards Net Zero and Energy Security

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Questions related to specific materials, methods, and services will be addressed at the conclusion of this presentation.

Course Description

Energy codes and the desire for energy security are changing how our buildings are designed, constructed, and operated, all of which seem to be leading towards near-zero or net-zero energy buildings being the norm some day. To be ready for this, Project Teams must have increasing familiarity with the drivers for high performance buildings, the definition and feasibility of net-zero energy buildings, as well as the tools and approach needed to design and maintain this level of performance for the life of the building.

Learning Objectives

At the end of the this course, participants will be able to:

1. Identify the drivers for high performance and net-zero energy buildings
2. Describe the tools and approaches needed to achieving low-energy or zero-energy buildings
3. Define net-zero energy building and describe their feasibility
4. Identify how to keep a building operating at peak efficiency for the long-term

High Performance Design Drivers

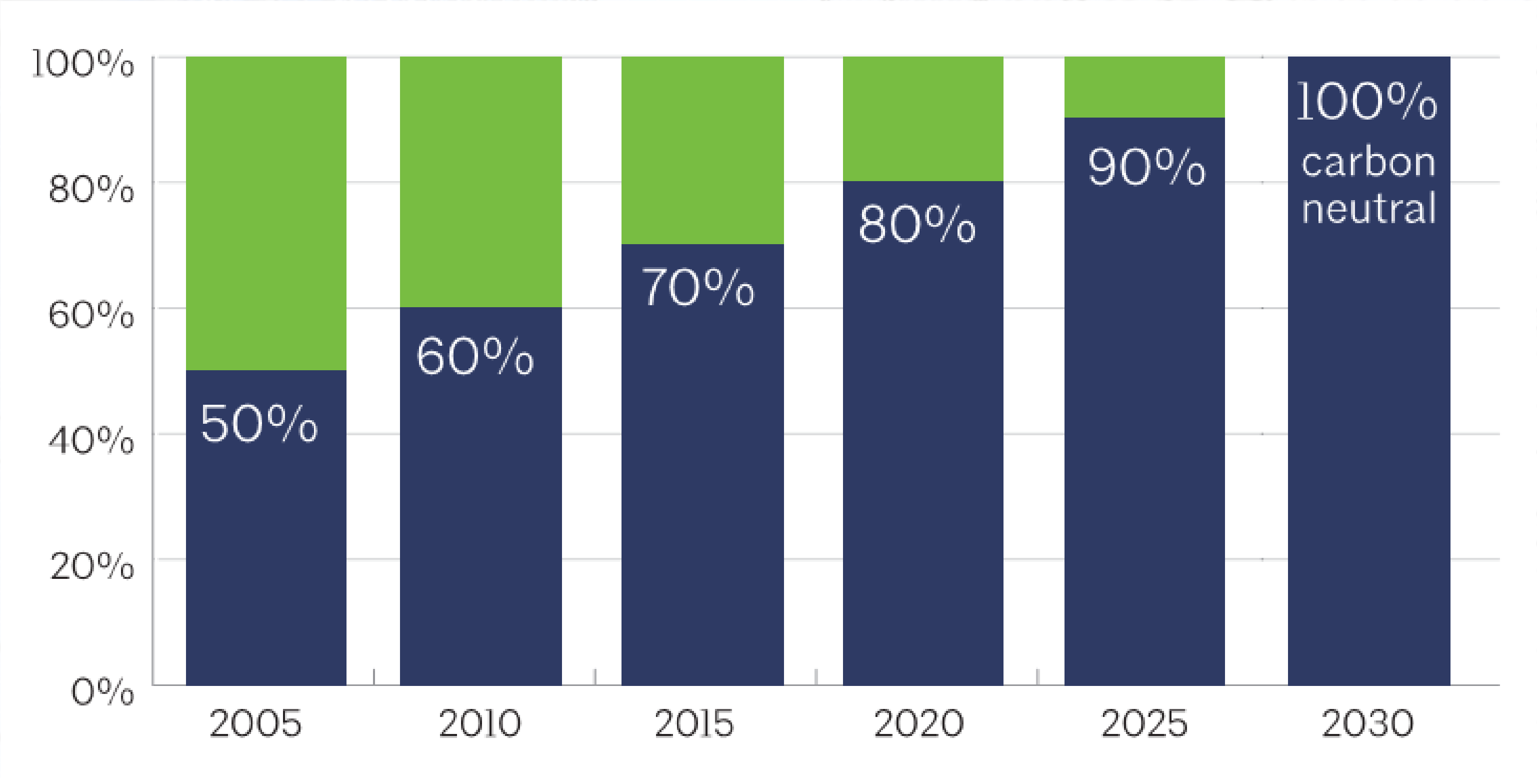
Requirements

- 10 CFR 433
- EISA of 2007
- Executive Order 13514
- ASHRAE 90.1 / 189.1
- IECC / IgCC

Incentives

- LEED
- Energy Star
- IRS Code Section 179(d)
- Utility Rebates
- ASHRAE bEQ

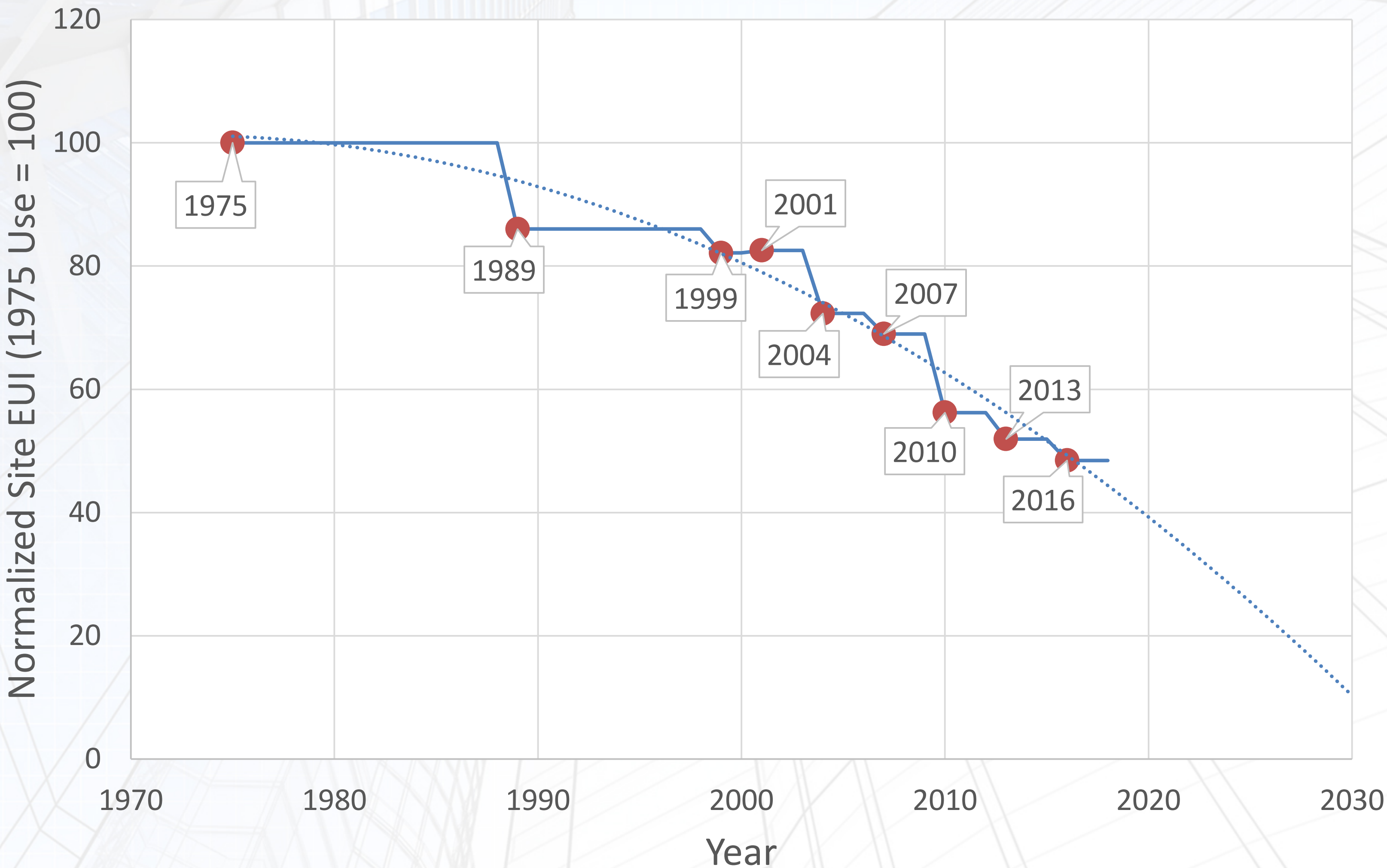
Architecture 2030 Challenge Goals



Source: Architecture 2030

Energy Code Stringency

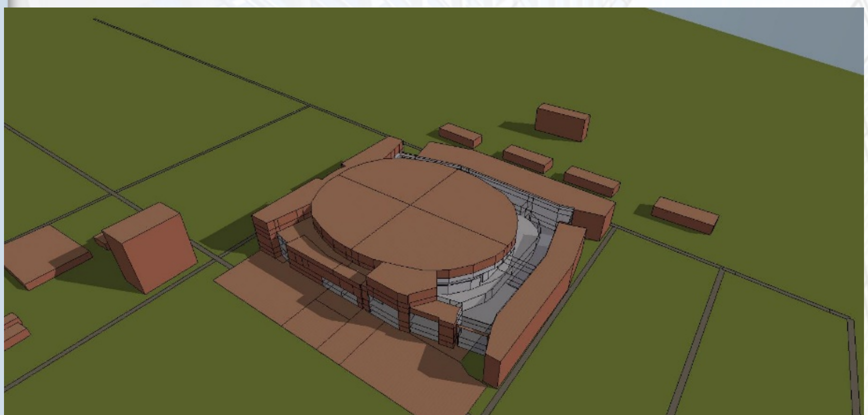
Changes to ASHRAE Standard 90.1 (1975 - 2016)

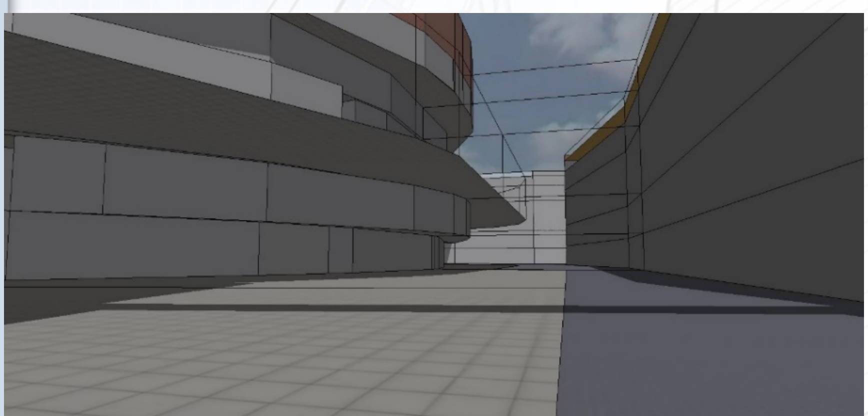


Source: PNNL, “ASHRAE 90.1 Determination of Energy Savings: Quantitative Analysis”

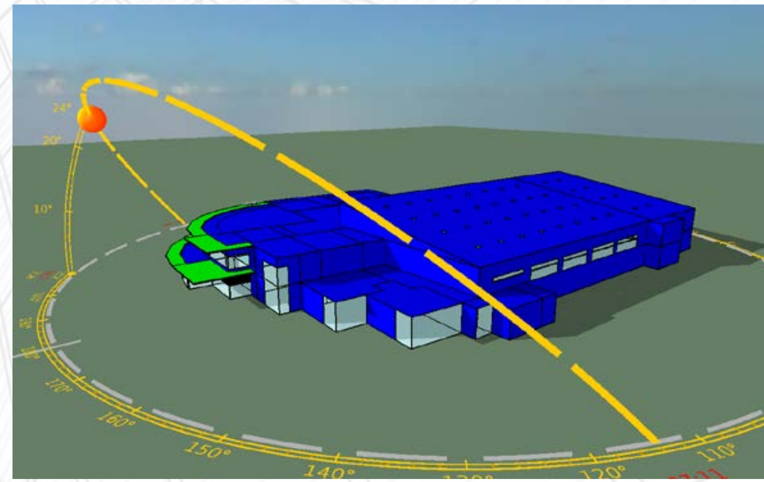
Energy Codes – Changing the face of architecture?

Too much skylight area?



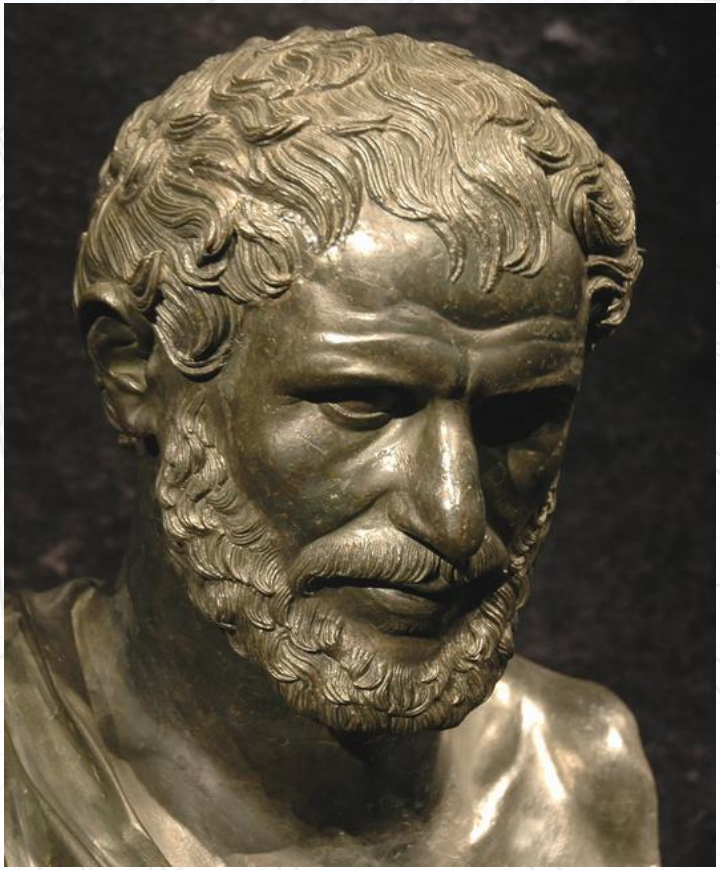


Not enough skylight area?



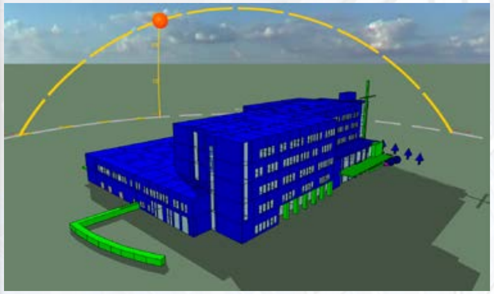
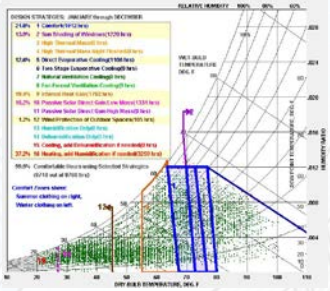
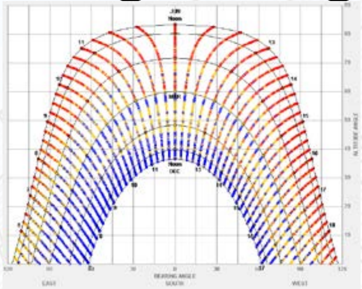
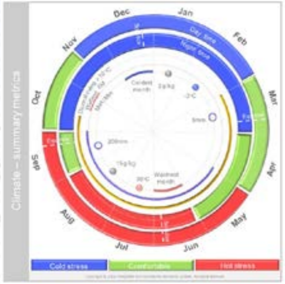
What’s the effect of all this change?

- More use of the performance (modeled) compliance path
- Energy modeling used early in design, just to show compliance!
- Changes to ASHRAE 90.1
  - Performance Rating Method can be used for compliance
  - PRM Baseline consistent with 90.1-2004
- Specialized code-compliance energy modeling software
  - California – CBECC-Com
  - Florida – FLACom

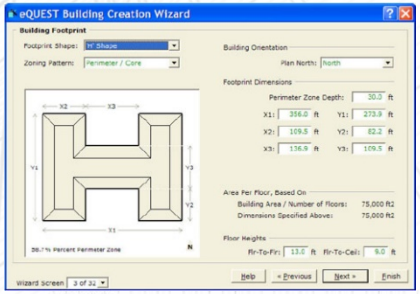


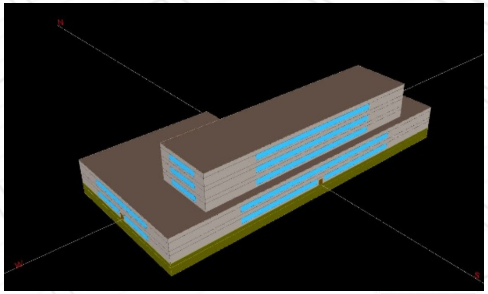
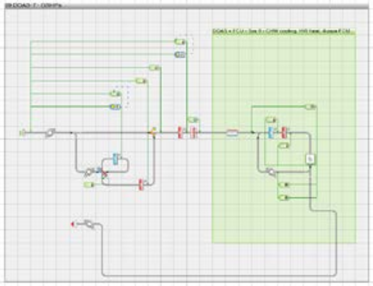
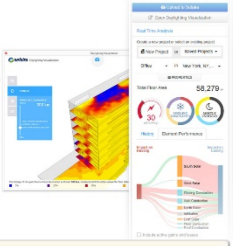
“The only constant is change.” - Heraclitus

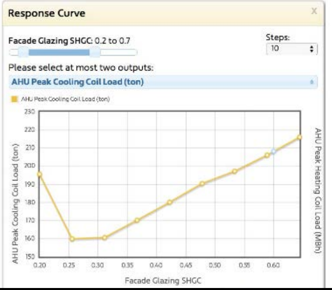
Qualities of Analysis Tools for High Performance Building Design

- gbXML import from Sketchup or Revit
- Climate, Shading, HVAC Loads, Energy, Daylighting, Natural Ventilation, CFD (preferably integrated into same 3D model)
- Optimization functions
- Financial (LCCA) analysis
- Adjustable level of detail as appropriate for each phase of design and operations ("Wizards")
- Robust and detailed HVAC system modeling

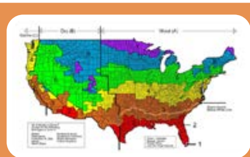


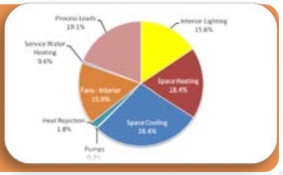


Taking the right steps in the right order

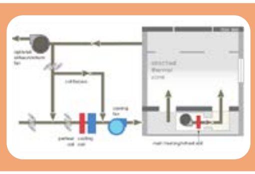
Define Needs and Goals



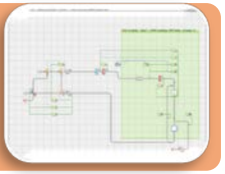
Identify Appropriate Strategies

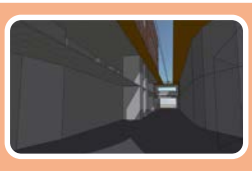


Reduce Building Loads



Select Appropriate & Efficient Systems



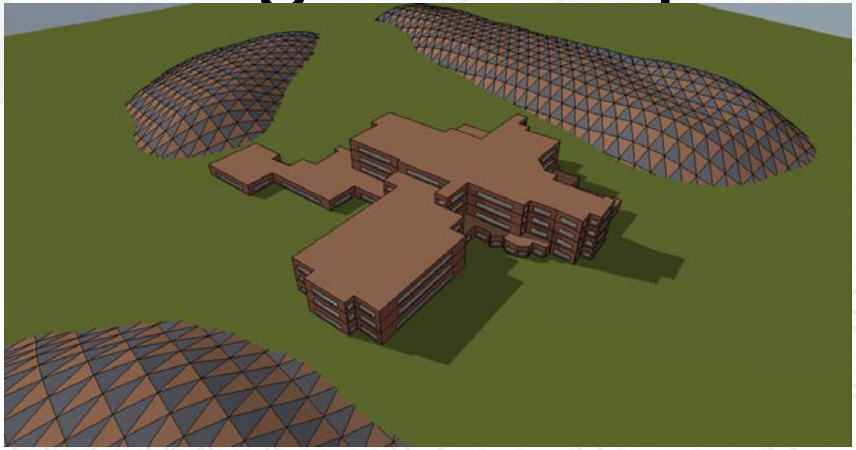


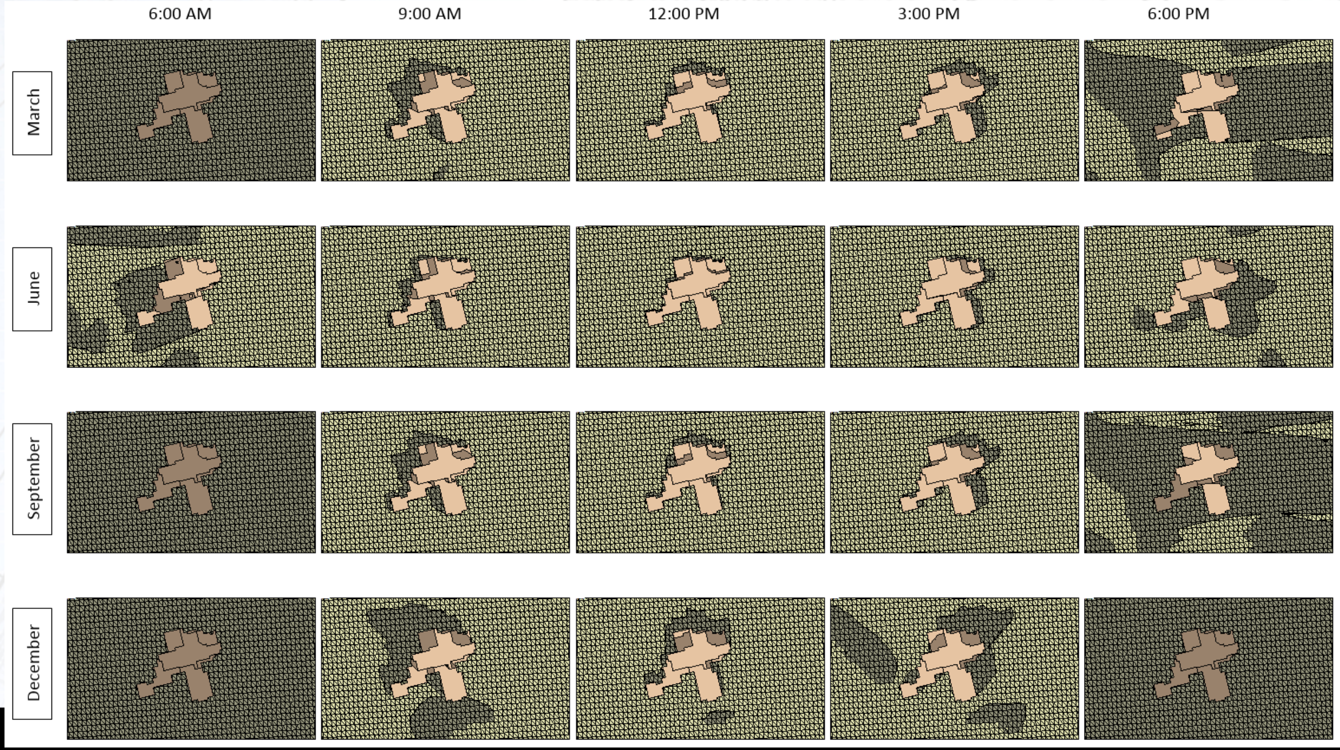
Optimize Controls & Operations for Part-load Conditions

Seek Synergies &Explore Alternative Power

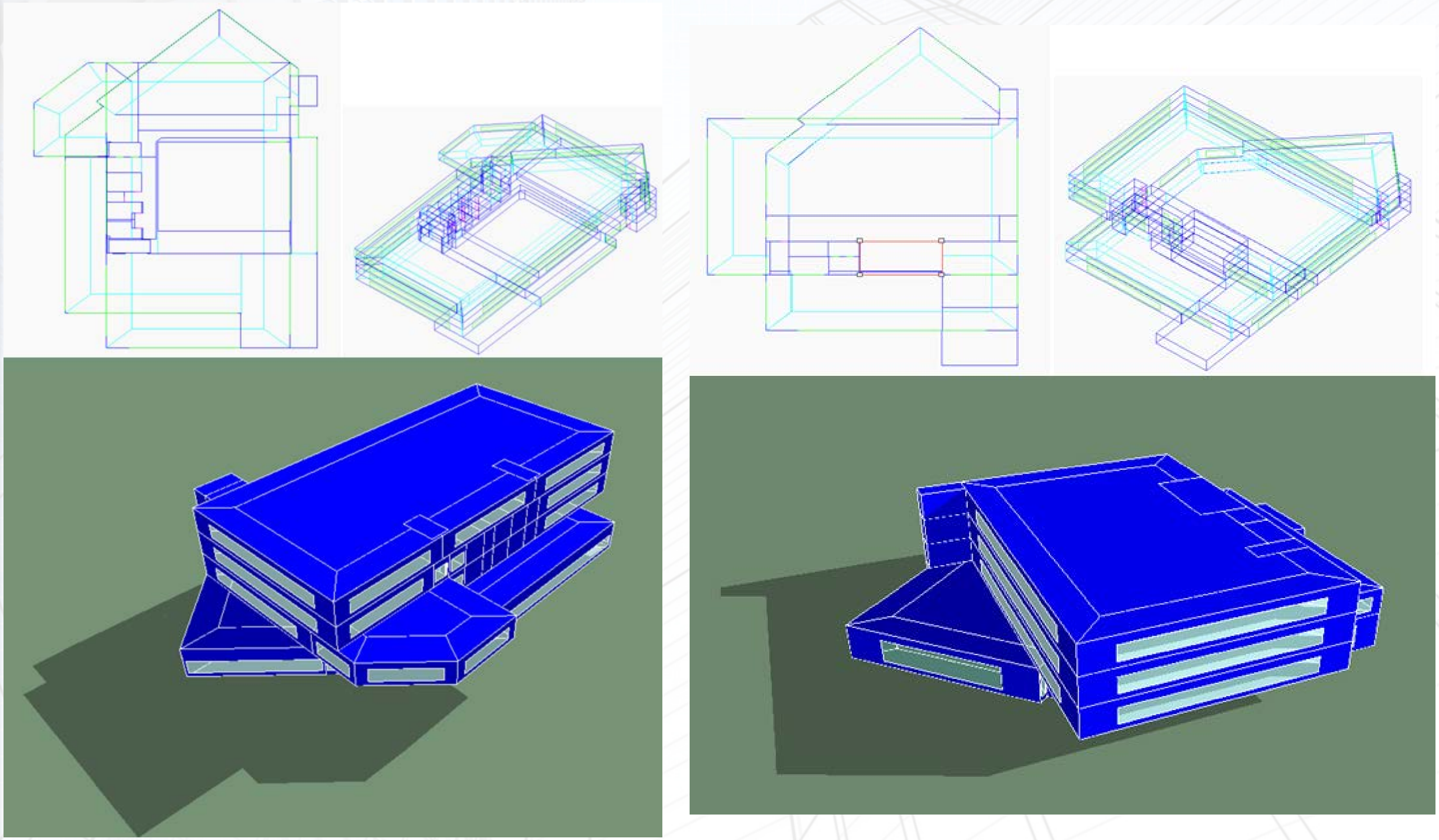
Modified from : ASHRAE / IBPSA-USA / RMI; Building Energy Modeling Training Workshop

Site Conditions – Virginia Hospital

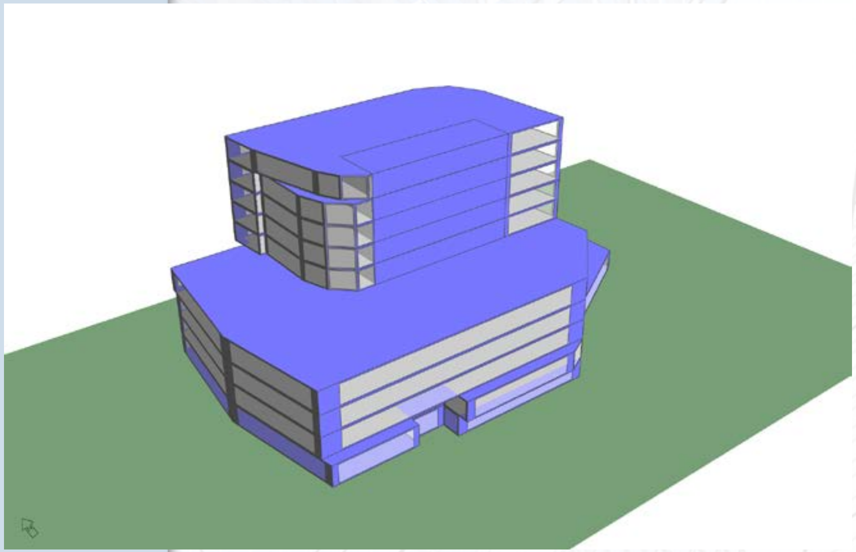




Building Orientation : Office Massing study



Load Reduction Modeling: Case Study



- 11-story office building in San Francisco
- Schematic Design
- Measures analyzed:
  - Wall insulation
  - Roof Insulation
  - Window U-value
  - Window SHGC
  - Roof Reflectance

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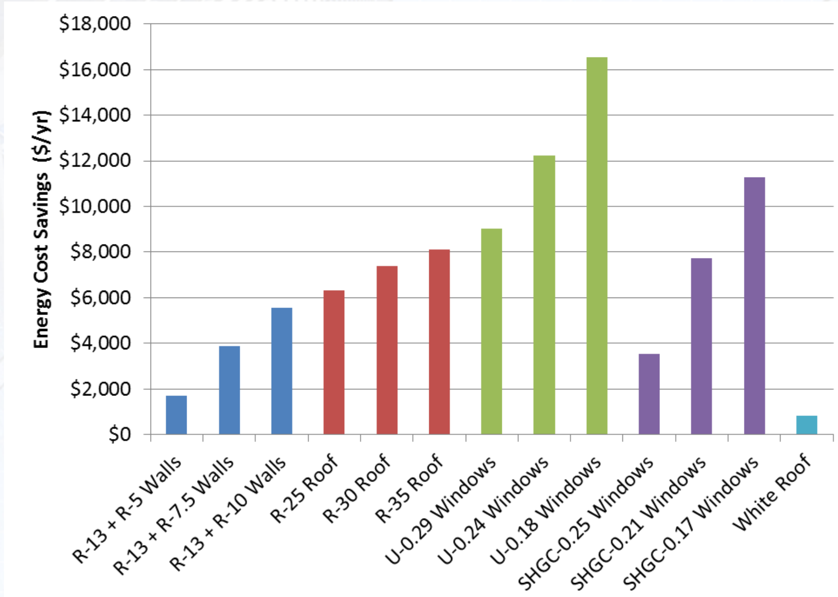
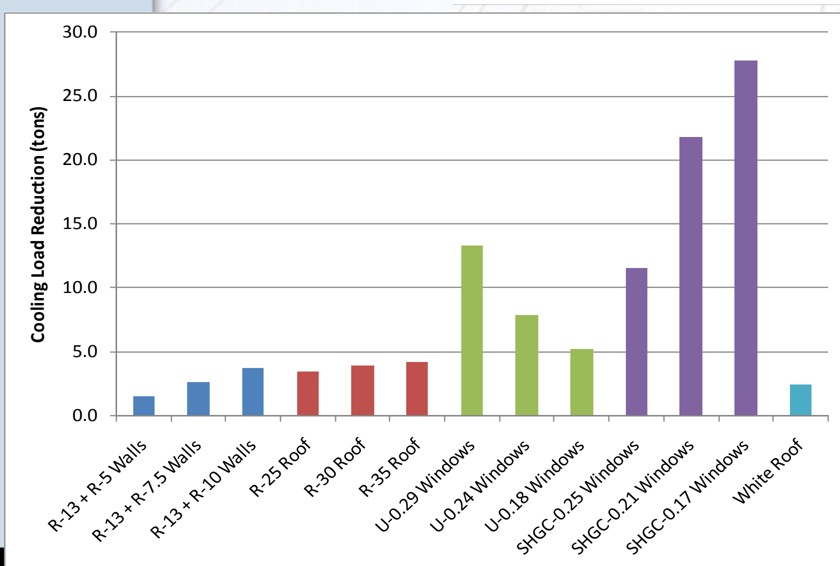
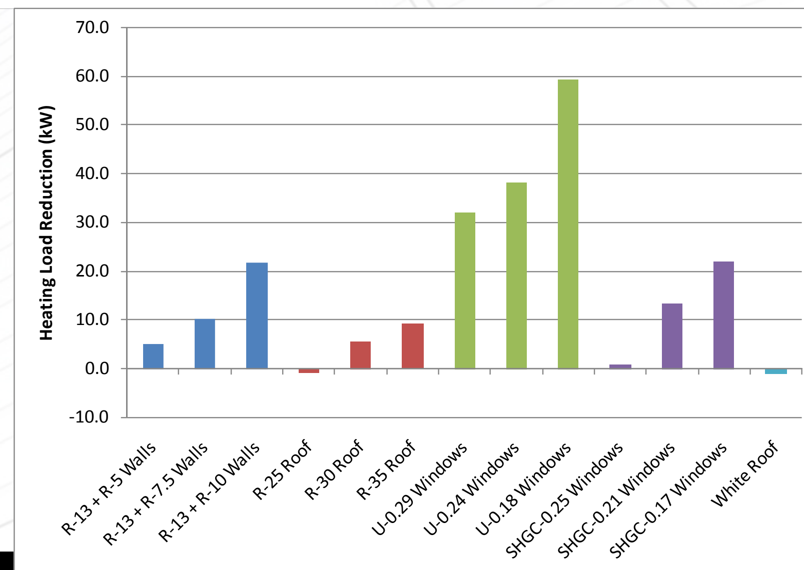
Energy and HVAC Load Results







Financial Analysis

LR	Description	Envelope Cost Change ($)	Energy Cost Savings ($/yr)	Simple Payback Period (yrs)
1-1	R-13 + R-5 Walls	$13,071	$2,041	6.4
1-2	R-13 + R-7.5 Walls	$36,930	$4,688	7.9
1-3	R-13 + R-10 Walls	$57,743	$6,770	8.5
2-1	R-25 Roof	$39,387	$7,705	5.1
2-2	R-30 Roof	$80,620	$9,047	8.9
2-3	R-35 Roof	$123,697	$9,956	12.4
5-1	White Roof	$0	$1,009	Immediate

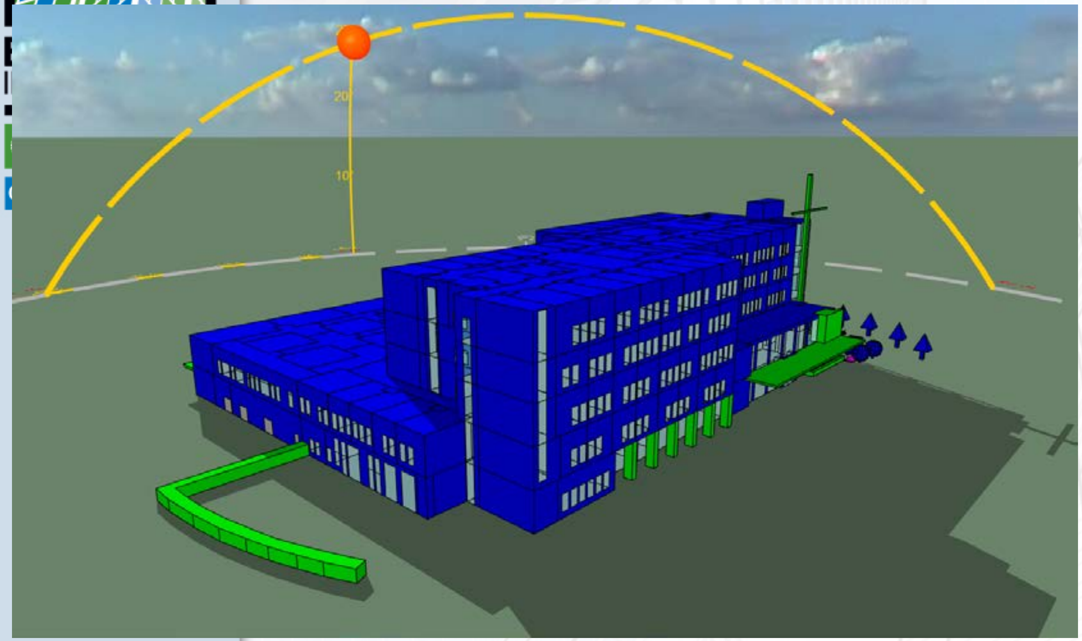
- RS Means provides envelope first cost estimates
- Relatively poor payback (6 – 12 years)

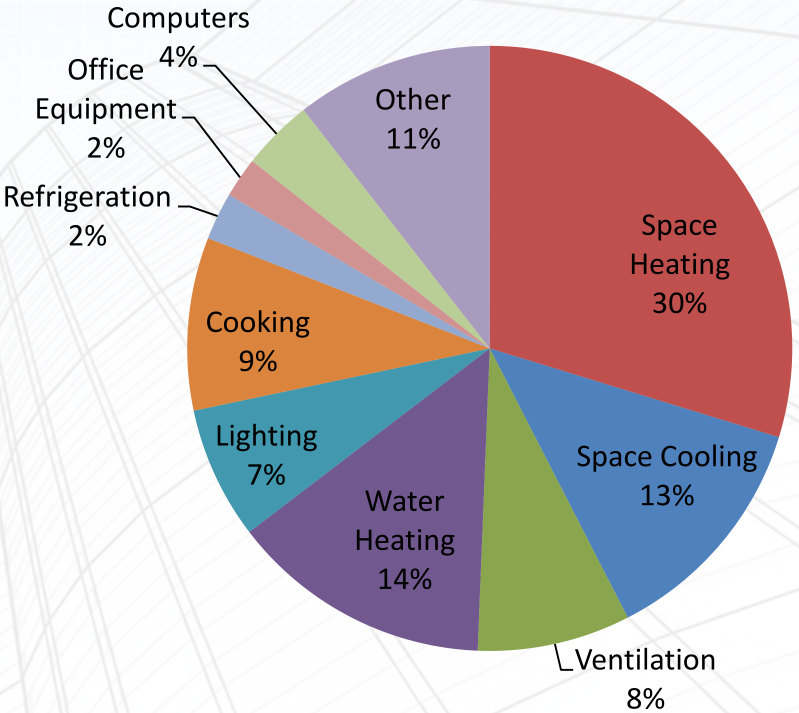
- What about HVAC equipment cost?
- Contractor provides HVAC cost estimates…

LR	Description	Envelope Cost Change ($)	Cooling		Heating		Net Construction Cost Change ($)	Energy Cost Savings ($/yr)	Simple Payback w/o HVAC (yrs)	Simple Payback w/ HVAC (yrs)
			Load Change (tons)	Mech Equip Cost Change ($)	Load Change (kW)	Mech Equip Cost Change ($)				
1-1	R-13 + R-5 Walls	$13,071	-1.5	-$13,486	-5.1	-$3,569	-$3,983	$2,041	6.4	Immediate
1-2	R-13 + R-7.5 Walls	$36,930	-2.6	-$22,990	-10.2	-$7,165	$6,776	$4,688	7.9	1.4
1-3	R-13 + R-10 Walls	$57,743	-3.7	-$32,667	-21.7	-$15,164	$9,912	$6,770	8.5	1.5
2-1	R-25 Roof	$39,387	-3.5	-$30,535	0.8	$533	$9,385	$7,705	5.1	1.2
2-2	R-30 Roof	$80,620	-3.9	-$34,520	-5.6	-$3,925	$42,174	$9,047	8.9	4.7
2-3	R-35 Roof	$123,697	-4.2	-$36,994	-9.2	-$6,424	$80,278	$9,956	12.4	8.1
5-1	White Roof	$0	-2.4	-$21,501	1.2	$832	-$20,669	$1,009	Immediate	Immediate

Bundle quick payback items with High Performance Glass, and keep going…

HVAC Selection - Case Study





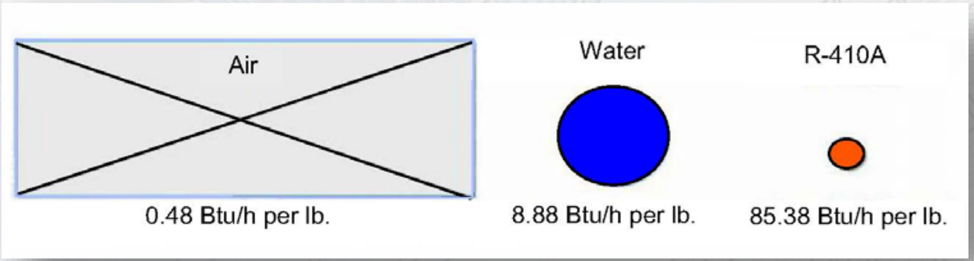
Typical Energy Use in Hospitals

Source: 2012 Commercial Building Energy Consumption Survey (CBECS)

- Methodist Olive Branch Hospital – Olive Branch, MS
- 206,000 sq. ft., 100 bed, greenfield hospital
- Analysis started during concept phase

Alternate HVAC Systems Investigated

Business-as-Usual = Chiller, Boiler, VAV Air Handlers



Air is a poor choice for a heat transfer medium

Choose water or refrigerant as predominant heat transfer medium, instead.

– Water Source Heat Pumps

– Variable Refrigerant Flow

– Active Chilled Beams

– Ground Source Heat Pumps

-Provide DOAS to decouple dehumidification from space cooling

- Reduce simultaneous cooling and reheating

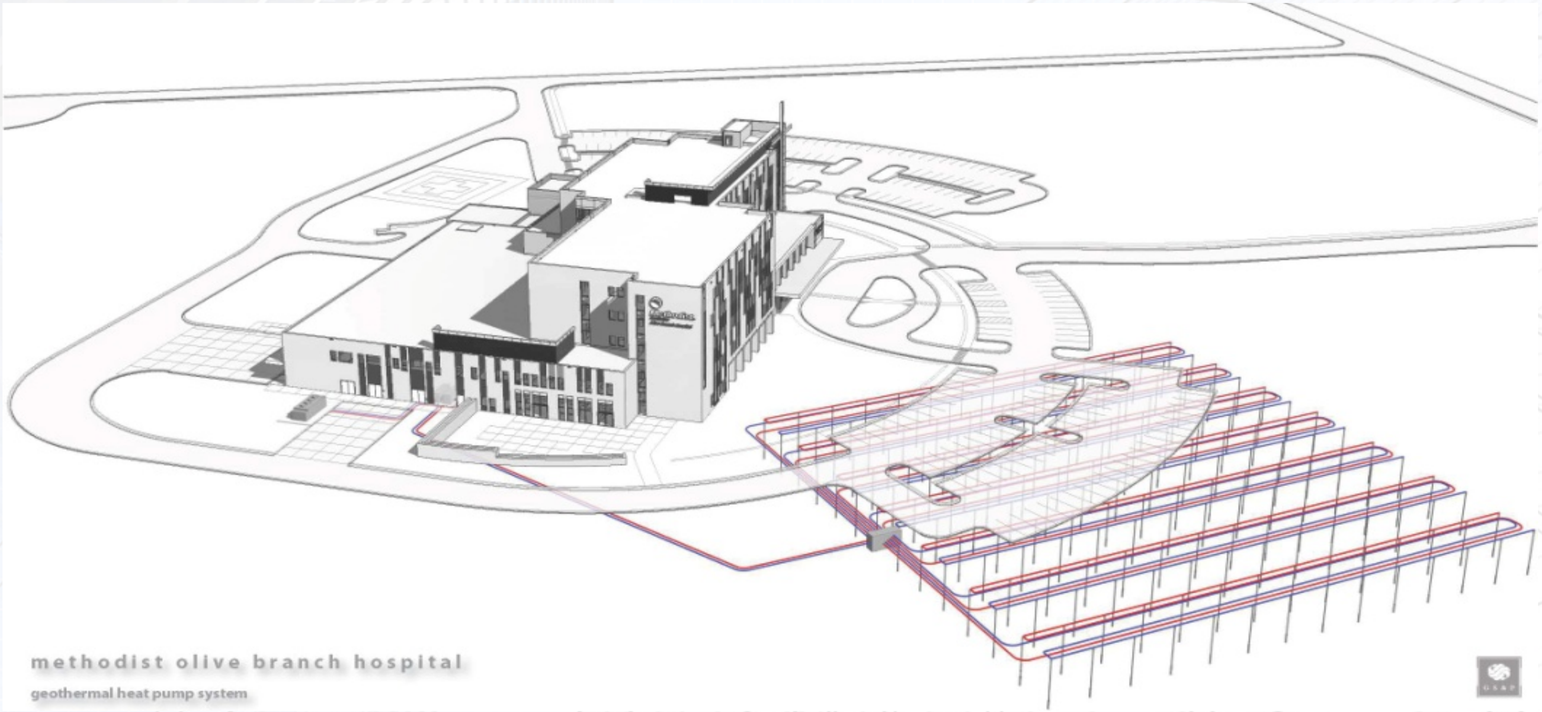
HVAC System Selection - Results

				Cumulative 7 Year Evaluation Timeline			Total 7 Year Investment
HVAC System	EUI*	Annual Energy $ / ft²	MEP First Cost	Energy	O&M	Total	
GSHP	158.3	$3.59	$ 27,206,429	$ 5,059,705	$ 4,532,776	$ 9,592,481	**$ 36,798,909**
WSHP	173.9	$4.09	$ 26,805,383	$ 5,757,045	$ 4,688,433	$ 10,445,478	**$ 37,250,861**
VRF	169.6	$3.88	$ 28,272,794	$ 5,467,189	$ 4,571,920	$ 10,039,109	**$ 38,311,903**
Chiller - VAV	182.7	$4.09	$ 28,387,134	$ 5,764,808	$ 5,017,941	$ 10,782,749	**$ 39,169,883**
Chilled Beam	176.2	$3.98	$ 28,023,893	$ 5,606,685	$ 4,781,578	$ 10,388,263	**$ 38,412,156**

- First Cost
  1. WSHP
  2. GSHP
  3. ACB
  4. VRF
  5. VAV AHU
- Energy & Water
  1. GSHP
  2. VRF
  3. ACB
  4. WSHP
  5. VAV AHU
- O&M
  1. GSHP
  2. VRF
  3. WSHP
  4. ACB
  5. VAV AHU
- Total
  1. GSHP
  2. WSHP
  3. VRF
  4. ACB
  5. VAV AHU

Energy cost savings alone probably wouldn't have been enough to justify GSHP! Thus, the importance of "Budget Sharing…"

HVAC Selection Results



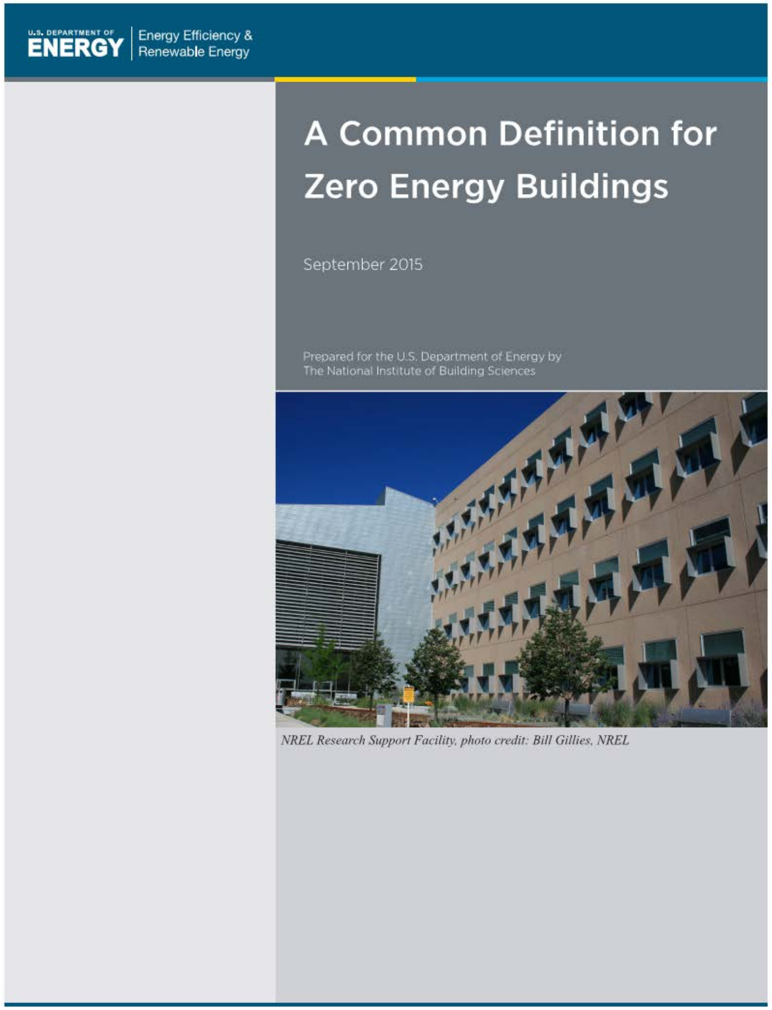
- Distributed Ground Source Heat Pumps (GSHPs)
- Rooftop DOAS units
- W-W GSHP for domestic HW
- No central steam
- 196 vertical bores, 300 ft. deep
- 80 ton fluid cooler
- Adaptive control & pumping system to manage borefield

- The first LEED for Healthcare Gold certified inpatient facility in the United States.
- One of six LEED for Healthcare certified facilities in the world.
- One of three LEED for Healthcare certified inpatient facilities in the United States
- Energy Star certified

What is a Net-Zero Energy Building?

- aka “Zero Energy Building”, “Zero Net Energy Building”

- 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.


U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

A Common Definition for Zero Energy Buildings

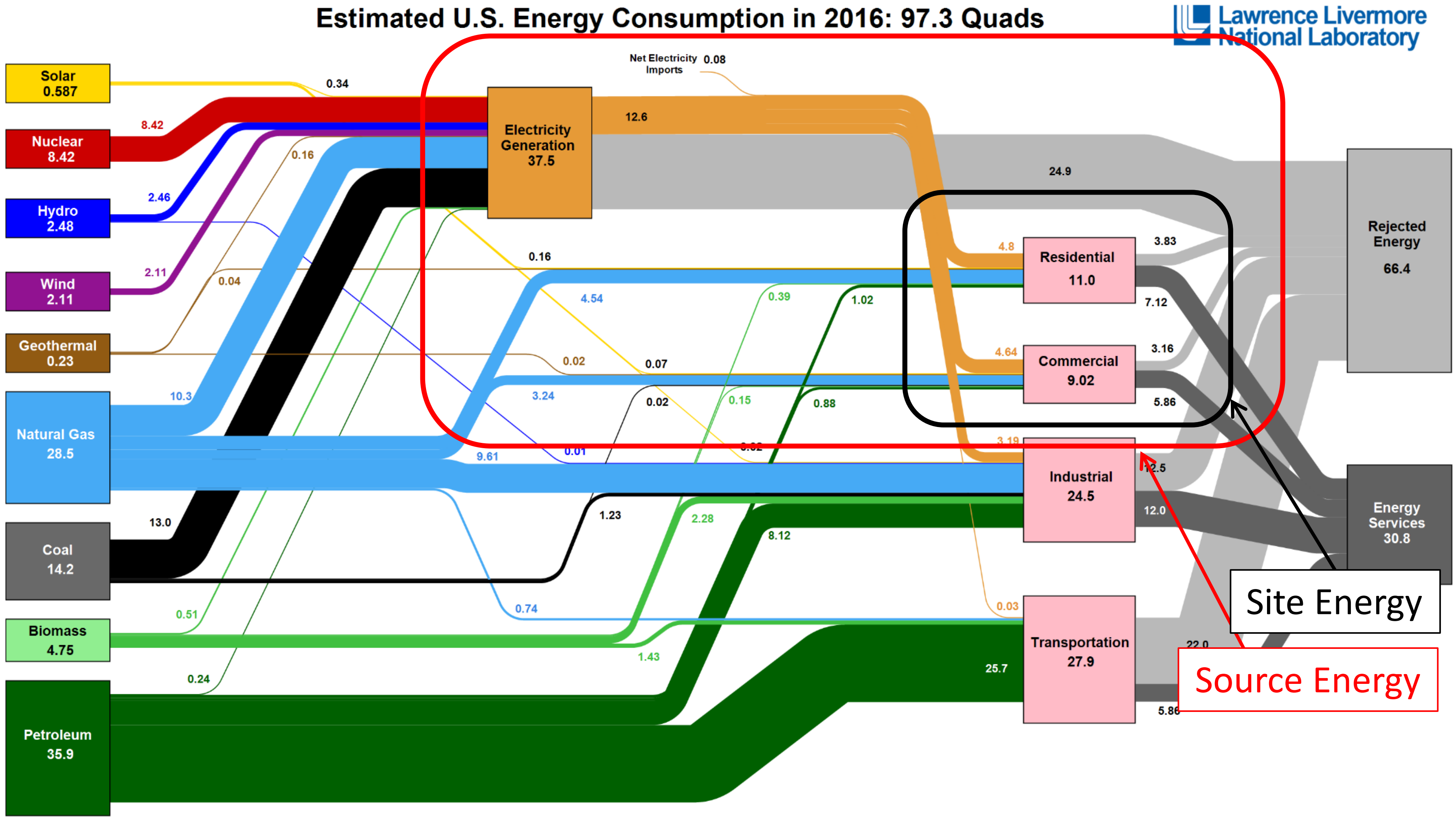
September 2015

Prepared for the U.S. Department of Energy by
The National Institute of Building Sciences

NREL Research Support Facility, photo credit: Bill Gillies, NREL

Site Energy vs. Source Energy

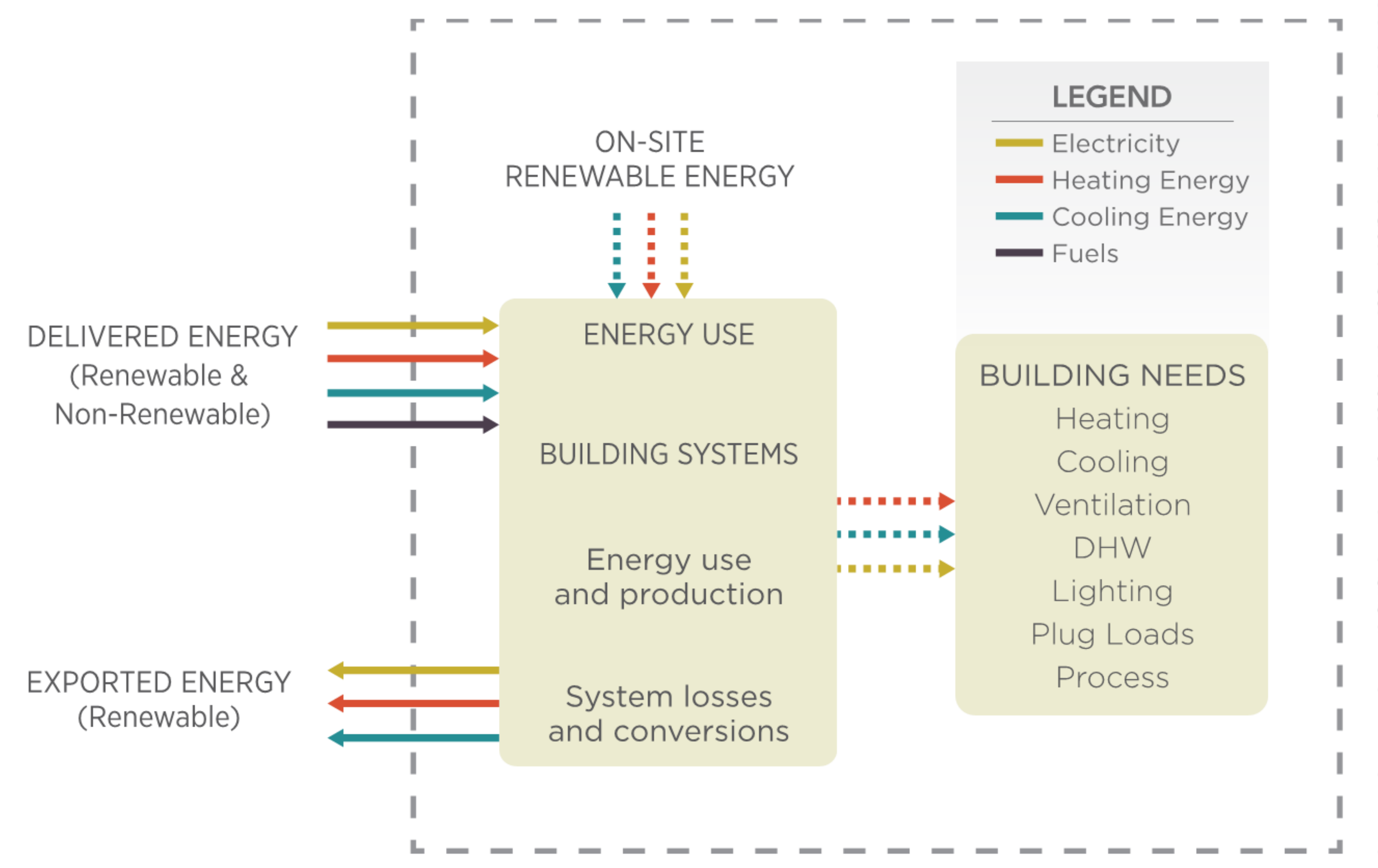
Estimated U.S. Energy Consumption in 2016: 97.3 Quads



Source: LLNL March, 2017. Data is based on DOE/EIA MER (2016). 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

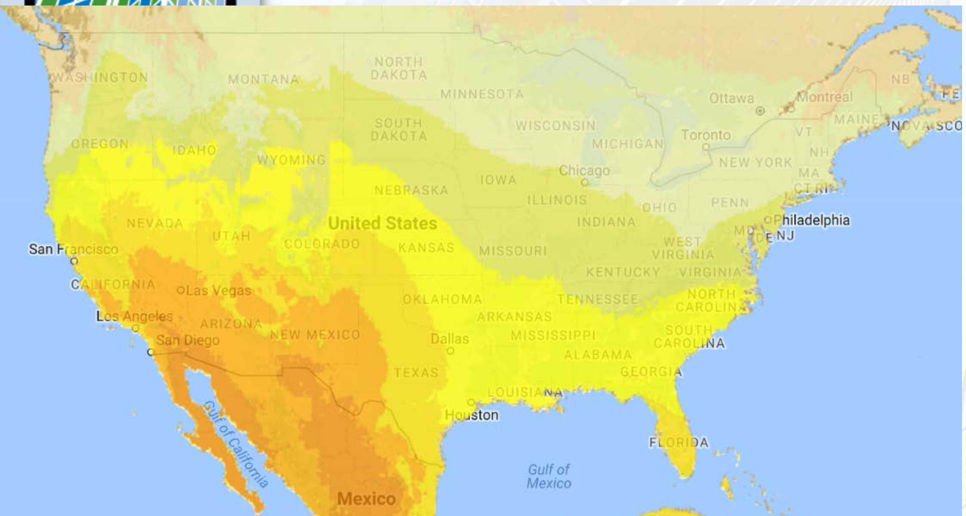
https://flowcharts.llnl.gov/

Site Boundary of Energy Transfer for Zero Energy Accounting

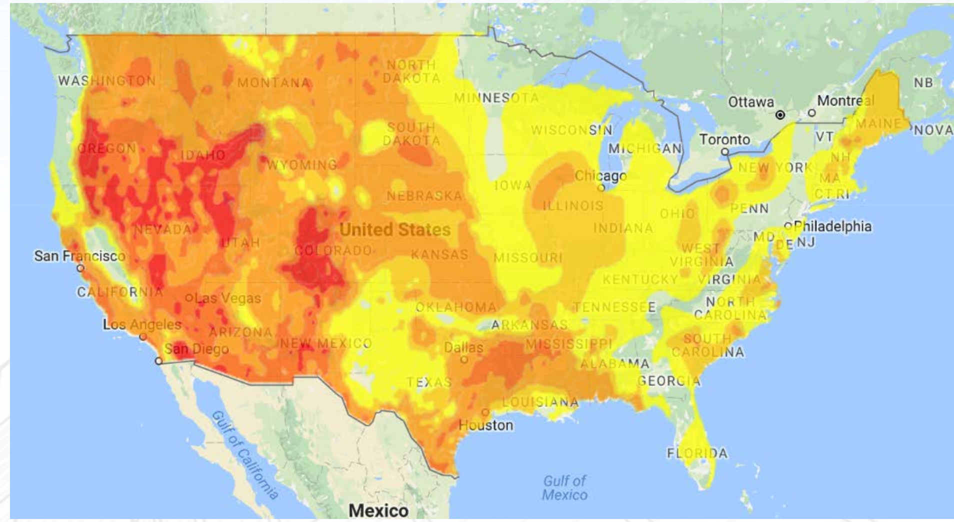


Source: A Common Definition of Zero Energy Buildings

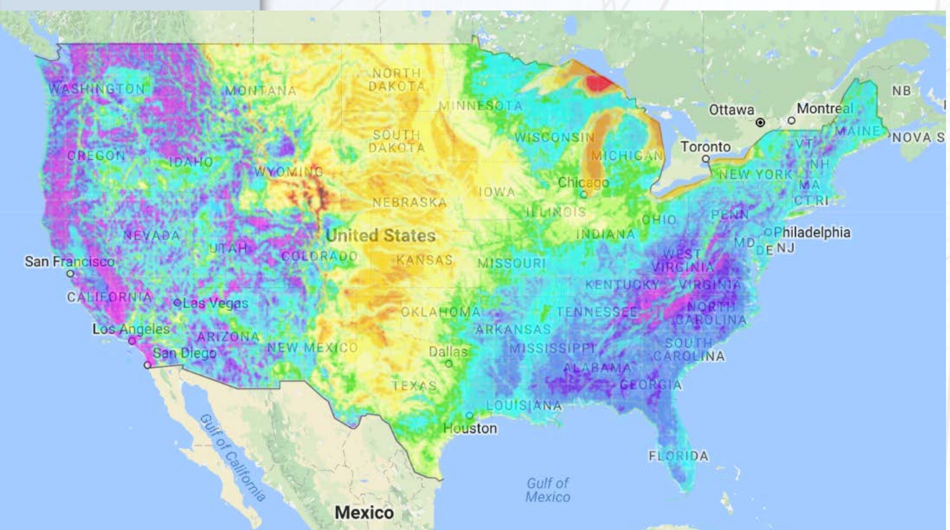
Renewable Energy Resources



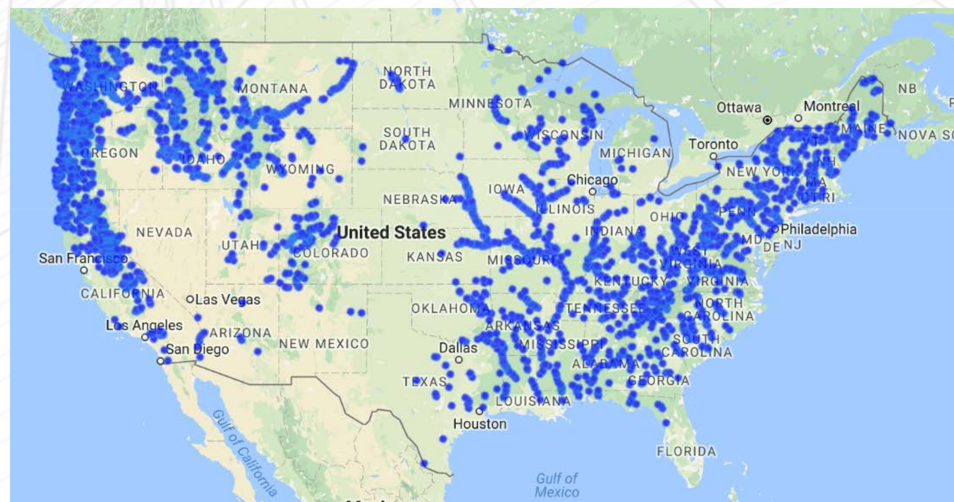
Global Horizontal Solar Irradiance



Geothermal / Hydrothermal Resources



Land-based wind speed – 80 meters



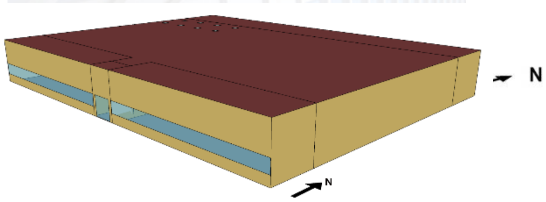
Feasible Small Hydroelectric Sites

ASHRAE 1651-RP

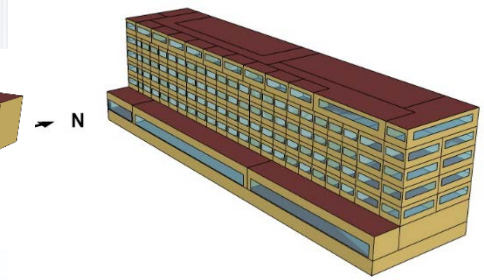
- Development of Maximum Technically Achievable Energy Targets for Commercial Buildings
  - 16 building types, 17 climate zones, 400 measures
  - 47.8% reduction from ASHRAE 90.1-2013
  - Measure application
    - Reduce Internal loads
    - Reduce building envelope loads
    - Reduce HVAC distribution system losses
    - Decrease HVAC equipment energy consumption
    - Major HVAC reconfigurations

DOE Commercial Prototype Building Models

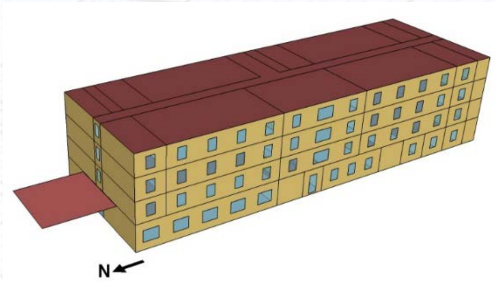
Midrise Apartment



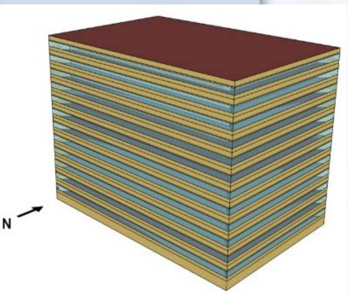
Standalone Retail



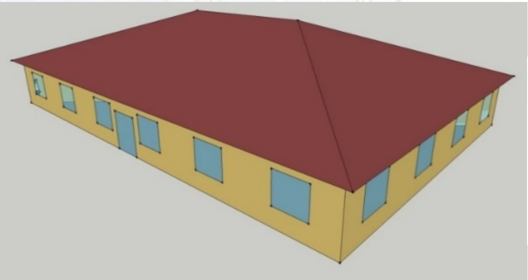
Large Hotel



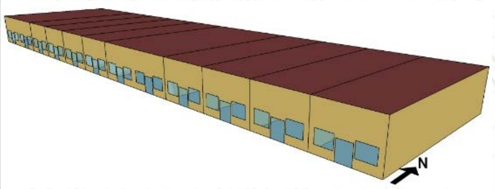
Small Hotel



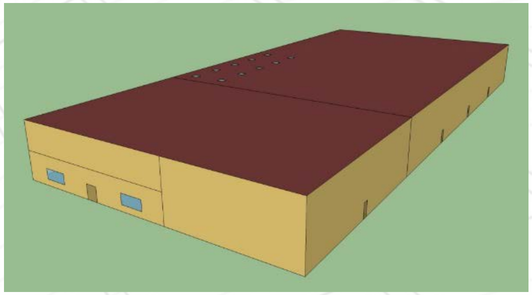
Large Office



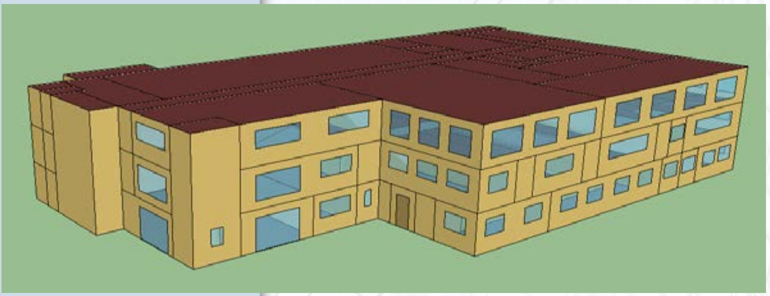
Small Office



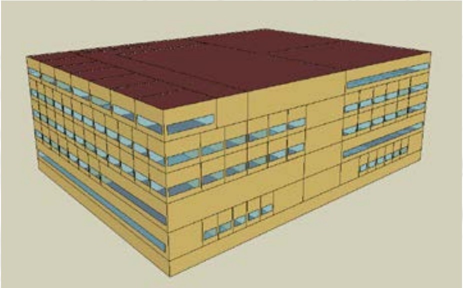
Stripmall Retail



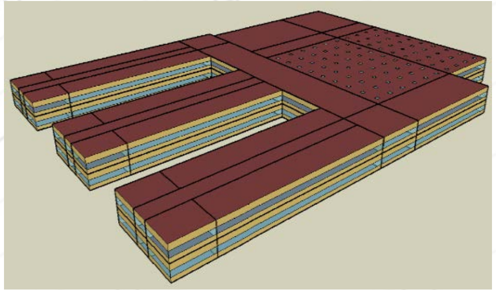
Warehouse



Outpatient Healthcare

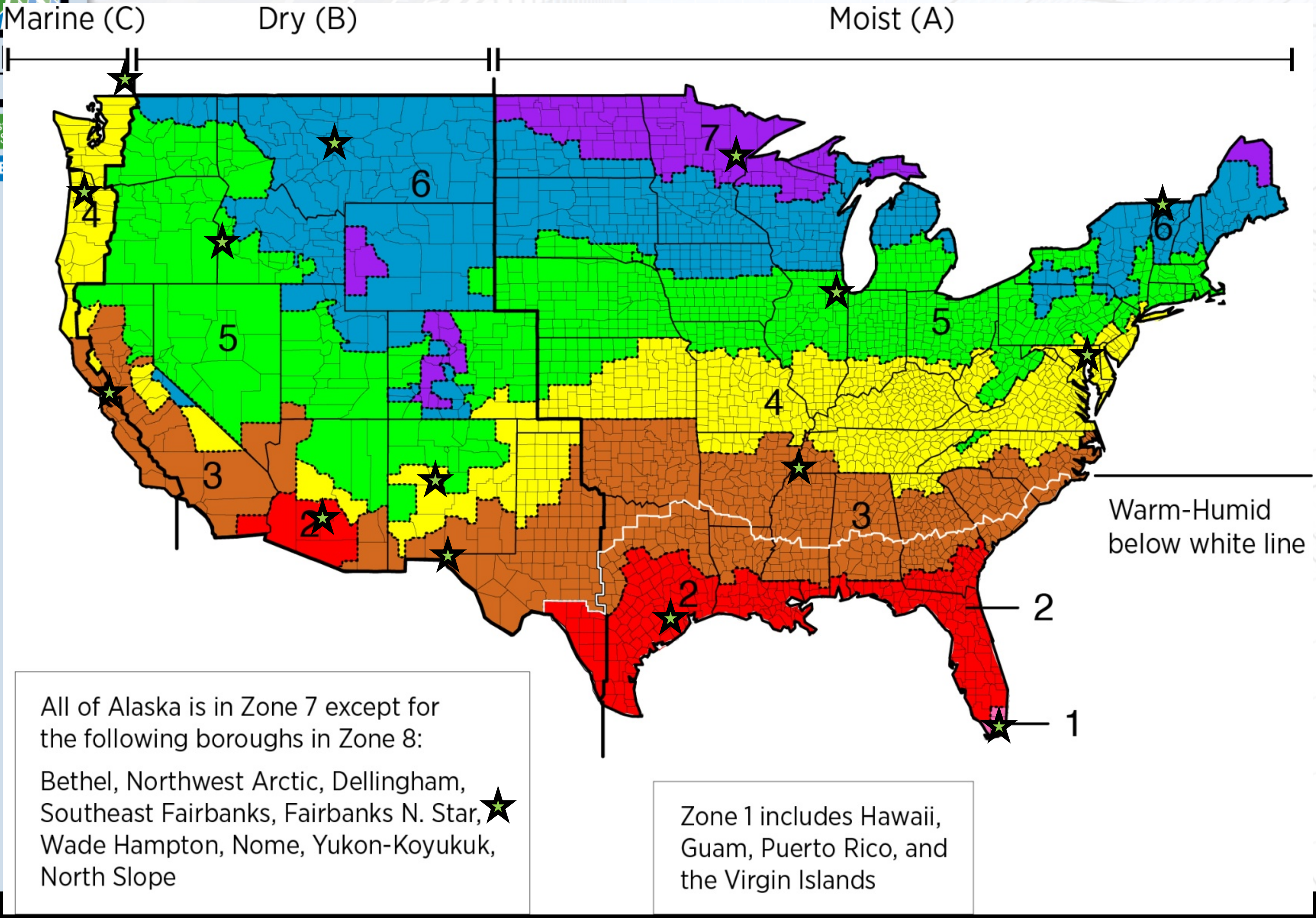


Hospital



Secondary School

ASHRAE Climate Zone Map

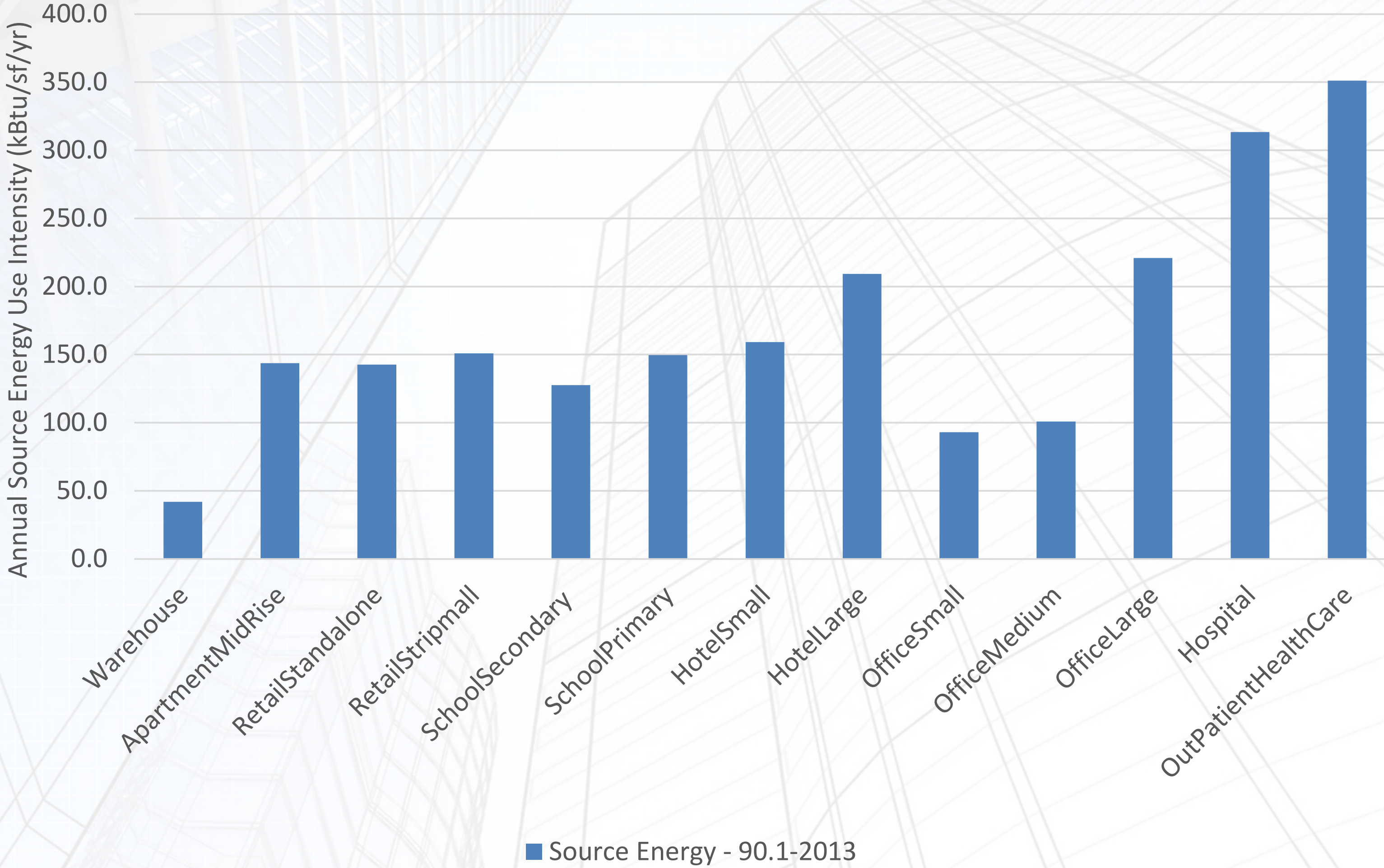


Energy Conservation Measures Analyzed in 1651-RP

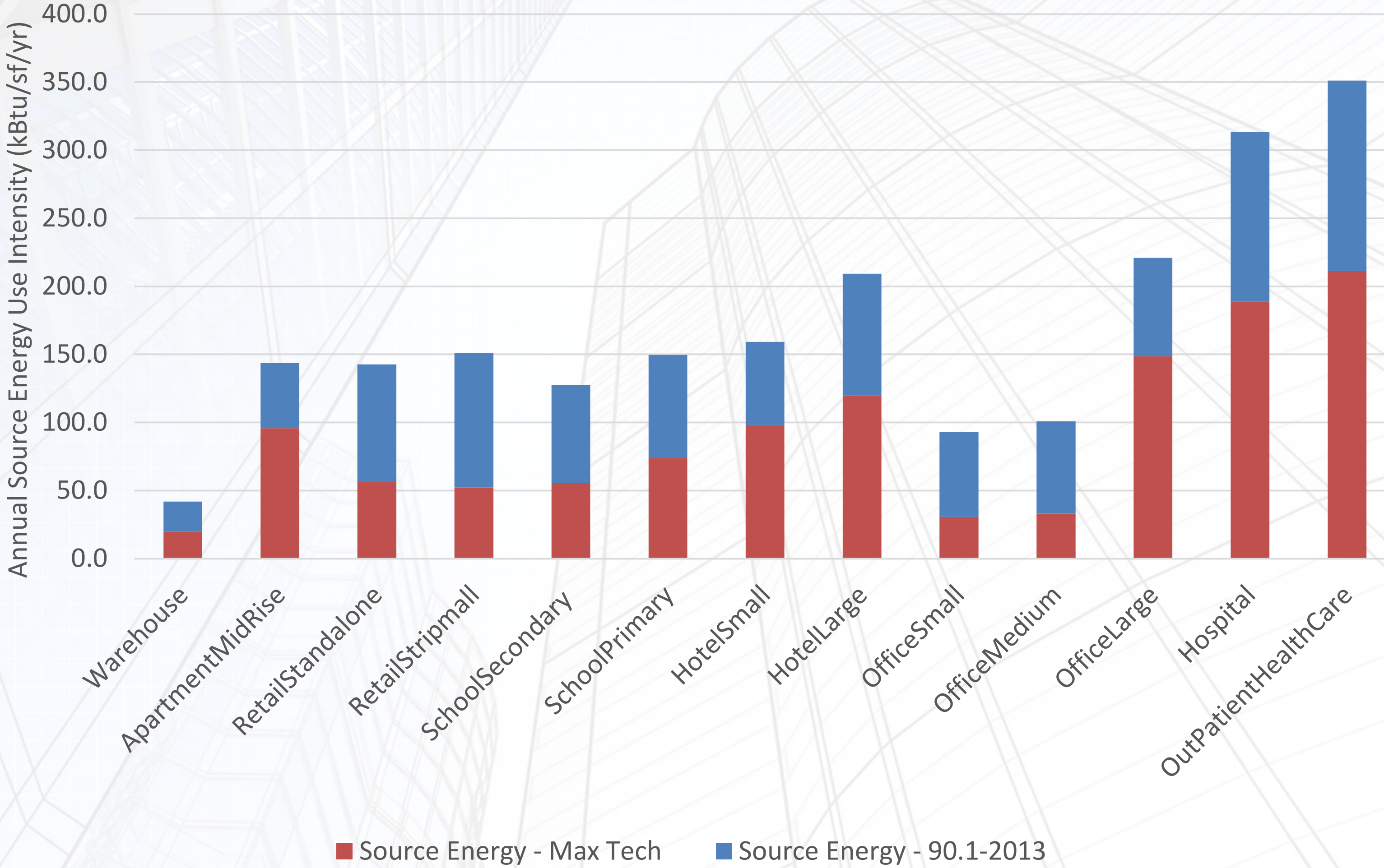
- LED Exterior Lighting
- Highest Efficiency Office Equipment
- High Performance Lighting (LED)
- Shift from General to Task Illumination
- Optimal Daylighting Control
- Optimal Roof Insulation Level
- Optimal Choice of Vertical Fenestration
- External Light Shelves
- Daylighting Control by Fixture
- High Performance Fans
- High Performance Ducts to Reduce Static Pressure
- Demand Controlled Ventilation/CO2 Controls
- Multiple-zone VAV System Ventilation Optimization
- Optimal Water/Air Cooling Coils
- Occupant Sensors for Air Handling Equipment
- Energy Recovery Ventilators
- Indirect Evaporative Cooling
- High Eff./Var. Speed Packaged DX Cooling
- High Efficiency Heat Pumps
- Ground Source Heat Pump
- High Efficiency and Variable Speed Chillers
- Heat Recovery from Chillers
- High Efficiency Boilers
- High Efficiency Building Transformers
- Chilled/Cooled Beam
- Dedicated Outside Air System with Heat Recovery
- Underfloor Air Distribution
- Hybrid/Mixed Mode Ventilation
- Radiant Heating and Cooling and DOAS
- Variable Refrigerant Flow Air Conditioning

Source: New Buildings Institute, “Getting to Zero 2012 Status Update: A First Look at the Costs and Features of Zero Energy Commercial Buildings”, March 2012

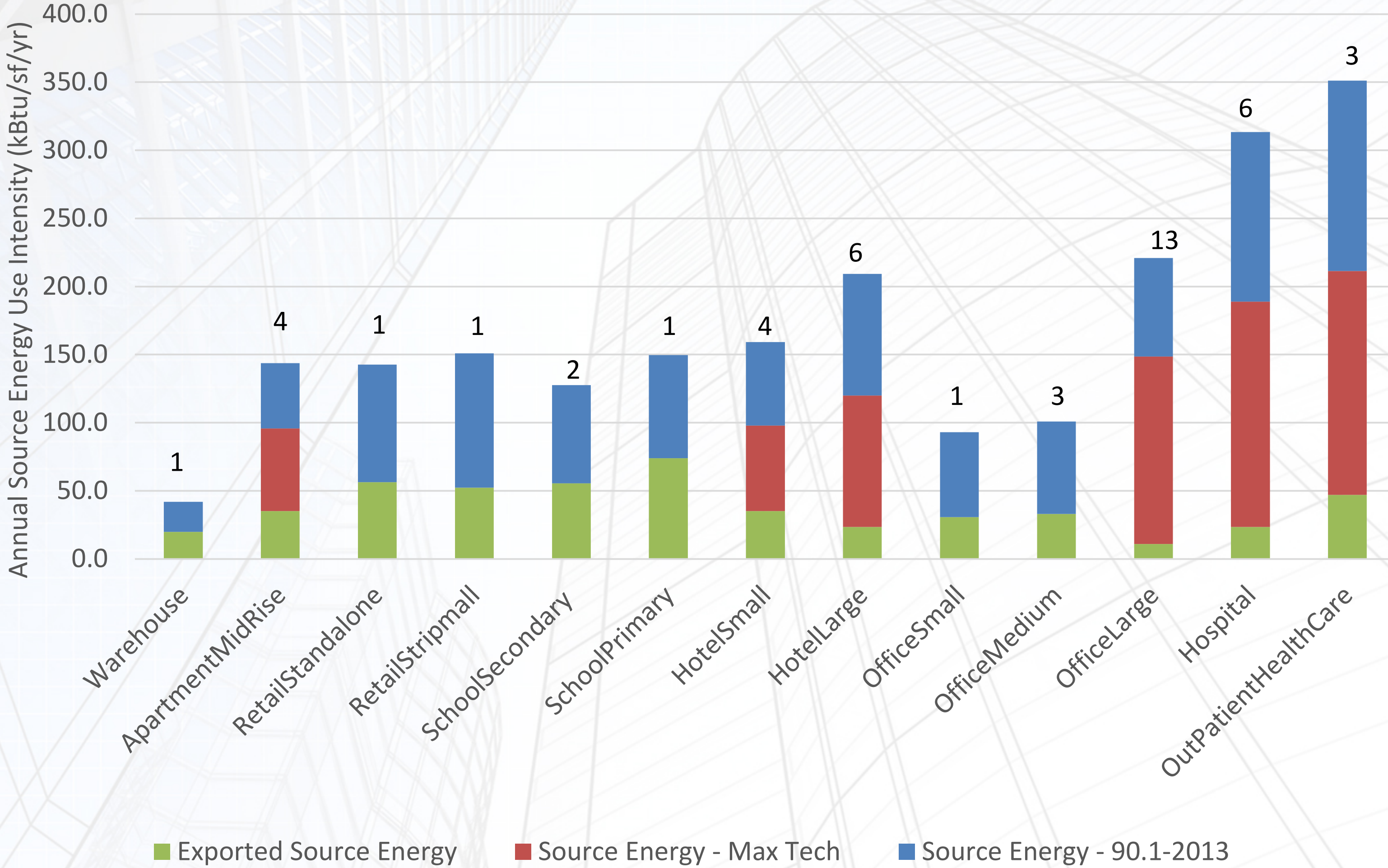
Feasibility of Zero Energy with Max Tech and Roof-mounted PV



Feasibility of Zero Energy with Max Tech and Roof-mounted PV



Feasibility of Zero Energy with Max Tech and Roof-mounted PV



The Dilemma: Predicted vs. Actual Energy Performance

"More feedback is needed from actual building performance results to design phase energy modeling. The current variability between predicted and measured performance has significant implications for the accuracy of the prospective life cycle cost evaluations for any given building."

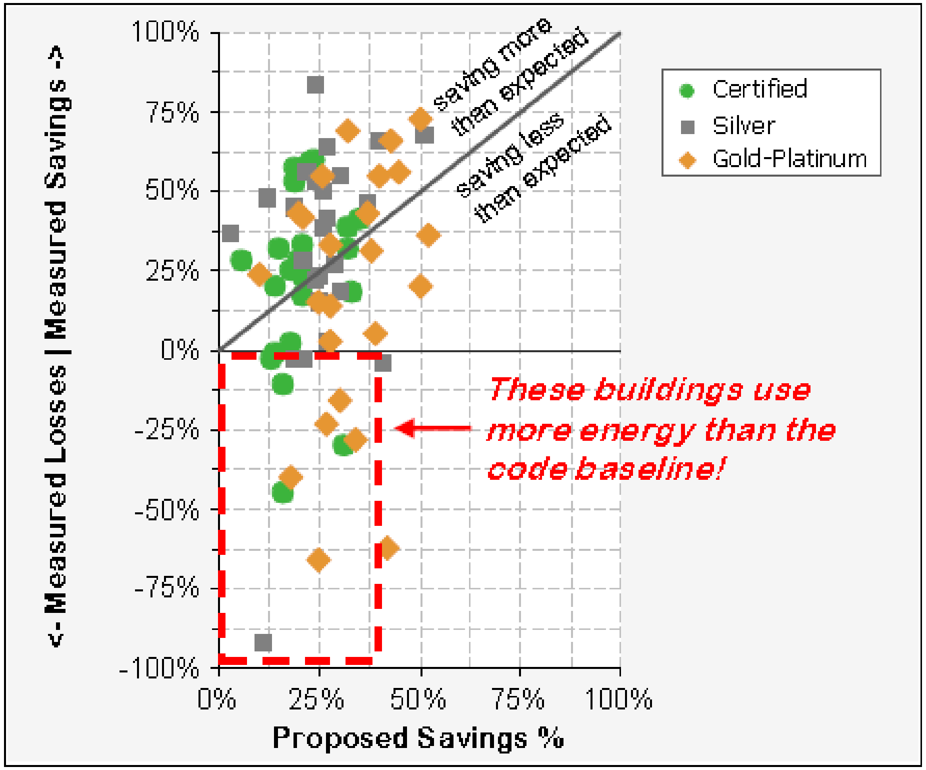


Figure ES- 5: Measured versus Proposed Savings Percentages

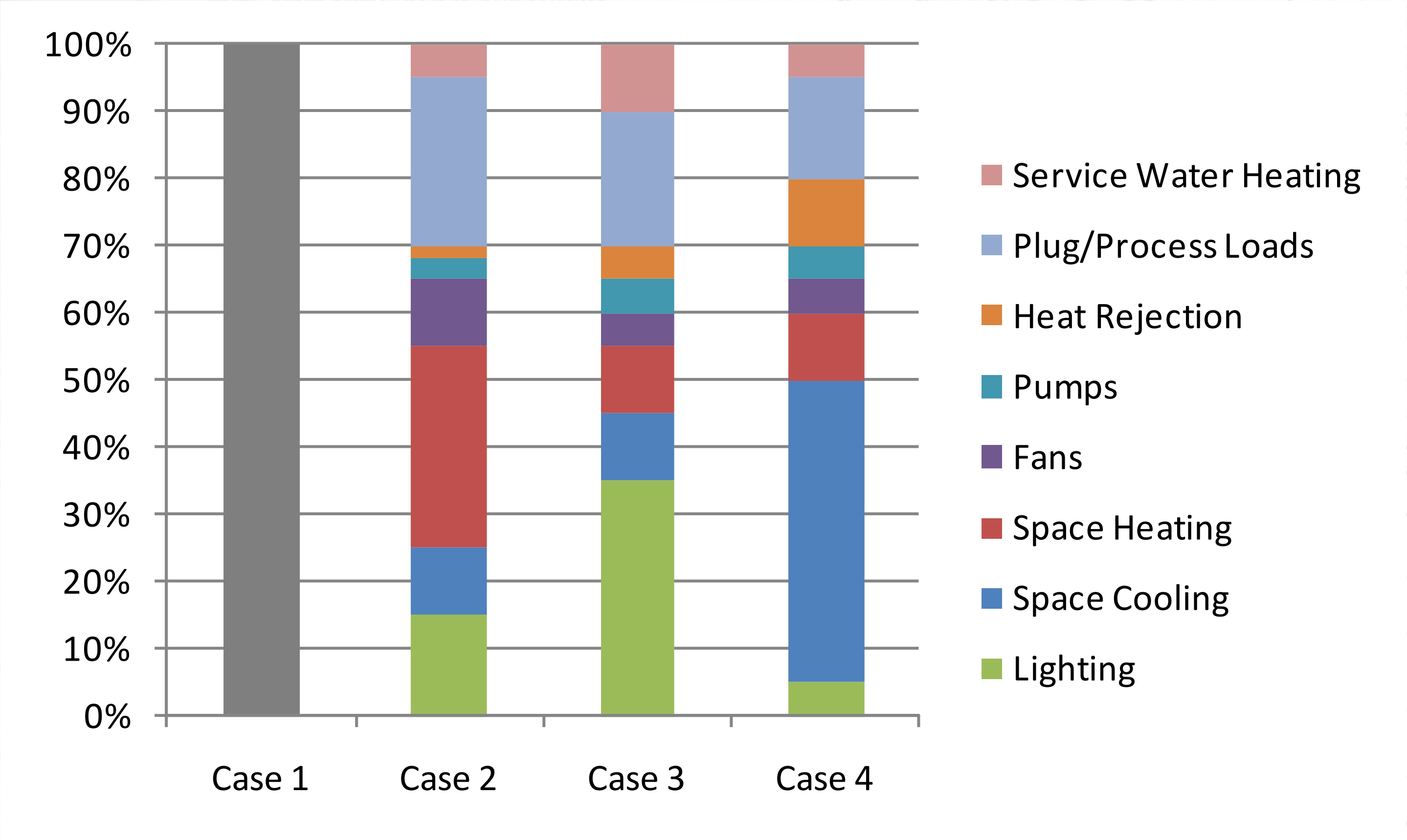
Source: "Energy Performance of LEED for New Construction Buildings", NBI, Turner, Frankel, March 2008

Feedback is important

We need this to operate a car…

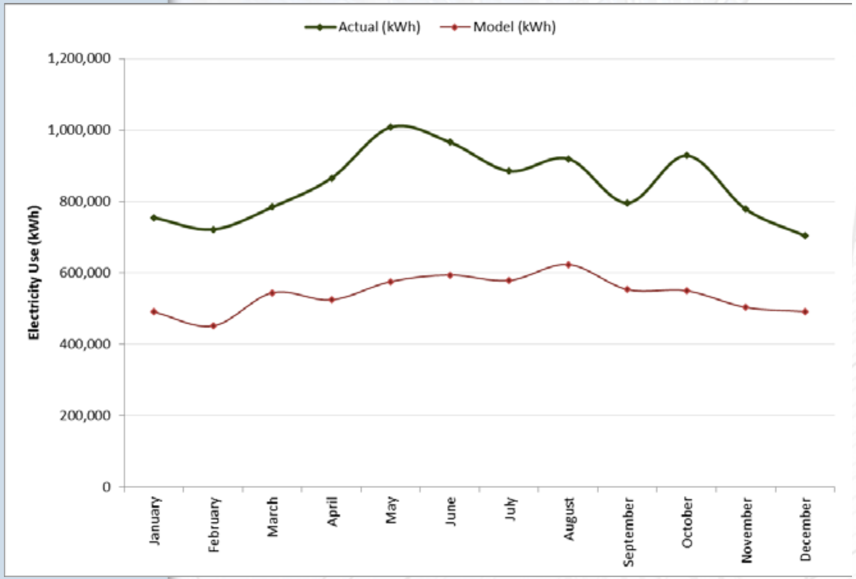
… so why operate a building with this?

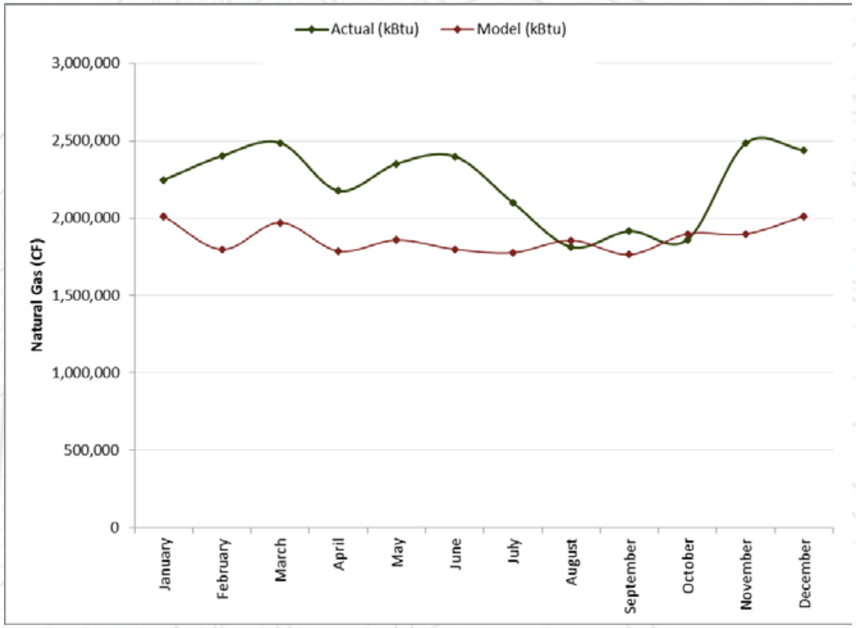
Importance of Sub-metering



Spirit of Metering: "You can't manage what you don't measure."

LEED 2009: Measurement & Verification

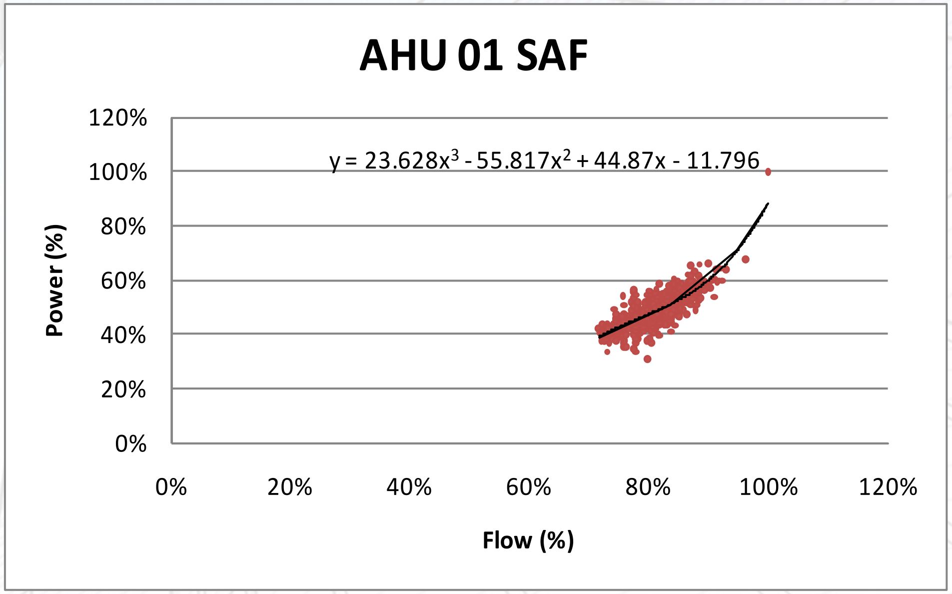


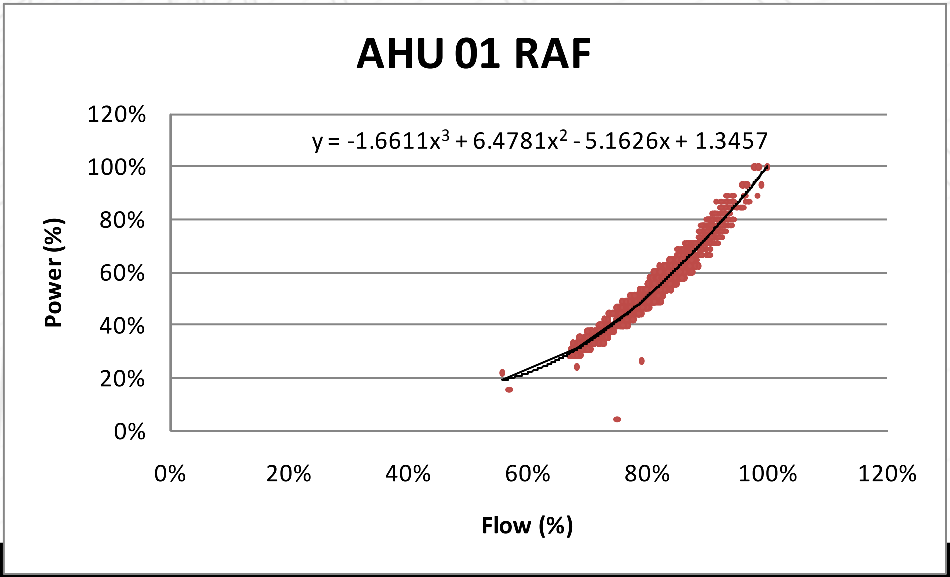


Energy Type	Electricity		Gas	
Error Metric	CV(RMSE)	NMBE	CV(RMSE)	NMBE
As-Built Model	38.3%	39.1%	15.7%	11.4%

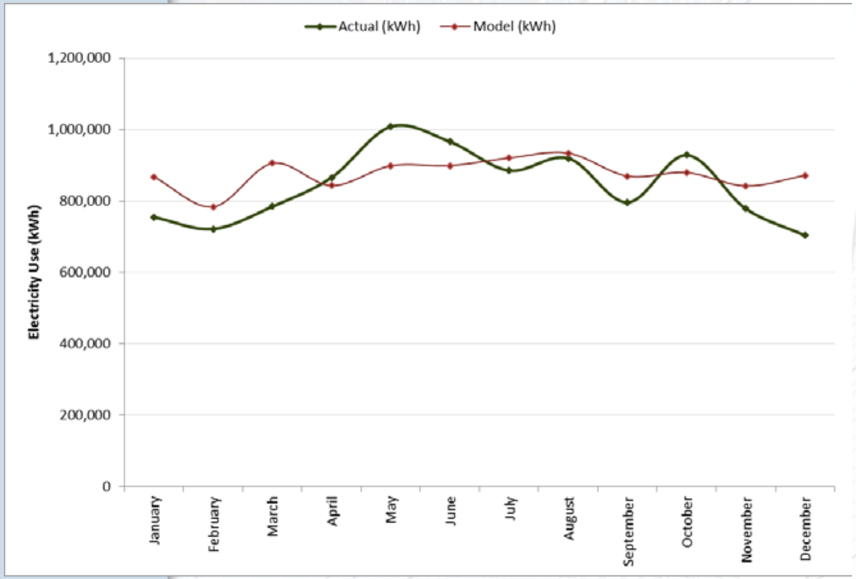
Model Calibration Process

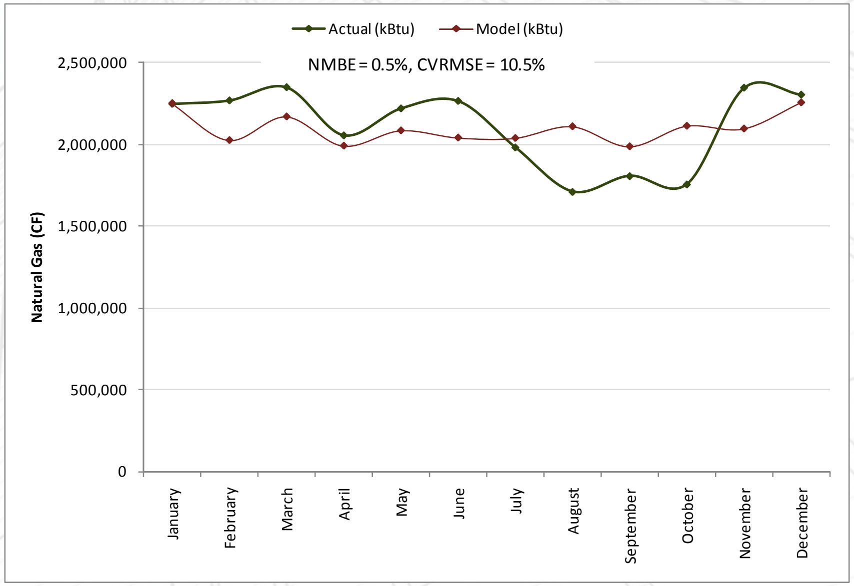
- Actual Weather Data
- More appropriate internal load schedules
- Reflect Actual HVAC Control Operations
  - Economizer
  - Exhaust Fans
  - Supply Air Temperature Reset
- More appropriate part-load performance curves
  - Supply & Return fans
- Test Unknown Values
  - Plug loads
  - Infiltration





Calibrated Model More Closely Matches Actual Performance





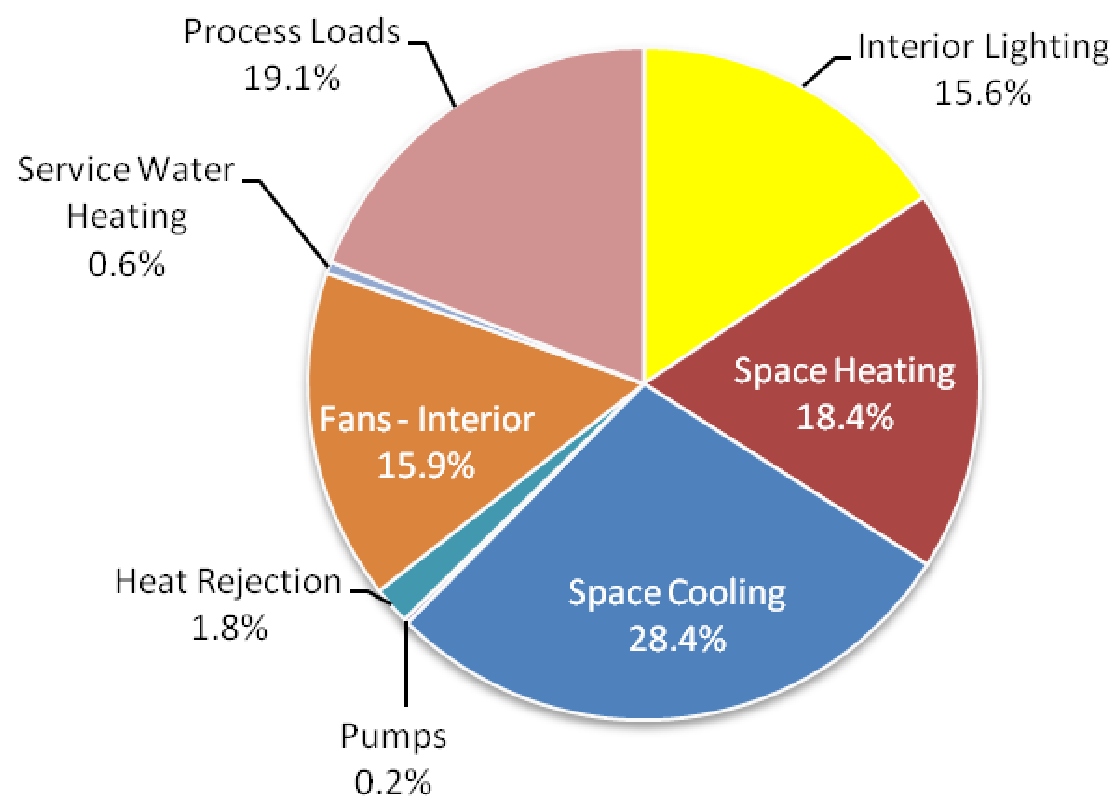
Energy Type	Electricity		Gas	
Error Metric	CV(RMSE)	NMBE	CV(RMSE)	NMBE
Calibrated Model	10.7%	4.3%	10.5%	0.5%

M&V Results = Actual Savings

	Designed			Calibrated		
Utility	Proposed	Baseline	Savings	Actual	Baseline	Savings
Electricity	$ 700,087	$ 859,747	18.6%	794,299	952,284	16.6%
Natural Gas	$ 186,952	$ 174,608	-7.1%	174,895	165,729	-5.5%
Total	$ 887,039	$1,034,355	14.2%	$ 969,193	$1,118,013	13.3%

- Electric savings worse than predicted
- Natural gas savings better than predicted
- Trend analysis identified economizer, humidifier, and boiler control and operation can be improved

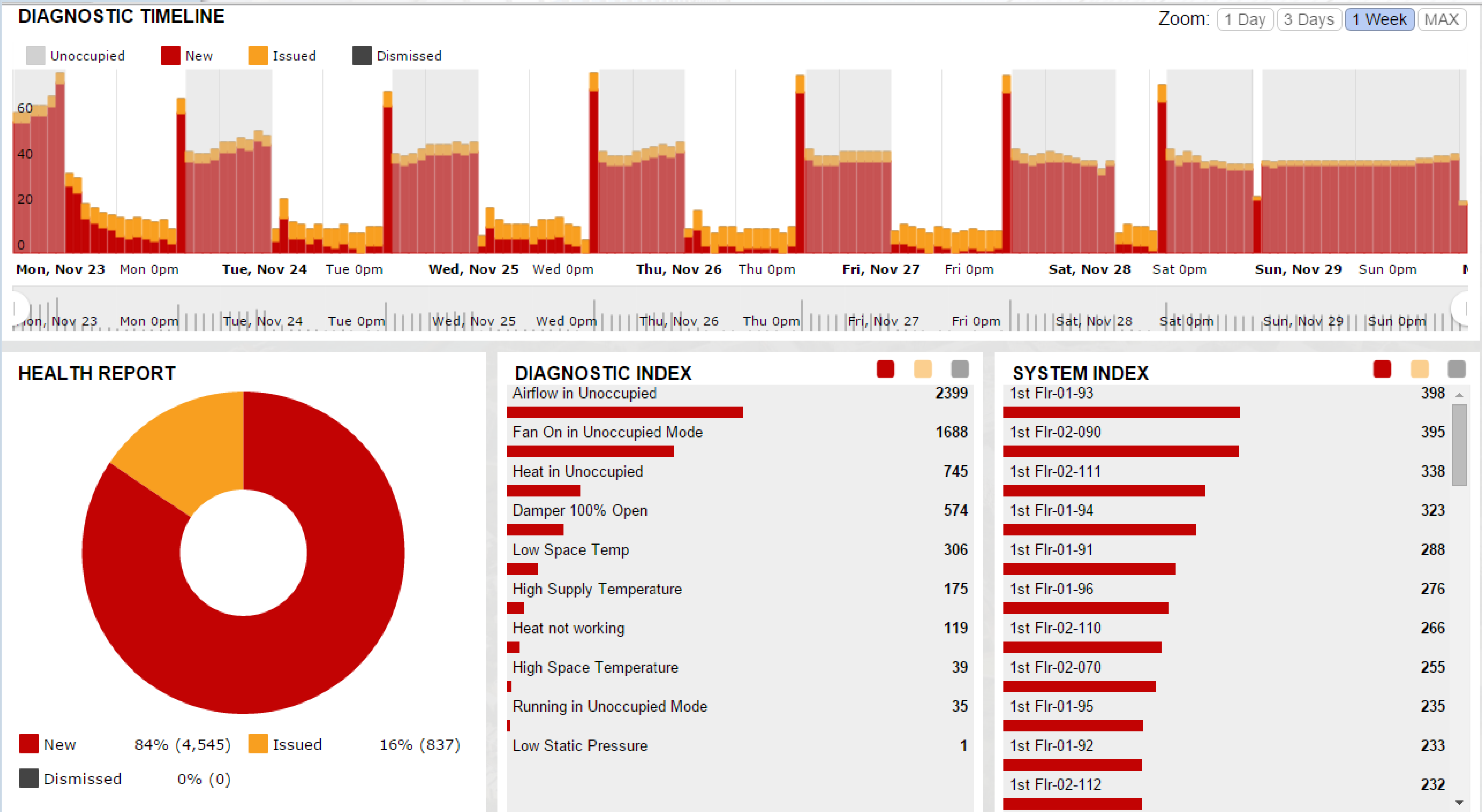
LEED v4 EA Credit: Advanced Energy Metering



LEED v4: Monitoring-Based Commissioning

System	Measure / Verification Component	Verify Measure / Condition	Monitoring Points
Hot Water	Variable-flow loop; hot water pumps equipped with VFDs.	- variable-flow operation, to maintain pressure differential set point between supply and return heating water piping mains - interlocked with boiler operation; two minute delay on boiler disable	- VFD speed - pump status - differential pressure between supply and return - water flow rate - heating water supply and return temperatures
Chillers	Equipped with VFDs. Reset chilled water supply temperature to maintain air handler discharge air temperature.	- chiller efficiency (NPLV = 0.50) - chiller VFD operation - chilled water supply temperature reset from 48ºF to maintain air handler discharge air temperature	- chiller power - chiller efficiency (calculated point) or/ - CHWS/RT - CHW flow

Automated Fault Detection and Diagnostic (AFDD) Example



Conclusions

- Energy codes and standards continue to get more stringent.
- Building technology and design continue to evolve with design assistance tools such as energy simulation software.
- Zero energy buildings are within reach for some building types, but the prices of energy sources (both renewable and non-renewable) still have a major impact.
- Maintaining high performance through M&V and Monitoring-based commissioning will be critical for a zero energy future.

Resources

- Architecture 2030
- PNNL, "ASHRAE 90.1 Determination of Energy Savings: Quantitative Analysis"
- https://flowcharts.llnl.gov/
- ASHRAE / IBPSA-USA / RMI; Building Energy Modeling Training Workshop
- U.S. DOE; Commercial Building Energy Consumption Survey; 2012
- ASHRAE, AIA, IESNA, USGBC, U.S. DOE; "Advanced Energy Design Guide for Large Hospitals – Achieving 50% Energy Savings Toward a Net Zero Energy Building"; 2012
- U.S. DOE, National Institute of Building Sciences, "A Common Definition for Zero Energy Buildings," September 2015
- Glazer, Jason. "ASHRAE 1651-RP: Development of Maximum Technically Achievable Energy Targets for Commercial Buildings." December 2015
- New Buildings Institute, "Getting to Zero 2012 Status Update: A First Look at the Costs and Features of Zero Energy Commercial Buildings", March 2012
- NBI, Turner, Frankel, "Energy Performance of LEED for New Construction Buildings," March 2008
- USGBC, Leadership in Energy and Environmental Design (LEED) v4

This concludes The American Institute of Architects Continuing Education Systems Course

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