AABC Commissioning Group

AIA Provider # 50111116

Energy Modeling for the Life of Your Building

AIA Course # CXENERGY1512

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4/29/15

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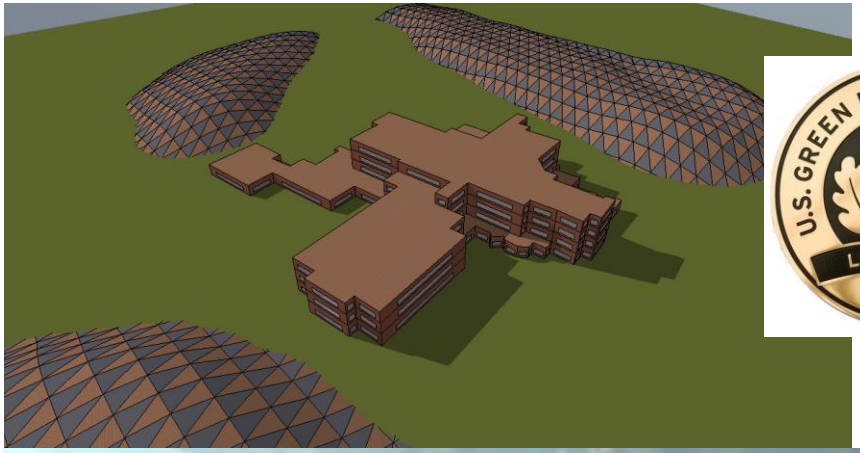
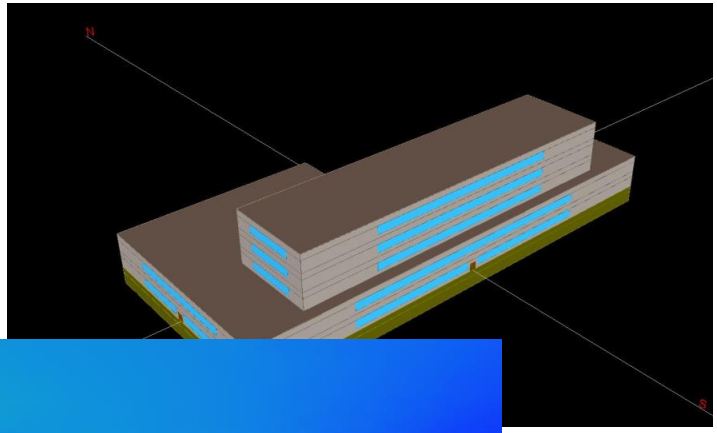
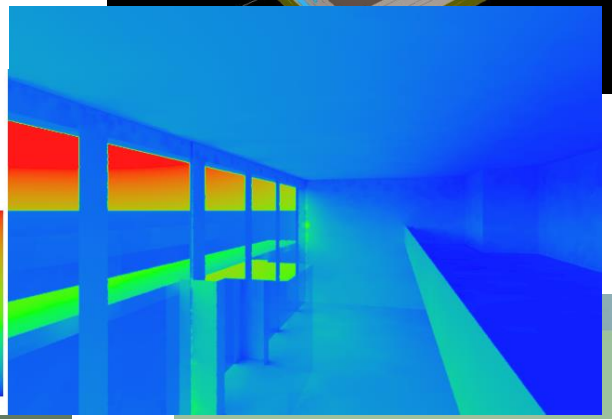
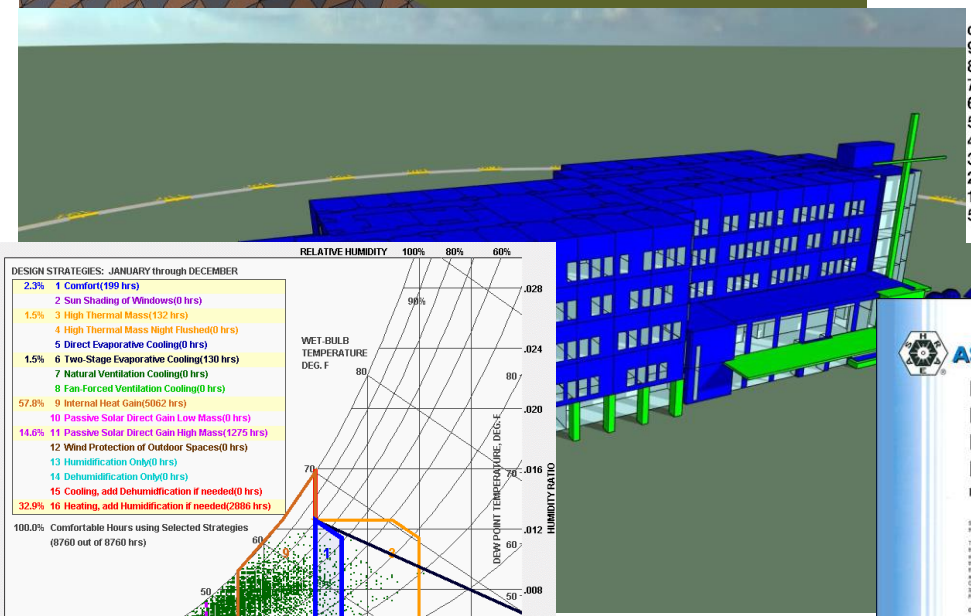
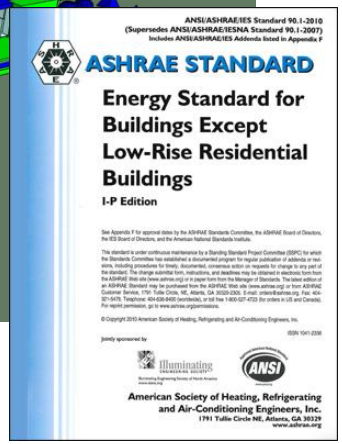
Course Summary

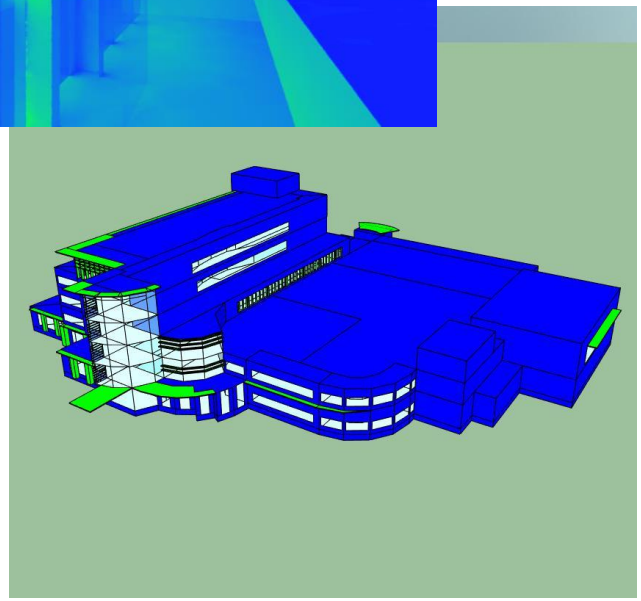












Learning Objectives

1. Learn how the growth of modeling software and the maturation of the modeler workforce affects building energy modeling.
2. Understand why energy analysis at all phases of a building's life cycle is a valuable part of the integrated design process.
3. Learn how energy modeling has been used to help designers and owners make more informed decisions from conceptual design to operations.
4. Understand how energy modeling can be used throughout a building's life cycle to implement measures to enhance energy efficiency.

Recent and Future Developments in Energy Modeling

Software

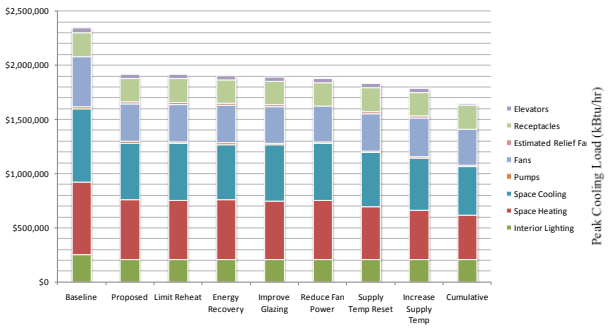
- BIM-based
- Cloud-based
- Early-phase Analysis
- Automated Baseline

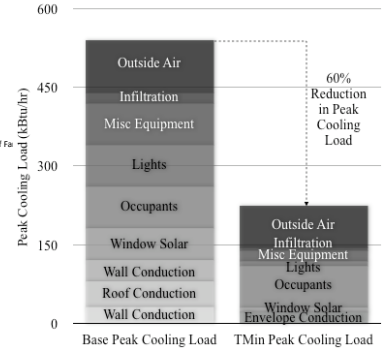
Energy Modelers

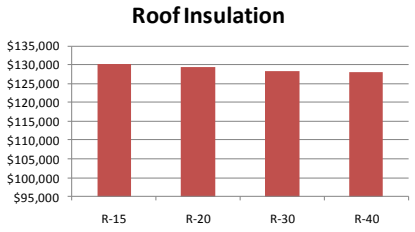
- Energy Modeler Credentials
- Energy Modeling Process Standard
- Industry Organizations
- Conferences

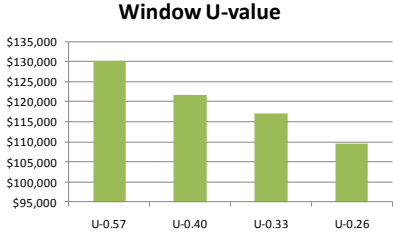
Some Uses for Energy Modeling

- Comparative Analysis
  - Decision-making tool
- Document progress towards Owner's energy goals
- Find areas of highest potential impact/savings and optimize design
- Identify synergies to reduce equipment size and save costs
- Identify counter-intuitive building performance relationships
- Green Building certifications and labels
- Utility rebates / incentives

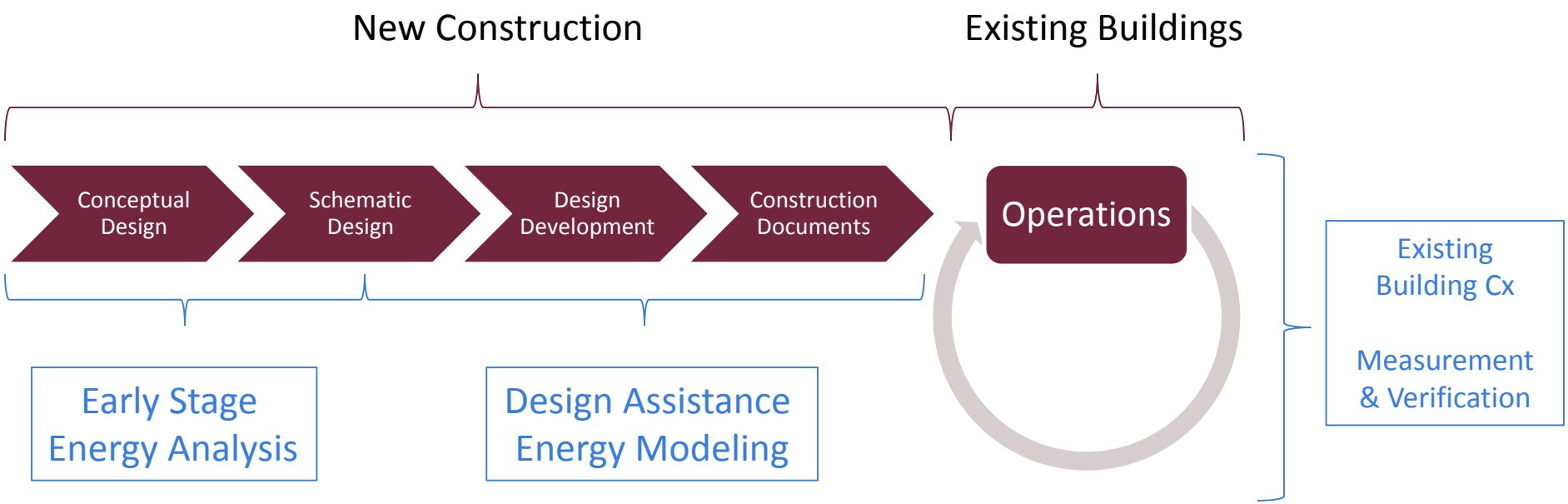




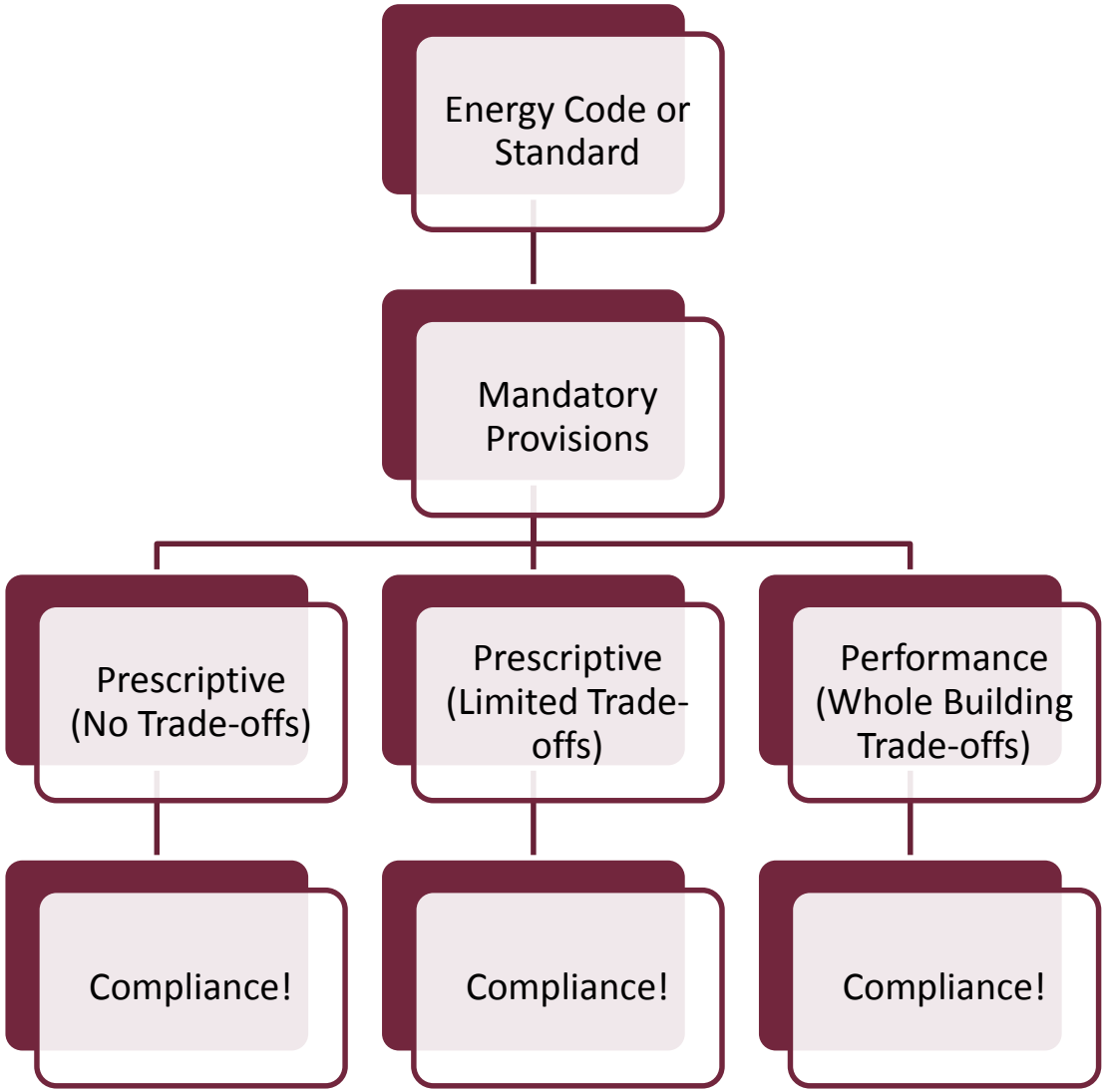




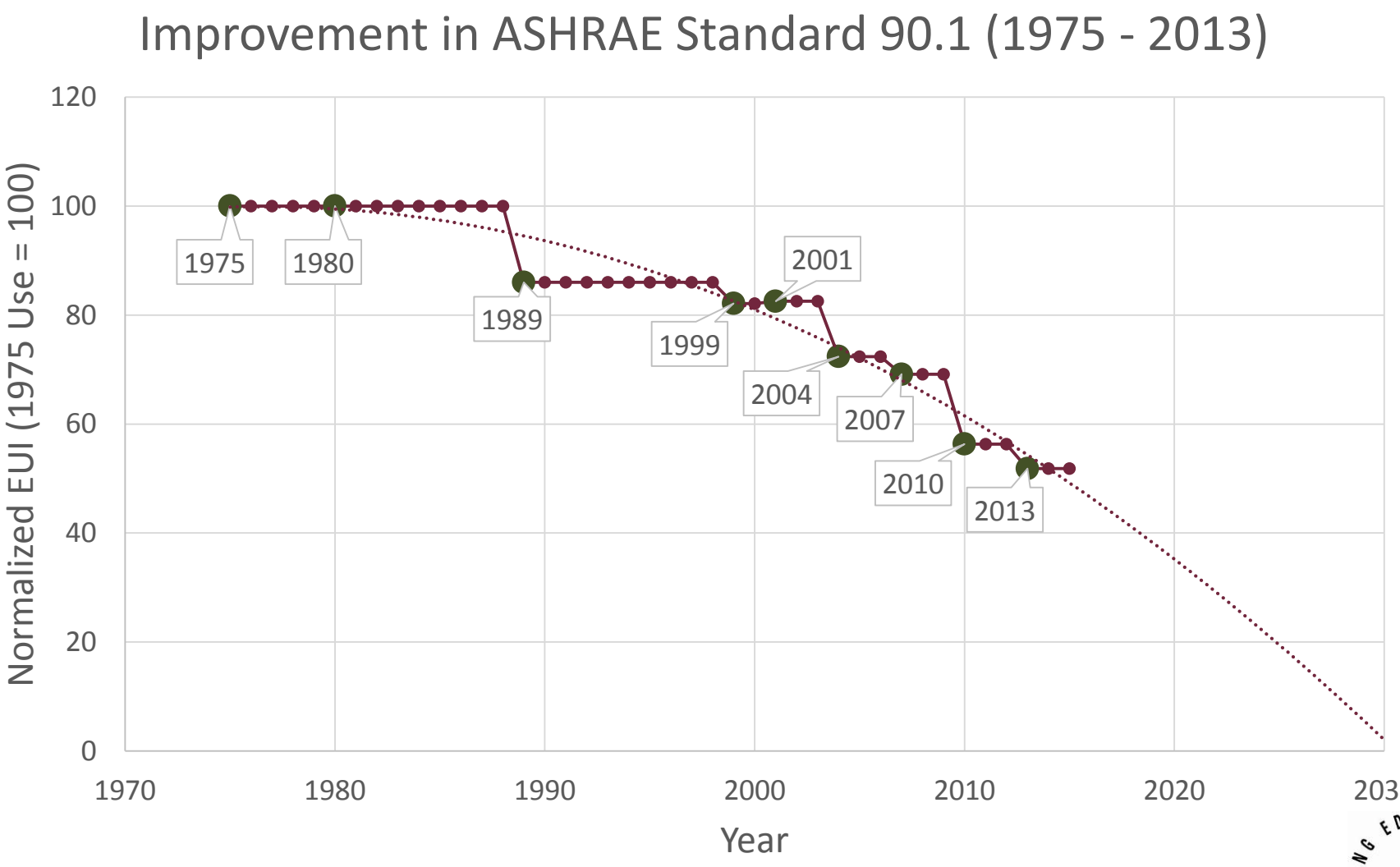
Project Timeline



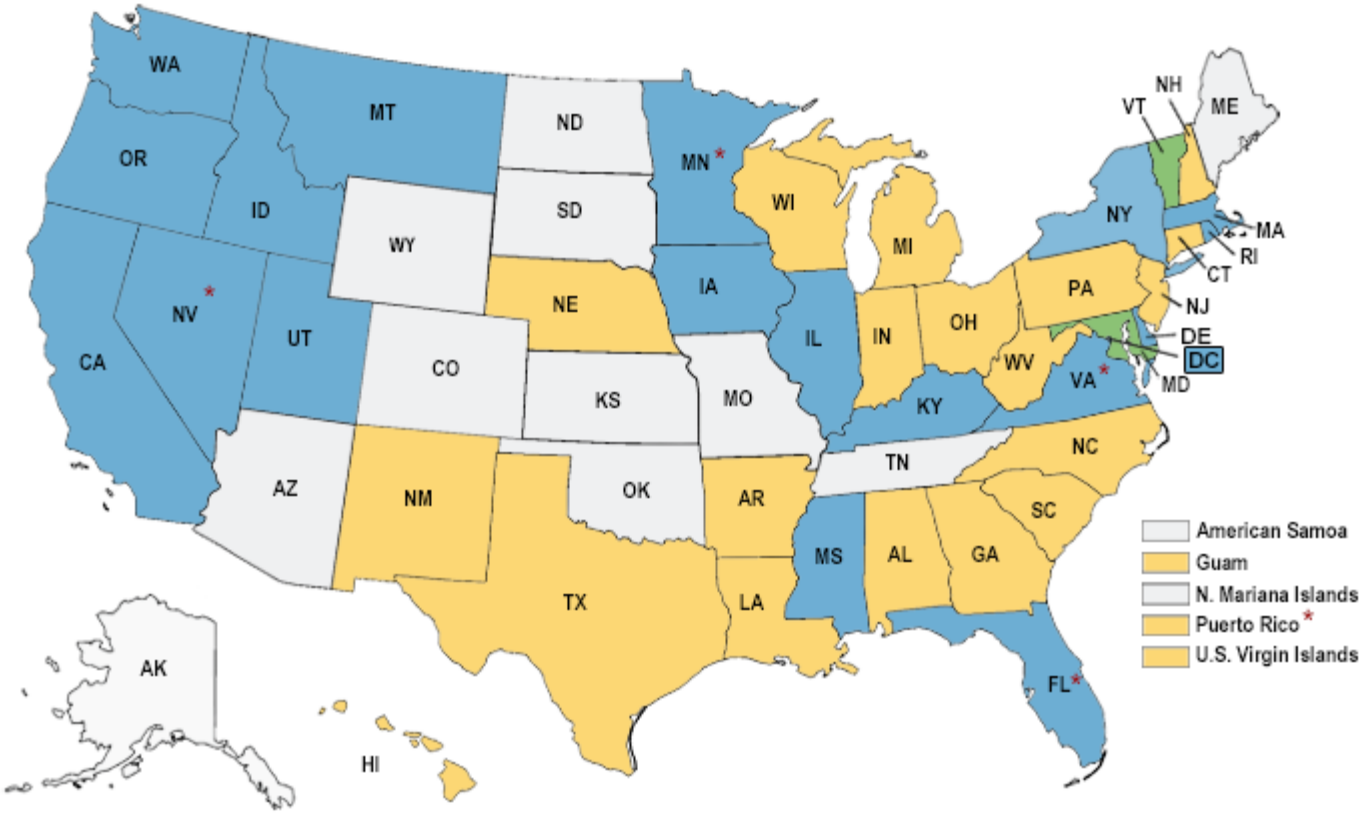
Typical Paths to Energy Code Compliance



Energy Code Stringency

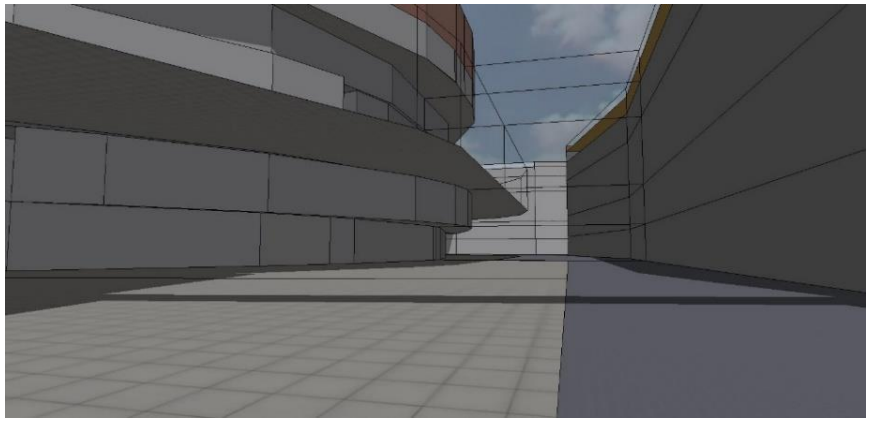


Energy Codes Across the Nation

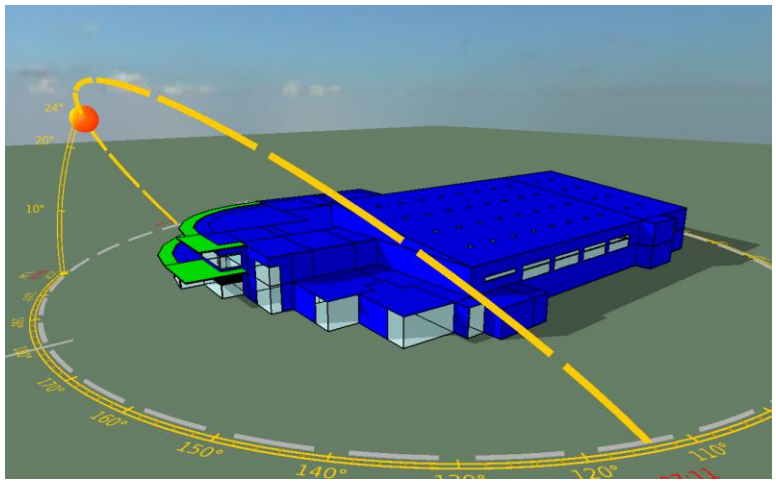


Energy Codes – Changing the face of architecture?

Too much skylight area

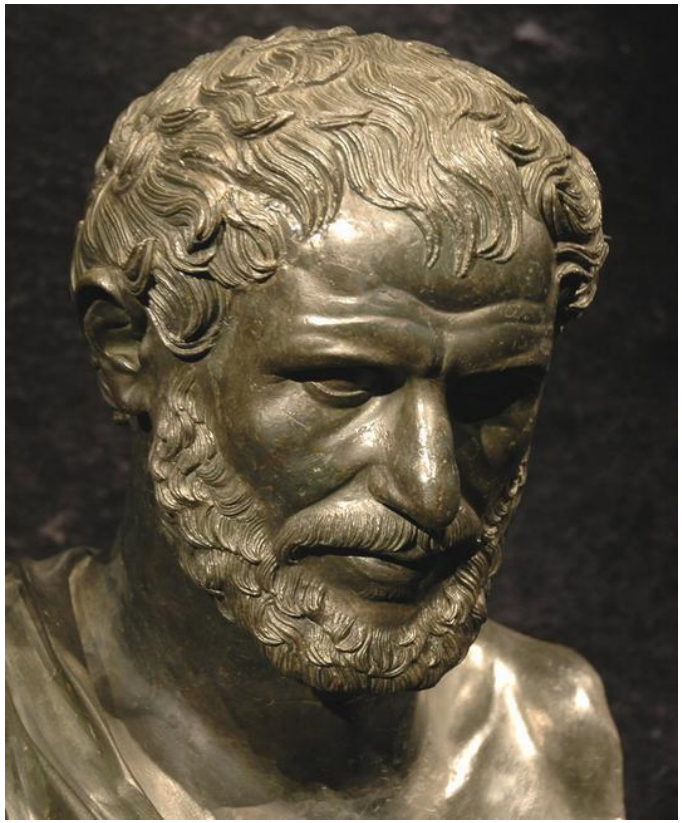


Not enough skylight area



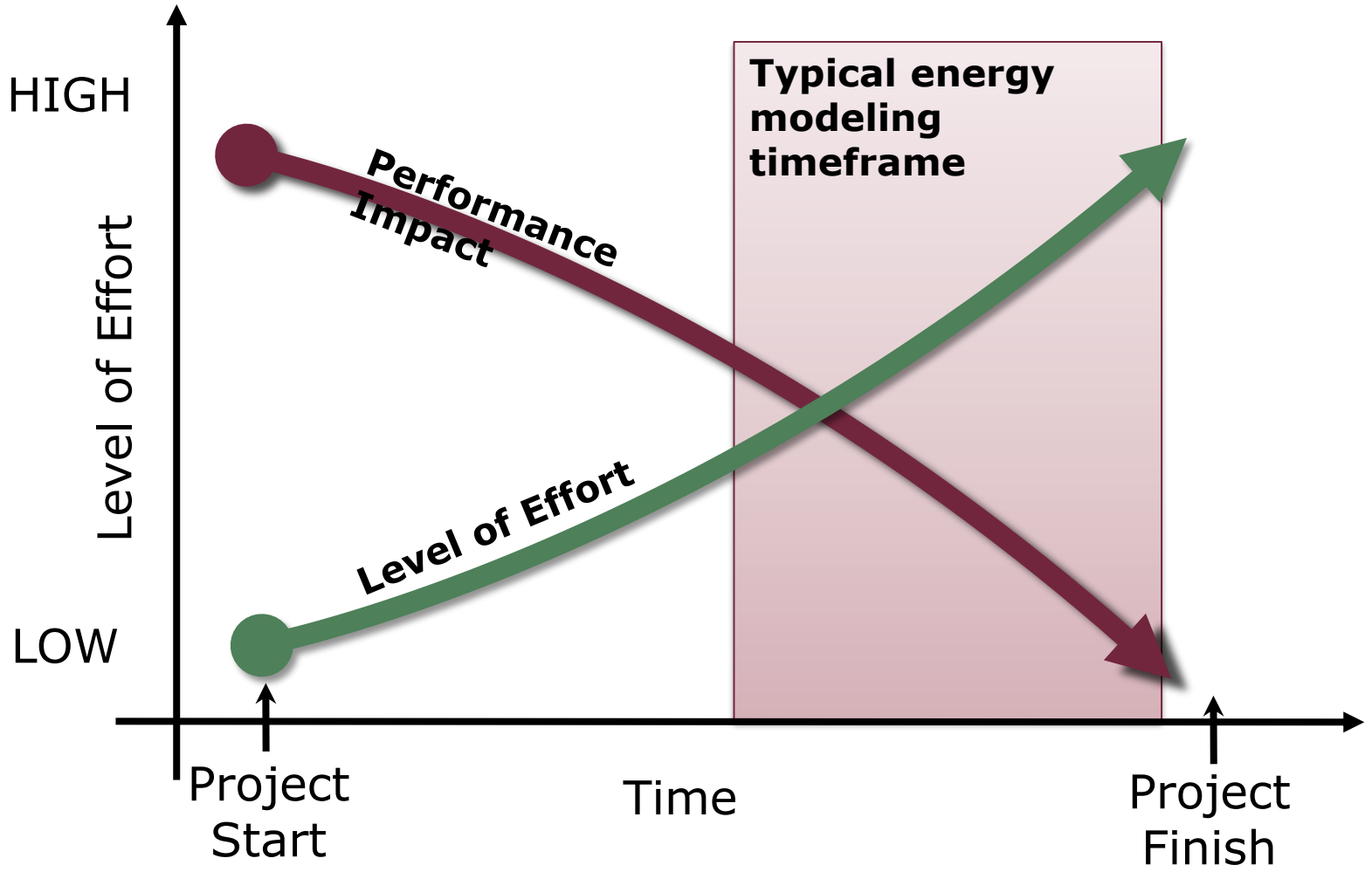
What's the effect of all this change?

- More use of the performance (modeled) compliance path
  - California – CBECC-Com
  - Florida – FLACom
- Changes to ASHRAE 90.1 Performance Compliance Path
  - Addendum 'bm' & zEPI
- Energy modeling used early in design, just to show compliance!

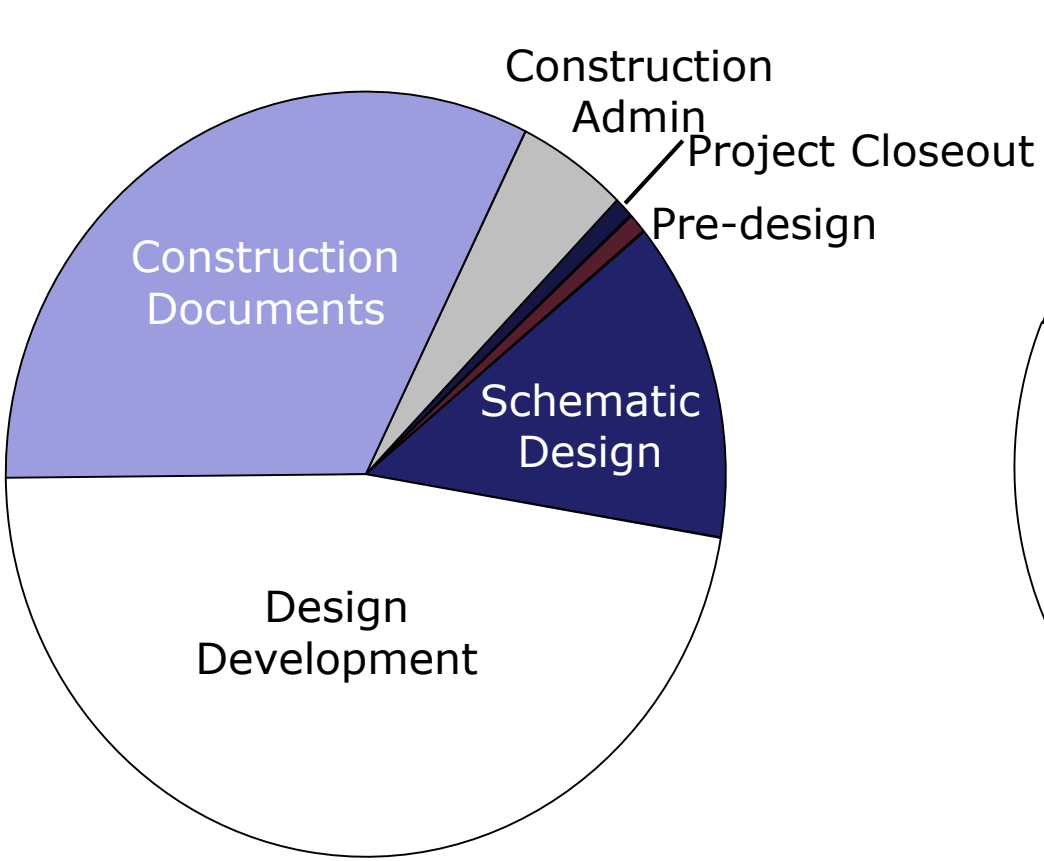


"The only constant is change." - Heraclitus

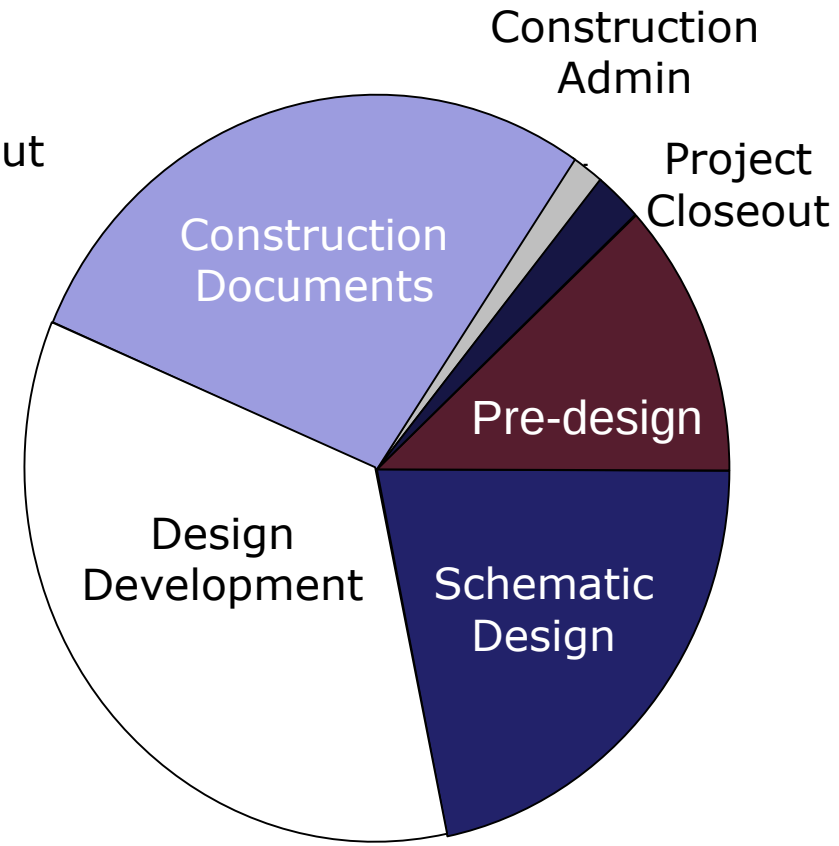
Timing Is Everything



Integrated Design Process - Time Comparison



Typical



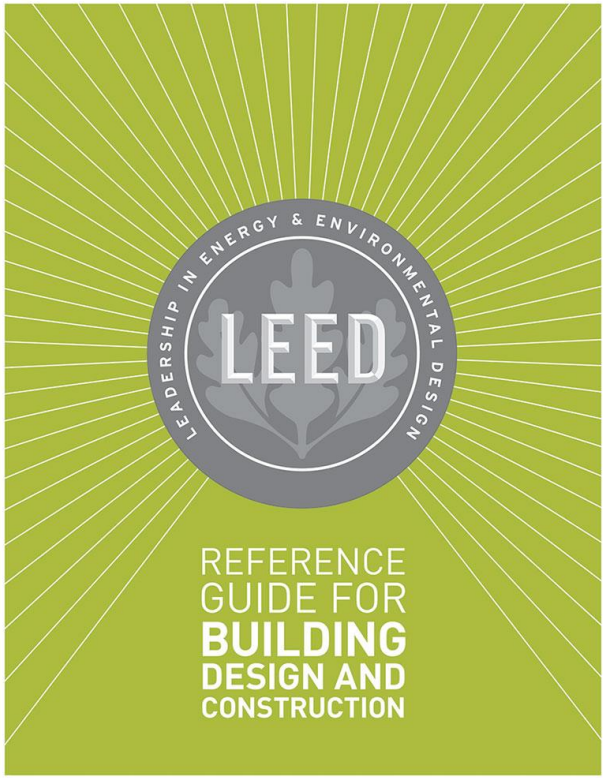
Integrated

Conceptual / Pre-Design

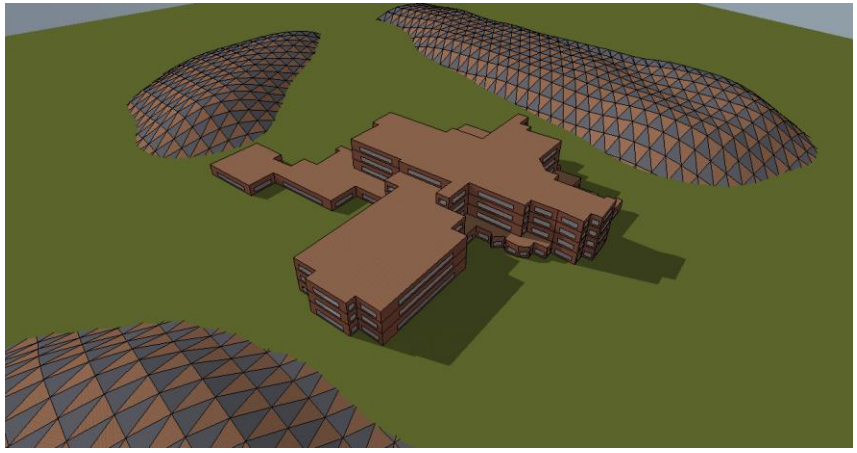
- Evaluate Building Site Conditions
- Analyze Local Climate
- Optimize Building shape, orientation, massing, daylighting potential
- Identify energy performance goals
- LEED v4 Integrative Process credit

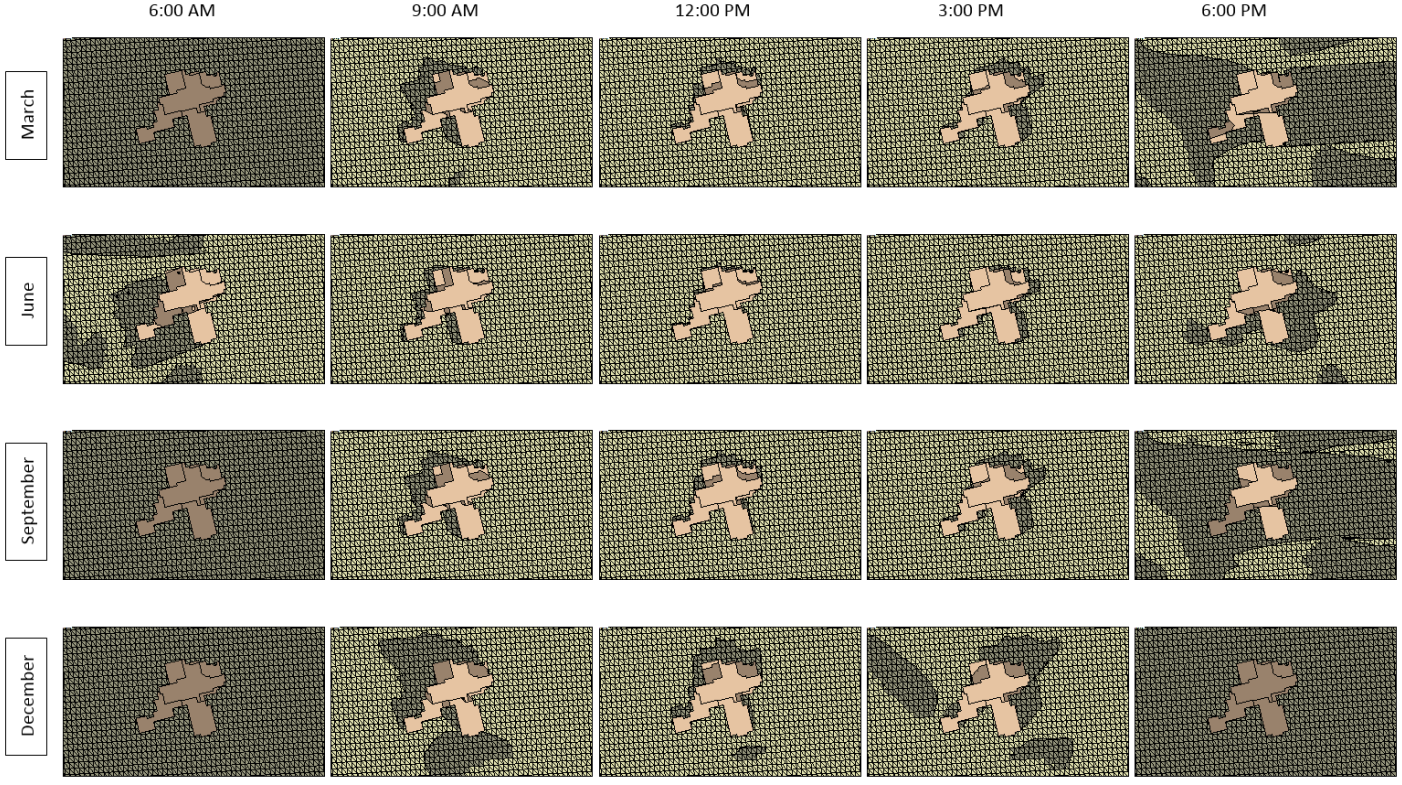
LEED v4 Integrative Process Credit

- By end of SDs, use “simple box” energy model to explore how to reduce energy loads, analyzing the following:
  - Site conditions
  - Massing and Orientation
  - Building envelope
  - Lighting Levels
  - Thermal Comfort ranges
  - Plug and process loads
  - Operational parameters



Site Conditions – Virginia Hospital

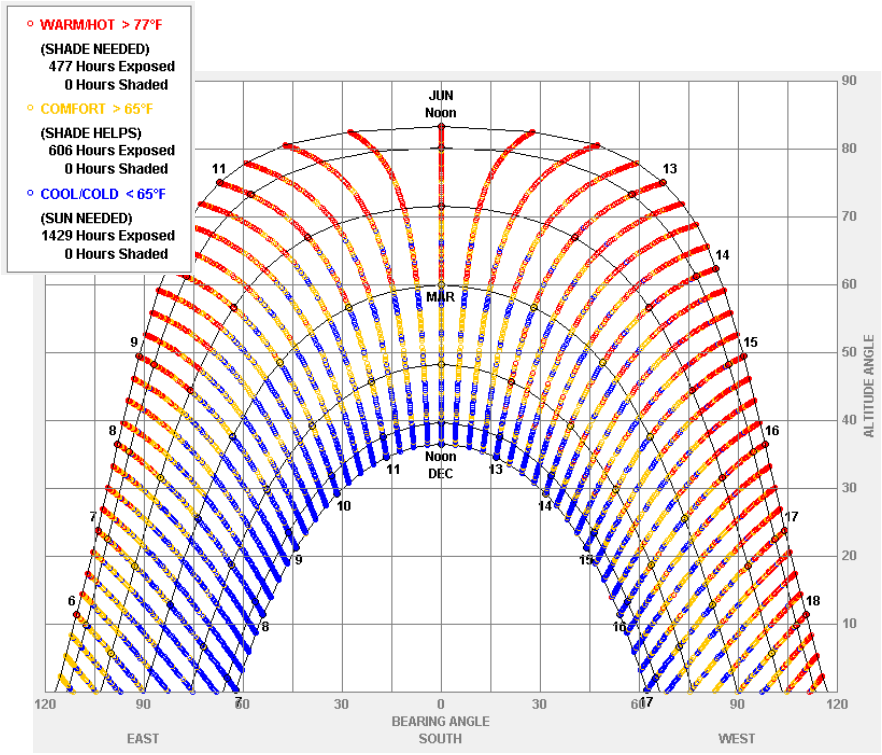


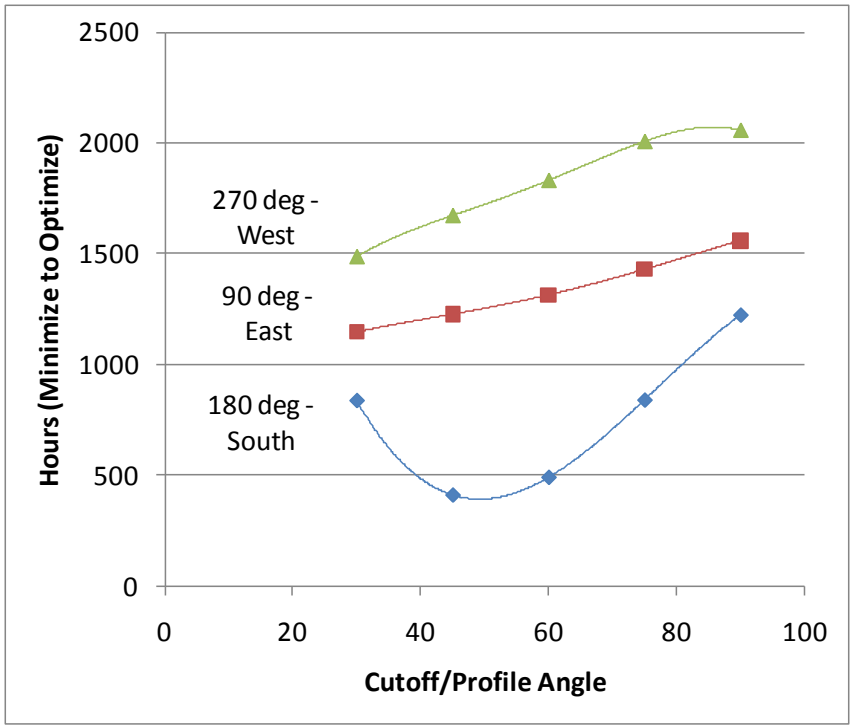


Pre-design: Climate Analysis

- Not all facades are created equal…

Sun Path Diagram - Solar Shading - Houston Office





Sun Path Diagram

-Combines Houston's hourly outside air temperatures with azimuth and altitude of sun

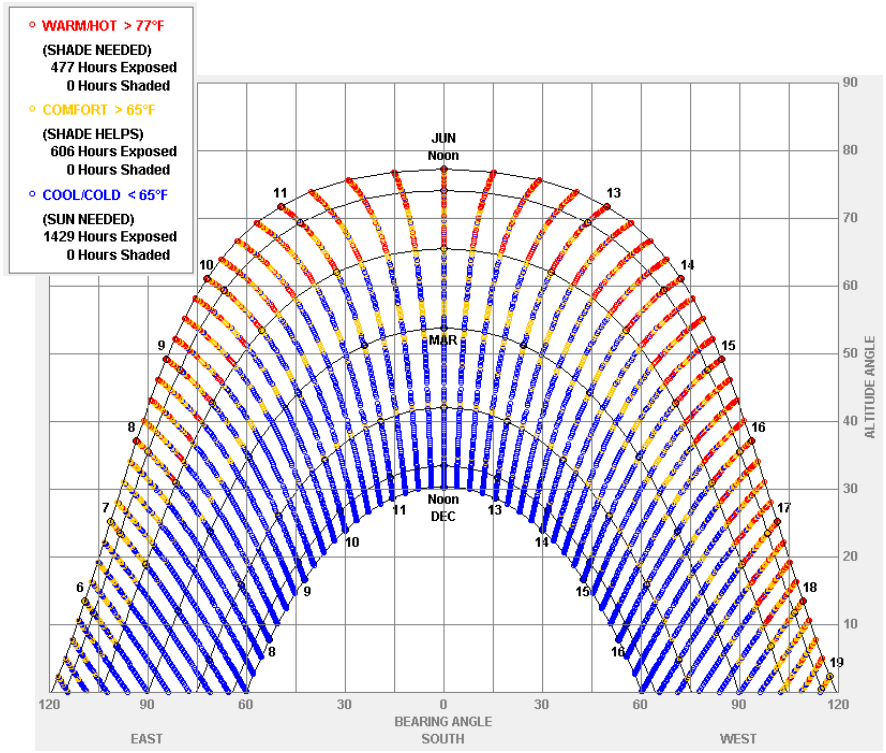
-Identifies when shade is needed and not needed

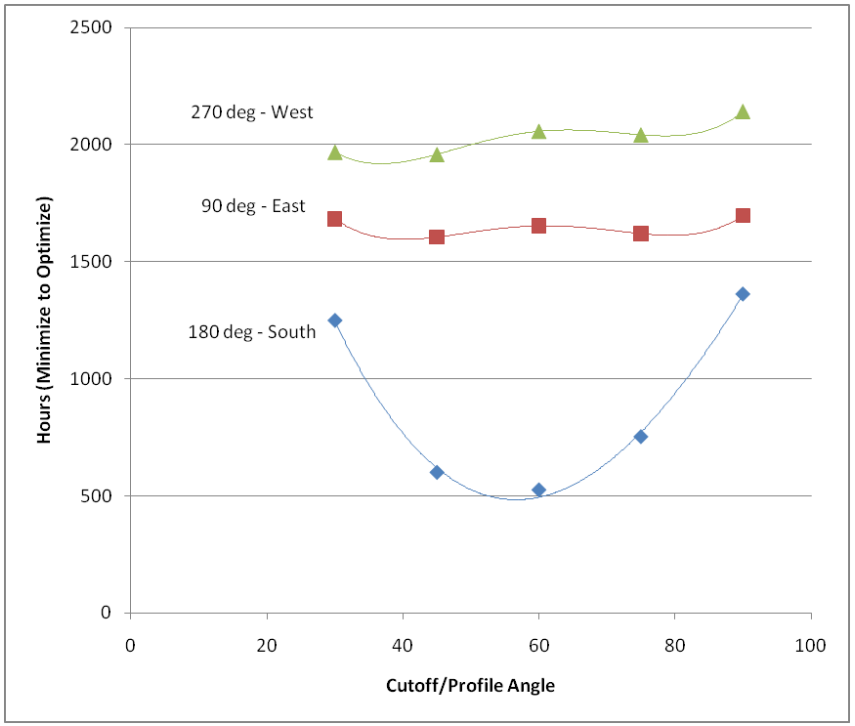
Shading Optimization by Orientation

-South façade has a shading "sweet spot" of <u>50°</u>

-East and West facades suggest the need for solar heat gain-resistant glazing (No shading)

Sun Path Diagram - Solar Shading - Nashville Office





Shading Optimization by Orientation

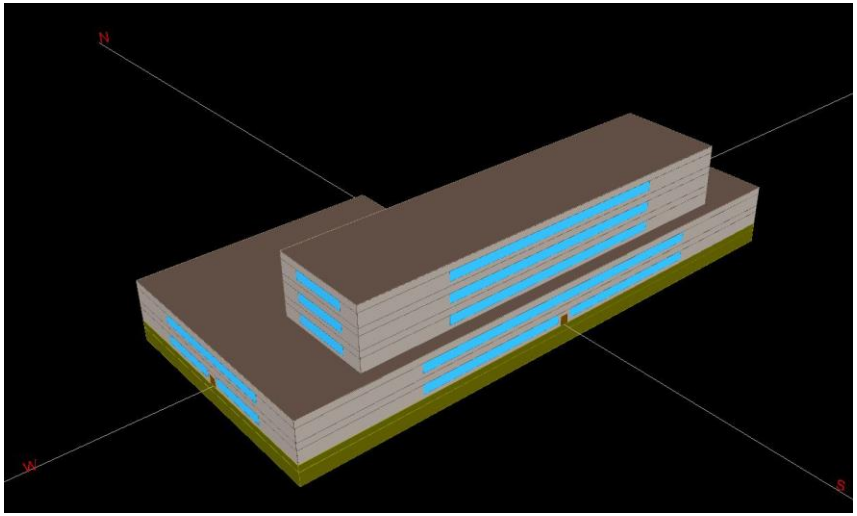
-South façade has a shading "sweet spot" of 55°

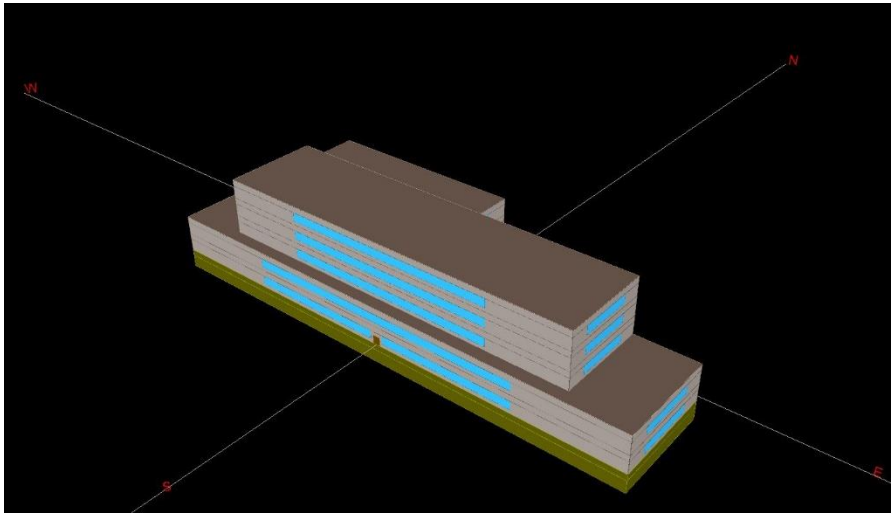
-East and West facades suggest no preferable sun-shades (Dynamic Glazing / Shading ???)

Building Orientation

- Related energy conservation strategies:
  - Daylight harvesting
  - Passive solar heating
  - Using shading reduce cooling loads
  - Natural ventilation
  - Orienting around the most populated spaces

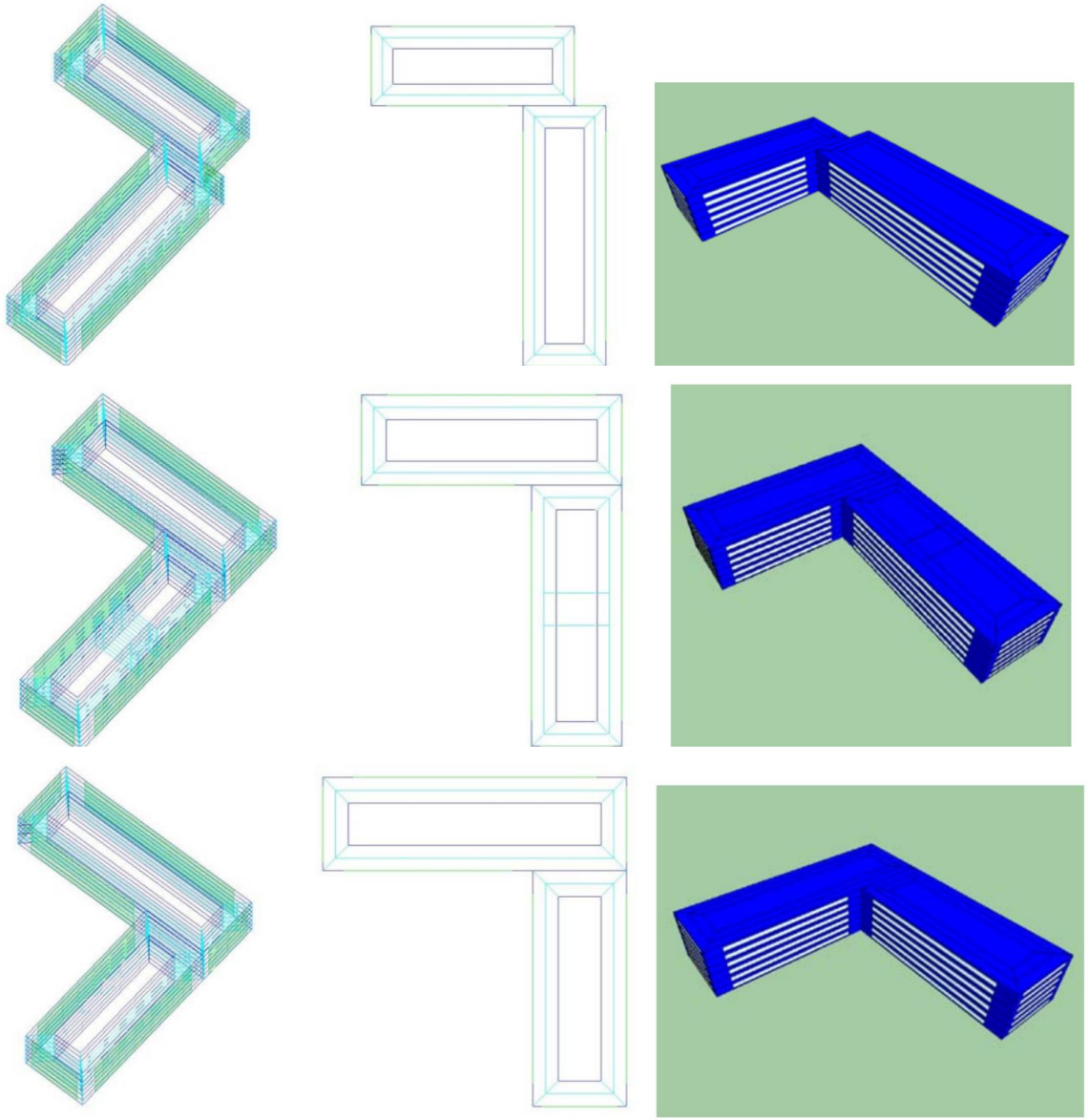
Predesign Case Study: Mississippi Hospital





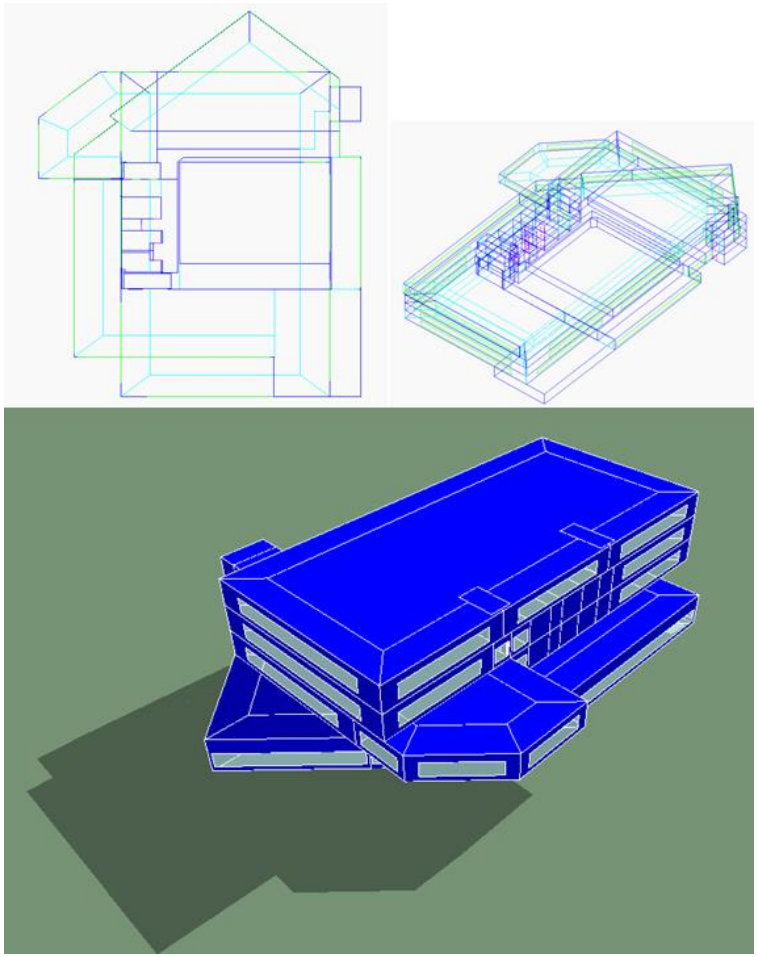
Best orientation saves << 1% energy

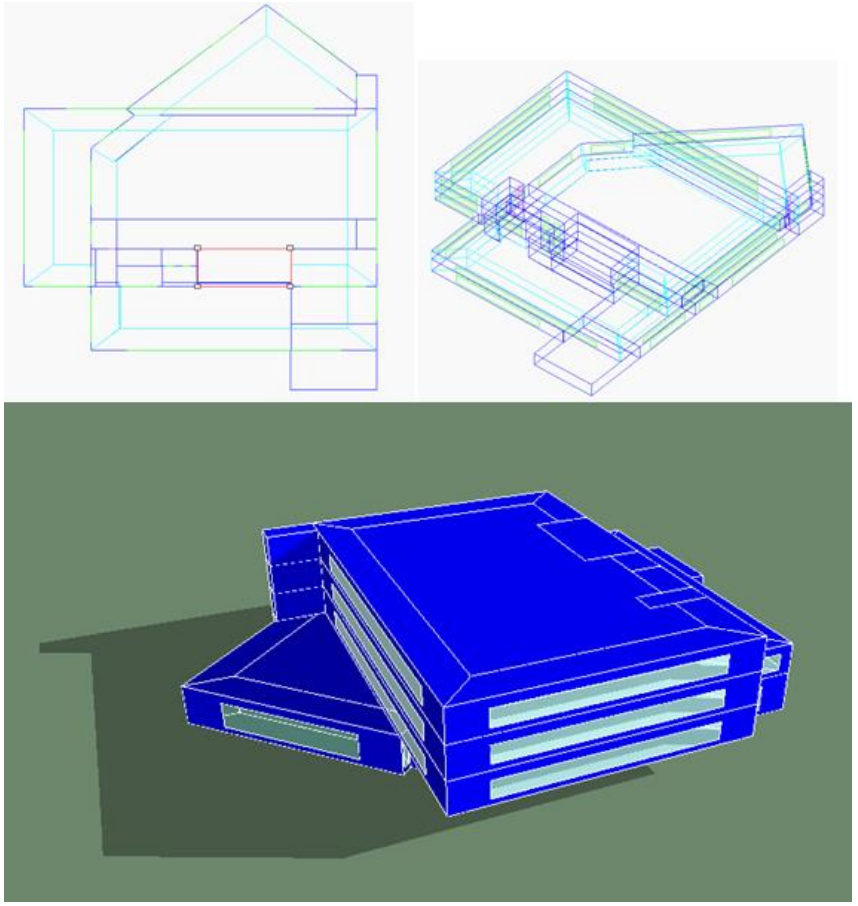
Pre-design Case Study: Houston Office #1



Massing option #3 gives 1.5% energy cost savings

Pre-design Case Study: Nashville Office





Massing option #2 gives 2.3% energy savings

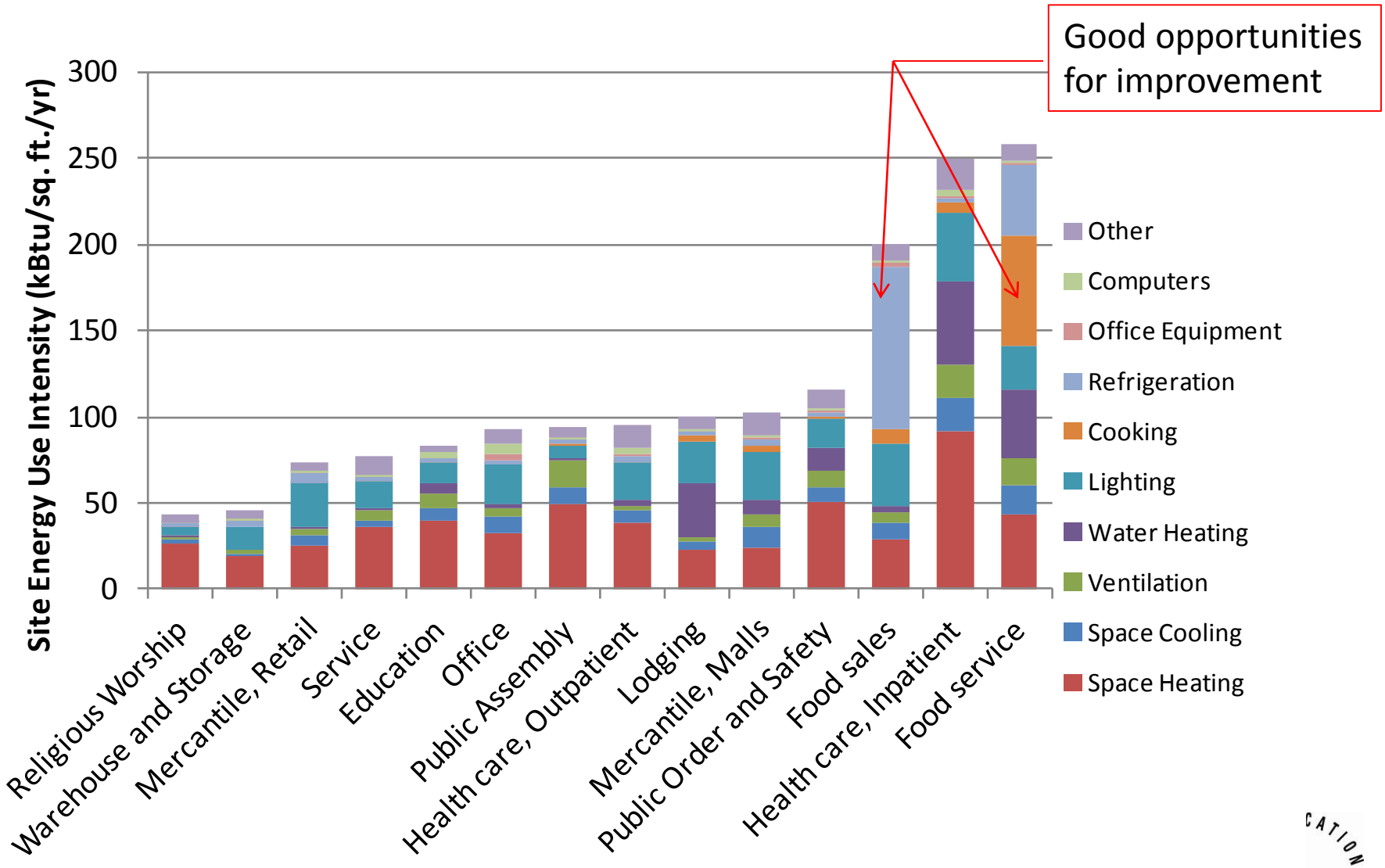
Massing and Orientation: Energy Model Results

- 1.5 - 2.3% savings is not insignificant
- Every little bit helps!
- Hospitals less sensitive to exterior loads than offices

Schematic Design

- Identify areas of greatest savings potential
- Load Reduction Analysis
- HVAC Systems Analysis
- Use LCCA when appropriate
- LEED v4 (Optimize Energy Performance)

Know how energy is used in your building



Based on 2003 Commercial Building Energy Consumption Survey (CBECS) data

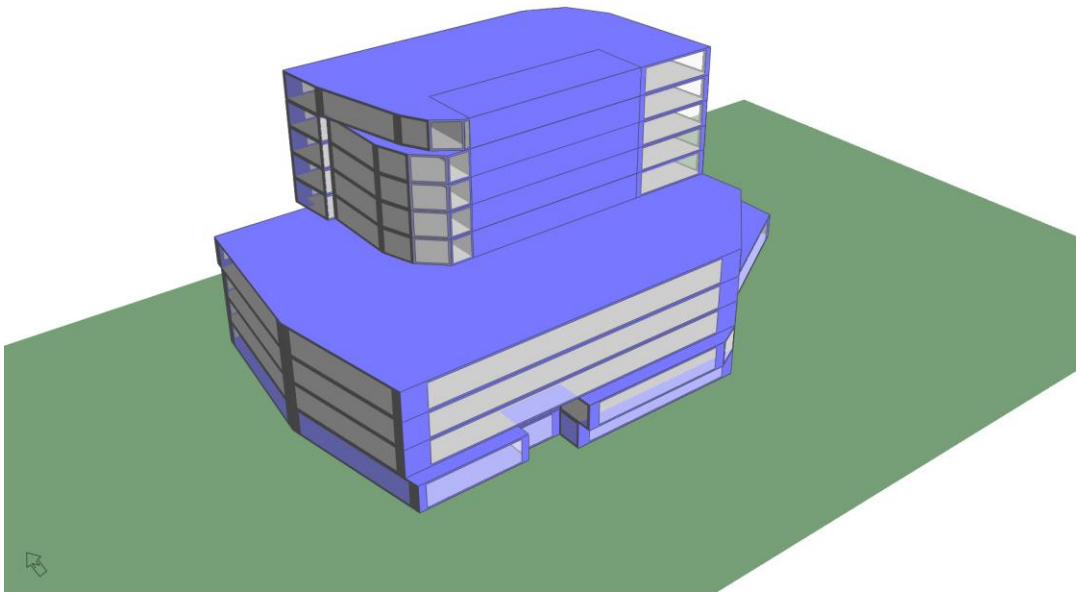
Envelope Performance and Mechanical Plant Size

- Building Envelope directly impacts Mechanical Systems
  - It reduces heating and cooling loads, resulting in smaller HVAC equipment
  - Can potentially eliminate systems

Potential Load Reduction Strategies

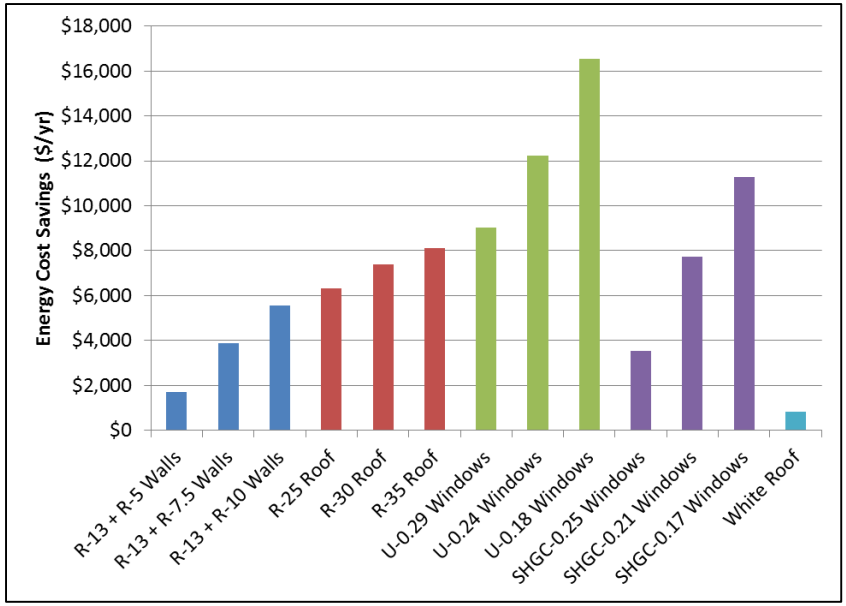
- Wall Insulation
- Roof Insulation
- Roof Reflectivity
- Window U-value
- Window SHGC
- Shading Devices
- Slab-on-Grade Insulation
- Window-to-Wall Ratio
- Reduced Infiltration

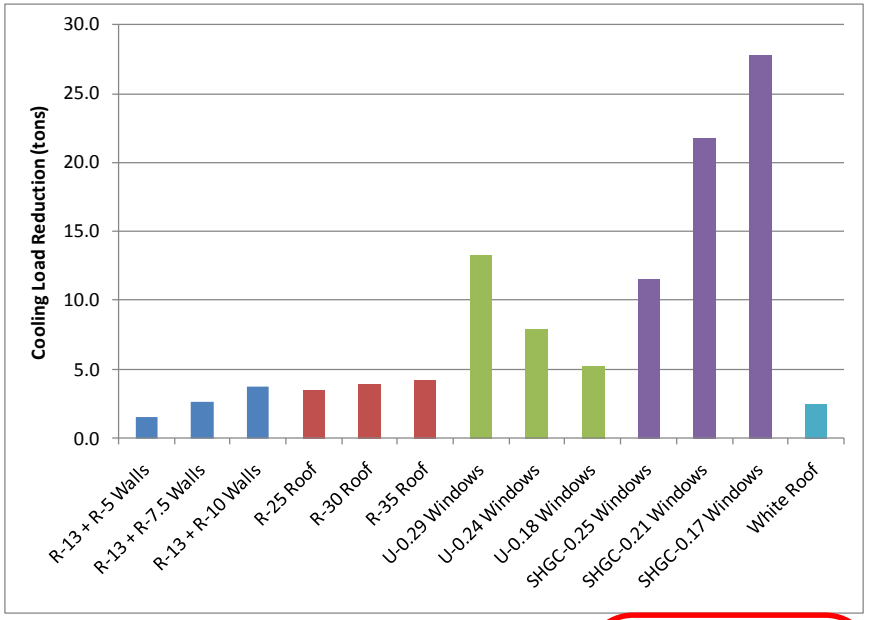
SD Case Study – San Francisco Office Building

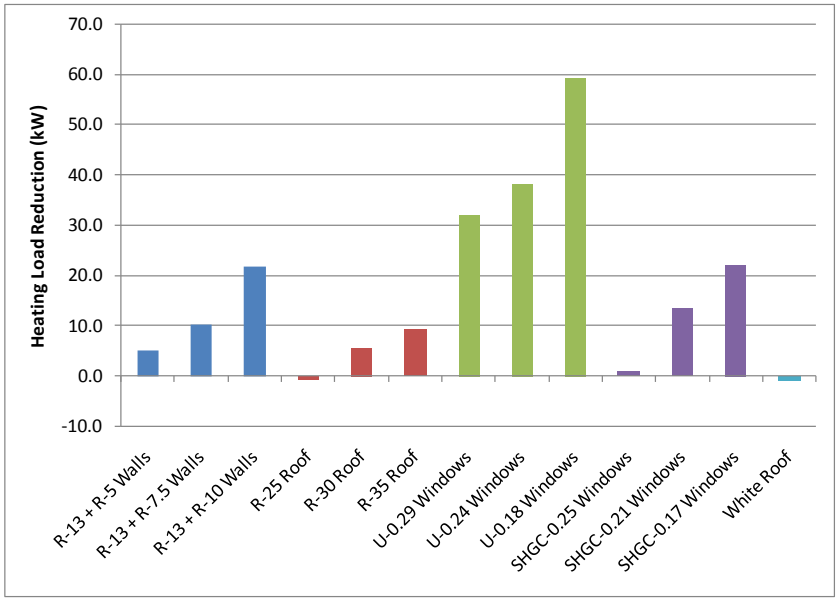


- 11-story office building in San Francisco
- Pursuing LEED Gold certification
- 60-70% glass

Envelope Insulation – San Francisco Office

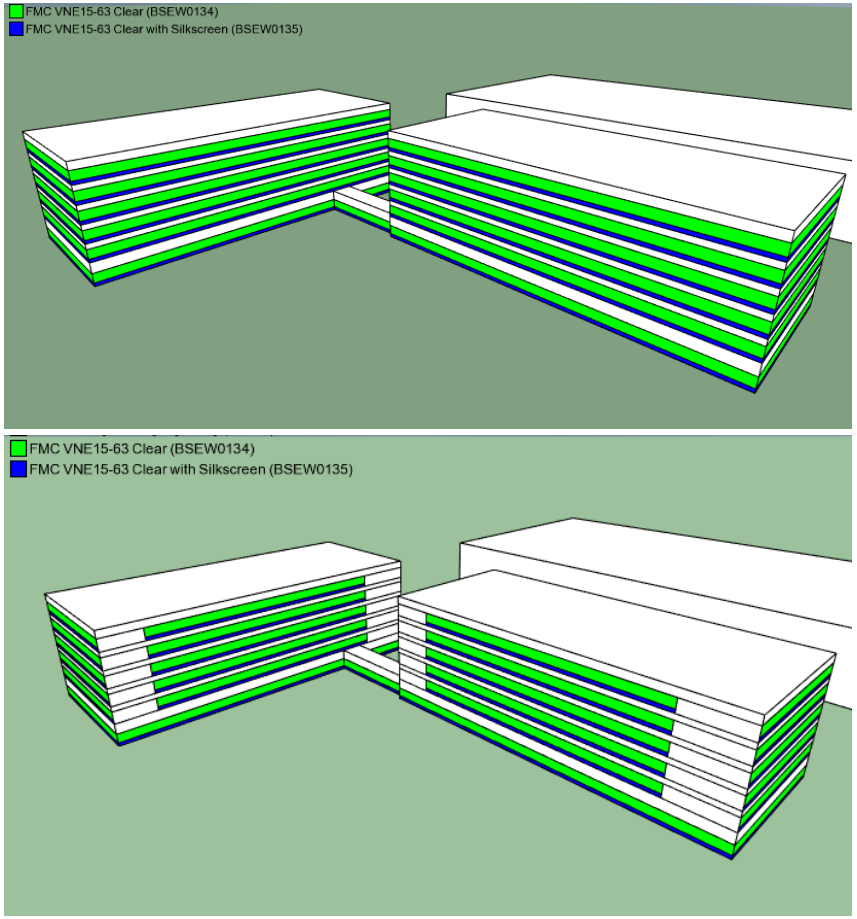






LR	Description	Net Construction Cost Change ($)	Energy Cost Savings ($/yr)	Simple Payback w/o HVAC (yrs)	Simple Payback with HVAC (yrs)
1-1	R-13 + R-5 Walls	-$3,983	$1,692	7.7	Immediate
1-2	R-13 + R-7.5 Walls	$6,776	$3,874	9.5	1.7
1-3	R-13 + R-10 Walls	$9,912	$5,569	10.4	1.8
2-1	R-25 Roof	$9,385	$6,316	6.2	1.5
2-2	R-30 Roof	$42,174	$7,404	10.9	5.7
2-3	R-35 Roof	$80,278	$8,130	15.2	9.9
5-1	White Roof	-$20,669	$817	Immediate	Immediate

Window to Wall Ratio – Houston Office #2

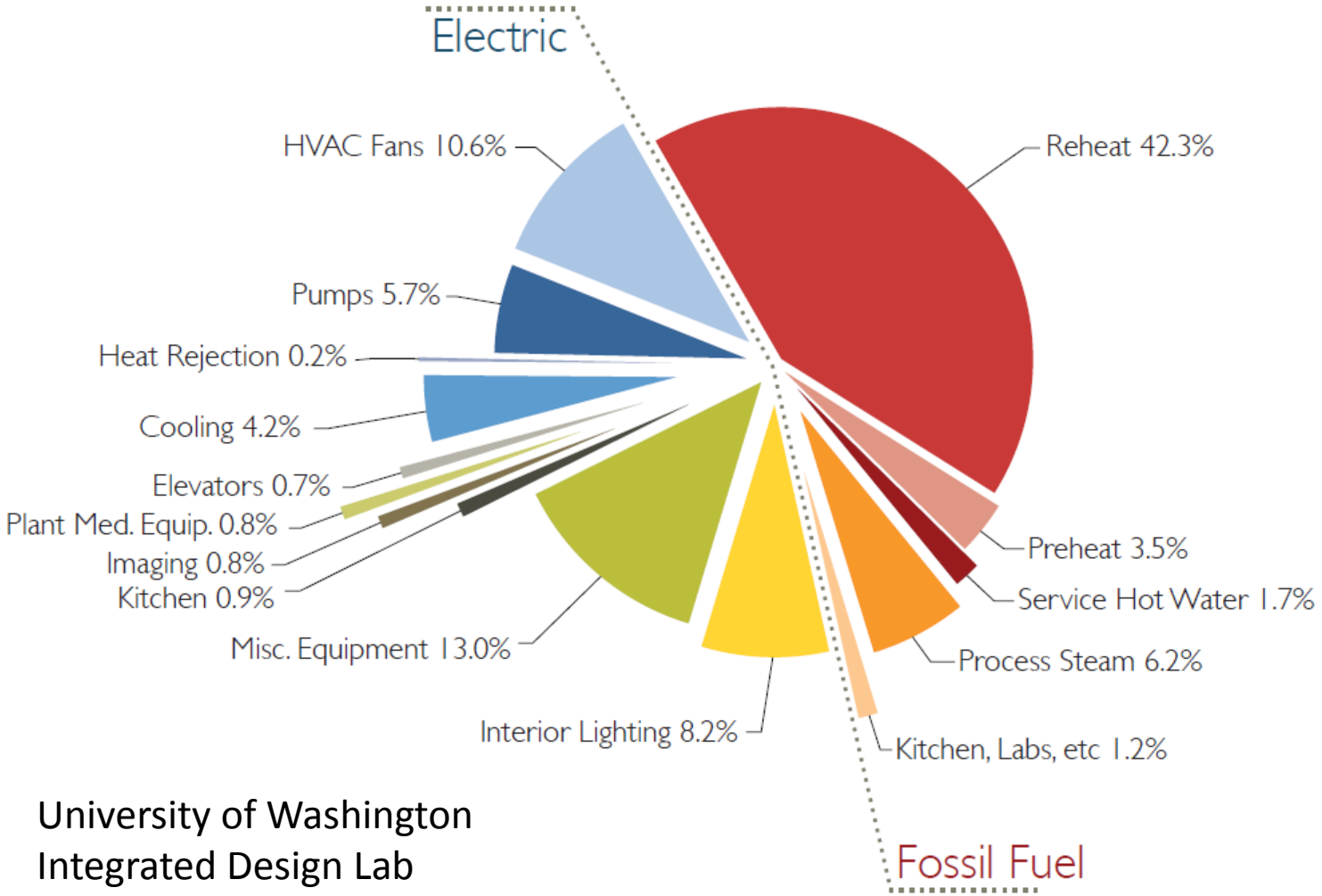


Opt.	Description	Energy Usage (kBtu/yr)	Energy Costs ($/yr)	Energy Costs Savings ($/yr)	Cooling Load Reduction (tons)	Heating Load Reduction (kW)	Airflow Reduction per AHU (cfm)
1A	Curtain Wall with PPG Glazing	30,175,636	$439,864	-	-	-	-
1B	Curtain Wall with Viracon Glazing	29,895,069	$437,292	$2,572	5.5	2.8	167
2A	Precast Walls with PPG Glazing	28,727,537	$421,614	$18,251	23.5	82.4	752
2B	Precast Walls with Viracon Glazing	28,486,141	$419,348	$20,517	27.2	86.4	898

SD Case Study 3: Mississippi Hospital

- 206,000 sf hospital, Joined during concept phase
- IPD contract, Contractor on-board from start
- LCCA to determine most cost effective HVAC system
- First Gold LEED-HC Inpatient Hospital in U.S.

Where does a typical hospital use energy?



University of Washington
Integrated Design Lab

Schematic Design – HVAC System Selection

- 5 Systems Investigated:
  - Chiller, Boiler, VAV Air Handlers
  - Water Source Heat Pumps
  - Variable Refrigerant Flow
  - Active Chilled Beams
  - Ground Source Heat Pumps

-Decouple dehumidification from space cooling

- Reduce simultaneous cooling and reheating

SD Case Study 3: LCCA Results

HVAC System	EUI*	Annual Energy $ / ft²	MEP First Cost	Cumulative 7 Year Evaluation Timeline: Energy	Cumulative 7 Year Evaluation Timeline: O&M	Cumulative 7 Year Evaluation Timeline: Total	Total 7 Year Investment
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 Costs
  - Equipment
  - Electrical
  - Floor space
  - Floor-to-floor height
- Budget Sharing

- Other costs
  - Energy Costs
  - O&M Costs

Energy Cost Savings alone probably wouldn't have been enough to justify GSHP!

Design Development & Construction Documents

- Refine Envelope, HVAC, and Lighting Design
- “Pre-Cx” Control Sequences
- Compare Equipment Selections
- Incorporate CxA Design Review Comments
- Value Engineering

DD Case Study 1: Brooklyn Sports Practice Facility

- 70,000 sf; Got involved during DDs
- Low-grade windows proposed by the Landlord in order to preserve historic aesthetic of building
- What effect does this have on system sizing?
- Can high performance envelope be cost-justified via LCCA?

DD Case Study 1: Glass Types

- Base Case – Double-pane clear window with AGC “Comfort E2” applied to Surface #3
  - U-0.32 (COG), SHGC-0.72
- Alternate – Double-pane clear window with AGC “Comfort Select40” applied to Surface #2
  - U-0.24 (COG), SHGC-0.39

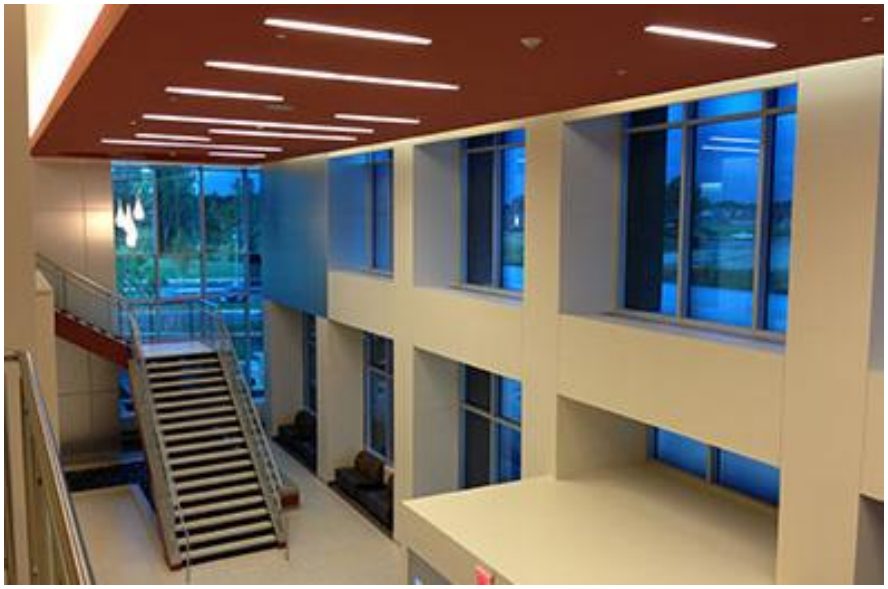
DD Case Study 1: Energy Analysis Results

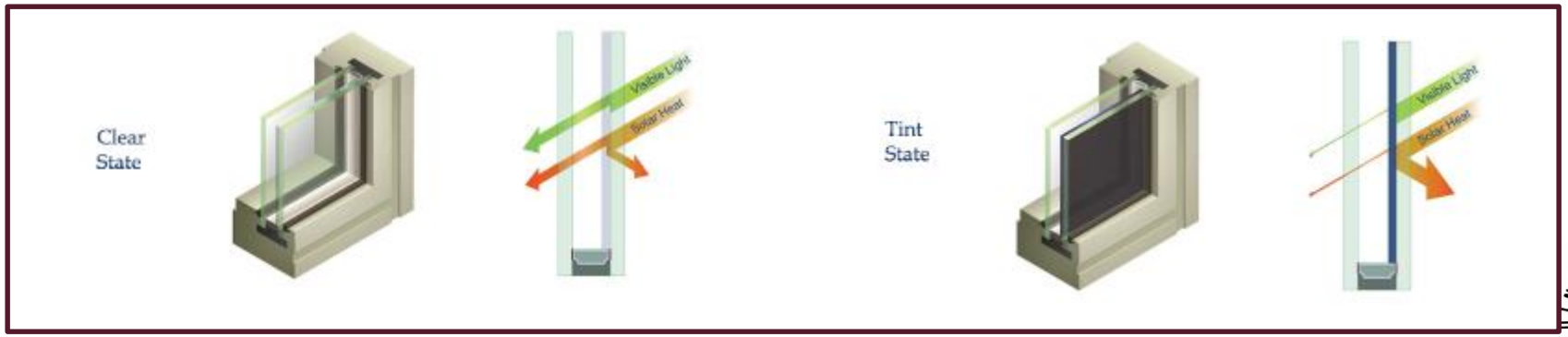
Glass Type	Electricity Use (kWh/yr)	Natural Gas Use (therms/yr)	Electricity Costs ($/yr)	Natural Gas Costs ($/yr)	Total Energy Costs ($/yr)	Cooling Load Reduction (tons)	Peak Airflow Reduction (cfm)
1	1,136,987	3,383	$109,806	$2,717	$112,523	-	-
2	1,110,668	3,349	$106,610	$2,690	$109,300	**14**	**5065**
Savings	**26,319**	**34**	**$3,196**	**$27**	**$3,223**		

- $3,223/yr energy cost savings
- $50,000 increase in glass first cost
- Simple payback = 15.5 years

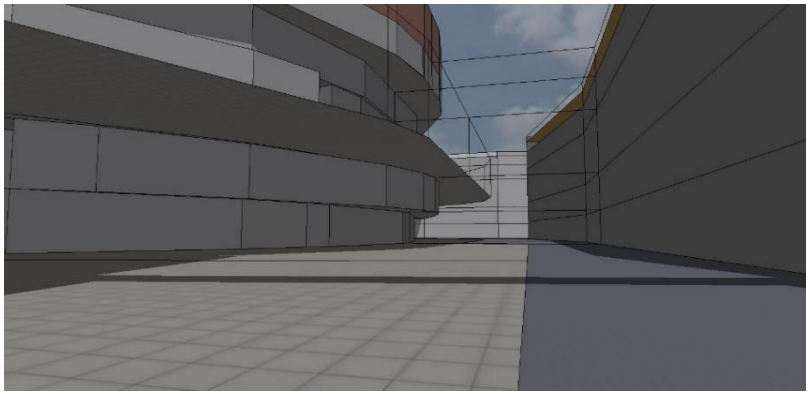
- $136,000 decrease in HVAC first cost
- Simple payback = Immediate

DD Case Study 2: Mississippi Hospital Dynamic Glazing





DD Case Study 3: Detroit Sports Facility



- ETFE makes up 31% of roof area
- Products with differing properties
- Choice affects illuminance, LEED, energy, appearance, and cost

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Jan	-	-	-	-	-	-	-	-	47	87	116	132	136	124	101	65	20	-	-	-	-	-	-	-
Feb	-	-	-	-	-	-	-	25	75	117	149	167	171	161	137	101	55	-	-	-	-	-	-	-
Mar	-	-	-	-	-	-	10	67	117	160	192	209	212	201	175	137	88	35	-	-	-	-	-	-
Apr	-	-	-	-	-	5	61	115	165	205	235	250	251	237	210	170	122	68	11	-	-	-	-	-
May	-	-	-	-	-	41	95	147	194	232	259	273	273	259	232	193	147	94	40	-	-	-	-	-
Jun	-	-	-	-	-	53	105	157	202	240	267	281	282	270	244	207	162	112	59	8	-	-	-	-
Jul	-	-	-	-	-	43	96	148	194	234	262	278	280	268	244	208	162	112	59	7	-	-	-	-
Aug	-	-	-	-	-	17	72	127	175	216	246	262	264	252	226	188	140	87	32	-	-	-	-	-
Sep	-	-	-	-	-	-	43	98	148	188	216	230	230	215	186	146	96	41	-	-	-	-	-	-
Oct	-	-	-	-	-	-	11	65	113	150	176	188	185	168	138	96	46	-	-	-	-	-	-	-
Nov	-	-	-	-	-	-	-	29	75	111	136	147	144	127	98	58	9	-	-	-	-	-	-	-
Dec	-	-	-	-	-	-	-	4	50	87	112	125	124	111	84	46	-	-	-	-	-	-	-	-

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Feb	-	-	-	-	-	-	-	35	106	166	210	237	242	228	194	143	78	-	-	-	-	-	-	-
Mar	-	-	-	-	-	-	15	95	166	227	272	296	301	284	247	194	125	49	-	-	-	-	-	-
Apr	-	-	-	-	-	7	86	163	233	291	333	354	356	335	297	241	172	96	16	-	-	-	-	-
May	-	-	-	-	-	58	134	208	275	329	367	387	387	367	329	274	208	133	57	-	-	-	-	-
Jun	-	-	-	-	-	76	149	222	287	340	378	399	400	382	345	293	230	158	83	12	-	-	-	-
Jul	-	-	-	-	-	60	136	209	275	331	371	394	396	380	345	294	230	158	83	10	-	-	-	-
Aug	-	-	-	-	-	25	102	180	249	306	348	371	373	357	320	267	199	124	45	-	-	-	-	-
Sep	-	-	-	-	-	-	62	139	209	267	306	326	326	305	264	207	137	58	-	-	-	-	-	-
Oct	-	-	-	-	-	-	16	92	160	213	250	267	263	238	195	137	66	-	-	-	-	-	-	-
Nov	-	-	-	-	-	-	-	41	106	157	193	208	204	180	139	82	13	-	-	-	-	-	-	-
Dec	-	-	-	-	-	-	-	6	71	123	158	178	176	157	119	66	-	-	-	-	-	-	-	-

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Feb	-	-	-	-	-	-	-	39	119	186	235	265	271	255	217	160	88	-	-	-	-	-	-	-
	-	-	-	-	-	-	17	106	186	254	304	331	336	318	277	217	140	55	-	-	-	-	-	-
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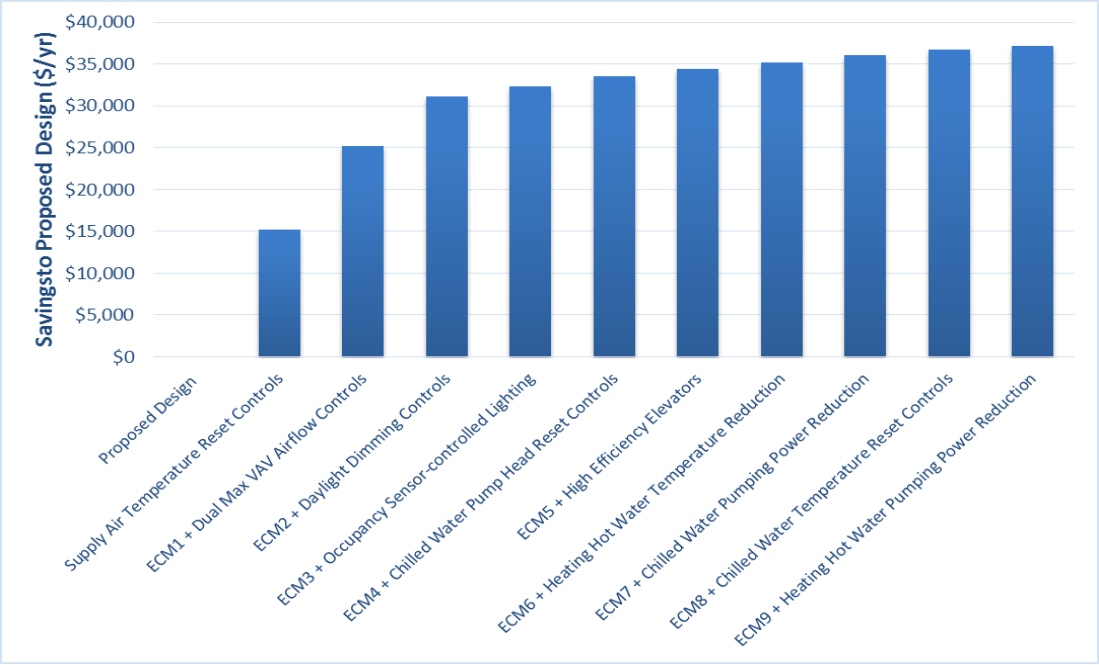
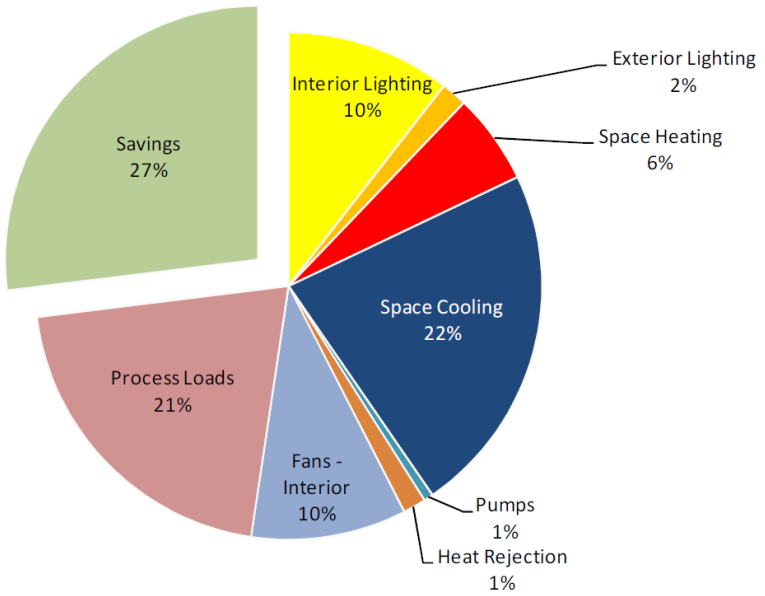
	-	-	-	80	204	301	369	398	391	345	267	158	26	-	-	-	-	-	-	-
	-	-	-	12	136	235	303	340	337	301	228	126	-	-	-	-	-	-	-	-

Description	Energy Costs ($/yr)	Savings to Proposed ($/yr)	% Energy Cost Savings to Baseline	LEED EAc1 Points	Cooling Load Increase (tons)	Mech Equip Cost Increase
Baseline Design per ASHRAE 90.1	$1,265,392	-	-	-	-	-
Proposed Design w/ Skylight 1	$1,126,372	-	11.0%	0	-	-
Skylight 2	$1,141,773	-$15,401	9.8%	N/A	90.2	$631,528
Skylight 3	$1,145,226	-$18,854	9.5%	N/A	85.0	$594,669
Skylight 4	$1,174,570	-$48,199	7.2%	N/A	156.9	$1,098,440

CD Case Study: New Orleans Wellness Center





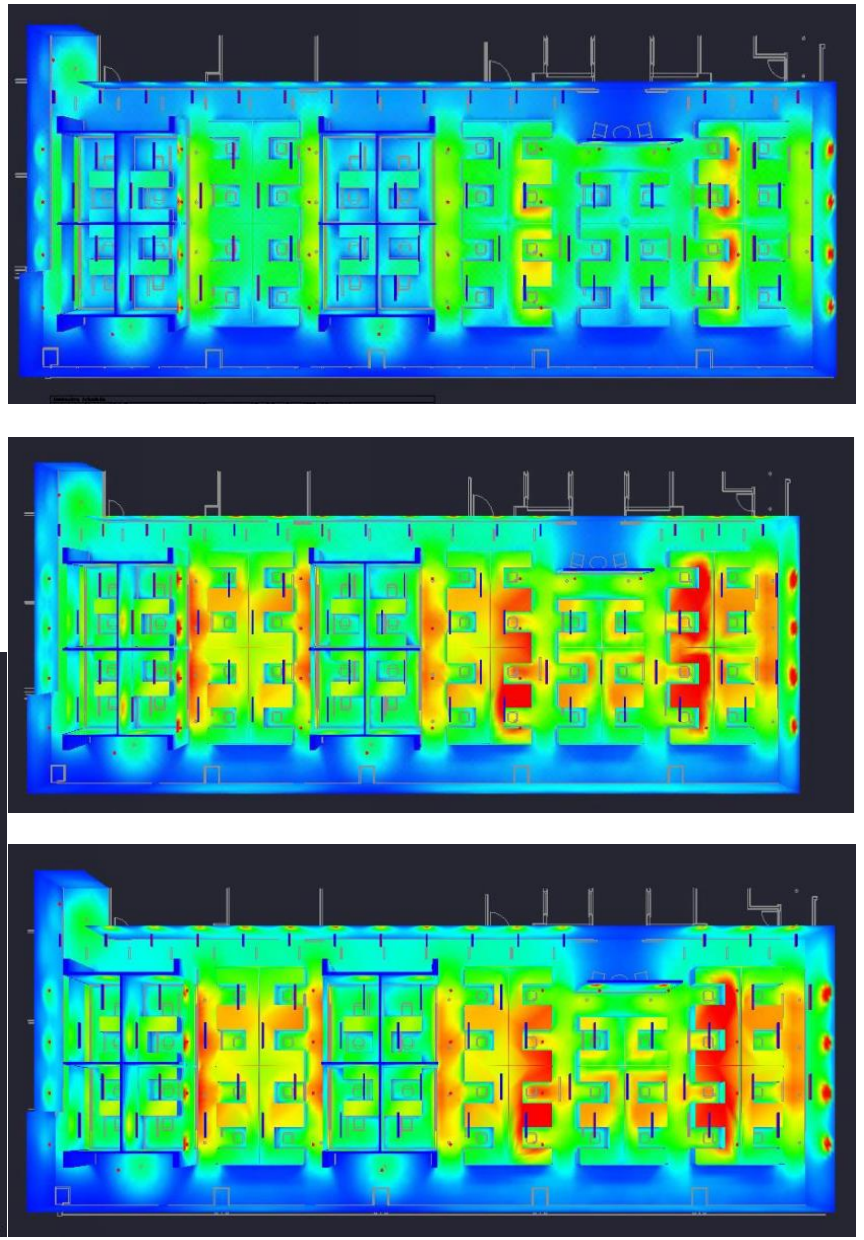
ECM	Description	Site EUI (kBtu/sf/yr)	Energy Costs ($/yr)	Savings to Proposed ($/yr)	Cumulative % Energy Cost savings over Baseline	Potential LEED EAc1 Points
	Baseline Design	101.6	$471,117		-	-
	Proposed Design	71.2	$344,846		26.8%	8
1	Supply Air Temperature Reset Controls	63.8	$329,594	$15,252	30.0%	10
2	ECM1 + Dual Max VAV Airflow Controls	66.9	$319,699	$25,146	32.1%	11
3	ECM2 + Daylight Dimming Controls	70.0	$313,701	$31,145	33.4%	11
4	ECM3 + Occupancy Sensor-controlled Lighting	70.9	$312,482	$32,364	33.7%	11
5	ECM4 + Chilled Water Pump Head Reset Controls	70.9	$311,344	$33,502	33.9%	11
6	ECM5 + High Efficiency Elevators	71.0	$310,477	$34,369	34.1%	12
7	ECM6 + Heating Hot Water Temperature Reduction	70.8	$309,616	$35,230	34.3%	12
8	ECM7 + Chilled Water Pumping Power Reduction	71.0	$308,760	$36,086	34.5%	12
9	ECM8 + Chilled Water Temperature Reset Controls	71.0	$308,119	$36,727	34.6%	12
10	ECM9 + Heating Hot Water Pumping Power Reduction	71.1	$307,729	$37,117	34.7%	12

Construction – Job Done!

- What could go wrong?
  - Change Orders
  - Requests for Information (RFIs)
  - Equipment Substitution Requests

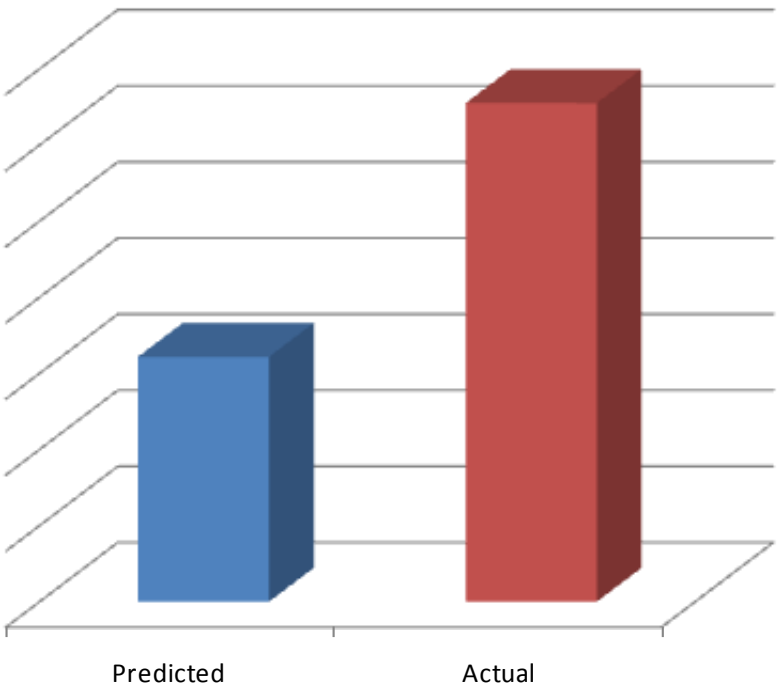
Construction Case Study: Houston Office #1

- Basis of Design: Overhead T8s with task lighting
- Task lighting removed; insufficient light levels
- T5HO and LEDs evaluated
  - T5HO = +$9,000/yr energy
  - LED = +$2,000/yr energy
- Loss of 2 LEED points



Operations

??????????????



Possible Causes

- Differing Weather
- Differing Building Usage
- Differing Control
- Equipment Installation and O&M
- Sub-optimal System Operations

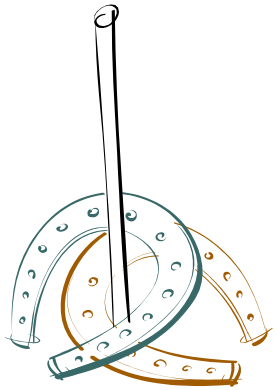
Measurement & Verification – Model Calibration

- A process where model inputs are adjusted so that the model outputs correlate better to actual performance

- Goals:
  - Calculate savings while taking into account operations-phase adjustments
  - Enhanced model accuracy
  - Increased level of confidence in simulation results

M&V: Energy Model Accuracy Criteria

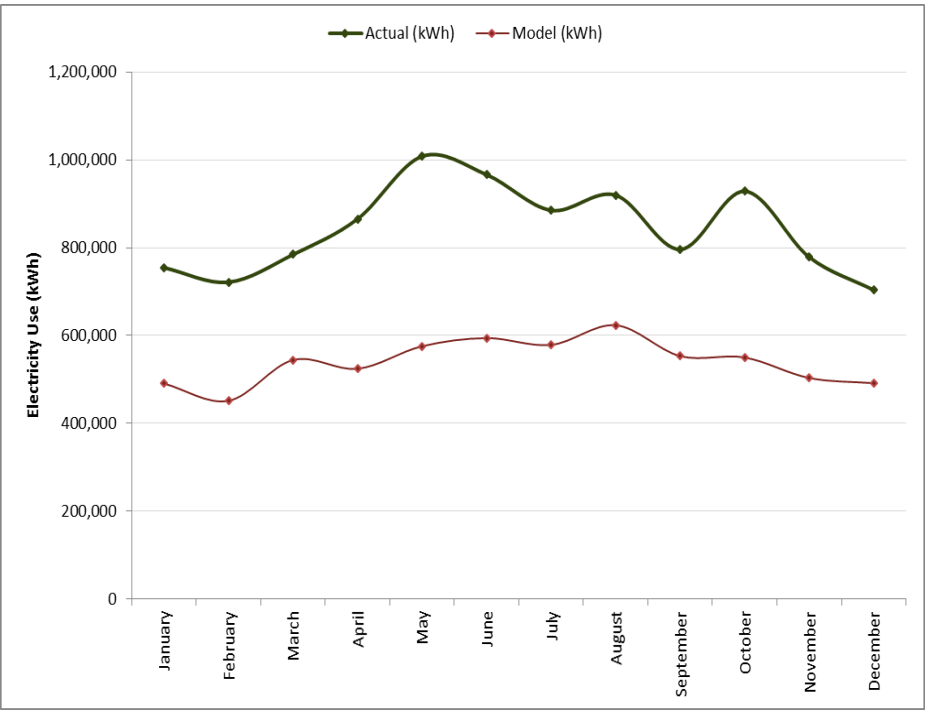
- How close is close enough?
- ASHRAE Guideline 14 provides accuracy criteria
- Normalized Mean Bias Error (NMBE)
  - A measure of the model accuracy relative to the mean of the data set
  - Guideline 14 specifies 5%
- Coefficient of variation of the Root Mean Squared Error [CV(RMSE)]
  - A measure of the residuals of the data set not accounted for by the model
  - Guideline 14 specifies 15%

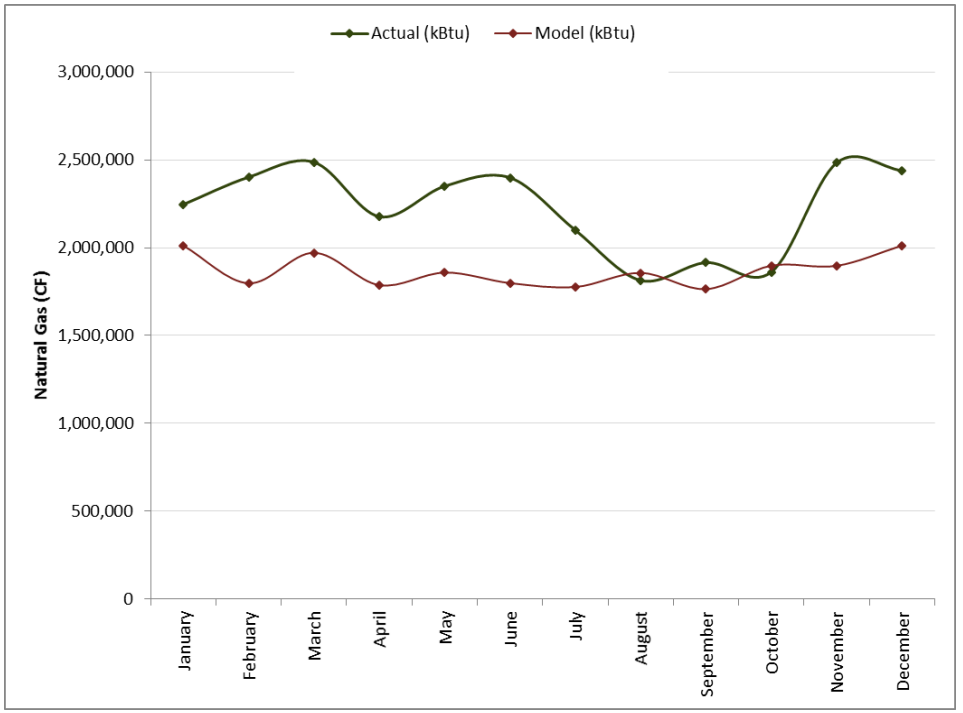


Ops Case Study: San Antonio Hospital

- LEED certified hospital
- Designed to achieve 14.2% energy cost savings over ASHRAE 90.1-2007
- How well did it really do? Can it be improved?

Ops Case Study: As-Built & Actual Performance





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

Generalized

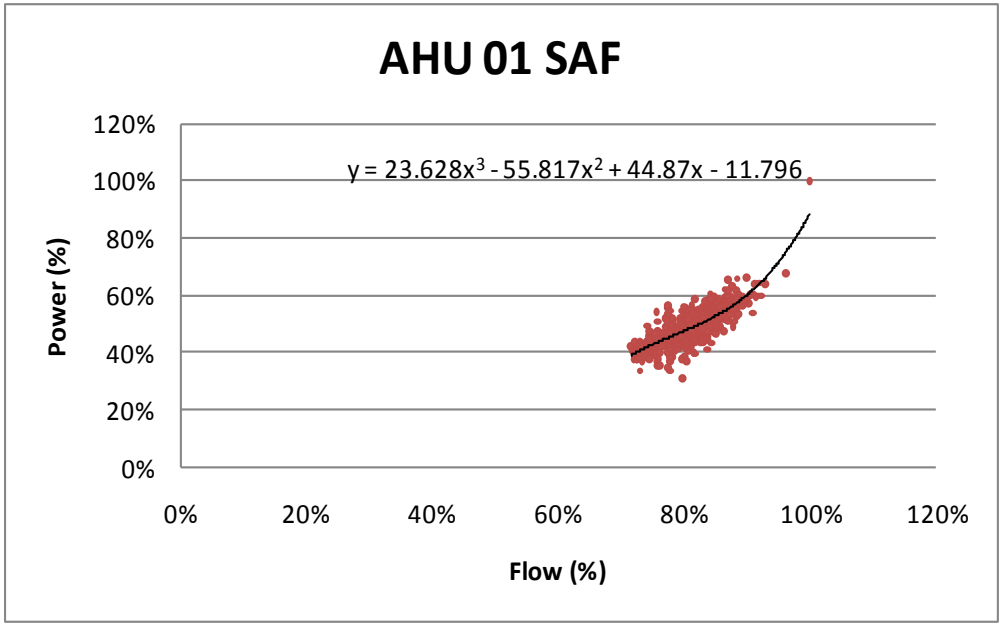
- Step 1: Calibrate to known data
  - 1a: Energy Demand
    - Installed lighting power, plug loads, peak occupants
    - Equipment capacities
  - 1b: Energy Consumption
    - BAS trends and setpoints
    - Known equipment or occupant schedules
    - Weather data
- Step 2: Calibrate to unknown data
  - Adjust unknown load schedules, infiltration, efficiencies, and part-load performance for fine tuning

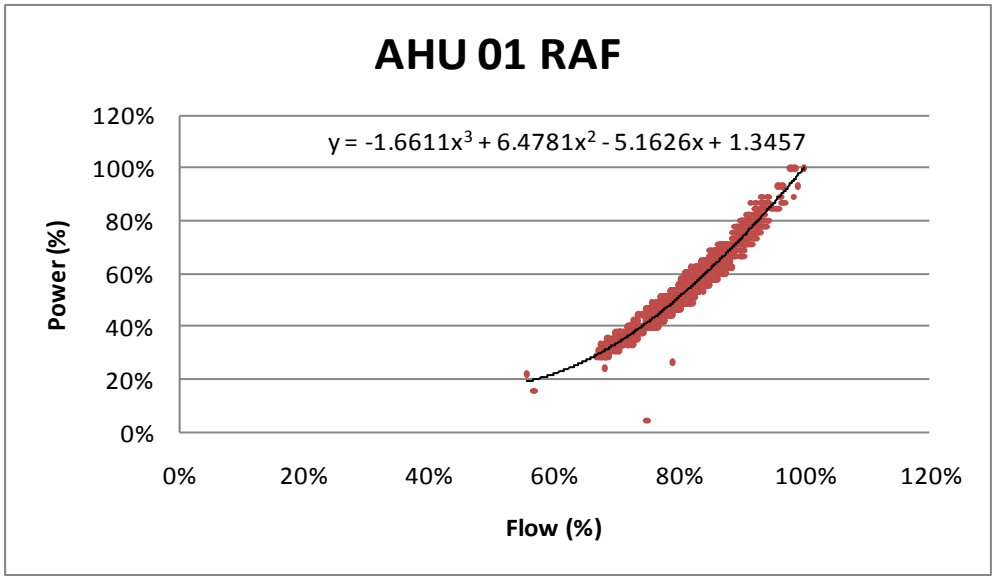
Case Study-specific

- 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

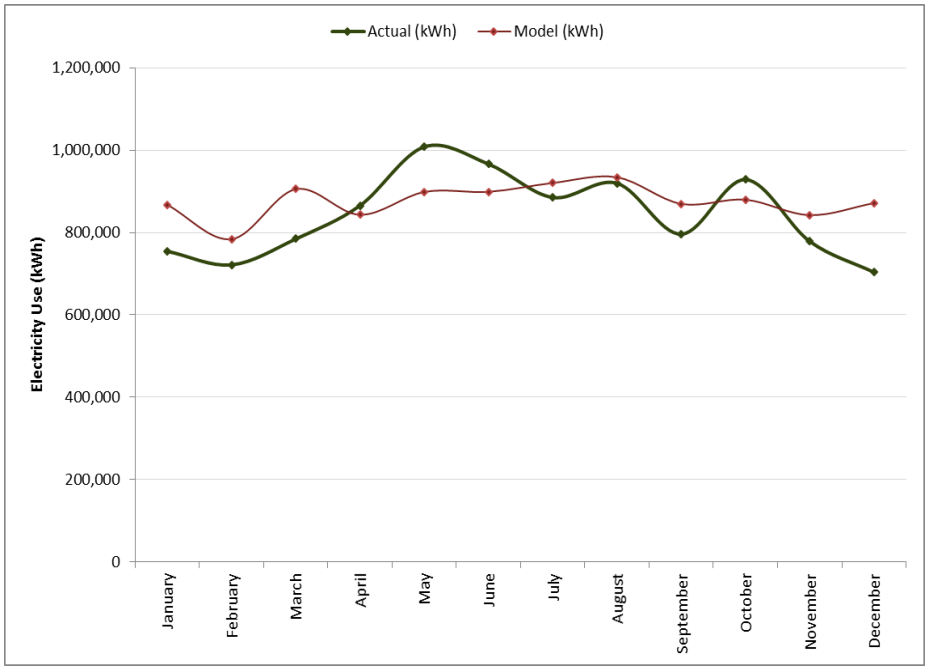
Trended Fan Airflow-to-Power relationship

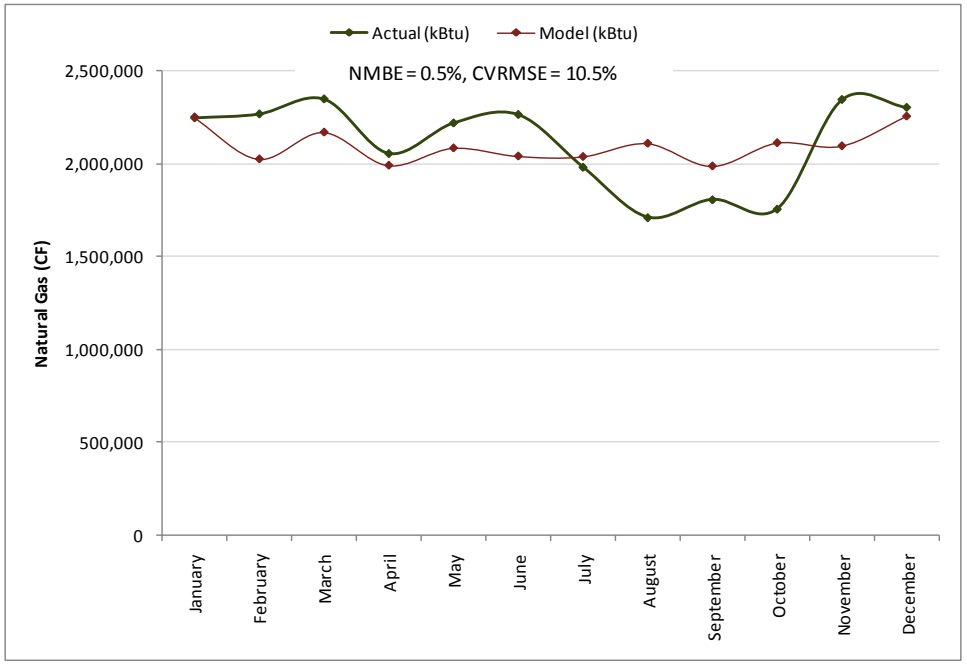
- Energy modeling programs have “canned” performance curves
- ASHRAE 90.1, App. G prescribes fan part-load performance curve
- Some empirical studies out there (Taylor Engineering)
- Actual trend data helps to create more accurate performance curves





Calibrated Model gives Actual Savings





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

	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

Energy Modeling in Existing Buildings

- Retro-Commissioning
- Energy Audits/Assessments
- Continuous Commissioning™

QUESTIONS?

This concludes The American Institute of Architects
Continuing Education Systems Course

Smith Seckman Reid, Inc.

Clark Denson

Building Performance Engineer

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