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Opening the Black Box of Building Performance Simulation and Building Enclosure

Drury B. Crawley, Ph.D., FASHRAE, BEMP, FIBPSA, AIA

Bentley Systems, Inc.

22 February 2018

CSI Chicago Chapter

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By Drury B. Crawley

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General CE hours

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LEED AP O+M

LEARNING OBJECTIVES

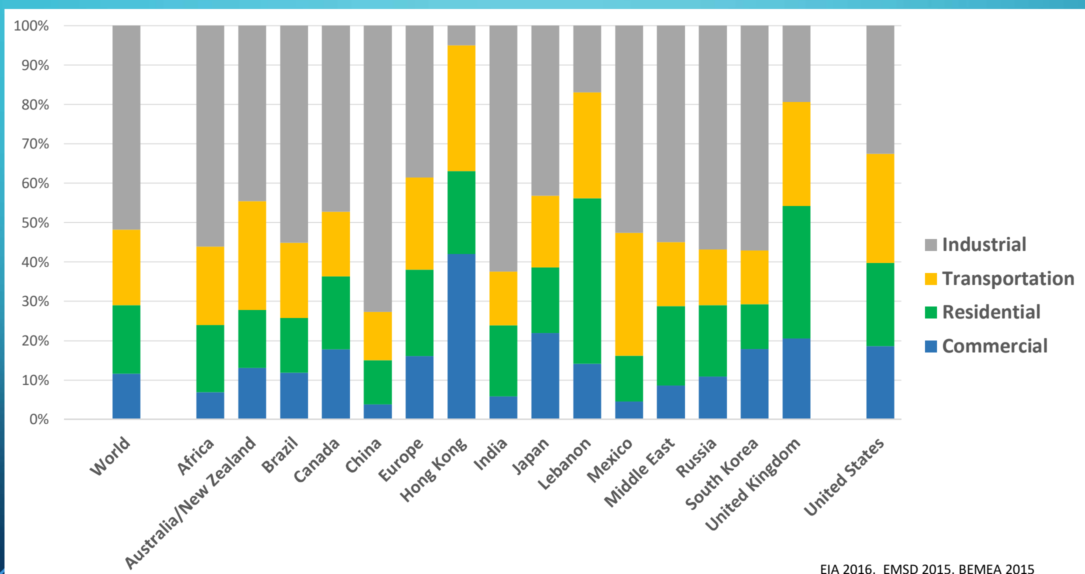
- Describe how buildings use energy and the building sector's relationship to overall energy use in the United States.
- Identify new technologies affecting energy use in buildings.
- Define BIM and explain methods for getting BIM data into building simulation software.
- Identify new methods for creating building models for existing buildings
- Provide strategies for specifying building enclosure materials to improve performance

COURSE DESCRIPTION

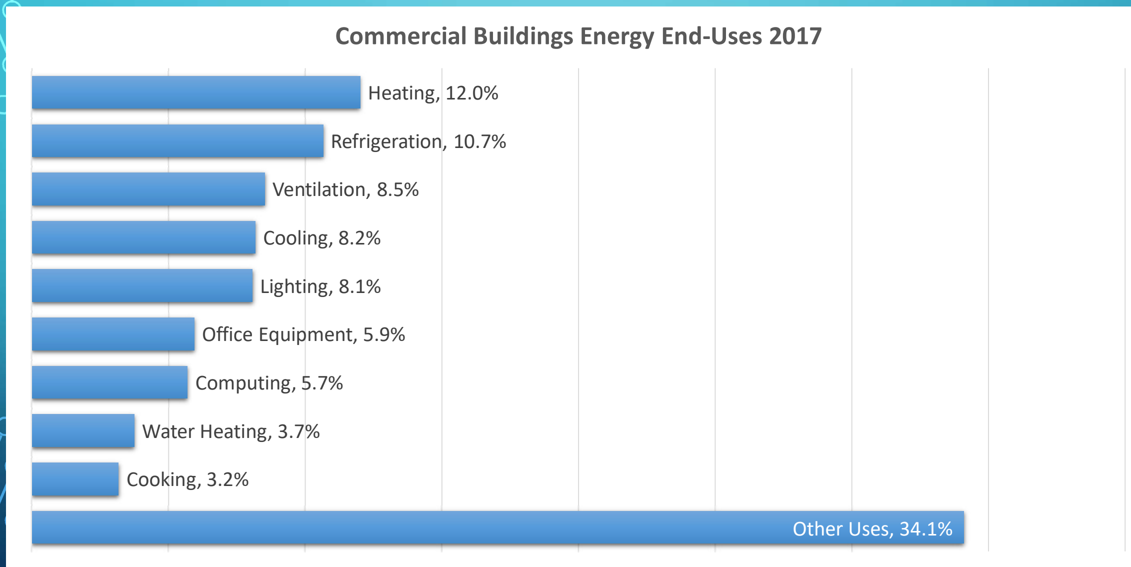
The building industry is undergoing profound change with amazing new technologies and systems available to make our buildings better—more sustainable, resilient and energy-efficient. Over the last 50 years, building simulation has evolved into a powerful tool for evaluating the energy performance of potential or existing buildings. Building simulation allows easy comparison of the energy and environmental performance of many hundreds of building envelope and other building systems. The buildings touted today as 'net-zero-energy' or 'sustainable' would not be possible without energy simulation—but no single simulation tool can model all aspects of our buildings today.

This presentation provides an overview of trends and drivers affecting building enclosure and the building industry as well as an overview of building performance simulation fundamentals and history, Building Information Modeling (BIM), what's in the black box of key simulation programs, comparing underlying simulation methods, and how these can be used to design better building envelopes.

BUILDINGS ENERGY USE WORLDWIDE



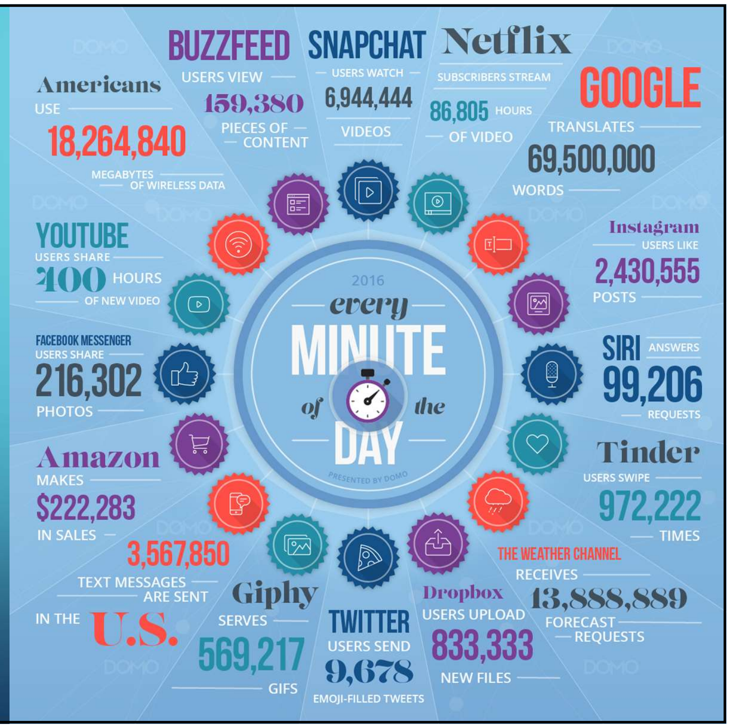
U.S. BUILDINGS ENERGY USE



US Energy Information Administration. 2018. *Annual Energy Outlook 2018* EIA-0383 (2018) (2017 data)

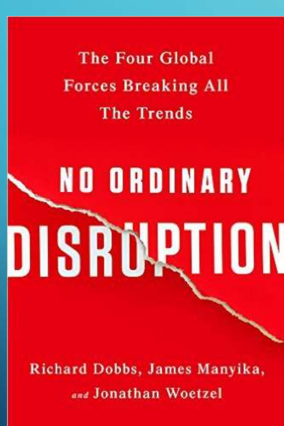
TRENDS: BUILDINGS, TECHNOLOGY, AND TOOLS

EVERY MINUTE



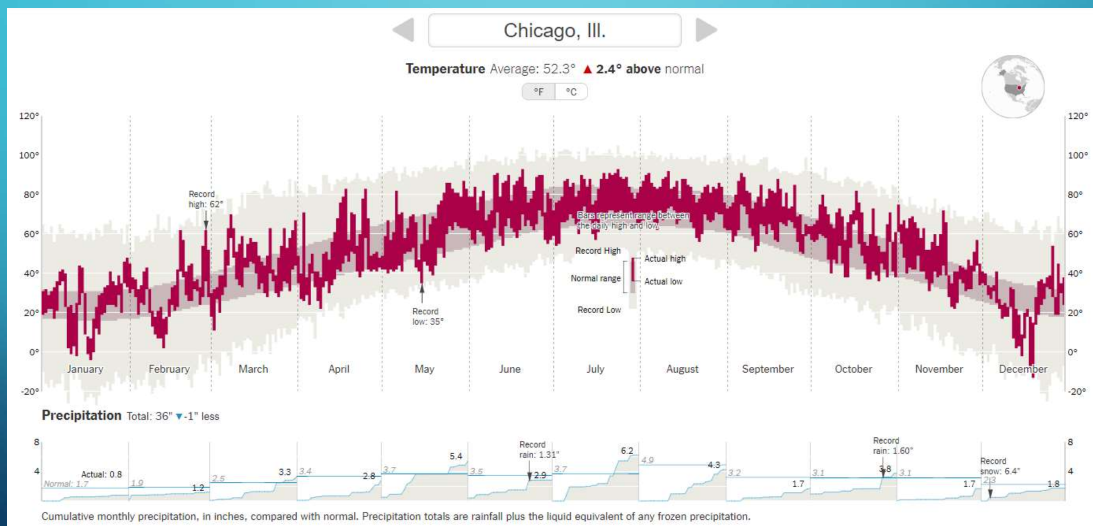
https://www.domo.com/learn/data-never-sleeps-4-0 2016

DISRUPTION



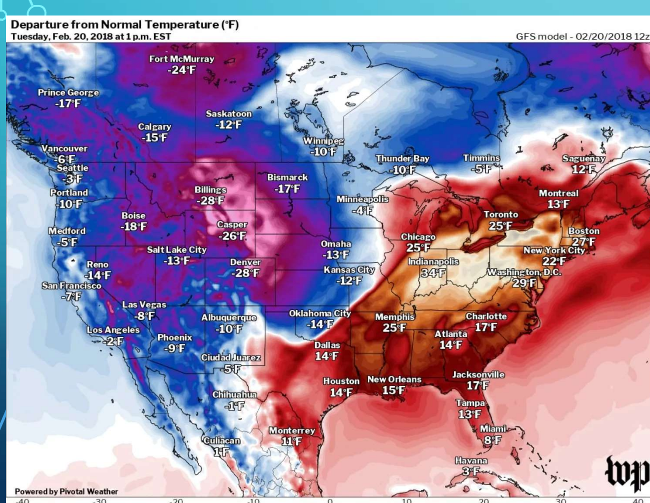
- Urbanization (Beyond Shanghai)
- Accelerating Technological Change (Tip of the Iceberg)
- Challenges of an Aging World (getting old isn't what it used to be)
- Greater Global Connections (trade, people, finance and data)

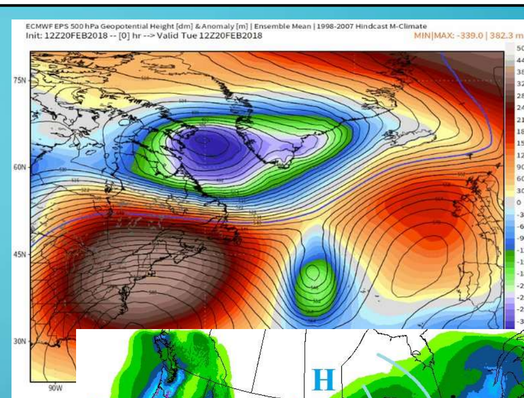
HOW MUCH WARMER WAS 2016?

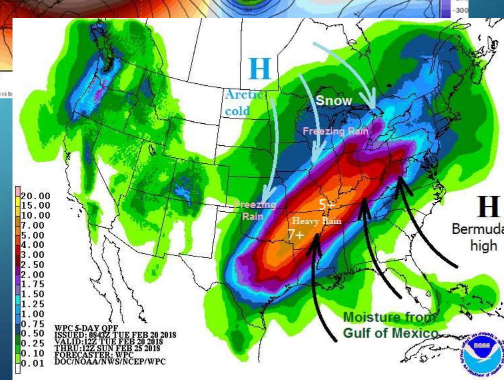


https://www.nytimes.com/interactive/2017/01/18/world/how-much-warmer-was-your-city-in-2016.html

CLIMATE DISRUPTION







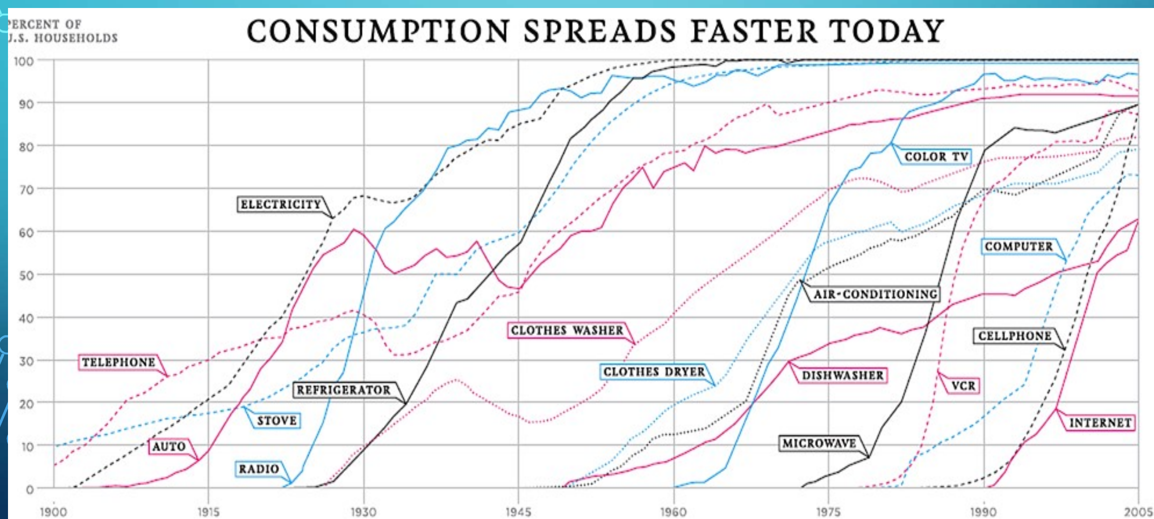
BUILDING INDUSTRY TRENDS

- Centralization of Ownership (large chains, owners)
- Energy price deregulation
- Climate change mitigation ~~/ carbon regulation~~
- Green/sustainable/living buildings
- BIM /digital modeling
- Benchmarking/data!
- NZEB/NZEC
- IoT/Smart everything
- Resilience

POLICY DRIVERS: BUILDINGS *ARE* GETTING BETTER

- Economic and environmental drivers
- Mandatory performance metrics: national and local codes and standards… but are they enforced?
- Voluntary performance metrics (LEED, BEAM, BREEAM, BEPAC, others)
- National and international policy
  - Climate Change but what are nations doing?
    - Kyoto Protocol/Paris Accord
    - EU began mandatory building performance labeling in 2009 (EPD) …
  - US energy policy continues to be voluntary approach, with mandatory minimum standards

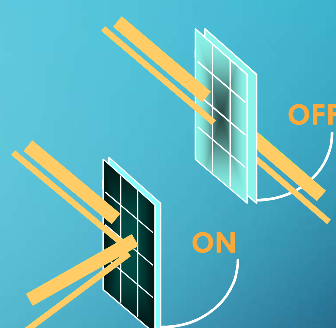
TECHNOLOGY PENETRATION IS ACCELERATING

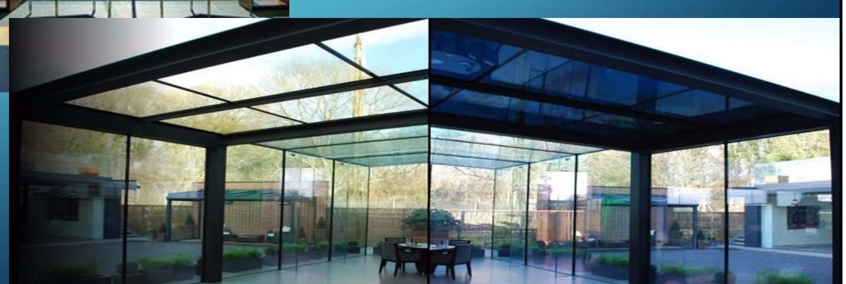


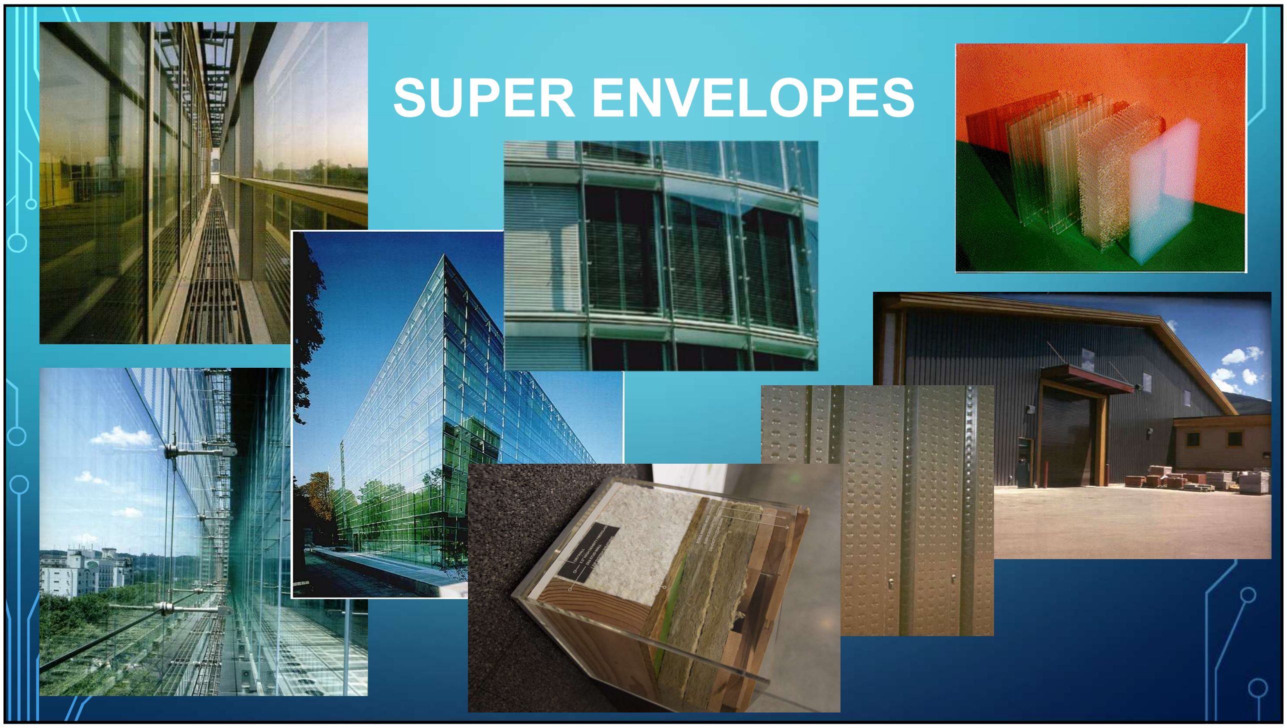
TECHNOLOGY CHANGE IN 20 YEARS

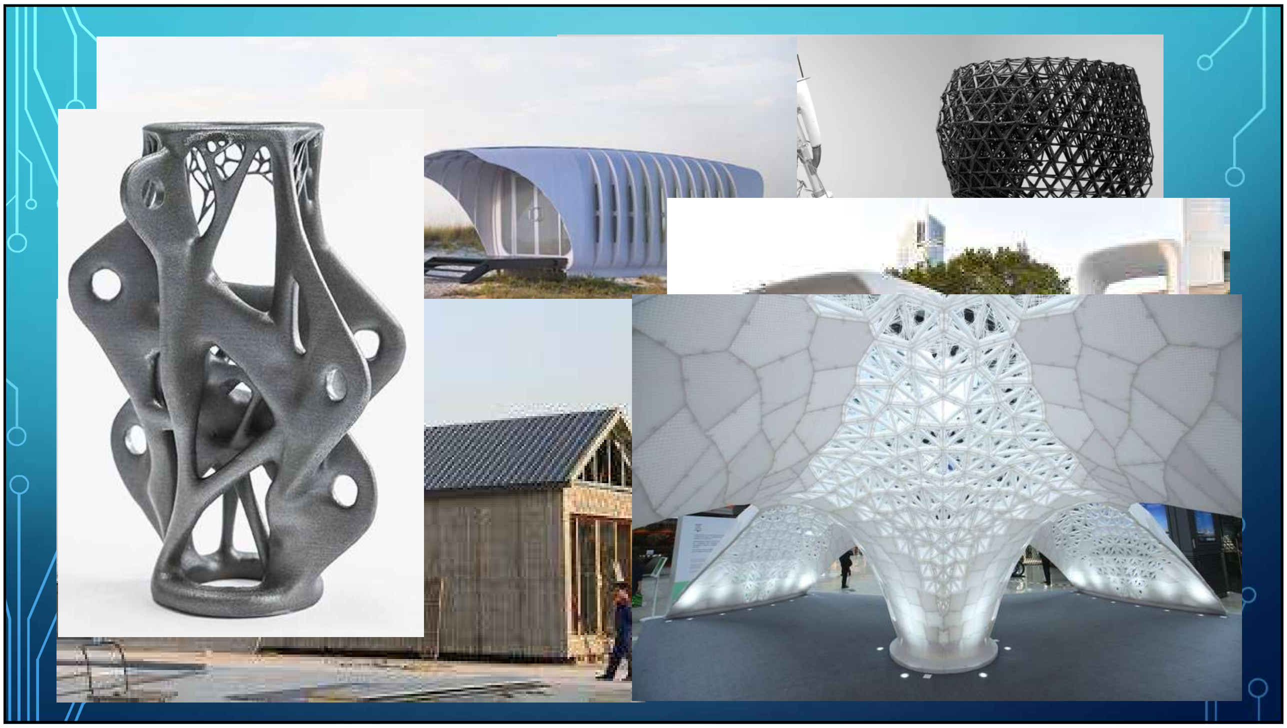
NEW BUILDING TECHNOLOGIES

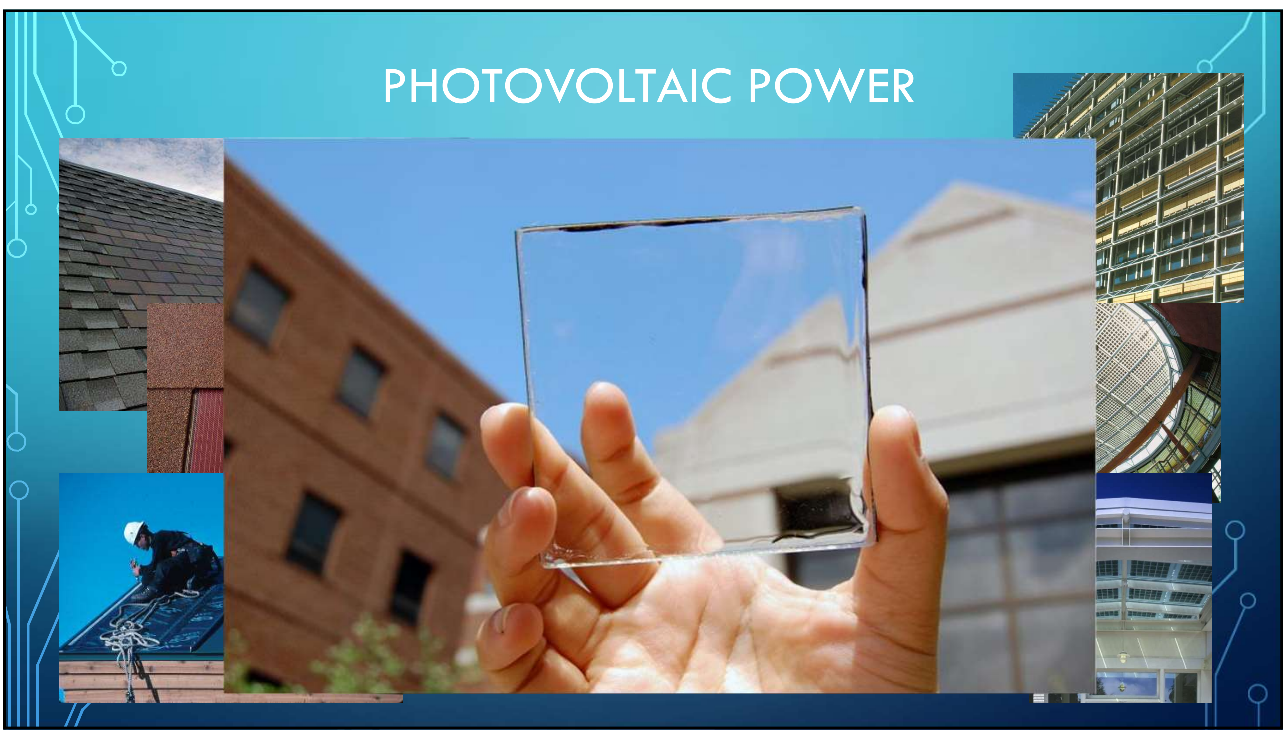
ELECTRO-
PHOTO-CHROMIC WINDOWS
THERMO-



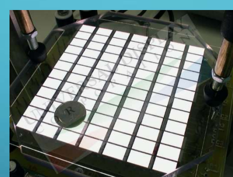


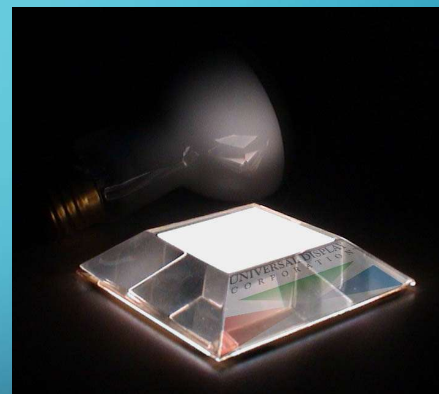

SUPER ENVELOPES




PHOTOVOLTAIC POWER

NEW TECHNOLOGY – SSL AND OLED





Lighting is undergoing a revolution: LEDs use much lower energy with expected life of years (decades?). New forms (no longer restricted to Edison shape lamps, 4 ft fluorescents)

NEXT TO HIT THE MARKET – OLEDS!

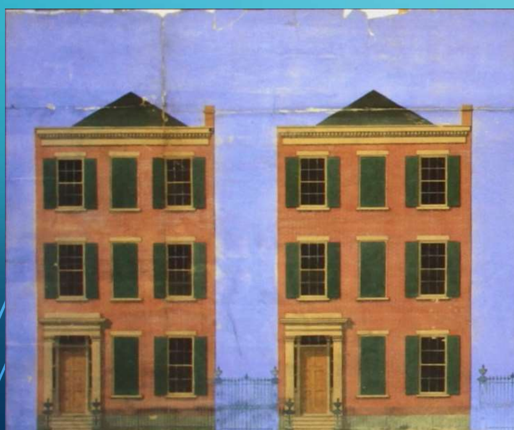
Prototype OLED Wallpaper


FUEL CELLS, MICROTURBINES, DC, BATTERIES
TESLA


MIMICKING NATURE
http://www.technologyreview.com/Energy/20379/page2/

"Every building is a forecast. Every forecast is wrong."

Stewart Brand
How Buildings Learn, What Happens after they're Built



BUILDING PERFORMANCE SIMULATION TRENDS

- New tools/capabilities in established tools
  - Interoperability—IAI IFC, XML, BIM Standards
  - Visualization/VR
  - Cloud
  - Integration—thermal, CFD, electrical, IEQ, visual
  - Risk assessment (insurance)
  - Embodied energy, LCI/LCA, toxicity of built environment
  - Emissions
- More tools, not fewer, customized to user needs
- Users continue to want more at lower effort

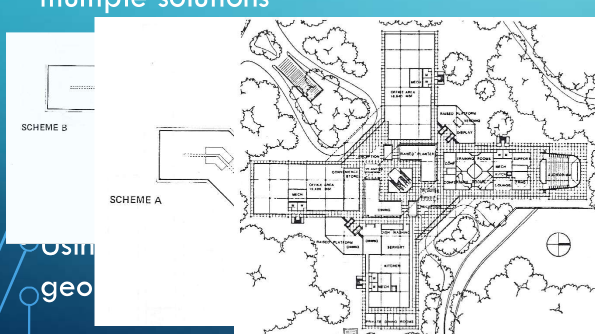
WARNING! Do you know what default values you're using?

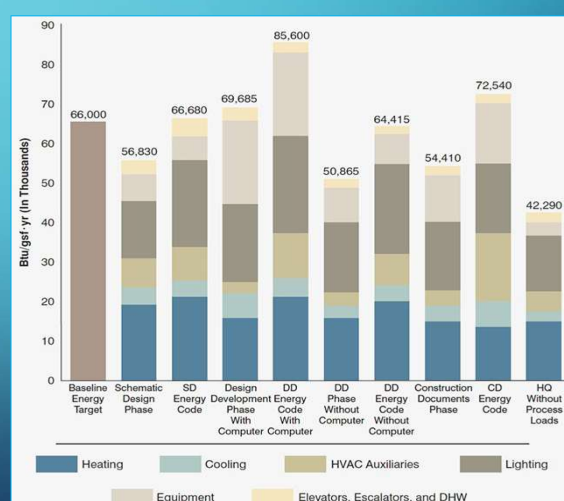
SIMULATION VS. OPERATING ENERGY

- Simulation critical in supporting decision-making for building design and operation of low- and zero-energy buildings
- BUT, compared to simulations, real buildings
  - use more energy
  - produce less power
  - have worse controls
  - have more occupant complaints
  - GIGO
  - Not enough information!

TRADITIONAL SIMULATION WORKFLOW CHALLENGES

- Early design through construction documents – with increasing detail, multiple solutions
- Usi
  geo





Nall and Crawley 2011

BUILDING INFORMATION MODEL/MODELING

- Building Information Model:
  - Digital representation of physical and functional characteristics of a facility. . . shared knowledge resource for information about a facility, forming a reliable basis for decisions during its life cycle from inception onward.[1]

- Building Information Modeling:
  - Using BIM software and other related software, hardware and technologies in a building information model.[2]

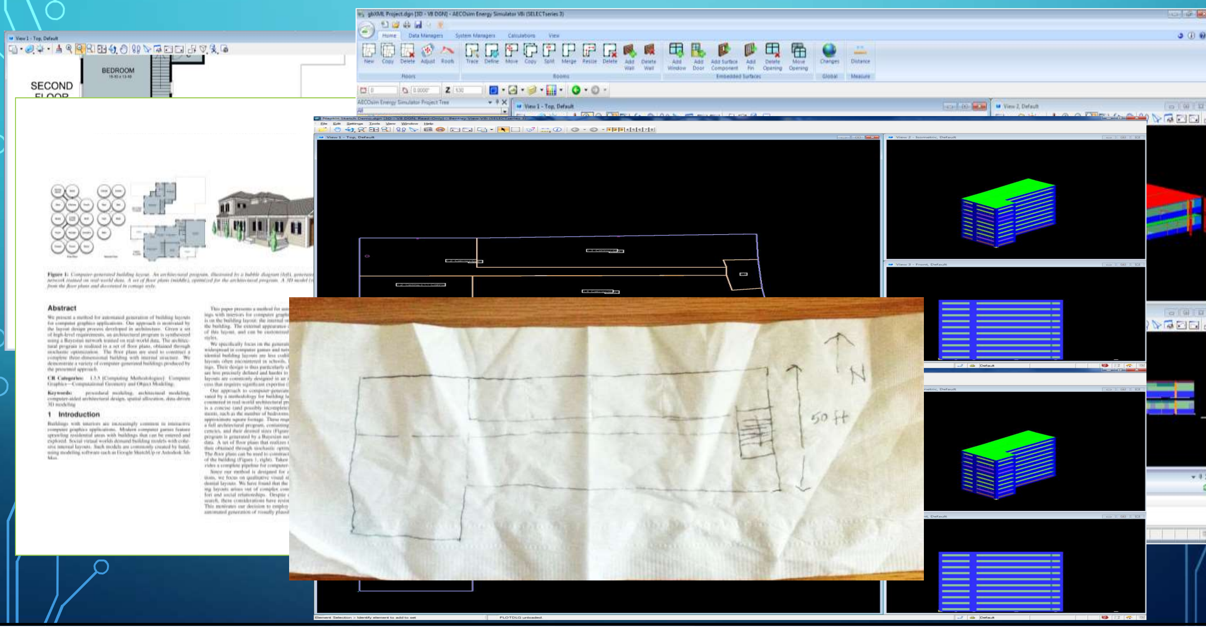
- 1 NIBS 2015
- 2 Jernigan 2007

→ ***Information Mobility***

BIM TO SIM(ULATION)

- Translate BIM to Simulation
  - BuildingSMART IFCs (Industry Foundation Classes)
    - Any BIM software that supports interoperability, available since 2001
    - **Limited** to what BIM tools decide to export—typically only geometry
  - gbXML
  - Autodesk Green Building Studio
    - Web-based conversion of major BIM formats to energy simulation inputs
    - Limited coverage
    - Can require users to create their BIM drawings in structured way (may not follow designer regular workflow)
- Direct from BIM to Simulation
  - Major tools have in-built simulation or directly export to one or more simulation tools
- Interoperability is key to getting energy simulation mainstream. Other drivers—zero-energy buildings and green building rating systems

2-D, 3-D, PDF BIM TO SIM



BIM TODAY IS NOT YOUR FATHER'S CAD

THE CHALLENGE OF EXISTING BUILDINGS

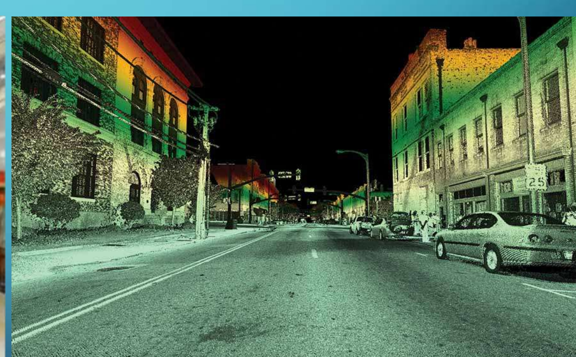
- Existing building often means no 3-D model, maybe no drawings
- Drawings often are design or construction – not as-built
- Result?
  - Takeoffs from drawings
  - Field verification/measurements
  - Manual translation/interpretation of data
  - Lots of time better spent evaluating alternatives

NEW MODELING TECHNOLOGIES AVAILABLE

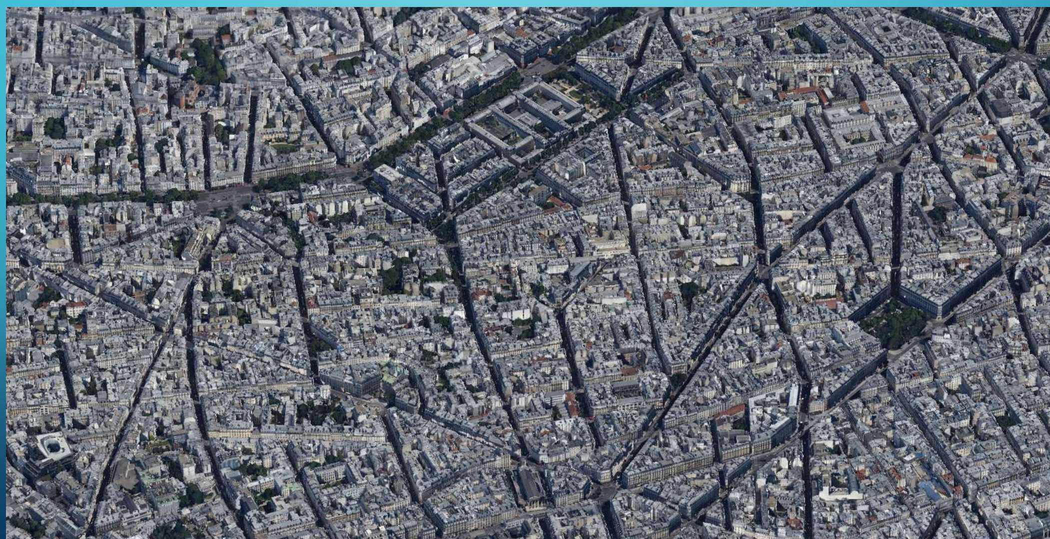
- LiDAR (Light and raDAR)
  - Remotely measures distance by illuminating a target with a laser and analyzing the reflected light
  - High resolution accuracy but limited density
  - Can be expensive to implement
- Photogrammetry
  - Uses automated triangulation of a series of photographs to mathematically create 3-D meshes or point clouds
  - Depends on quality of photos and fit of triangulation
  - Can be used for creating a 3-D mesh with draped images
  - Works well with aerial drones

LIDAR

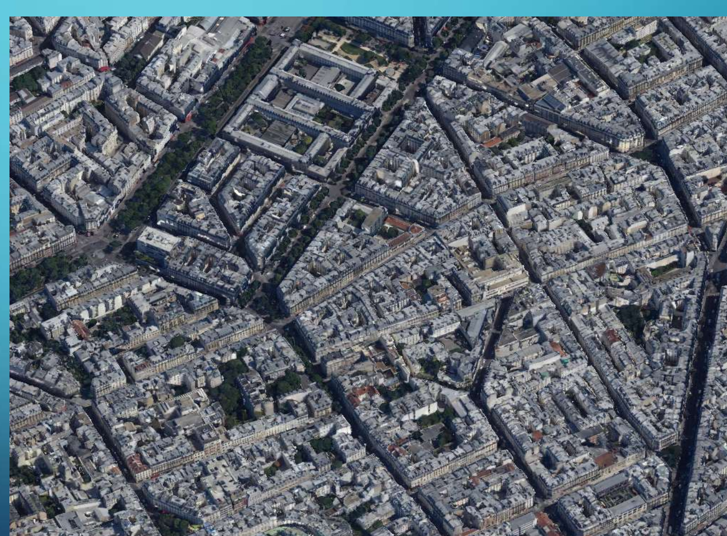
LIDAR



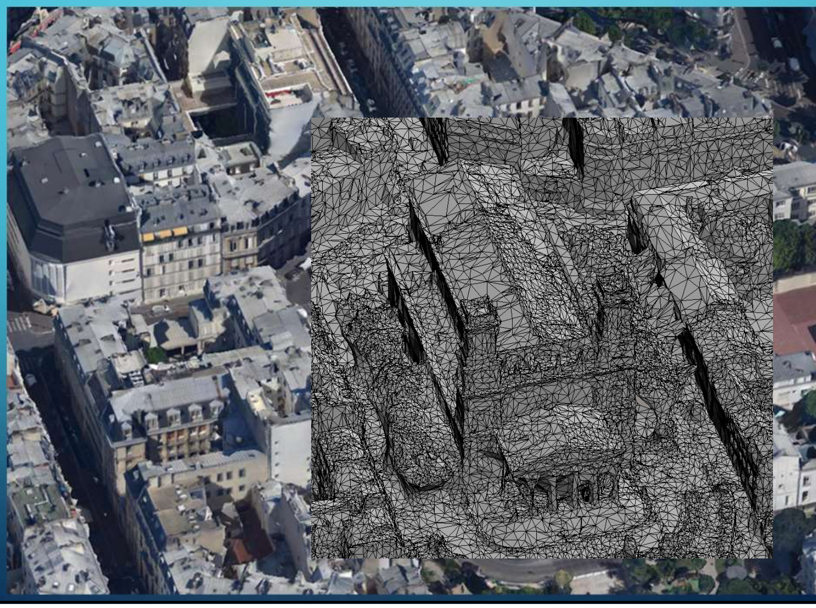
PHOTOGRAMMETRY



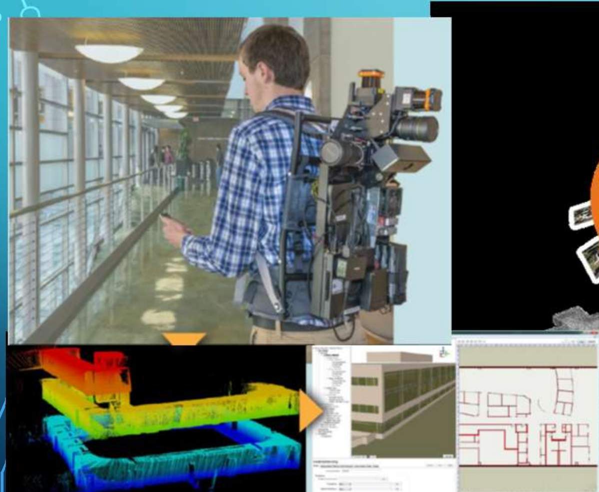
PHOTOGRAMMETRY



PHOTOGRAMMETRY



CREATING MODELS FROM PHOTOS OR CAPTURED DATA



Images courtesy of Indoor Reality

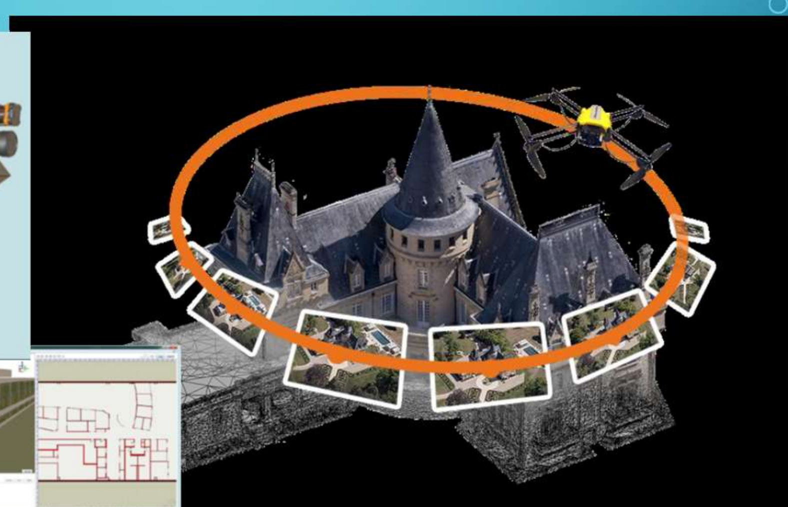
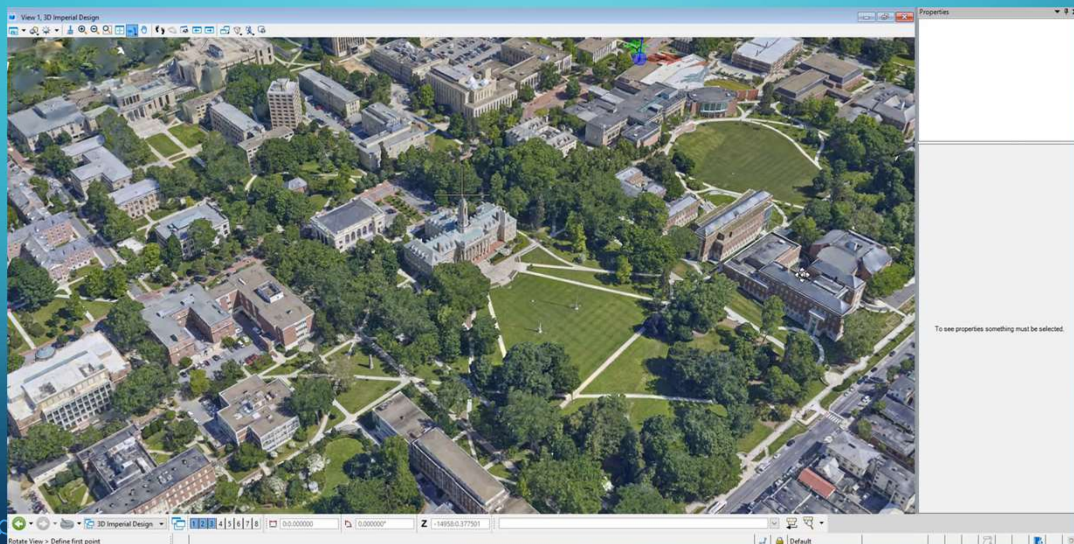
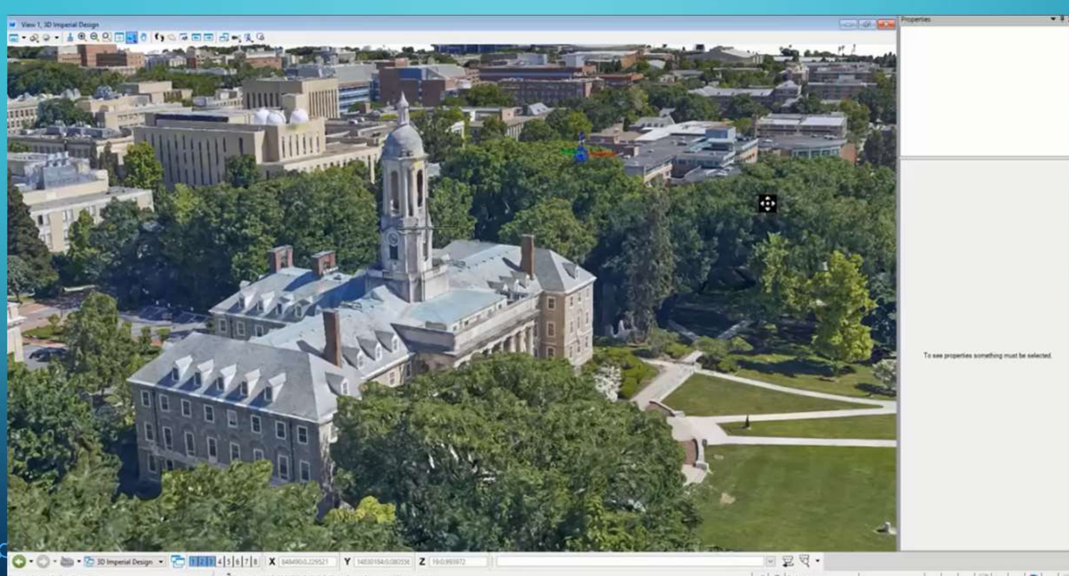


Image courtesy of Acute3D

MODELING THE CAMPUS

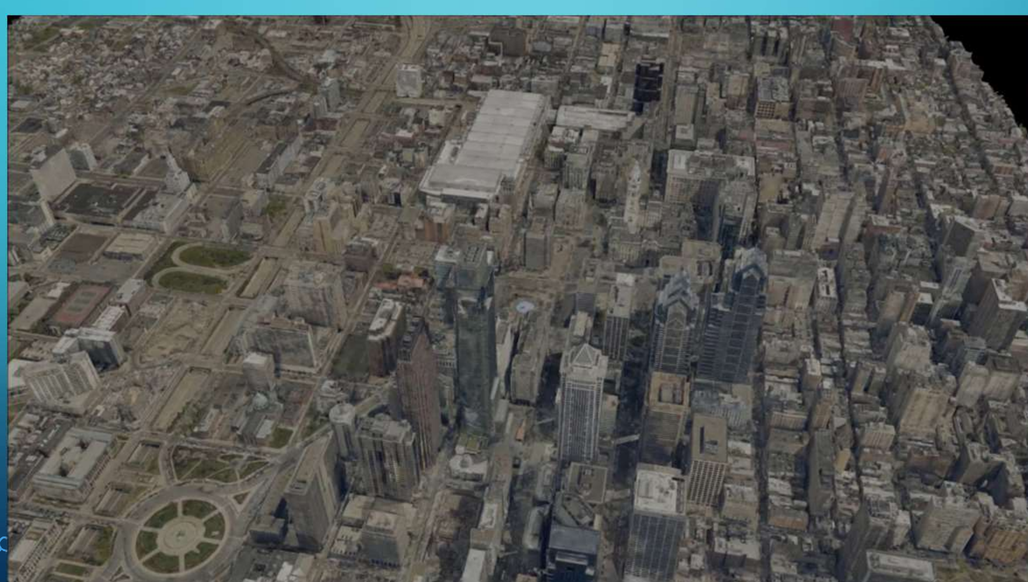


VISUALIZE SPACE UTILIZATION

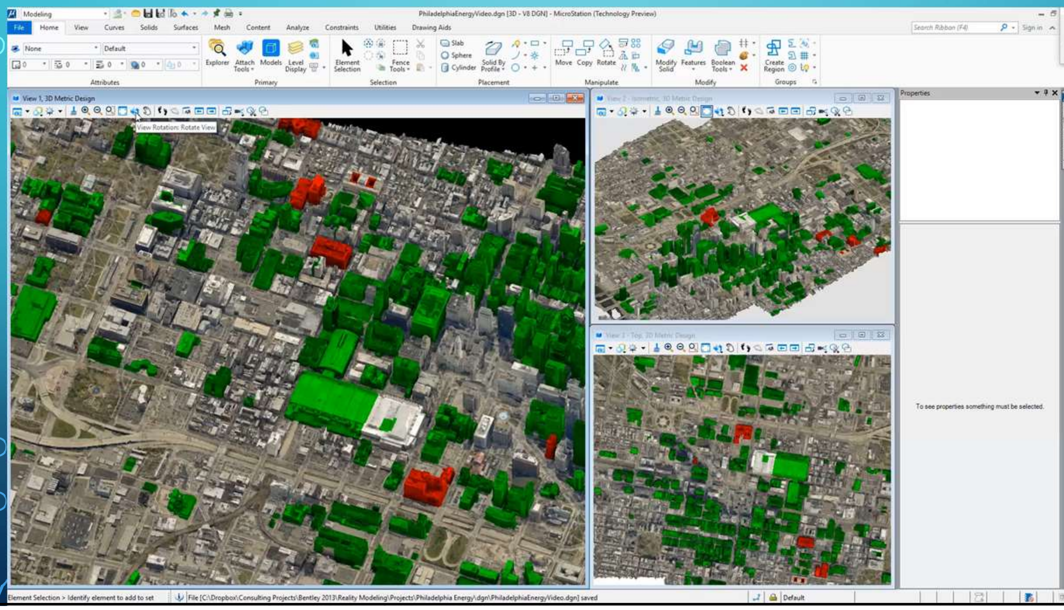


MERGING VIRTUAL REALITY MODEL WITH DATA

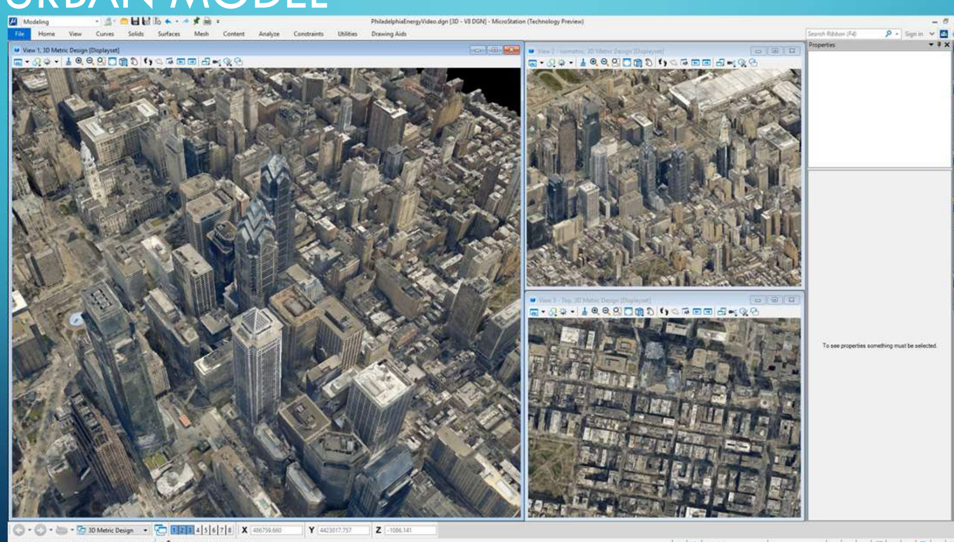
ENERGY AND WATER



EXPLORING INDIVIDUAL BUILDINGS



EXPLORING BUILDING DATA WITHIN THE URBAN MODEL



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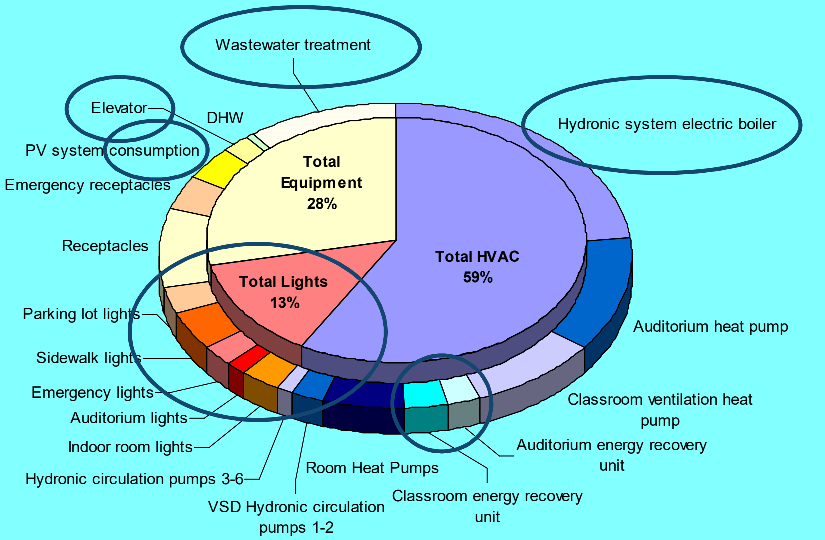
Building Performance Simulation

END-USE ENERGY: MORE DETAILS ARE BETTER!



WHAT IS BUILDING PERFORMANCE SIMULATION?

Software which emulates the ***dynamic interaction*** of heat, light, mass (air and moisture) and sound ***within the building*** to predict its ***energy and environmental performance*** as it is exposed to climate, occupants, conditioning systems, and noise sources

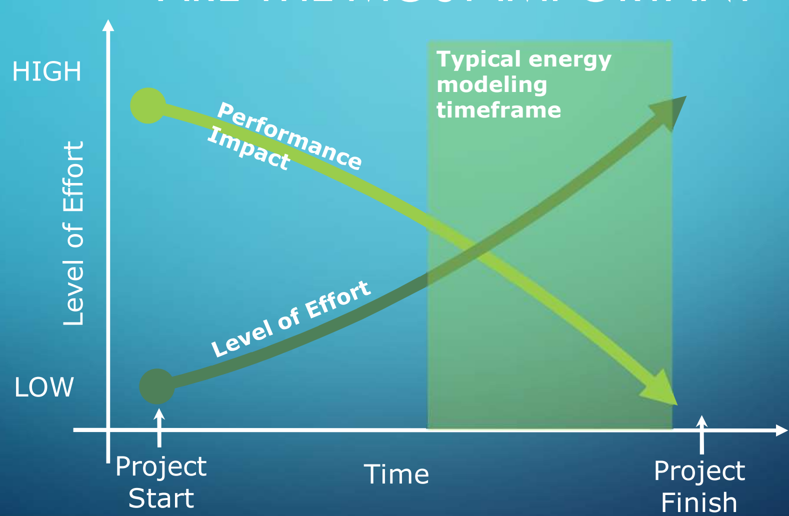
TYPES OF PROGRAMS AVAILABLE

- Simpler programs for overall energy consumption assessment, peak temperature prediction, heating/cooling loads calculations
- More complex programs for (sub)hourly simulation of heat, moisture, light and air movement
- Specialist packages, for lighting, computational fluid dynamics (CFD), acoustics, two- and three-dimensional conduction calculations
- Integrated design and analysis systems combining several

Building Practitioners

Experts

EARLY DECISIONS ARE THE MOST IMPORTANT



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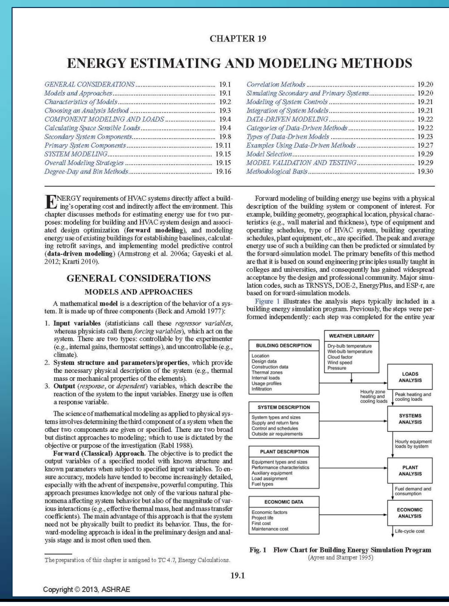
Chapter 19

Energy Estimating and Modeling Methods



CHAPTER 19

ENERGY ESTIMATING AND MODELING METHODS

ENERGY requirements of HVAC systems directly affect a building's operating cost and indirectly affect the environment. This chapter discusses methods for estimating energy use for two purposes: modeling for building and HVAC system design and associated design optimization (**forward modeling**), and modeling energy use of existing buildings for establishing baselines, calculating retrofit savings, and implementing model predictive control (**data-driven modeling**) (Armstrong et al. 2006a; Gayeski et al. 2012; Krarti 2010).

GENERAL CONSIDERATIONS

MODELS AND APPROACHES

A mathematical **model** is a description of the behavior of a system. It is made up of three components (Beck and Arnold 1977):

1. **Input variables** (statisticians call these *regressor variables*, whereas physicists call them *forcing variables*), which act on the system. There are two types: controllable by the experimenter (e.g., internal gains, thermostat settings), and uncontrollable (e.g., climate).
2. **System structure and parameters/properties**, which provide the necessary physical description of the system (e.g., thermal mass or mechanical properties of the elements).
3. **Output** (*response*, or *dependent*) variables, which describe the reaction of the system to the input variables. Energy use is often a response variable.

The science of mathematical modeling as applied to physical systems involves determining the third component of a system when the other two components are given or specified. There are two broad but distinct approaches to modeling; which to use is dictated by the objective or purpose of the investigation (Rabl 1988).

Forward (Classical) Approach. The objective is to predict the output variables of a specified model with known structure and known parameters when subject to specified input variables. To ensure accuracy, models have tended to become increasingly detailed, especially with the advent of inexpensive, powerful computing. This approach presumes knowledge not only of the various natural phenomena affecting system behavior but also of the magnitude of various interactions (e.g., effective thermal mass, heat and mass transfer coefficients). The main advantage of this approach is that the system need not be physically built to predict its behavior. Thus, the forward-modeling approach is ideal in the preliminary design and analysis stage and is most often used then.

Forward modeling of building energy use begins with a physical description of the building system or component of interest. For example, building geometry, geographical location, physical characteristics (e.g., wall material and thickness), type of equipment and operating schedules, type of HVAC system, building operating schedules, plant equipment, etc., are specified. The peak and average energy use of such a building can then be predicted or simulated by the forward-simulation model. The primary benefits of this method are that it is based on sound engineering principles usually taught in colleges and universities, and consequently has gained widespread acceptance by the design and professional community. Major simulation codes, such as TRNSYS, DOE-2, EnergyPlus, and ESP-r, are based on forward-simulation models.

Figure 1 illustrates the analysis steps typically included in a building energy simulation program. Previously, the steps were performed independently: each step was completed for the entire year

BUILDING DESCRIPTION: Location, Design data, Construction data, Thermal zones, Internal loads, Usage profiles, Infiltration
WEATHER LIBRARY: Dry-bulb temperature, Wet-bulb temperature, Cloud factor, Wind speed, Pressure
LOADS ANALYSIS
Hourly zone heating and cooling loads
Peak heating and cooling loads
SYSTEM DESCRIPTION: System types and sizes, Supply and return fans, Control and schedules, Outside air requirements
SYSTEMS ANALYSIS
Hourly equipment loads by system
PLANT DESCRIPTION: Equipment types and sizes, Performance characteristics, Auxiliary equipment, Load assignment, Fuel types
PLANT ANALYSIS
Fuel demand and consumption
ECONOMIC DATA: Economic factors, Project life, First cost, Maintenance cost
ECONOMIC ANALYSIS
Life-cycle cost

Fig. 1 Flow Chart for Building Energy Simulation Program
(Ayres and Stamper 1995)

The preparation of this chapter is assigned to TC 4.7, Energy Calculations.

19.1

EARLY DAYS OF SIMULATION IN US – NBSLD 1970S

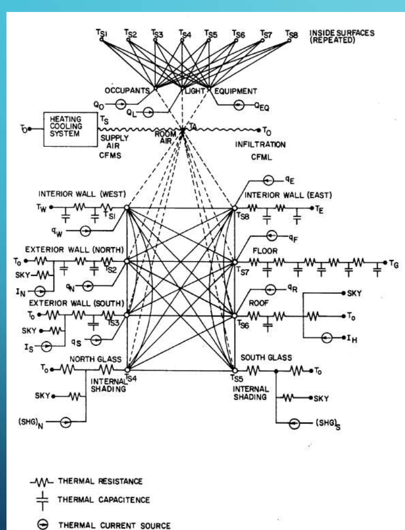


Fig. 1. Analogous electric circuit for heat exchange process in a room.

Walton 2001

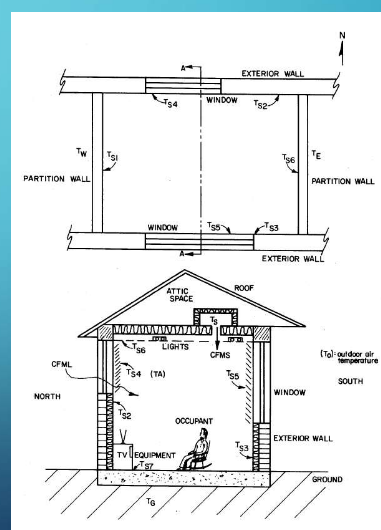
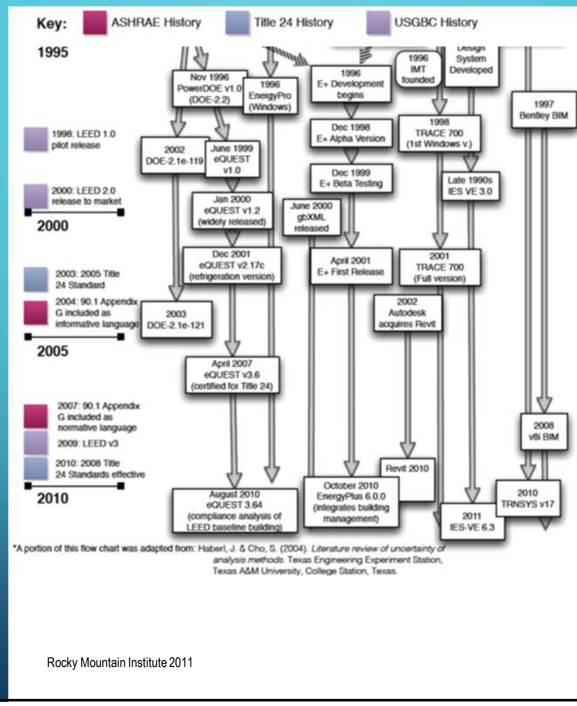


Fig. 2. Physical model of a typical room represented by the circuit in Fig. 1.



SO MANY TOOLS…
WHERE DO I LEARN MORE?

SIMULATION RESOURCES

- Methods and Techniques:
  - *ASHRAE Handbook 2017 Fundamentals*
    Chapter 19 Energy Estimating and Modeling Methods
  - *Building Performance Simulation for Design and Operation*
  - *Contrasting the Capabilities of Building Energy Performance Simulation Programs*
- Available Tools:
  - Building Energy Software Tools Directory
    www.buildingenergysoftwaretools.com

Hensen and Lamberts 2011

GENERAL MODELING FEATURES

Table 1 General Modeling Features	BLAST	BSim	DeST	DOE-2.1E	ECOTECT	Ener-Win	Energy Express	Energy-10	EnergyPlus	eQUEST	ESP-r	HAP	HEED	IDA ICE	IES <VE>	PowerDomus	SUNREL	Tas	TRACE	TRNSYS
Simulation solution																				
▪ Sequential loads, system, plant calculation without feedback	X			X															X	
▪ Simultaneous loads, system and plant solution	X^{2}	X	X		3	X	X	X^{4}	X	X^{5}	X	X^{6}	X	X	X	X	X^{7}	X		X
▪ Iterative non-linear systems solution		X			3			X	X		X	X	X	X	X	X		X	X	X
▪ Coupled loads, systems, plant calculations		X					X	X^{4}	X	X	X		X	X	X	X	X			X
▪ Space temperature based on loads-systems feedback	X	X	X		X^{8}	X	X	X	X		X	X	X	X	X	X	X	X	X	X
▪ Floating room temperatures[9]	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Time step approach															X					
▪ User-selected for zone/environment interaction	X^{2}	X^{10}	R					X^{11}	X^{12}		X^{13}			X	X	X^{14}	X			X^{15}
▪ Variable time intervals for zone air/HVAC system interaction	X^{2}	X^{10}					X		X	X^{16}	X					R				
▪ User-selected for both building and systems											X			X	X	X				X^{17}
▪ Dynamically varying based on solution transients									X		X			X^{18}						
Full Geometric Description																				
▪ Walls, roofs, floors	X	X	X	X	X	X	X		X	X	X		X	X	X	X	X	X	X	X^{19}
▪ Windows, skylights, doors, and external shading	X	X	X	X	X	P	X		X	X	X		X	X^{20}	X	X	X	X	X	X

[2] Only in IBLAST, an unreleased, integrated simulation version of BLAST. BLAST simultaneously calculates all zones in the "building" heat balance.
[3] ECOTECT exports its models to the native file formats of EnergyPlus, ESP-r, HTB-2, and Radiance, invoking calculations and then importing results for display and analysis.
[4] CNE simulation engine used by Energy-10 uses iterative convergence to achieve energy balance (thermal network coupled with building systems) at each time step.
[5] HVAC air-side and water-side combined calculation
[6] Loads and HVAC airside systems integrated with feedback. Plant is sequential with system/loads.
[7] Idealized HVAC equipment only in release version. Research version with more realistic HVAC models.
[8] Based on CIBSE Admittance Method for early design decision-making and analysis
[9] No environmental controls
[10] Up to 256 timesteps per hour
[11] For Energy-10 the CNE engine runs in 15-minute time steps with results reported on an hourly basis.
[12] 15-minute default, 10 minute to 1 hour time steps. Use can modify so that 1 minute time steps can be done but not recommended due to stability issues.
[13] 1 minute to 1 hour time steps for zones and flow networks and a multiple of that for detailed systems.
[14] 1-hour default, 1-second to 24-hour time steps. 1-minute time interval schedules.
[15] Building and system use the same time step. 1-hour default, user can select down to 0.1 second
[16] 5 minute time step for electric heat/cool/fan equipment for demand vs. energy cost calculation
[17] Type 56 (building) uses an internal time step for airflow and envelope coupling. Other components (e.g. storage tanks) have internal time steps
[18] User-specified tolerance controls time step and integration order
[19] Taking into account geometry for view factors, detailed shading, direct radiation distribution requires additional input data.
[20] Skylights with multiple beam reflections

Version 1.0 22 July 2005

ZONE LOADS AND ENVELOPE

Table 1 ***Zone Loads*** *(11 of the 18 rows in the report)*	BLAST	Bsim	DOE-2.1E	Ecotect	Energy-10	EnergyPlus	Ener-Win	eQUEST	ESP-r	IDA IES	IES <VE>	HAP	HEED	PowerDomus	SUNREL	Tas	TRACE	TRNSYS
Interior surface convection																		
• Dependent on temperature	X	X				X			X				X	X	X	X		X
• Dependent on air flow	X					P			X		X		X			X		E
• Dependent on surface heat coefficient from CFD									E		X							
• User-defined coefficients		X				X			E		X		X	X	X	X		X
Internal Thermal Mass	X	X	X	X		X		X	X		X		X	X	X	X	X	X
Automatic design day calculations for sizing																		
• Dry bulb temperature	X	X	X	X	X	X		X				X	X	P		X	X	
• Dew point temperature or relative humidity						X		X				X				X	X	
• User-specified minimum and maximum						X		X				X	X			X		
• User-specified steady-state, periodic or dynamic design conditions																X		X

Table 2 ***Building Envelope and Daylighting*** *(10 of the 54 rows in the report)*	BLAST	BSim	DOE-2.1E	Ecotect	Energy-10	EnergyPlus	Ener-Win	eQUEST	ESP-r	IDA ICE	IES <VE>	HAP	HEED	PowerDomus	SUNREL	Tas	TRACE	TRNSYS
▪ Outside surface convection algorithm																		
▪ BLAST/TARP	X					X											X	
▪ DOE-2			X			X		X									X	
▪ MoWiTT						X			X								X	
▪ ASHRAE simple	X				X	X							X			X	X	
▪ User-selectable						X			X		X			X		X	X	X
▪ Inside radiation view factors		X				X			X							X		
▪ Radiation component separate from convection		X				X		X	X		X					X	P	X
▪ Detailed solar and daylighting inter-reflection from building components and other buildings		P		X		X			X		X							X
▪ Shading of sky IR by obstructions			X			X		X			X					X		X

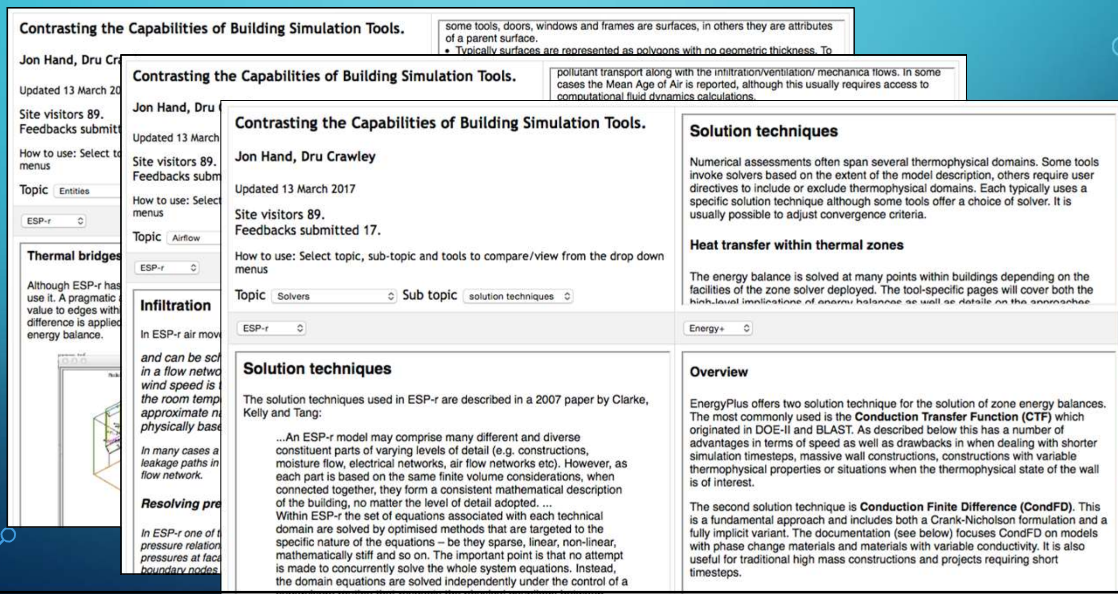
AIRFLOW, HVAC AND ECONOMICS

Table 4 ***Infiltration, Ventilation, Room Air and Multizone Airflow***	BLAST	BSim	DOE-2.1E	Ecotect	Energy-10	EnergyPlus	Ener-Win	eQUEST	ESP-r	IDA ICE	IES <VE>	HAP	HEED	PowerDomus	SUNREL	Tas	TRACE	TRNSYS
Single zone infiltration	X	X	X	X	X	X		X			X	X	X	X	X	X	X	X
Automatic calculation of wind pressure coefficients		X				X					X				X	X		
Natural ventilation (pressure, buoyancy driven)		X				X		X	X		X			X	X	X		O
Multizone airflow (via pressure network model)		X				X			X		X				X	X		O
Hybrid natural and mechanical ventilation		X							I		X					X		O
Control window opening from simulation variables						X					X							O
Displacement ventilation						X			X		X					X		O
Mix of flow networks and CFD domains									E									
Contaminants, microtoxins (mold growth)		P							R					P				

Tables 7 & 8 ***HVAC Systems and components*** *(summary)*	BLAST	BSim	DOE-2.1E	Ecotect	Energy-10	EnergyPlus	Ener-Win	eQUEST	ESP-r	IDA ICE	IES <VE>	HAP	HEED	PowerDomus	SUNREL	Tas	TRACE
Idealized HVAC systems	X			X		X			X								
User-configurable HVAC systems		X				X			X		X	X	X	X	R	X	
Pre-configured systems (among 32 identified, X+O)	14	14	15	0	7	30	ND	24	13	ND	24	26	10	9	11	23	21
Discrete HVAC components (among 98 identified, X+O)	59	24	43	0	11	72	ND	59	26	ND	33	41	7	21	13	26	57

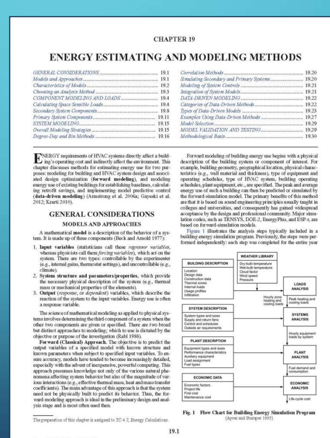
Table 11 ***Economic Evaluation*** *(energy costs portion)*	BLAST	BSim	DOE-2.1E	Ecotect	Energy-10	EnergyPlus	Ener-Win	eQUEST	ESP-r	IDA IES	IES <VE>	HAP	HEED	PowerDomus	SUNREL	Tas	TRACE	TRNSYS
Energy Costs																		
• Simple energy and demand charges		X	X	X	X	X		X	X		X	X	X	X		X	X	X
• Complex tariffs including fixed, block, and demand charges, ratchets		X	X			X		X			X	X	X				X	E
• Scheduled variation in all rate components		X	X			X		X			X	X	X			X	X	X
• User selectable billing dates			X			X		X					X				X	E

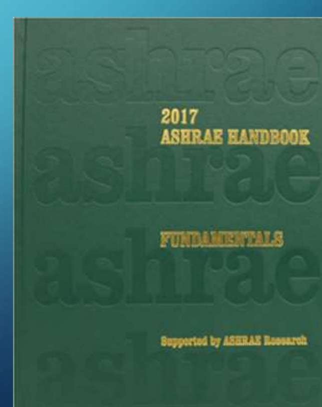
CONTRASTING WHITE PAPER → WEB SITE



WHAT SHOULD I LOOK FOR IN PERFORMANCE SIMULATION TOOLS?

- Accuracy
- Sensitivity
- Versatility
- Speed and cost
- Reproducibility
- Ease of Use
- Validation





Integrating Energy Modeling in the Design Process

Section 1 – Energy is a Design Problem

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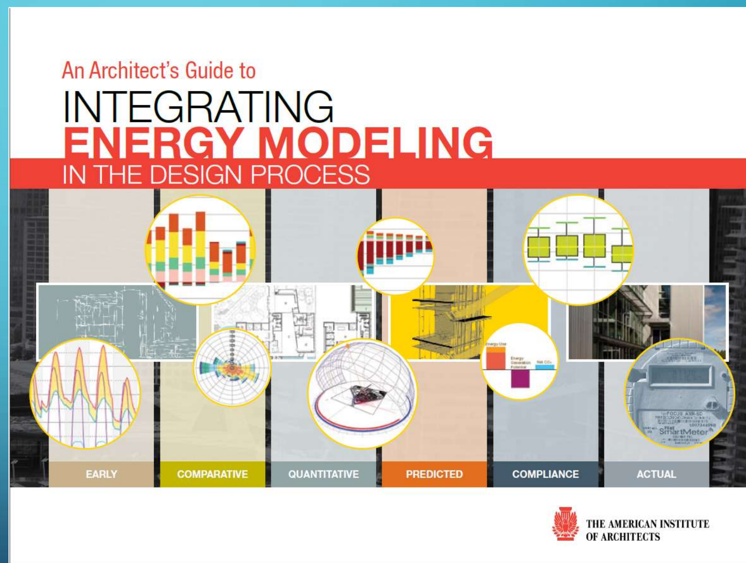
Section 5 – Current Tools

Section 6 – Our Future Begins Today



http://www.aia.org/practicing/AIAB097932

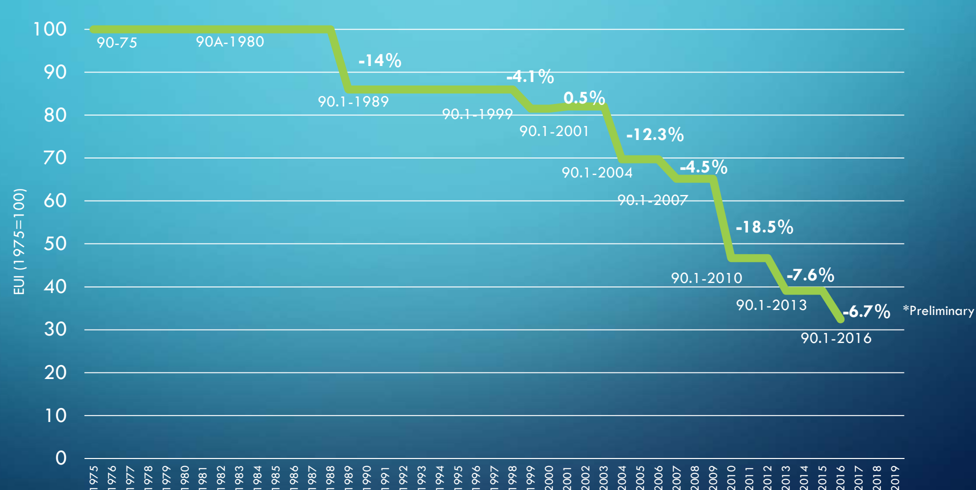
HOW DO I DECIDE WHICH BUILDING PERFORMANCE TOOL(S) TO USE?

- What are you trying to assess?
  - Simple change in performance may warrant a simpler tool – such as bin method or degree-day
  - Interactions among building systems often warrants dynamic simulation tools

- Make sure the tool can predict the physics you're interested in, such as radiant systems, moisture, daylight illuminance, ground heat transfer, or a specific HVAC system configuration

HOW TO CREATE A ZERO-ENERGY BUILDING TODAY?

INCREASED STRINGENCY IN ENERGY EFFICIENCY AND GREEN STANDARDS

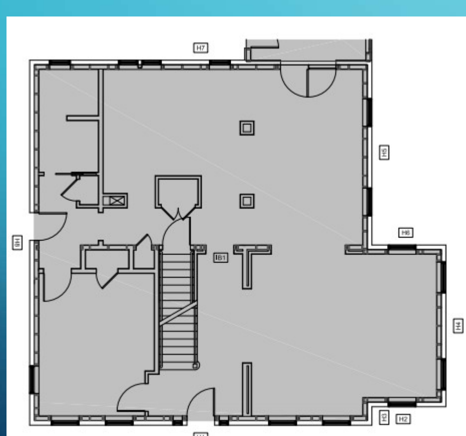


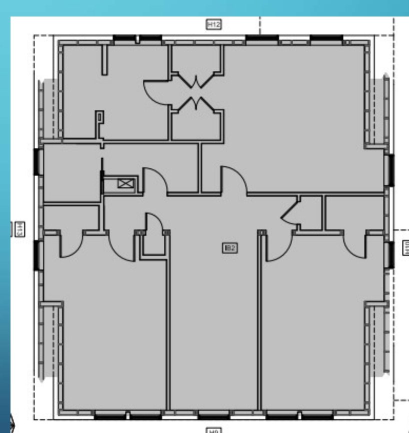
Source: PNNL 2011, 2014, 2017

NIST NET-ZERO ENERGY RESIDENTIAL TEST FACILITY

GAITHERSBURG, MARYLAND, USA

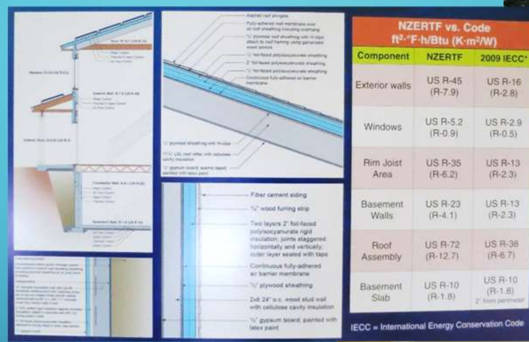
FLOOR PLANS





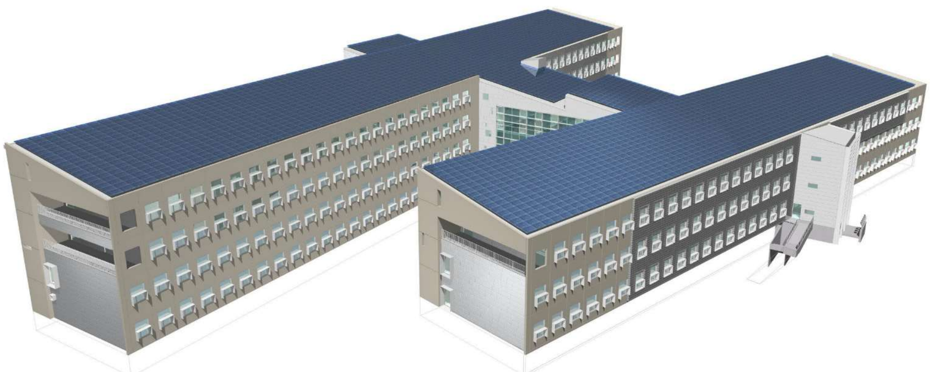
TECHNOLOGIES BEING TESTED

- Photovoltaic power
- Thermal solar
- Heat pump water heater
- Super insulated walls, roof, floors, windows, foundation
- Heat recovery ventilator
- Building envelope air tightness
- IAQ/VOCs
- Dedicated outside air
- Decoupled dehumidification
- High efficiency appliances (washer, dryer, cooktop, dishwasher)
- Geothermal heat exchanges (vertical borehole, horizontal u-tube, horizontal slinky configurations installed)
- Long-term net-zero energy impacts



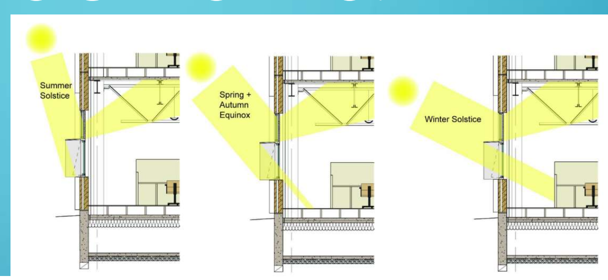
LARGE ZERO ENERGY BUILDING!

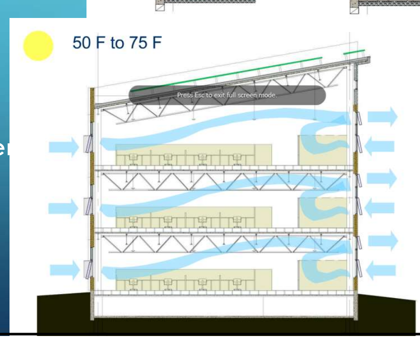
Massing



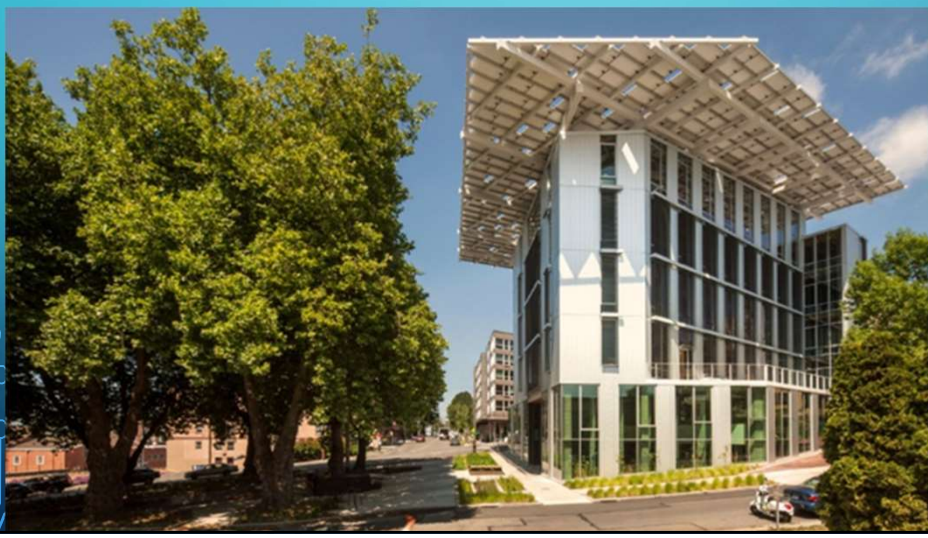
TECHNOLOGIES TO GET TO ZERO?

- Modularity
- Massing (long axis E-W)
- Double skin
- Daylighting – Shading
- Natural Ventilation
- Thermal labyrinth
- Data center heat recove
- Data center cooling
- PV





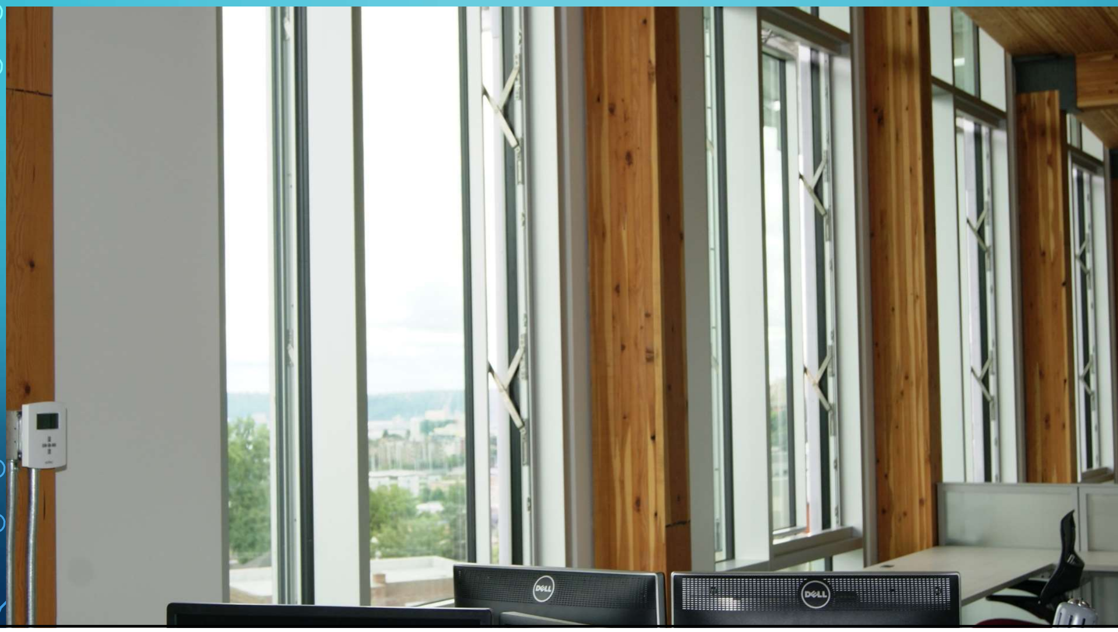
BULLIT CENTER
SEATTLE, WASHINGTON



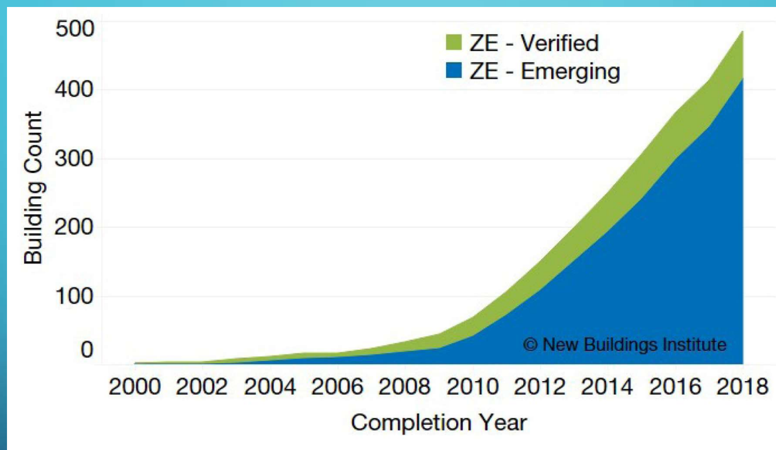
WHAT FEATURES DID THEY INCORPORATE?

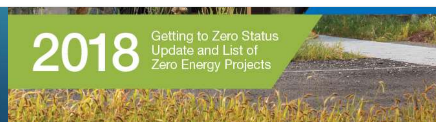
- EUI of 16 kBtu/ft^2-y (180 MJ/m^2-y)
- Triple-glazed, low-e, operable windows (natural ventilation)
- Daylighting for all occupants
- Rainwater harvesting, vortex, ceramic filters (reverse osmosis) and UV treatment for potable water
- Composting toilets
- Durability – structure designed for 250-year life
- Local and safe materials
- Ground-source heating pump
- Solar canopy (242 kW) covers roof and provides overhangs
- No net energy or water cost to tenants

Passive Heating/Cooling/Natural Ventilation



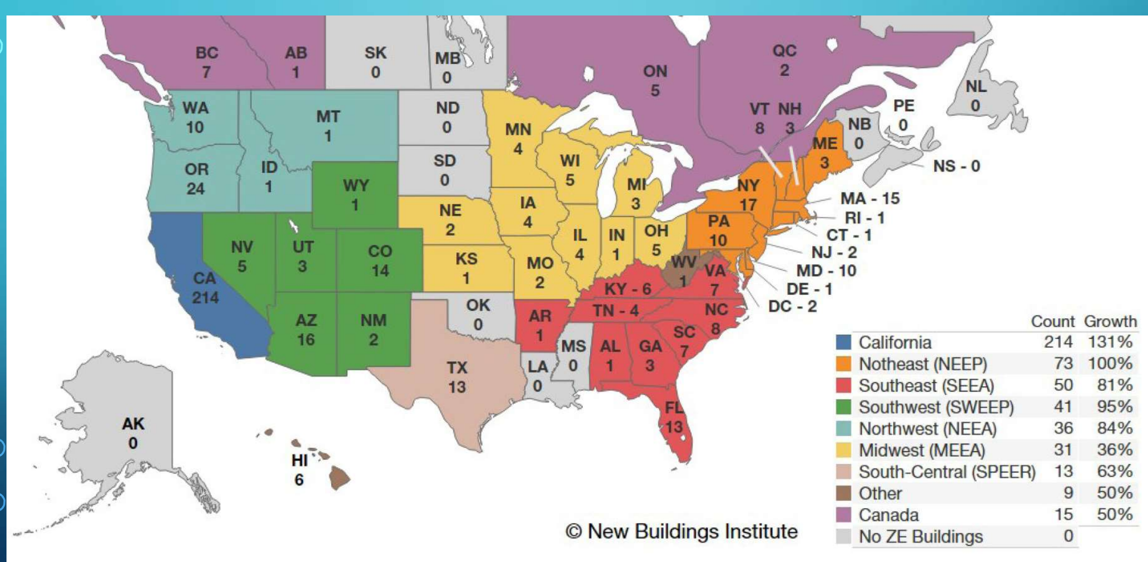
MANY NEW ZEBS AND ZECS!





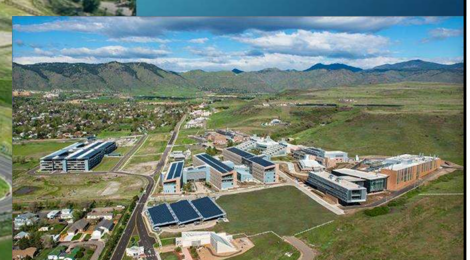
New Buildings Institute. 2018. Getting to Zero Status Update and List of Zero Energy Projects, Vancouver, WA.
newbuildings.org/wp-content/uploads/2018/01/GTZ_StatusUpdate_ZE_BuildingList_2018.pdf

GROWTH IN ZERO ENERGY



SO, IS THIS THE BUILDING OF TOMORROW?

BUILDING OF THE FUTURE? PROBABLY MORE LIKE NREL RSF



OR THESE RECENT NZE BUILDINGS

OR EVEN APPLE'S NEW HQ

SUMMARY

- Changes in building technologies over the next decades , especially building enclosure materials and construction methods, will continue to be significant
- New software capabilities and data acquisition methods are making it easier to create building models and simulate performance
- Getting data from BIM to Sim through interoperability still a significant challenge – often incomplete, insufficient for simulation → blackbox defaults!
- LiDAR and photogrammetry offer means to capture existing buildings in a mesh that can easily be imported by BIM and energy analysis tools
- Quality of simulation results only as good as the data entered: GIGO – the more data about the building and how it operates the better quality the results.
- Building performance simulation is a powerful tool for evaluating and comparing building systems and technologies throughout the building life-cycle

NO SINGLE METRIC TELLS THE BUILDING PERFORMANCE STORY

Energy

Demand

Cost

Water

IEQ

Carbon

Business

(sales, student, occupied room, beer barrels)

QUESTIONS? THANK YOU!

Dru Crawley

Dru.Crawley@Bentley.com

in DruCrawley

@DruCrawley

Drury_Crawley

GBCI Approved | 2 CE Hour | 0920010363 and 0920010371
AIA Approved | 2 LU/HSW | CRAWLEY02 and CRAWLEY07

15th Annual Building Enclosure Event

CSI Chicago Chapter

Thank you for attending.

Continuing Education:

2.0 AIA/CES LU/HSW (Courses: CRAWLEY02 and CRAWLEY07)
2.0 CE GBCI (Courses No: 0920010363 and 0920010371)

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HILTI

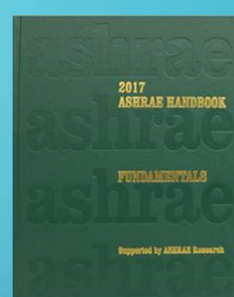
ROCKWOOL

BIM AND SIMULATION RESOURCES

- ASHRAE Fundamentals 2017, Chapter 19 www.ashrae.org
- Hensen, Jan L.M. and Roberto Lamberts. 2011. *Building Performance Simulation for Design and Operation*. London: Spon Press.
- IBPSA-USA Building Energy Software Tools Directory (formerly DOE) http://www.buildingenergysoftwaretools.com/
- Contrasting the Capabilities of 20 Building Simulation Programs (2005): http://climate.onebuilding.org/papers/2005_07_Crawley_Hand_Kummert_Griffith_contrasting_the_capabilities_of_building_energy_performance_simulation_programs_v1.0.pdf
- GSA BIM Guide for Energy Performance (2012) http://www.gsa.gov/graphics/pbs/GSA_BIM_Guide_Series.pdf
- National BIM Standard (2012) http://www.nationalbimstandard.org/
- Daniel H. Nall, Drury B. Crawley. 2011. "Energy Simulation in the Building Design Process," *ASHRAE Journal*, republished from November 1983. pp. 36-43, Vol. 53, No. 7 (July).

RESOURCES

- ASHRAE Handbook 2017 Fundamentals
  Chapter 19 Energy Estimating and Modeling Methods www.ashrae.org
  www.techstreet.com/ashrae/standards/2017-ashrae-handbook-fundamentals-i-p-includes-cd-in-i-p-and-si-editions?product_id=1975069
- Hensen, Jan L.M. and Roberto Lamberts, editors. 2011. Building Performance Simulation for Design and Operation. London: Spon Press.
- Crawley, D.B., J. W. Hand, M. Kummert, B.T. Griffith. 2005.Contrasting the Capabilities of Building Energy Performance Simulation Programs. climate.onebuilding.org/papers/2005_07_Crawley_Hand_Kummert_Griffith_contrasting_the_capabilities_of_building_energy_performance_simulation_programs_v1.0.pdf
- Building Energy Software Tools Directory
- www.buildingenergysoftwaretools.com



Hensen and Lamberts 2011

AMERICAN INSTITUTE OF ARCHITECTS

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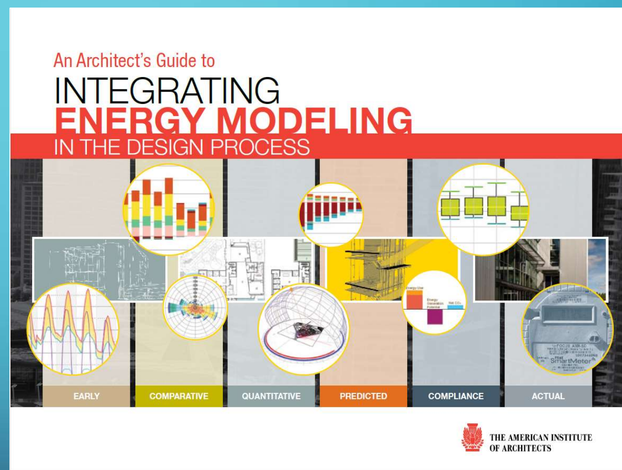
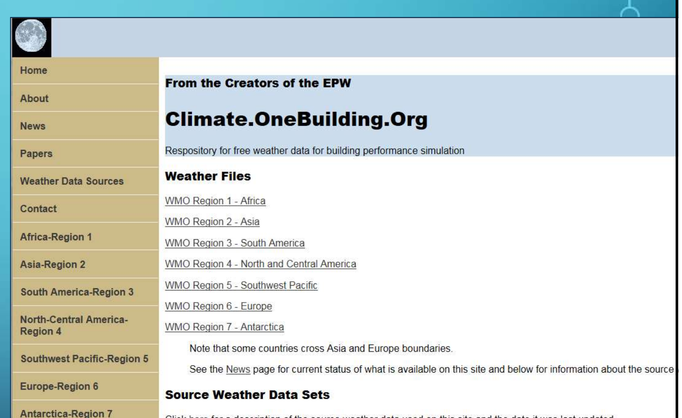


THE AMERICAN INSTITUTE OF ARCHITECTS

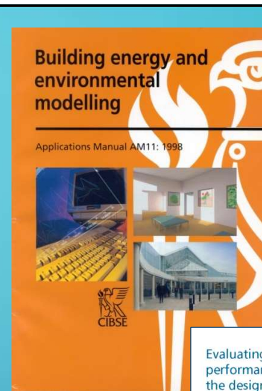
www.aia.org/practicing/AIAB097932

NEED CLIMATE DATA?

- climate.onebulding.org
- Annual and monthly design conditions
- Verified, up-to-date location names:
- USA_VA_Arlington-Reagan.Washington.National.AP or USA_VA_Dulles-Washington.Dulles.Intl.AP instead of Washington, DC
- Hourly precipitation in a separate file for direct use in simulations (where source data includes precipitation)
- Extensive quality checking to identify and correct data errors and out of normal range values where appropriate.
- EnergyPlus (EPW), DAYSIM/Radiance (WEA), ESP-r (CLM) format files included along with summary statistics and design conditions



- Building Energy and Environmental Modeling
  www.cibse.org/Knowledge/CIBSE-AM/AM11-Building-Energy-and-Environmental-Modelling



- Evaluating Operational Energy Performance of Buildings at the Design Stage
  www.cibse.org/Knowledge/CIBSE-TM/TM54-Evaluating-Operational-Energy-Performance-of

IBPSA-USA BEMBOOK WIKI

- bembook.ibpsa.us
- Building Energy Modeling (BEM) Wiki
- Knowledge areas:
  - Practitioner's BEM Overview
  - BEM in the Project Context
  - Developing Whole Building Models
  - ASHRAE 90.1 PRM
- Workshops

STANDARD 189.1 RESOURCES

- Information on ASHRAE standards: www.ashrae.org
  then follow "Standards",
  includes listserv for Standard 189.1

- Information on USGBC programs: www.usgbc.org

- Information on IES programs: www.iesna.org

50% AEDGS AVAILABLE

- Small to Medium Offices
- K-12 Schools
- Medium to Big Box Retail
- Large Hospitals
- Grocery Stores

- All the AEDGs available as free PDF download from:
  www.ashrae.org/aedg

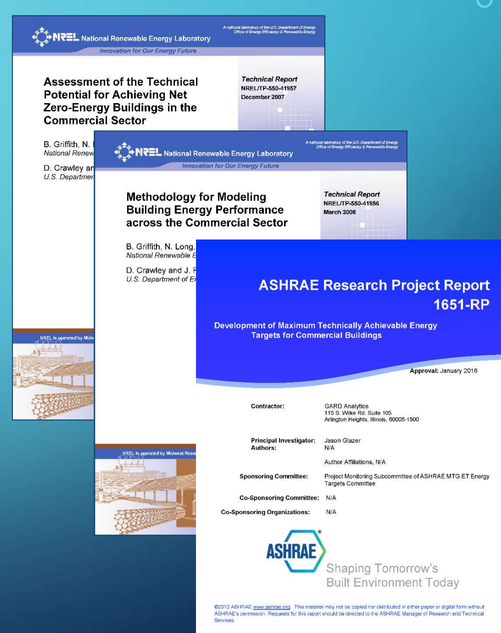
- Technical support documents describing the process and results are available here
  http://energy.gov/eere/buildings/advanced-energy-design-guides

50% AEDG TECHNICAL SUPPORT DOCUMENTS

Medium Box Retail
www.nrel.gov/docs/fy08osti/42828.pdf
Grocery Stores
www.nrel.gov/docs/fy08osti/42829.pdf
Highway Lodging
www.pnl.gov/main/publications/external/technical_reports/PNNL-18773.pdf
Medium Office Buildings
www.pnl.gov/main/publications/external/technical_reports/PNNL-18774.pdf
General Merchandise
www.nrel.gov/docs/fy09osti/46100.pdf
Small Office Buildings
www.pnl.gov/main/publications/external/technical_reports/PNNL-19341.Pdf
Large Hospital
www.nrel.gov/docs/fy10osti/47867.pdf
Large Office
www.nrel.gov/docs/fy10osti/49213.pdf
Quick-Service Restaurant
www.pnl.gov/main/publications/external/technical_reports/PNNL-19809.pdf

ZEB Technical Potential

- Assessment of the Technical Potential for Achieving Net Zero-Energy Buildings in the Commercial Sector
  www.nrel.gov/docs/fy08osti/41957.pdf
- Methodology for Analyzing the Technical Potential for Energy Performance Across the Commercial Sector
  www.nrel.gov/docs/fy08osti/41956.pdf
- ASHRAE Research Project 1651-RP (completed in 2016) updated this analysis for ASHRAE energy standards development; savings of >45% over 90.1-2010. Report free for members:
  rp.ashrae.biz/researchproject.php?rp_id=674



NIST NET-ZERO ENERGY RESIDENTIAL TEST FACILITY

- https://www.nist.gov/el/net-zero-energy-residential-test-facility
- Documentation, plans, technical specifications
- Data, research reports, annual energy use and production

IEA ANNEX CASE STUDIES OF ZERO ENERGY BUILDINGS WORLDWIDE

- Case studies:
- http://www.iea-ebc.org/fileadmin/user_upload/docs/Annex/EBC_Annexx_52_Solution_Sets_for_NZE_Buildings.pdf
- Other publications:
- http://www.iea-ebc.org/projects/completed-projects/ebc-annex-52/

MORE ON NZEB NREL RESEARCH SUPPORT FACILITY

- NREL RSF web site:
  http://www.nrel.gov/sustainable_nrel/rsf.html
- "The Design-Build Process for the Research Support Facility"
  http://www.nrel.gov/docs/fy12osti/51387.pdf
- Energy Performance Update
  http://www.nrel.gov/sustainable_nrel/pdfs/rsf_operations.pdf
- Reducing Data Center Loads for a Large-Scale, Net Zero Office Building
  http://www.nrel.gov/sustainable_nrel/pdfs/52785.pdf

OTHER RESOURCES/REFERENCES

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