
Energy Modeling and Simulation

Applications in Building Sustainability Rating

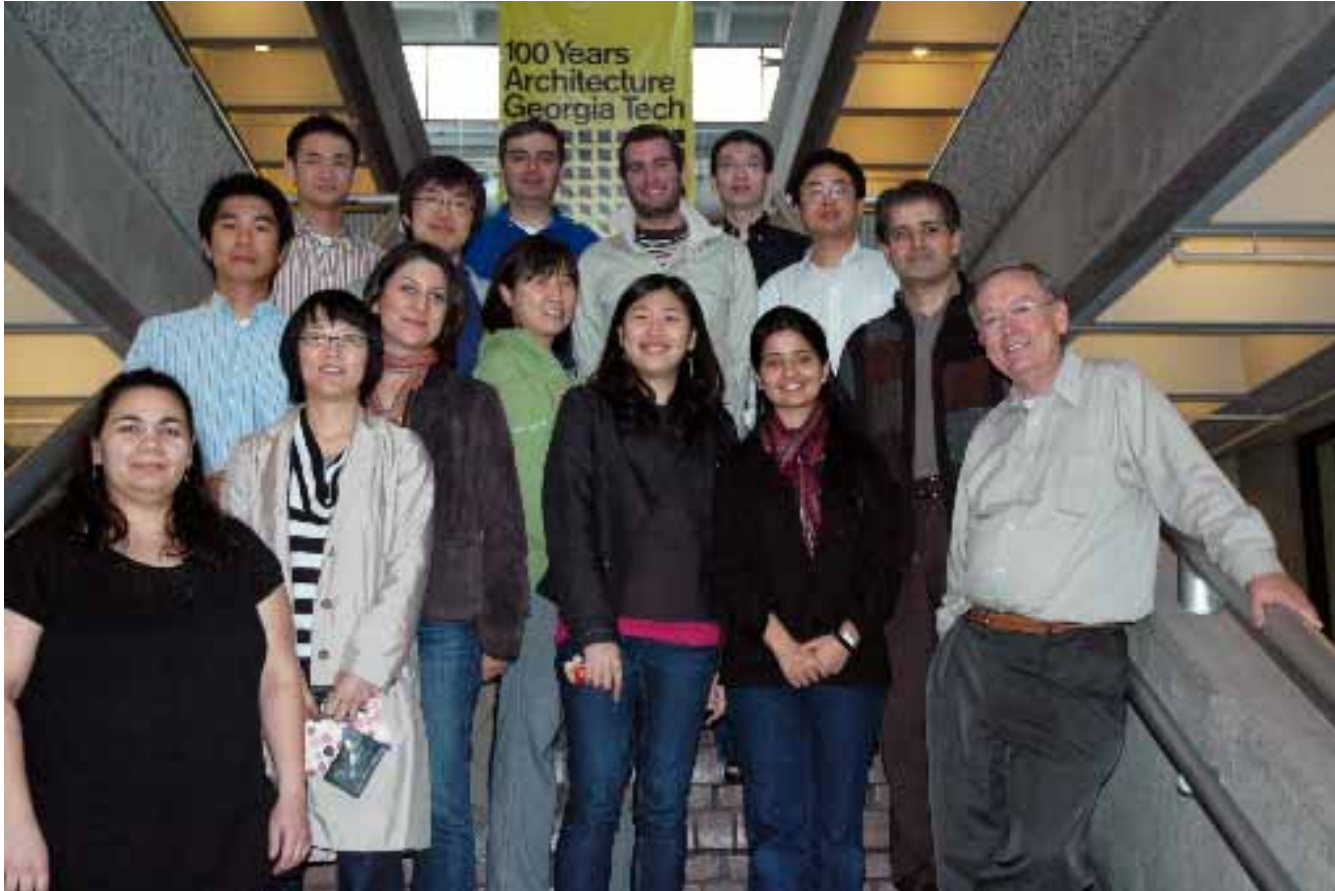
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The High Performance Building group at Georgia Tech

12 PhD students

6 MS students

4 visitors (Korea, China, Mexico)



Building simulation in the broader context

In 1999, then Director Dr. Rita R. Colwell declared simulation as the *third branch* of science.

In a more recent report entitled, “ Simulation - based Engineering Science: Revolutionizing Engineering Science through Simulation” the NSF made the following recommendation:

“ The Panel recommends that NSF underwrite an effort to a sweeping overhaul of our engineering educational system to reflect the multidisciplinary nature of modern engineering and to help students acquire the necessary modeling and simulation skills. ”

Simulation - Based Engineering Science: Final Report, May 2006

Your questions first

What you always wanted to know about Energy Modeling
and Building Simulation.....

History of BS

- 1975: first attempts at building simulation tools
- 80s: better models and computational methods
 - f.d.m. and f.e.m.
- 90s: leap in functionality:
 - Flow of heat and mass through enclosures
 - Air flow in and around buildings
 - High octane lighting simulation and renderings
 - Acoustic simulation
- 00s: design support; coupled simulation; dynamic control
 - New simulation kernels (Modelica, Object oriented)
 - High fidelity models, better physics, 3D

Course in HPB Masters: Building Simulation in Design Practice

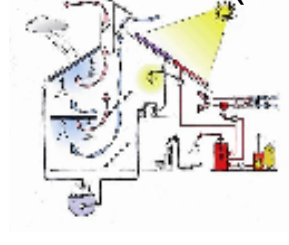
Week 1-2 (ind.)



Climate analysis
Shading studies
Daylight analysis
Wind

EcoTect

Week 3-4 (ind.)



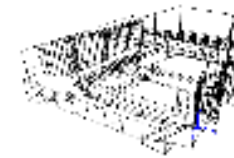
Energy analysis

- Simple calculators:

EPSCT

- Simulation: eQUEST

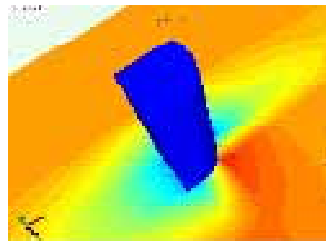
Week 5-10 (teams)



Detailed energy analysis

- System design and control
- Different tools – comparison (E+, IES, IDA, CONTAM)
- Lighting study RADIANCE

Week 11-15

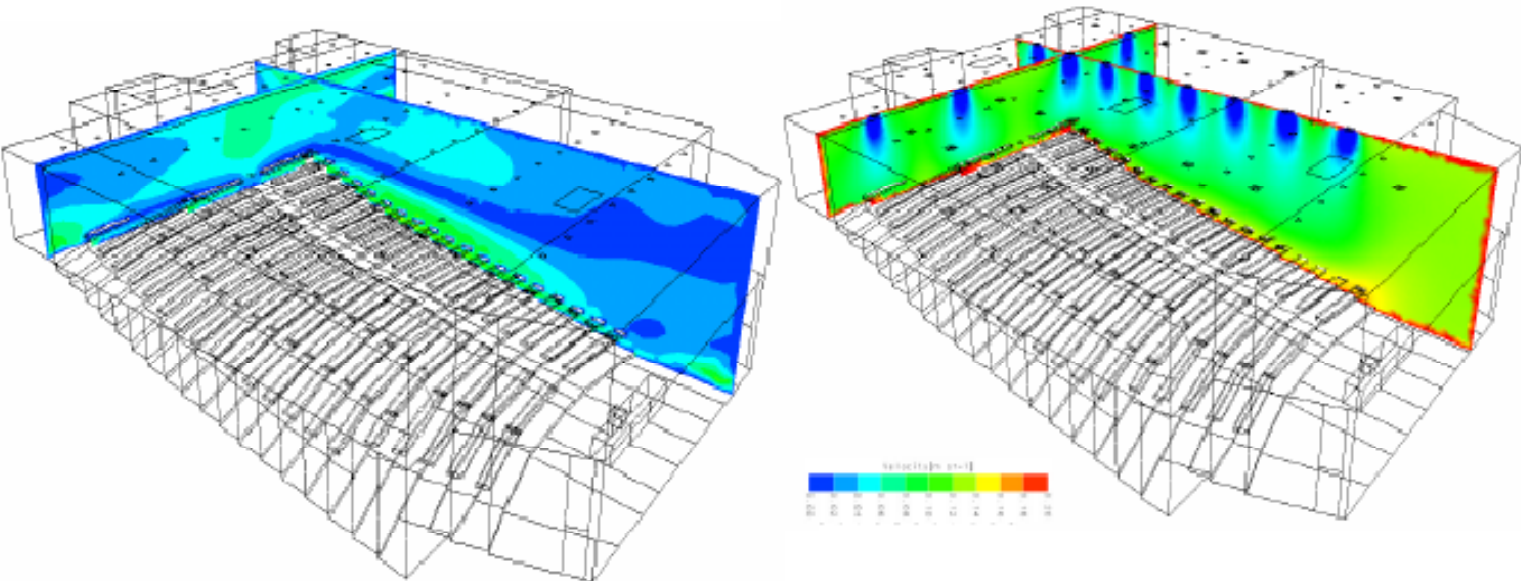


CFD applications: FLOVENT

Reading about tools

- Go to DOE site: http://apps1.eere.energy.gov/buildings/tools_directory/
- Familiarize yourself with the categories of tools and read about your favorites
- Download the linked paper “Contrasting functionalities....”; this should provide a good overview of relevant features of the energy simulation tools

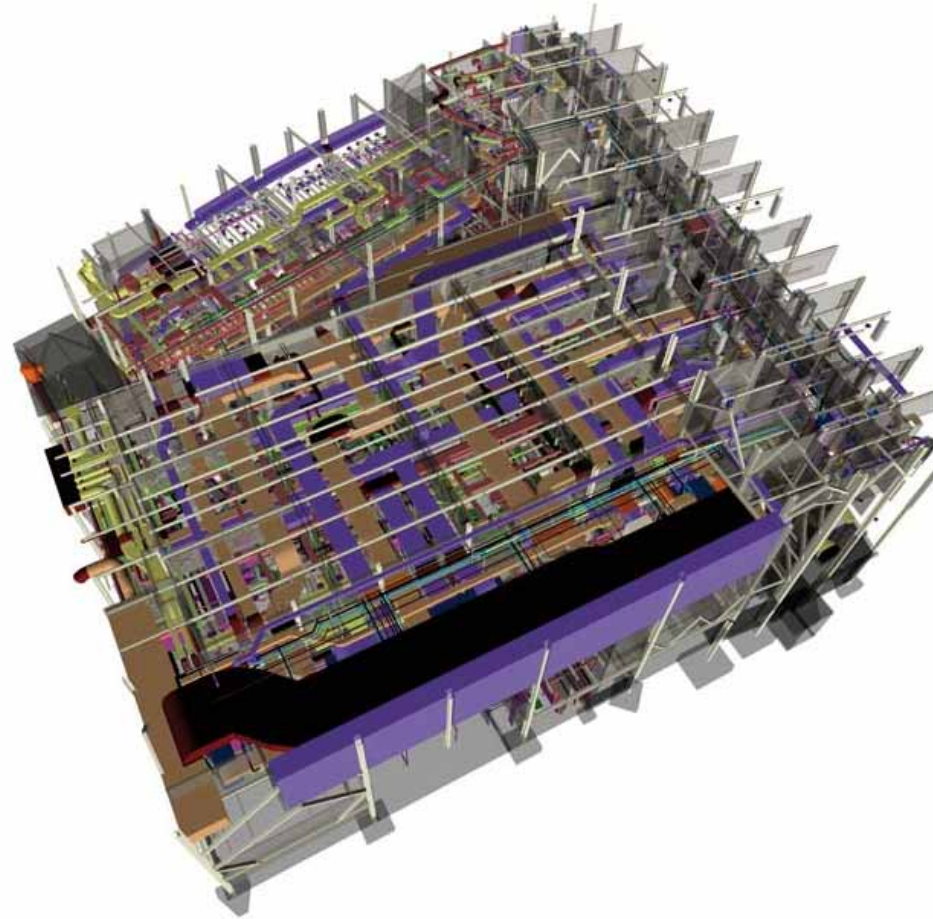
Flow simulation (CFD)



Light simulation and renderings



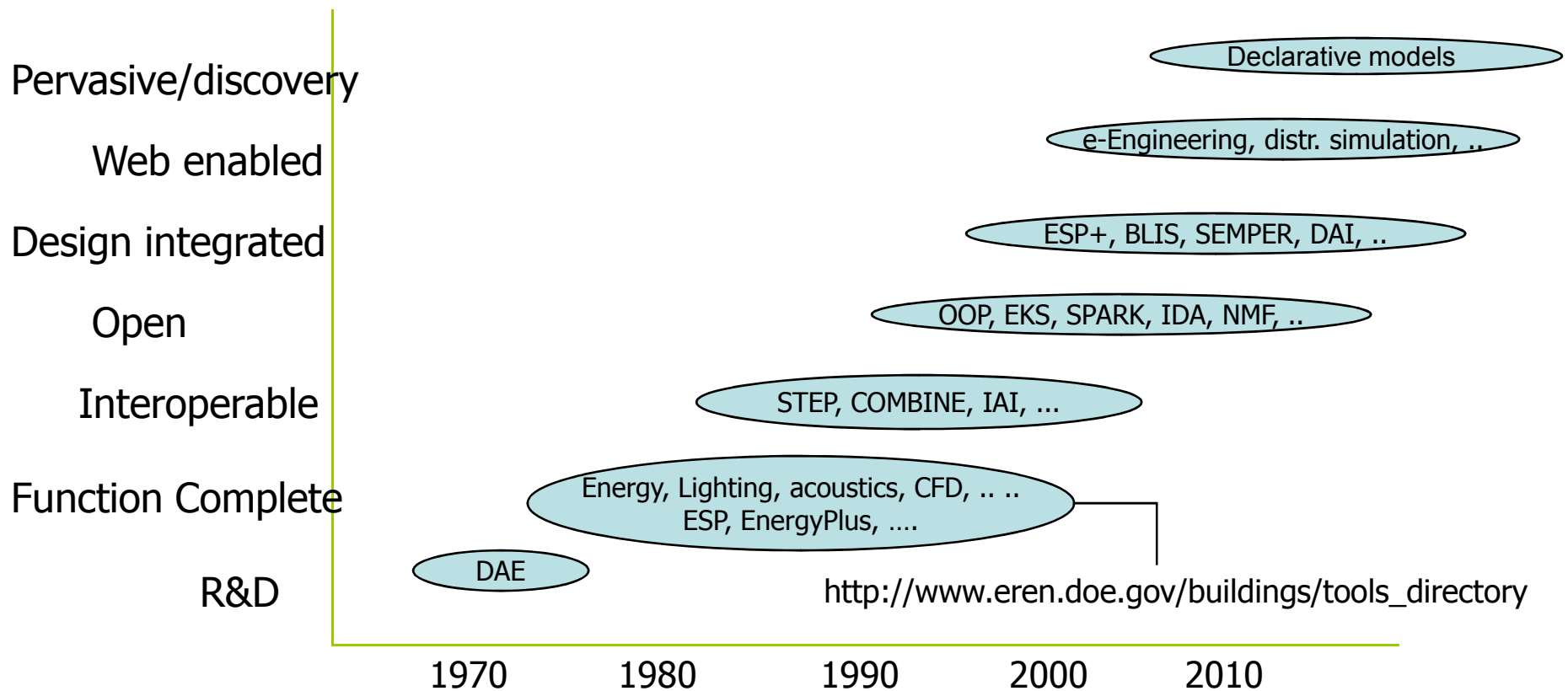
MEP



HVAC system simulation



The past, present and future



So how well are we doing?



Leading “full” BS software packages:

- EnergyPlus (plus 3rd party)
- DOE-2 and eQuest
- ESP-r

Close followers:

- IES-VE
- TAS
- IDA

Toolboxes/Platform:

- TRNSYS
- Matlab
- Modelica

I would only trust the most experienced modelers to tackle this

Growing “Simulationist Guild”

- Fast growing group of “energy modelers”
- Drivers: ASHRAE 90.1 and LEED (soon ASHRAE 189)
 - Good: lots of work
 - But: ASHRAE 90.1 + LEED cumbersome duo
- Challenges:
 - Training
 - Quality assurance
 - Effectiveness and productivity
 - Capture shared knowledge
- Personal crusade: improve understanding of the role of uncertainty and stochastic nature of building behavior and operation

Simulation discipline is on the move

- Simulation → Decision making
- Number crunching → Process of simulation
- Tool integration → Team deployment
- Static → Configurable
- Deterministic → Uncertainty
(one experiment is not enough)
- Raw outputs → Quantitative expressions of performance

Application in High Performance Building



Swiss Re Tower
London



Menara Mesiniaga
Malaysia



Edificio Malecon
Buenos Aires

Double whammy: HPB = “architectural fashion statement” and “high performing”

Success stories



Gwenzyme HQ
Cambridge



NY Times, Manhattan



ABN-AMRO HQ
Amsterdam

Then there is the outrageous



Bahrain WTC



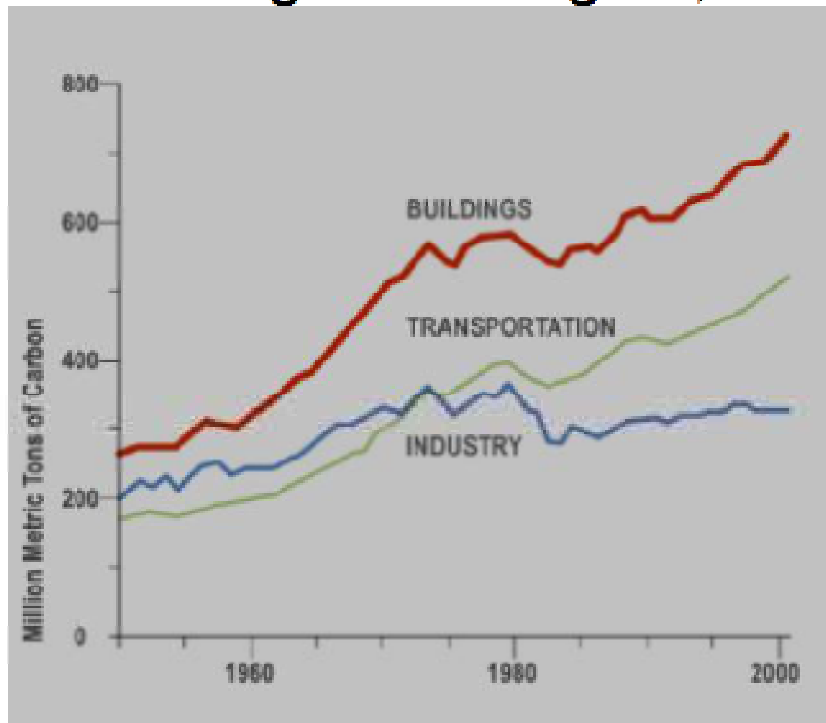
Discovery tower
Houston



Sabah Al Ahmed IFC
Kuwait

Energy consumption

U.S. Energy/Carbon End-Use: Buildings are Largest, Fastest Growing



Building

***Energy Use:
39% total U.S.
energy***

***40% of carbon
emissions***

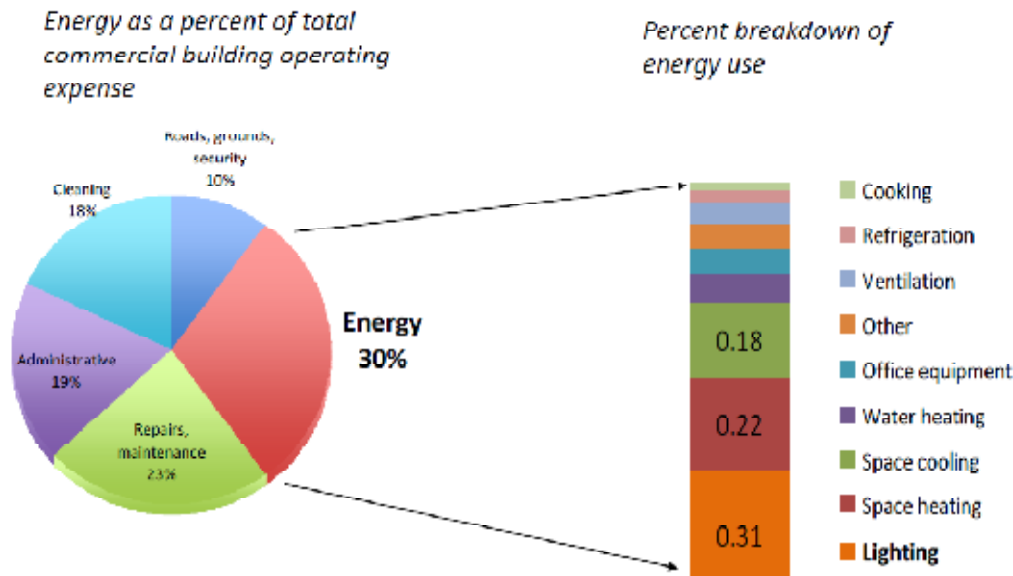
71% electricity

***54% of natural
gas***

***Fastest growth
rate!***

Saving energy, GHG and \$\$: “Extreme BS challenge”

Total Commercial Building Operating Expense



Source: U.S. Environmental Protection Agency; Energy Information Administration

➤ AIA standards

- ❑ Reduce fossil fuel and GHG emissions by 50% by 2010
- ❑ By 100% by 2030

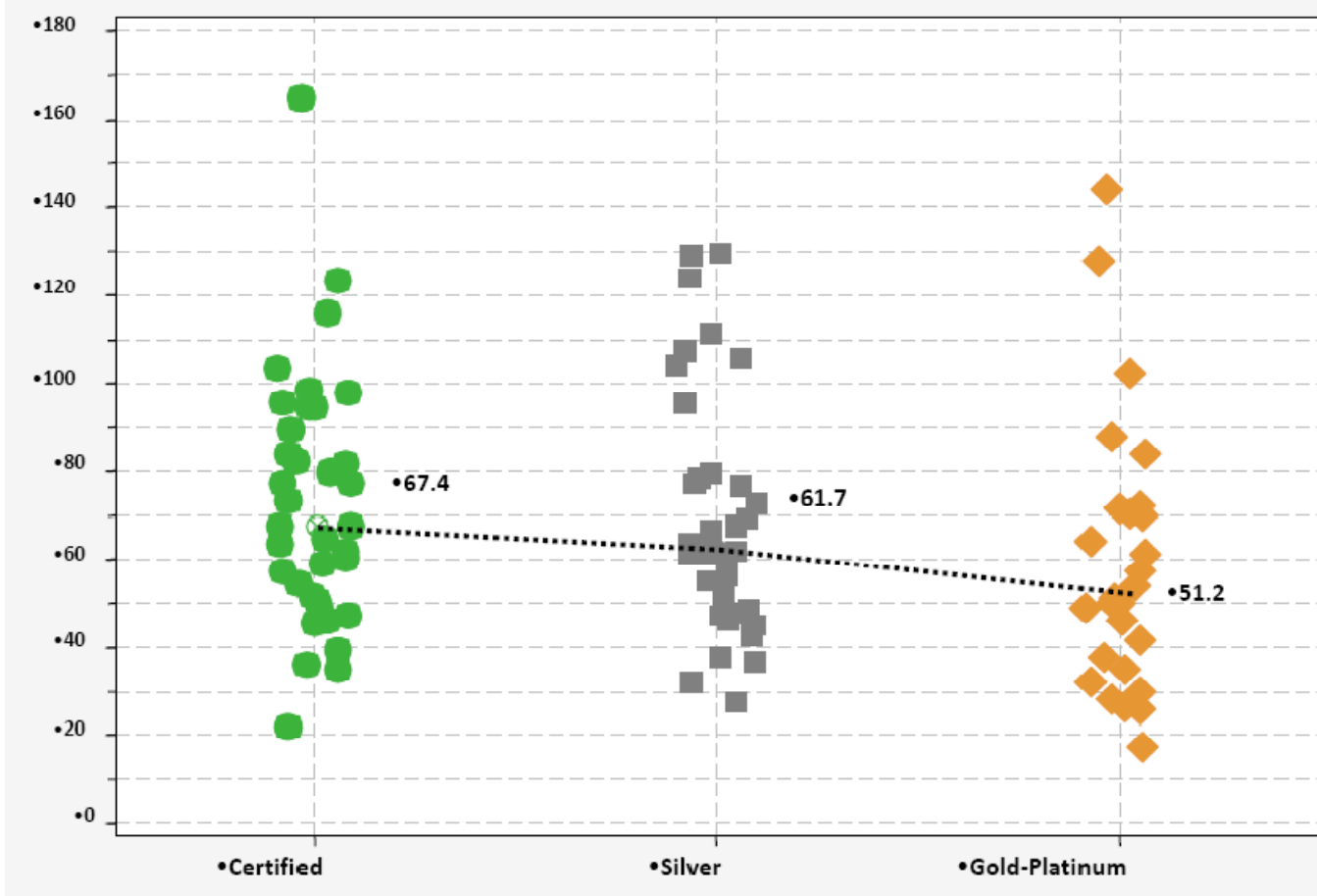
➤ ASHRAE standards

- ❑ 30% reduced energy required in new buildings as of 2010
- ❑ Net zero energy building standards to be issued by 2015
- ❑ NZEB's by 2030

How do we measure “Low/Net-zero Energy” performance?

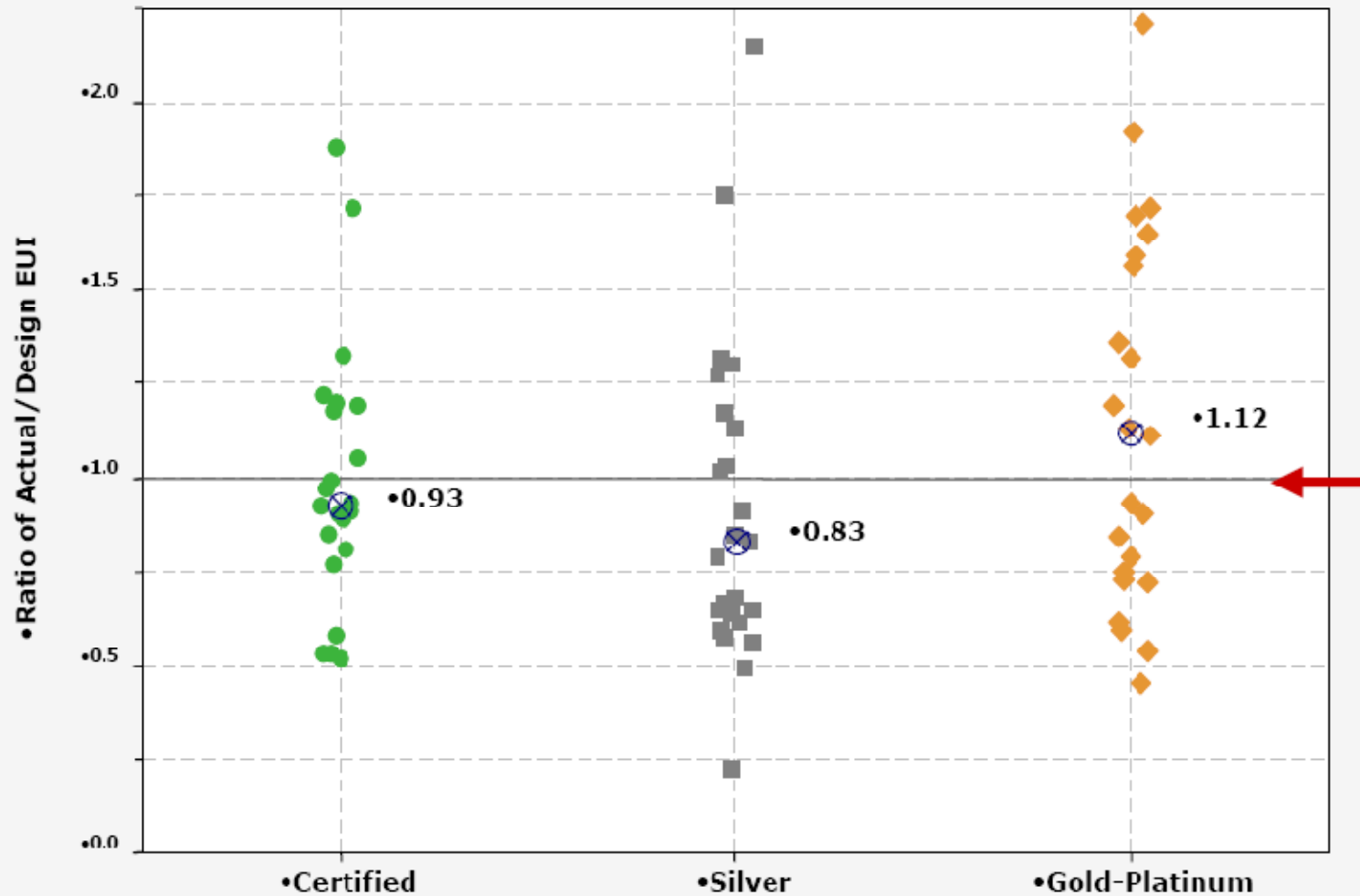
- Sustainability rating method, such as LEED?
- Energy Star (EPA)?
- Building Energy Quotient (ASHRAE)?

LEED rating no guarantee



Actual EUI by LEED level

Energy Prediction accuracy



Can simulation results be trusted?

- Novice results are all over the place
- Skilled tool user IS NOT THE SAME as good energy modeler
- Energy modeling is a skill that needs extensive training
- Always needs checking against simple model
- Don't over-engineer your model (keep objective in mind)

An alternative approach to simulation in rating systems: Energy Performance Coefficient (EPC)

- Objective measure of energy performance
- Based on normative calculation: ISO-CEN standard
 - Model is prescribed → no modeler bias
 - Input: Macro building and system properties

DOES NOT REQUIRE BUILDING SIMULATION!

[E] Energy_Rating and Certification methodology: EPC

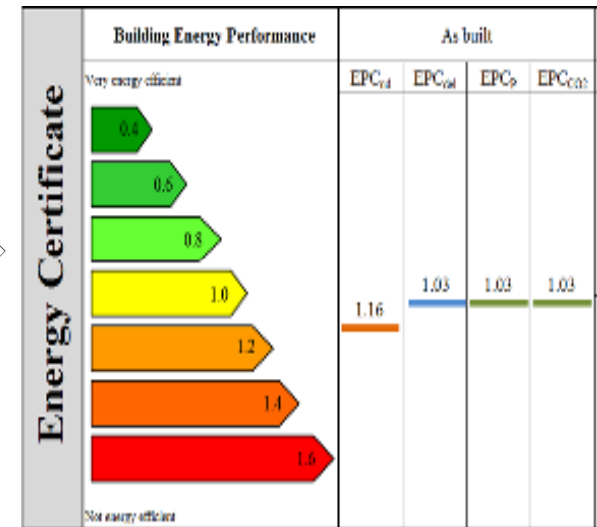
E_{design} : Calculated energy use

Calculated based on energy standard

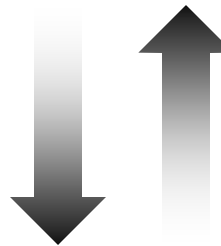
E_{ref} : Reference Energy use

Energy consumption of a basket of buildings that represent local building practices.

$$EPC = \frac{E_{design}}{E_{ref}}$$



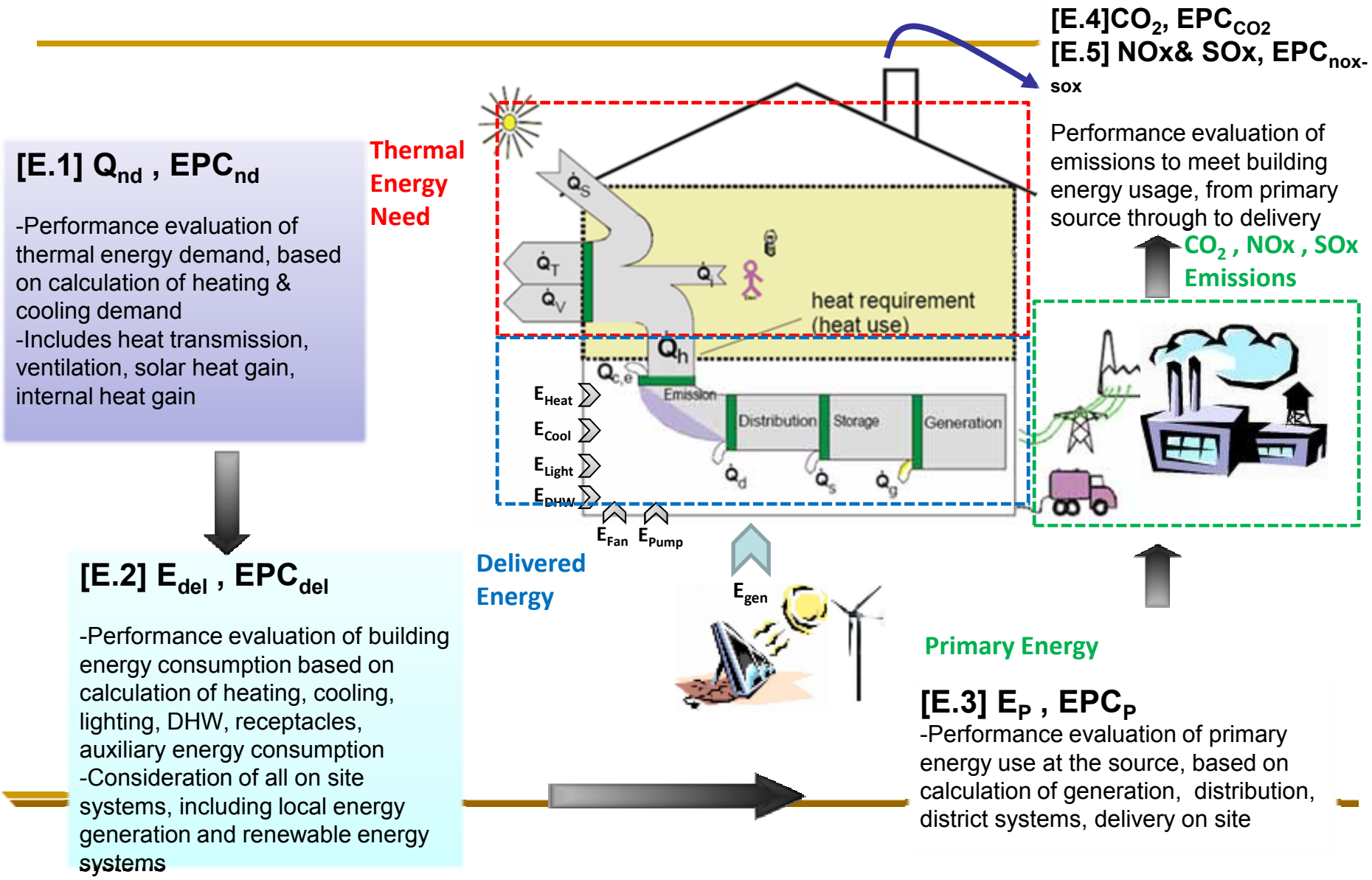
EPC



Energy Performance

An example of how The EPC is used to "rank" a building

[E] Energy_Building Energy Performance Rating at 5 Levels



Rating Methodology: EPC

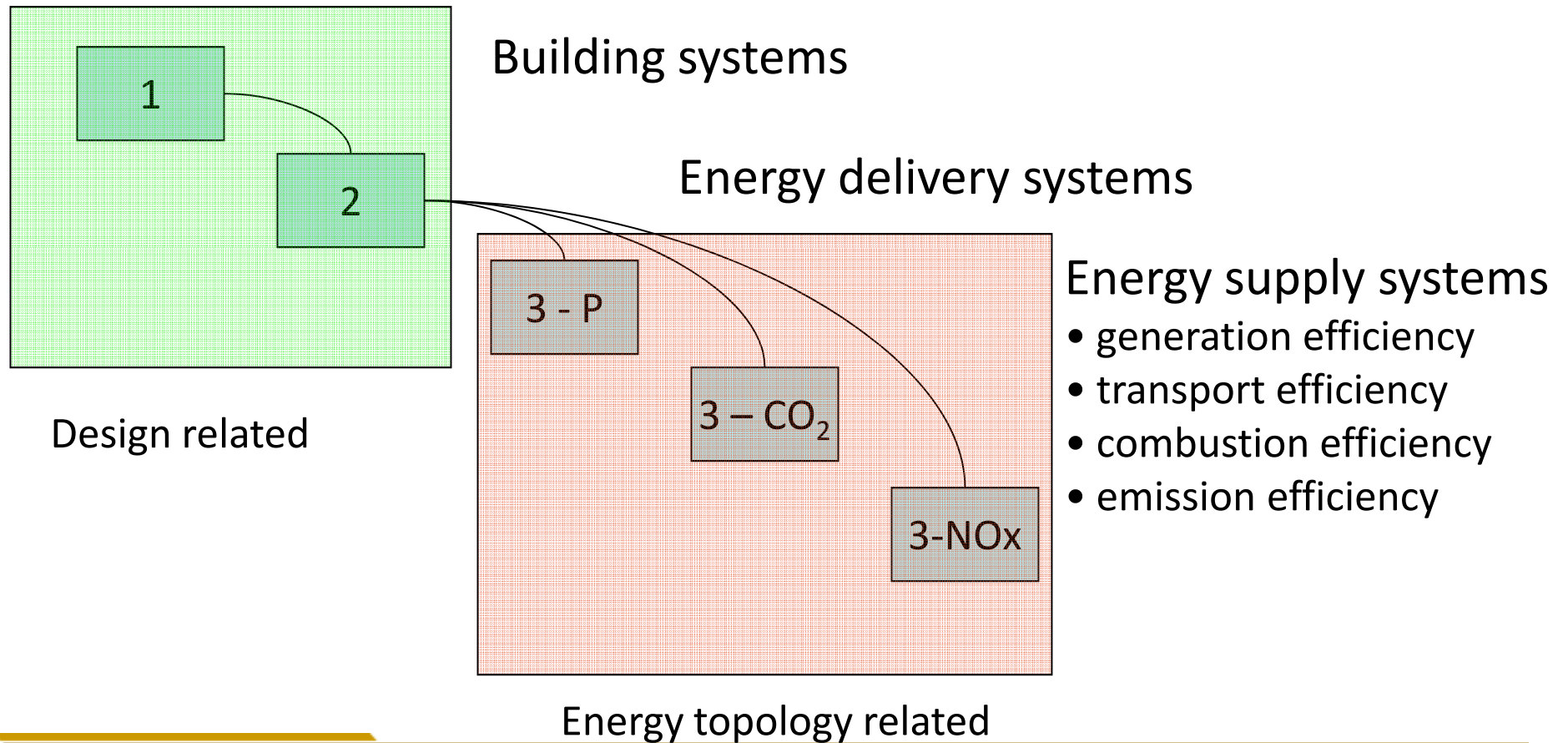
The three levels of EPC measurement support different rating strategies:

- Level 1: EPC_{nd}
Used to rate and certify the envelope and internal energy use in the building.
- Level 2: EPC_{del}
Used to rate and certify the building systems
Deals with all HVAC systems including district cooling, DHW, Lighting controls, auxiliary equipment, on-site renewable energy systems and strategies.
- Level 3: $EPC_P, EPC_{CO_2}, EPC_{NOx/SOx}$;
Used to rate and certify the building as consumer of all primary energy resources specifically fossil energy, and direct and indirect producer of CO_2 emissions
This level takes the total energy generation and transport topology from power plant to building site into account.

Factors that affect EPC at different levels

- EPC_{nd} and provisions for improving it
 - Building Site selection
 - Building Envelope
 - Building Internal loads
- EPC_{del} and provisions for improving it
 - HVAC Systems
 - Renewable Energy Systems
- EPC_P , EPC_{CO2} , $EPC_{NOx/SOx}$ and provisions for improving it
 - Building site selection
 - Resource Utilization Factor
 - Powerplant efficiency, fuel type, renewable systems, CO2 and NOx/SOx capture and sequestration

[E] The overall energy improvement



[E.1] Calculator - Residential

[E.1] Energy Demand Performance: General Building Information	
Building type	Residential - Group
Area for Living Room + Kitchen for dwelling [m ²]	2378
Other conditioned area of the dwelling [m ²]	3153
Total floor area of dwelling [m ²]	5531
Area of public services [m ²]	2669
Total building gross area [m ²]	8200
Building height [m]	17.8
Building volume for conditioned space [m ³]	29192
Number of units for 1 bedroom type	0
1 Bedroom unit area [m ²]	0
Number of units for 2 bedroom type	20
2 Bedroom unit area [m ²]	97.91
Number of units for 3 bedroom type	30
3 Bedroom unit area [m ²]	119.1
Number of units for 4 bedroom type	0
4 Bedroom unit area [m ²]	0

[E.1] Calculator - Residential

[E.1] Energy Demand Performance: Internal Temperature Set Point		
Internal set point for cooling [°C]	26	
Internal set point for heating [°C]	20	
Material		
U-value for opaque wall material [W/(m²K)]	0.39	240mmConc/60mmInsul
U-value for roof material [W/(m²K)]	0.31	ballast/Prot.Layer/Poly Ins/Membrane/320mmSlab
U-value for door material [W/(m²K)]	2.90	Double glazing door for the public main entrance
U-value for window type 1 [W/(m²K)]	2.90	Double glazing
U-value for window type 2 [W/(m²K)]	5.80	Single glazing
Solar Transmittance window type 1	0.78	Double glazing
Solar Transmittance window type 2	0.87	Single glazing
Shading device factor	User-moveable	
Envelope Heat Capacity (J/(Km²))	Heavy: 260,000 J/K	

[E.1] Calculator - Residential

Envelope Area for Dwelling Space									
Elevation area	SW	S	SE	E	NE	N	N W	W	Hor
Shading correction factor (Refer to REFERENCE sheet)		1		1		1		1	
Opaque area [m ²]	-	441.1		1,236.8		441.1	-	1,236.8	1,640.0
Door area [m ²]	-	5.4		3.6		5.4	-	3.6	-
Window type 1 area [m ²]	-	73.7		161.3		73.7	-	161.7	-
Window type 2 area [m ²]	-	-		6.5		-	-	6.5	-
Total area [m ²]		520.1		1,408.1		520.1		1,408.5	1,640.0

[E.1] Calculator - Residential

[E.1] Energy Demand Performance: Heating Needs									
Month	QH,tr [MJ]	QH,ve [MJ]	QH,ht [MJ]	QH,sol [MJ]	QH,int [MJ]	QH,gn [MJ]	η_{H_gn}	QH,nd [MJ]	QH,nd [kWh/m ²]
Jan	17,695	60,687	78,381	50,760	150,507	201,267	0.382	1,481	0.05
Feb	799	2,741	3,540	52,554	135,942	188,495	0.019	0	0.00
Mar	(19,464)	(66,756)	(86,220)	53,956	150,507	204,463	(0.422)	-	-
Apr	(55,652)	(190,870)	(246,522)	53,752	145,652	199,404	(1.236)	-	--
May	(95,551)	(327,709)	(423,260)	58,248	150,507	208,755	(2.028)	-	-
Jun	(109,592)	(375,867)	(485,460)	54,367	145,652	200,019	(2.427)	-	-
Jul	(127,401)	(436,946)	(564,347)	54,187	150,507	204,694	(2.757)	-	-
Aug	(130,940)	(449,083)	(580,023)	56,382	150,507	206,889	(2.804)	-	-
Sep	(107,880)	(369,994)	(477,874)	56,162	145,652	201,814	(2.368)	-	-
Oct	(76,087)	(260,954)	(337,040)	58,049	150,507	208,556	(1.616)	-	-
Nov	(37,672)	(129,204)	(166,877)	50,034	145,652	195,686	(0.853)	-	-
Dec	(885)	(3,034)	(3,919)	47,173	150,507	197,680	(0.020)	-	-
Total	(742,630)	(2,546,991)	(3,289,621)	645,622	1,772,099	2,417,721	N/A	1,481	0.05

The beyond...

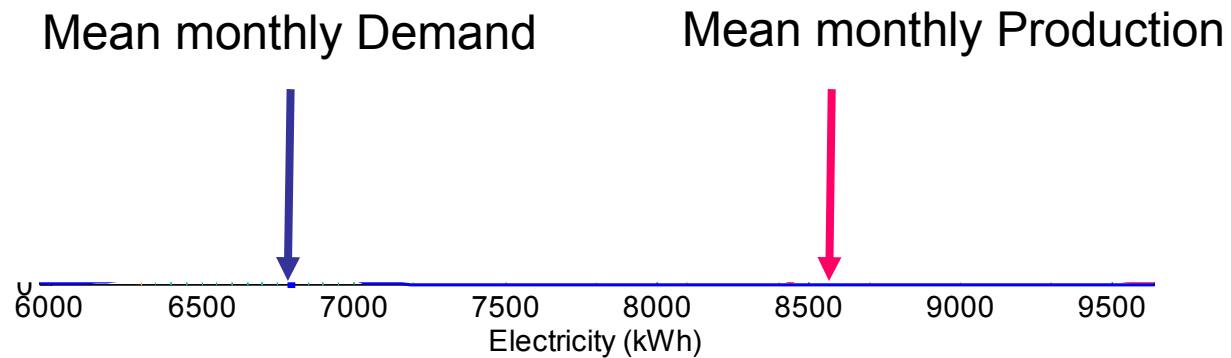
- Zero energy target: why we need risk analysis
- “America Retrofit” agenda: why the emphasis is shifting to large scale building energy engineering

Net zero energy: solar decathlon

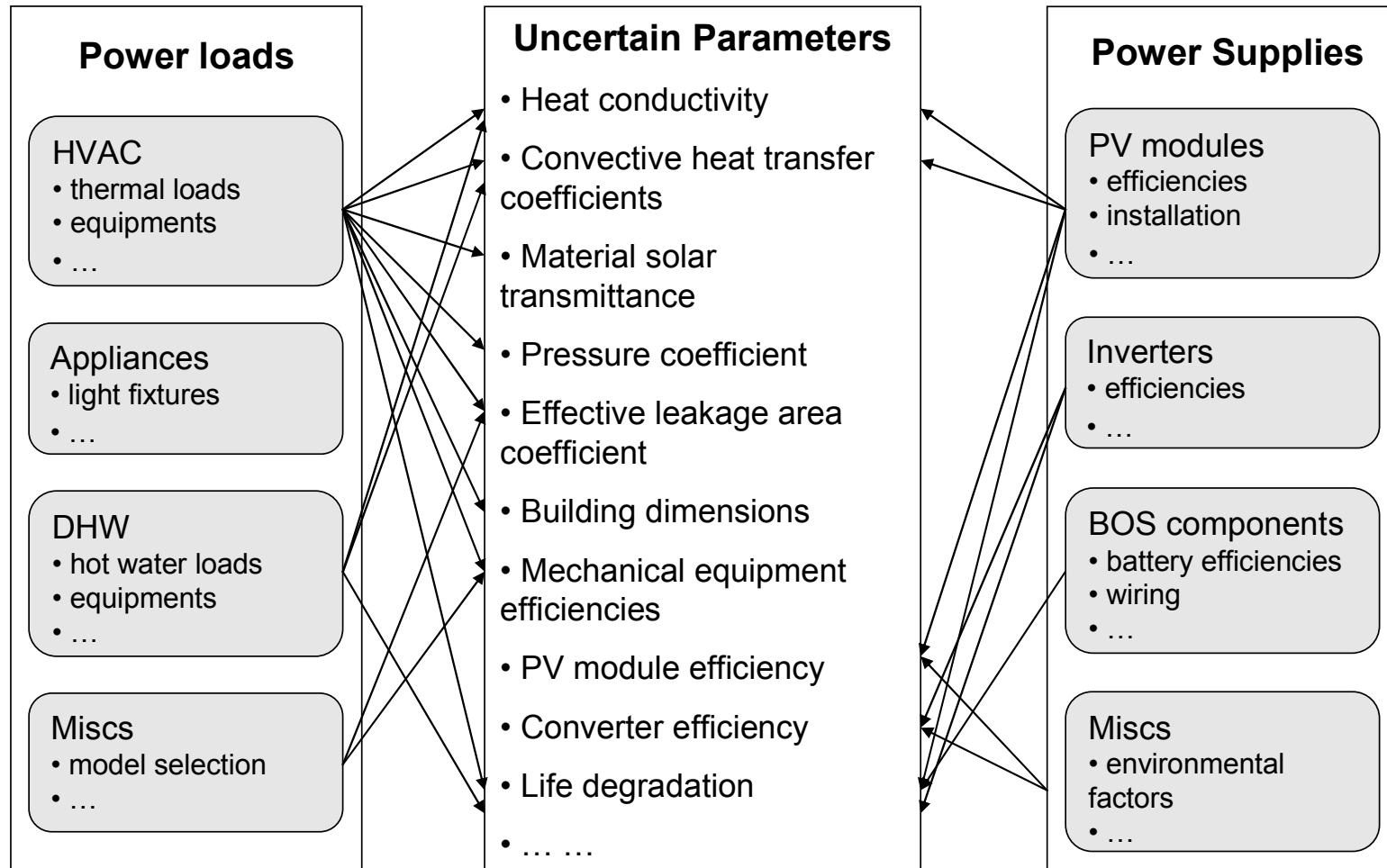


Predicting the reliability of the house

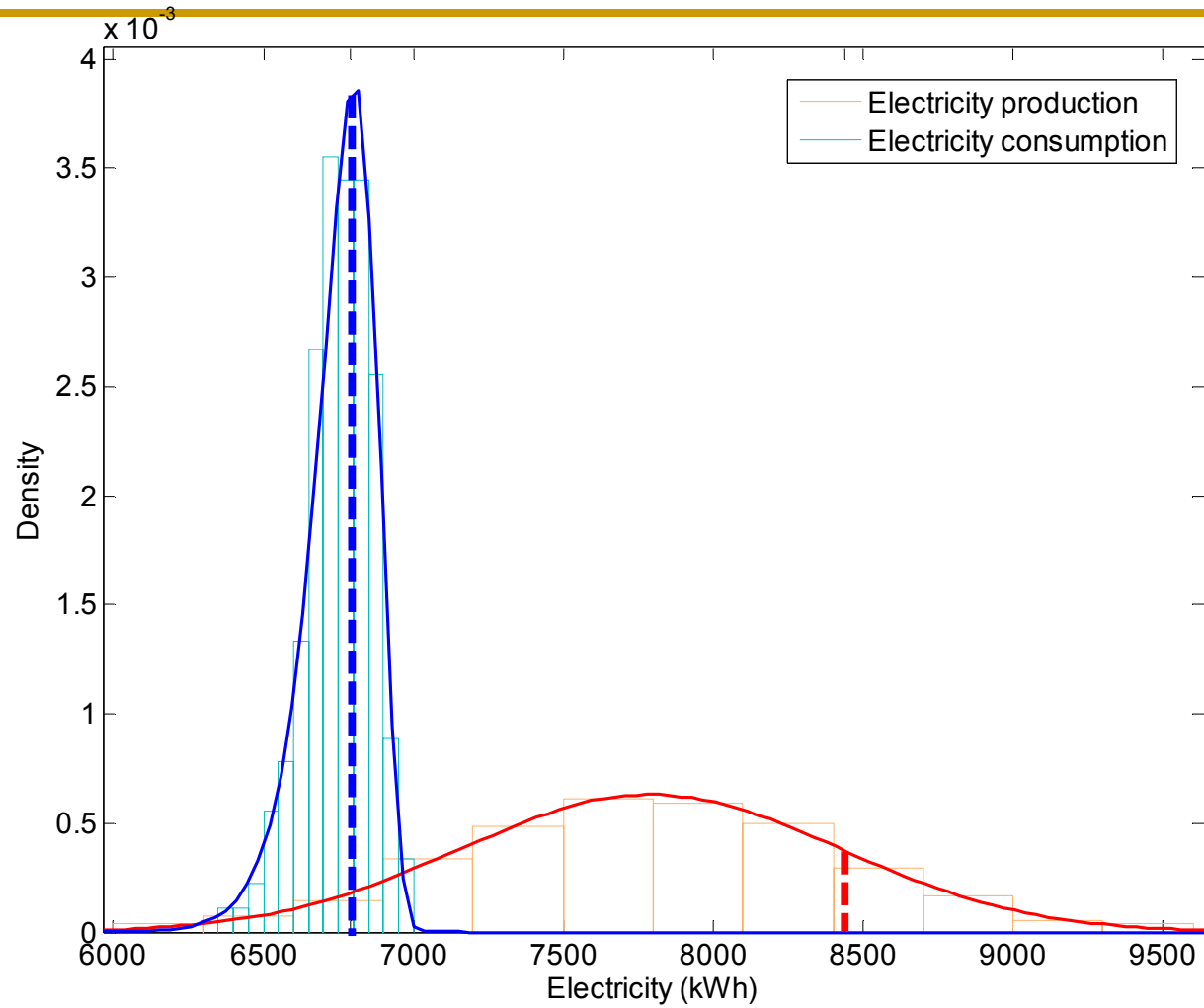
You size the system such that in every month $\text{Production} > 1.2 \times \text{Demand}$



Many Uncertain Variables



Uncertainty analysis



Tracking down systemic failures in buildings

- According to some studies up to 25% failure losses in large complex buildings
- Reason: Complexity of systems and unpredictable load patterns
- Problem: Not replicated in standard (causal) simulation
- Research: Deep physical models using declarative model specs (use of Modelica)
- Research: what can intelligent building control systems do to improve reliability

Final thoughts

- Building simulation is integral to energy saving agenda
- Tools available but not perfect
 - Risk analysis
 - Deep auditing
 - Control and BEMS integration in simulation
- Education is still the key issue
- In MS HPB focus on
 - understanding the issues
 - separating fad from fact
 - proper use of the tools: analyze the question before you start modeling