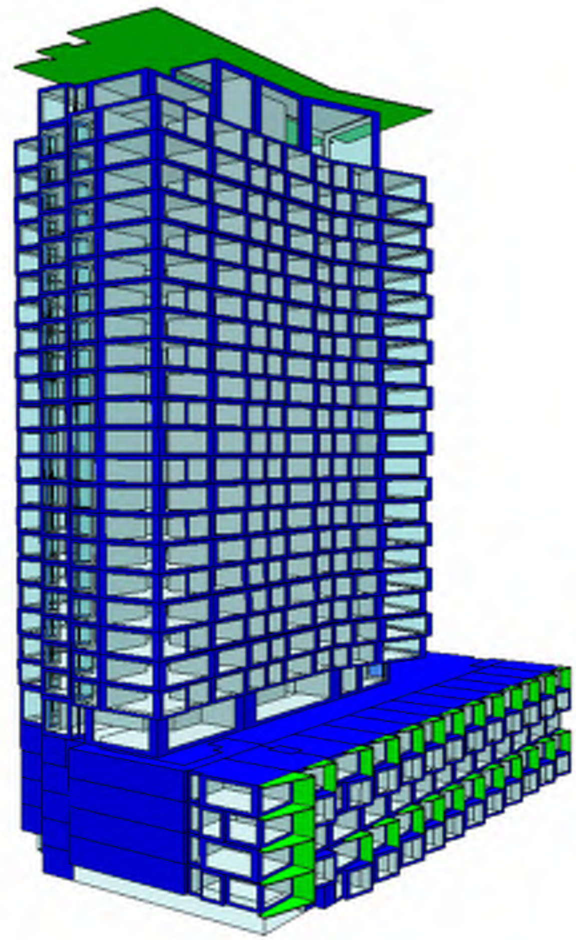
Taking the "garbage" out of energy modeling through calibration

Presented to the
Madison Chapter of ASHRAE
February 8, 2016



Presented by Benjamin Skelton P.E. BEMP
President, Cyclone Energy Group

ASHRAE

Acknowledgments

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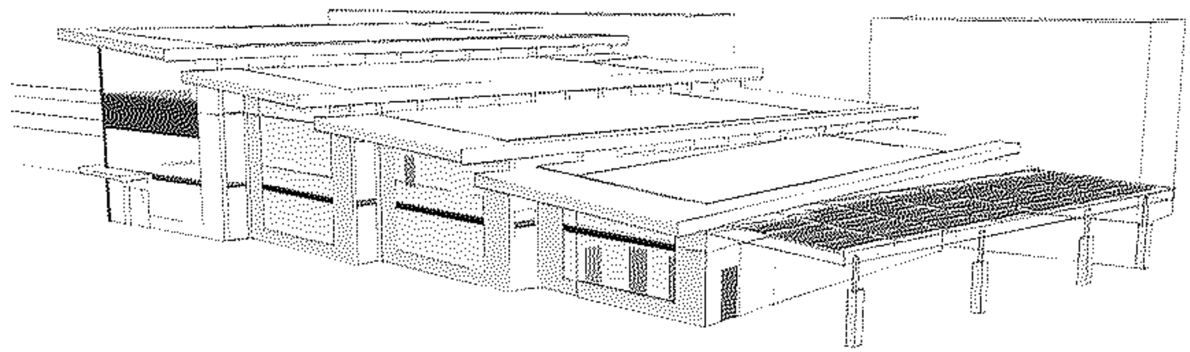
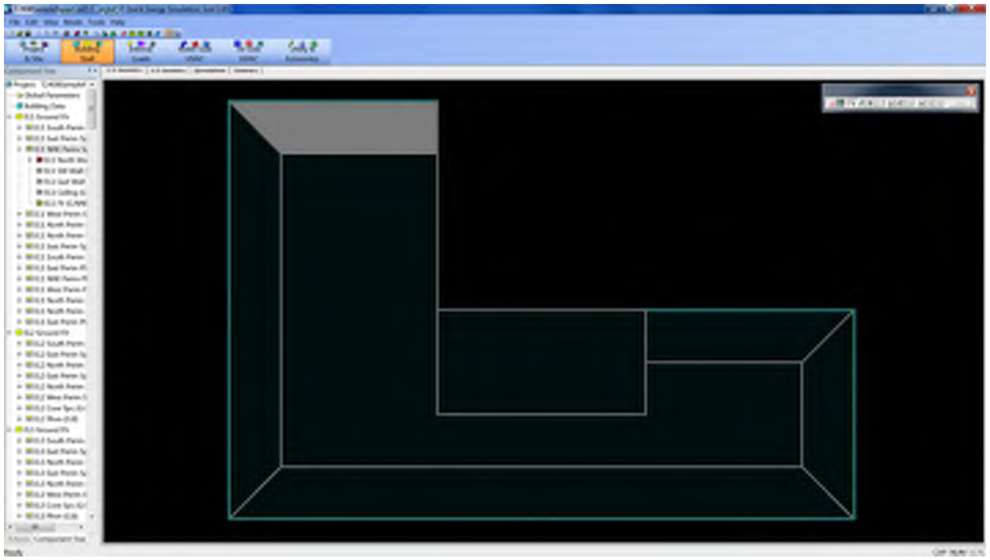
- Nathan Kegel – IES
- Irina Susorova – Cyclone Energy Group
- Igor Seryapin – Cyclone Energy Group
- Joanne Choi – Cyclone Energy Group

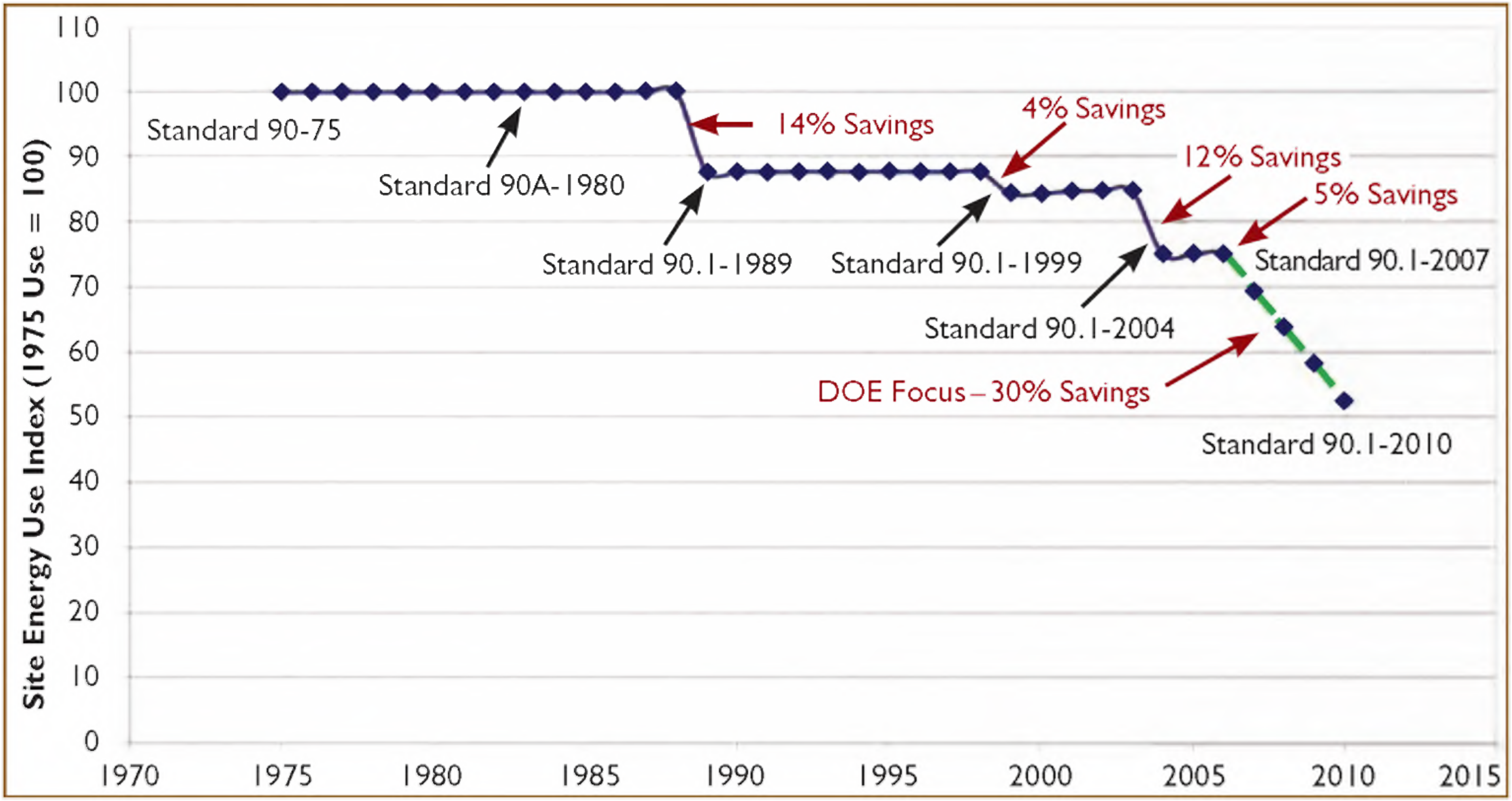


Agenda

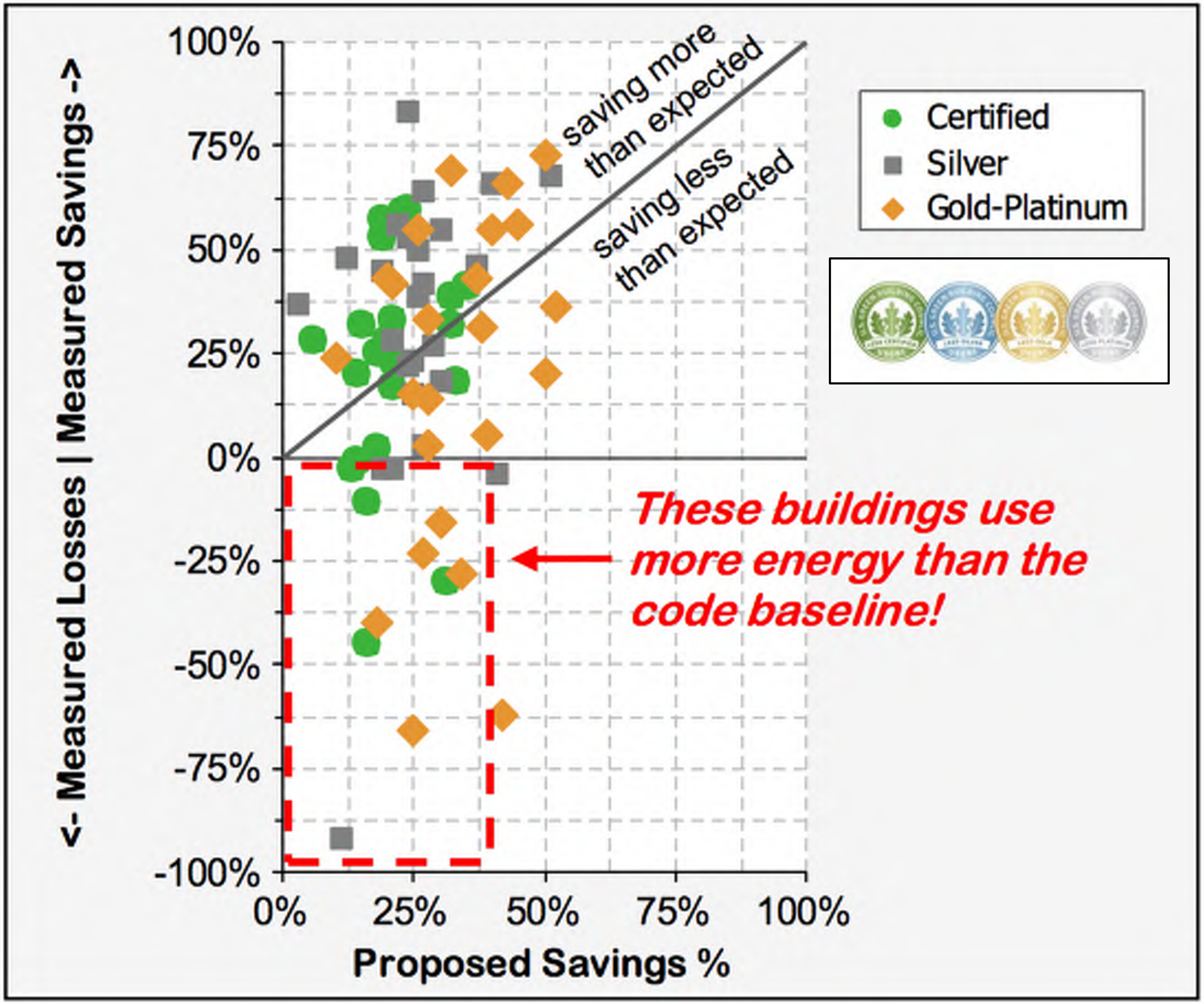
- Do You Know Your Energy Modeling Basics?
- Why Do We Need Calibrated Energy Models?
- How Do You Calibrate A Model Without Losing Years of Your Life?
- A Real World Example
- Questions



History of 90.1 Performance



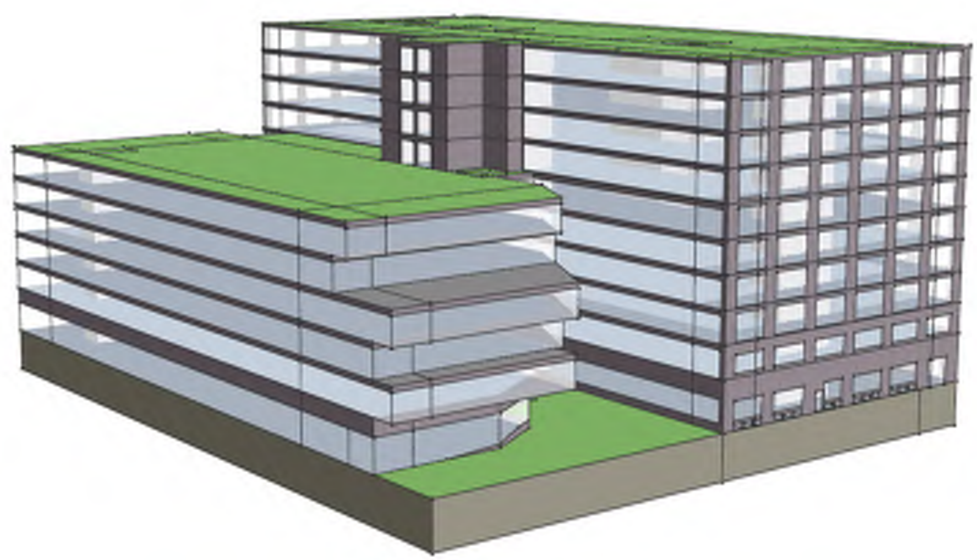
How accurate are energy models?



Source: NBI
Energy Performance of LEED for New Construction

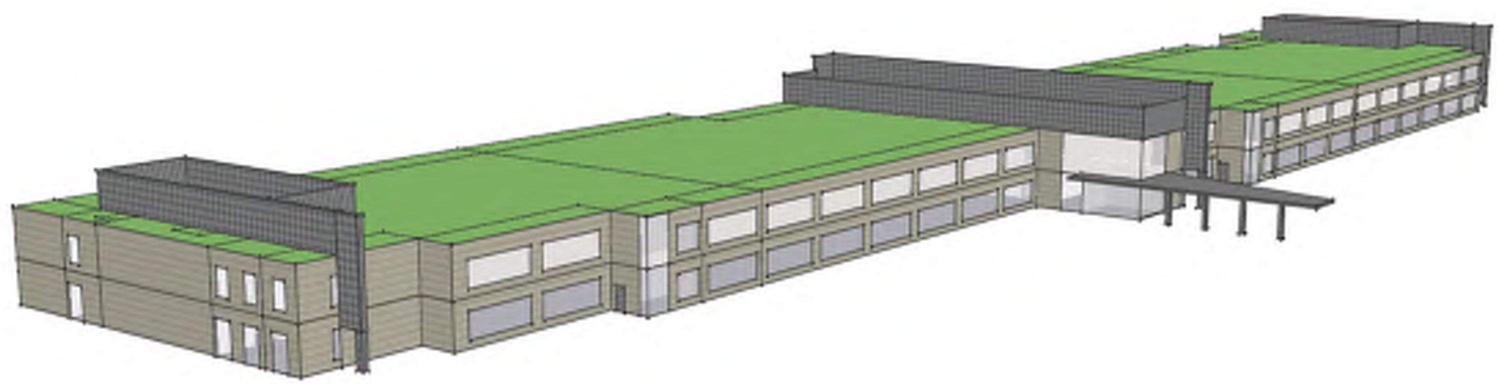
What is an energy model?

- A *model* is a device or structure that helps us:
  - Understand the world around us,
  - Understand a piece of the world around us,
  - A simplified representation of our surroundings in order that we may pursue understanding



What is an energy model?

- Can be simple or complex
- Can be time consuming
- Both an art and a science
- Only as good as the person creating the model
- Not the same as a load model!



What is an energy model?

2009 ASHRAE Handbook - Fundamentals (IP)

MADISON DANE CO REGIONAL ARPT, WI, USA

WMO#: **726410**

Lat: **43.14N** Long: **89.35W** Elev: **866** StdP: **14.24** Time Zone: **-6.00 (NAC)** Period: **82-06** WBAN: **14837**

Annual Heating and Humidification Design Conditions

Coldest Month	Heating DB		Humidification DP/MCDB and HR						Coldest month WS/MCDB				MCWS/PCWD to 99.6% DB	
			99.6%			99%			0.4%		1%			
	99.6%	99%	DP	HR	MCDB	DP	HR	MCDB	WS	MCDB	WS	MCDB	MCWS	PCWD
1	-9.1	-2.9	-18.1	2.1	-7.6	-12.1	3.0	-1.5	26.9	20.0	24.8	18.7	8.1	300

Annual C n, and Enthalpy Design Conditions

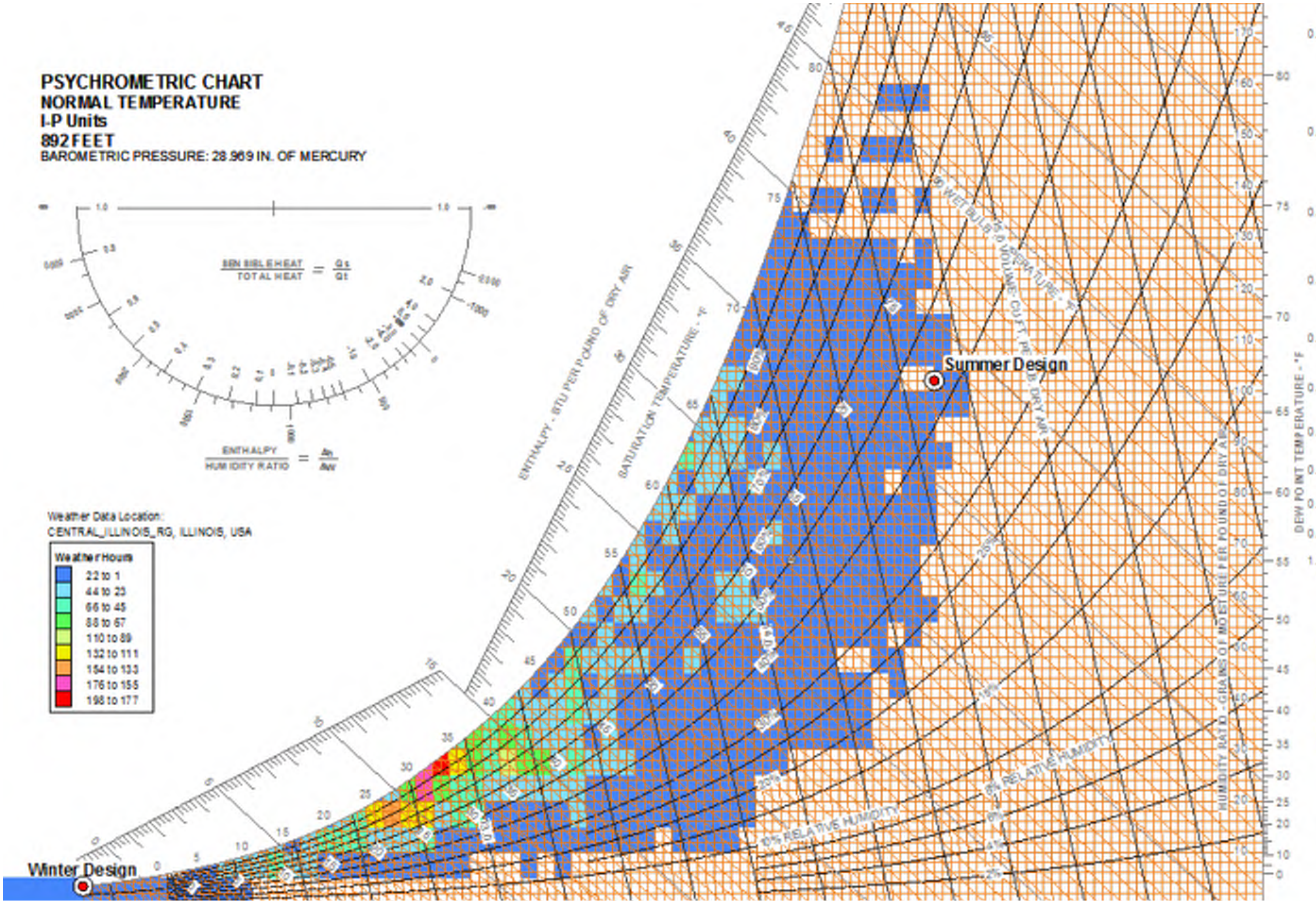
Hottest Month	Hottest Month DB Rang	Cooling DB/MCWB						Evaporation WB/MCDB						MCWS/PCWD to 0.4% DB	
		0.4%		1%		2%		0.4%		1%		2%			
		DB	MCWB	DB	MCWB	DB	MCWB	WB	MCDB	WB	MCDB	WB	MCDB	MCWS	PCWD
7	20.0	89.8	74.4	86.8	72.8	84.0	71.1	77.1	86.4	75.0	83.5	73.2	81.3	11.4	180

Dehumidification DP/MCDB and HR									Enthalpy/MCDB						Hours 8 to 4 & 55/69
0.4%			1%			2%			0.4%		1%		2%		
DP	HR	MCDB	DP	HR	MCDB	DP	HR	MCDB	Enth	MCDB	Enth	MCDB	Enth	MCDB	
74.0	131.0	83.5	72.2	123.0	80.7	70.4	115.7	78.4	41.1	86.1	39.0	83.7	37.3	81.5	636

Extreme Annual Design Conditions

Extreme Annual WS			Extreme Max WB	Extreme Annual DB				n-Year Return Period Values of Extreme DB							
				Mean		Standard deviation		n=5 years		n=10 years		n=20 years		n=50 years	
1%	2.5%	5%		Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
23.6	20.2	18.3	84.7	-15.3	94.2	7.2	3.2	-20.5	96.5	-24.8	98.4	-28.8	100.2	-34.0	102.6

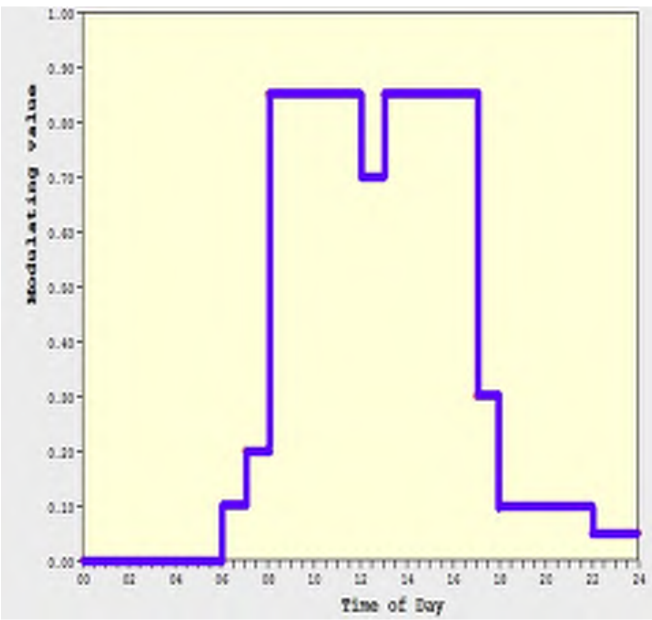
How is it different than a load model?



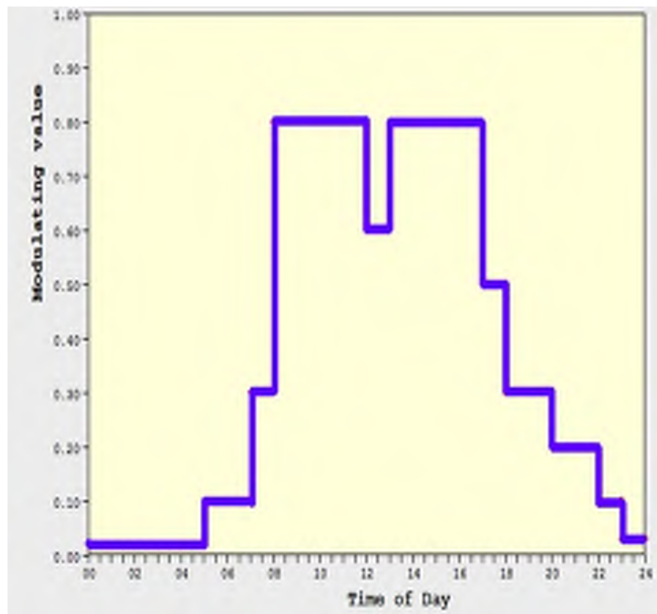
How is it different than a load model?

Scheduled Pattern of Use

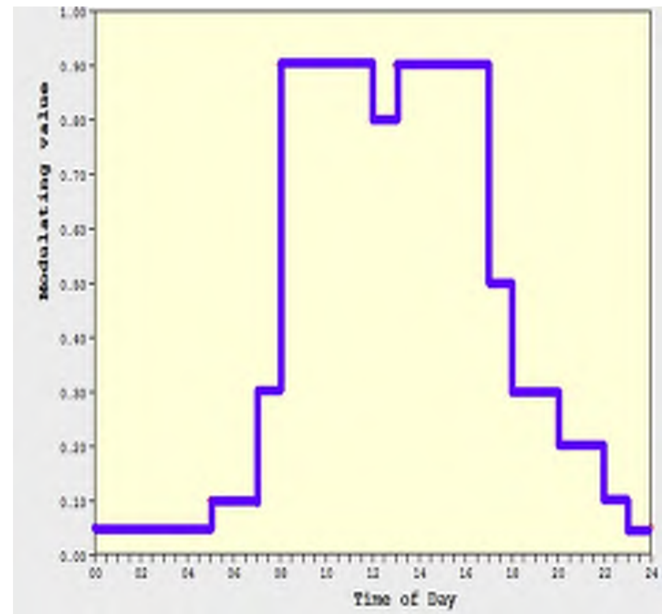
Occupancy



Lights



Equipment



What is an energy model?

- Input variables
  - Controllable variables (e.g. internal gains)
  - Uncontrollable variables (e.g. weather)
- System structure & parameters/properties
  - Physical description (e.g. thermal properties)
- Output
  - Response variables

**Fundamentals Handbook 2013 – Chapter 19*

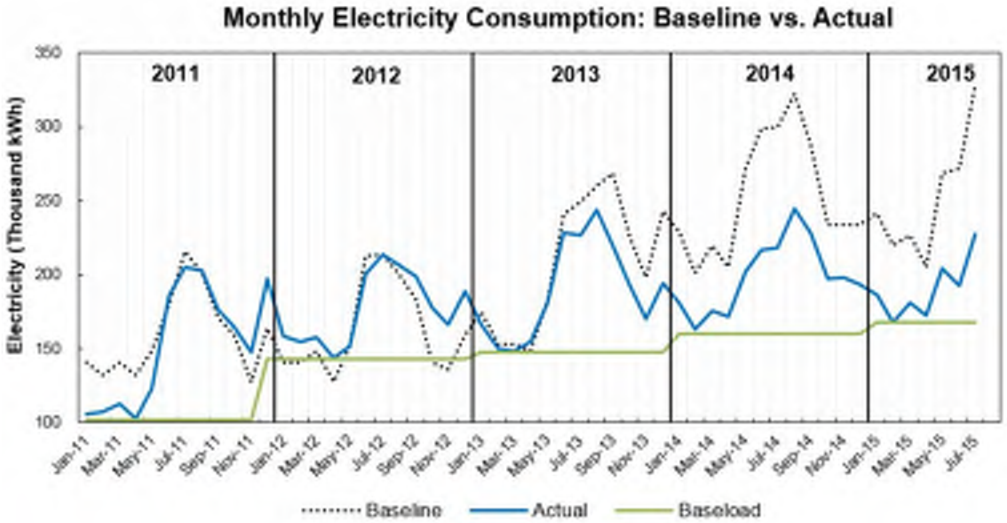
What is an energy model?

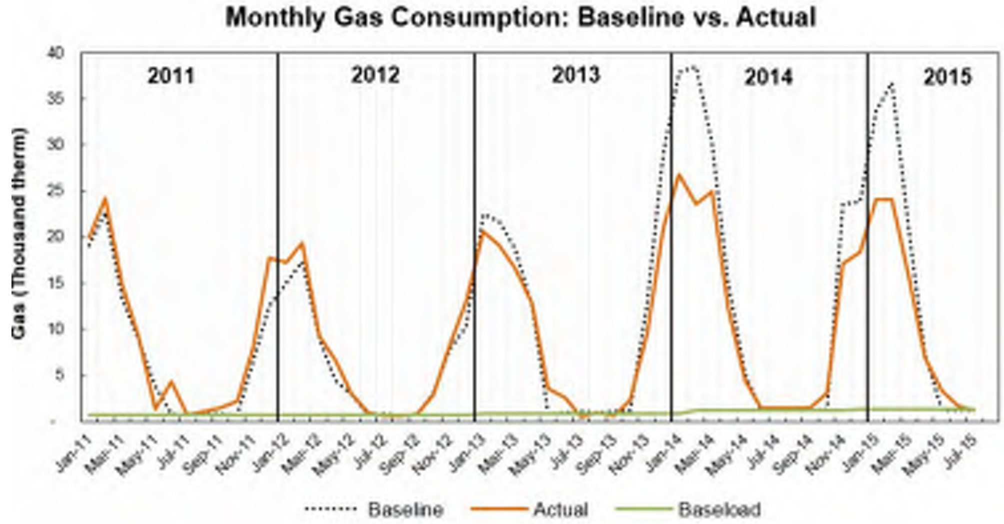
- Two types of energy models:
  - – Data-driven Modeling (Existing Building)
  - – Forward Modeling (Design)

**Fundamentals Handbook 2013 – Chapter 19*

What is a *Data-Driven* Model?

- Input & output variables are known and measured, the objective is to create a mathematical description of the system and estimate parameters.
  - Steady State *System* Modeling Methods:
    - BIN Method
    - Degree Day
    - Regression





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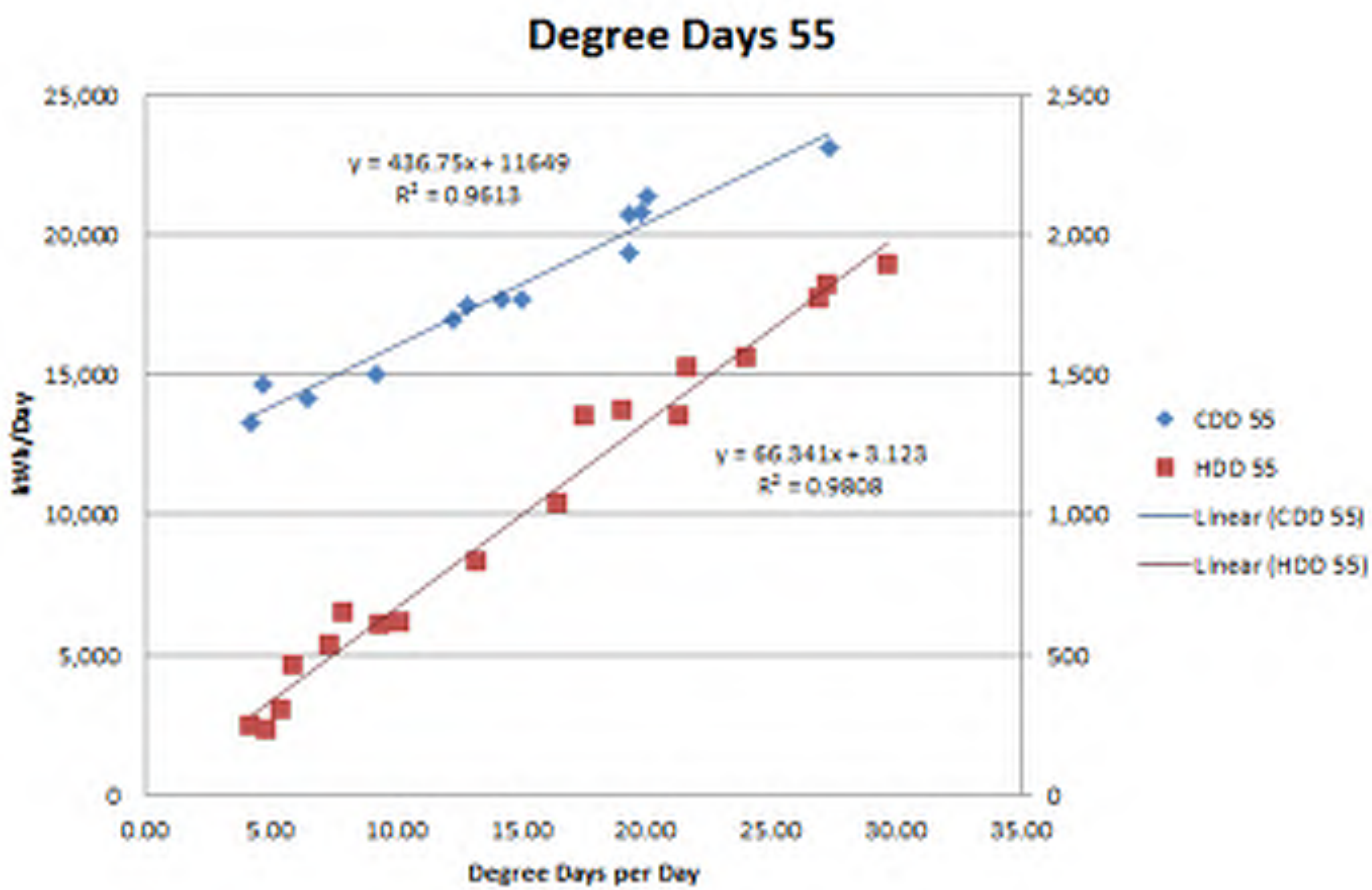
Degree Day Analysis

- $R^2 = 1.00$ – Perfect correlation (idealistic)
- Recommendations
  - Performance Measurement Protocols for Commercial Buildings (PMP)
    - $R^2 > 0.80$
  - International Performance Measurement & Verification Protocol
    - $R^2 > 0.75$

Regression



Degree Days 55
y = 436.75x + 11649
R² = 0.9613
y = 66.341x + 3.123
R² = 0.9808
kWh/Day
Degree Days per Day
CDD 55
HDD 55
Linear (CDD 55)
Linear (HDD 55)

BIN Calculation

FILL OUT CELLS IN YELLOW

		Filter Efficiency Data				Motor Data				
Number of Filters	CFM per filter	Existing Pre-filter Final Resistance	Existing Filter Final Resistance	V-bank Filter Initial Resistance	V-bank Filter Final Resistance	Supply Motor HP	Fan Efficiency	Motor Efficiency	Drive Efficiency	Overall Efficiency
60	**1,604**	1.25	1.00	0.17	1.50	150	60.00%	94.50%	98.00%	55.57%

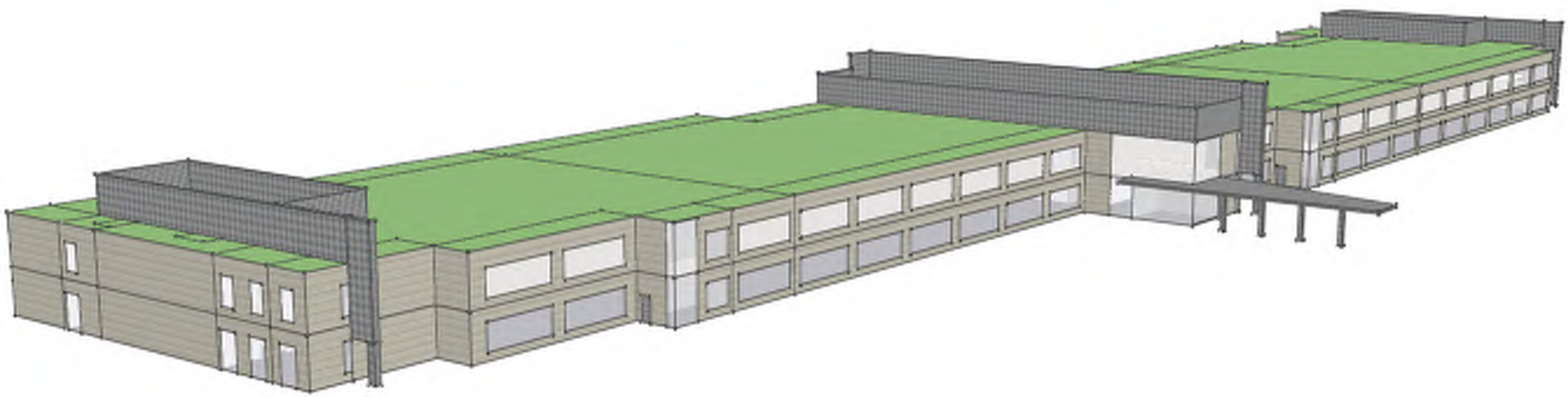
Consumption Summary			
Current kWh	**Proposed kWh**	**kWh Savings**	**kW Savings**
82,470	43,864	**38,606**	**104.6**

Cooling
Indermediate / Economizer
Heating

CHICAGO WEATHER DATA								EXISTING CONDITIONS			PROPOSED CONDITIONS				
2° BINS										82,470.2			43,864.4	38,606	104.64
From	To	Midpoint	Hours	Supply Fan Power	Exhaust Fan Power	Airflow (CFM)	Airflow per Filter	Initial SP Existing	Average SP Existing	Fan Energy (Existing)	Initial SP Proposed	Average SP Proposed	Fan Energy (Proposed)	kWh Savings	kW Savings
94	96	95	0												
92	94	93	12	158.07	23.22	96,234	1,604	0.69	1.21	294.9	0.19	0.63	153.8	141.1	11.76
90	92	91	24	157.04	23.30	95,608	1,593	0.68	1.20	584.2	0.19	0.63	304.9	279.3	11.64
88	90	89	40	156.01	23.39	94,982	1,583	0.68	1.20	964.4	0.19	0.63	503.9	460.5	11.51
86	88	87	65	154.98	23.47	94,357	1,573	0.67	1.20	1,552.3	0.19	0.63	812.0	740.3	11.39
84	86	85	75	153.96	23.56	93,731	1,562	0.67	1.19	1,773.9	0.19	0.62	928.9	845.0	11.27
82	84	83	81	152.93	23.64	93,105	1,552	0.66	1.19	1,897.3	0.19	0.62	994.6	902.7	11.15
80	82	81	98	151.90	23.72	92,480	1,541	0.65	1.19	2,273.2	0.18	0.62	1,192.9	1,080.3	11.02
78	80	79	127	150.87	23.81	91,854	1,531	0.65	1.18	2,917.2	0.18	0.62	1,532.5	1,384.7	10.90
76	78	77	80	149.84	23.89	91,228	1,520	0.64	1.18	1,819.6	0.18	0.62	956.9	862.7	10.78
74	76	75	184	148.82	23.98	90,603	1,510	0.64	1.18	4,143.8	0.18	0.62	2,181.5	1,962.2	10.66
72	74	73	228	147.79	24.06	89,977	1,500	0.63	1.17	5,083.7	0.18	0.62	2,679.3	2,404.4	10.55
70	72	71	137	146.76	24.14	89,351	1,489	0.63	1.17	3,024.2	0.17	0.62	1,595.6	1,428.6	10.43
68	70	69	155	145.73	24.23	88,725	1,479	0.62	1.16	3,387.2	0.17	0.62	1,789.1	1,598.1	10.31
66	68	67	101	144.71	24.31	88,100	1,468	0.62	1.16	2,184.9	0.17	0.61	1,155.3	1,029.6	10.19
64	66	65	113	142.36	23.32	86,670	1,444	0.60	1.15	2,387.9	0.17	0.61	1,265.9	1,122.0	9.93
62	64	63	112	145.86	24.92	88,800	1,480	0.62	1.17	2,450.5	0.17	0.62	1,294.2	1,156.3	10.32
60	62	61	124	143.97	24.83	87,652	1,461	0.61	1.16	2,662.9	0.17	0.61	1,409.2	1,253.7	10.11
58	60	59	39	137.27	24.29	83,572	1,393	0.58	1.14	782.5	0.16	0.61	417.2	365.3	9.37
56	58	57	100	134.00	24.35	81,580	1,360	0.56	1.12	1,939.0	0.15	0.60	1,037.6	901.5	9.01
54	56	55	137	137.02	24.97	83,421	1,390	0.58	1.13	2,741.8	0.16	0.61	1,462.1	1,279.7	9.34
52	54	53	100	139.36	25.94	84,845	1,414	0.59	1.14	2,050.0	0.16	0.61	1,090.4	959.6	9.60

What is a *Forward* Model?

- Predict the output variables of a model based on known parameters and specified input variables.



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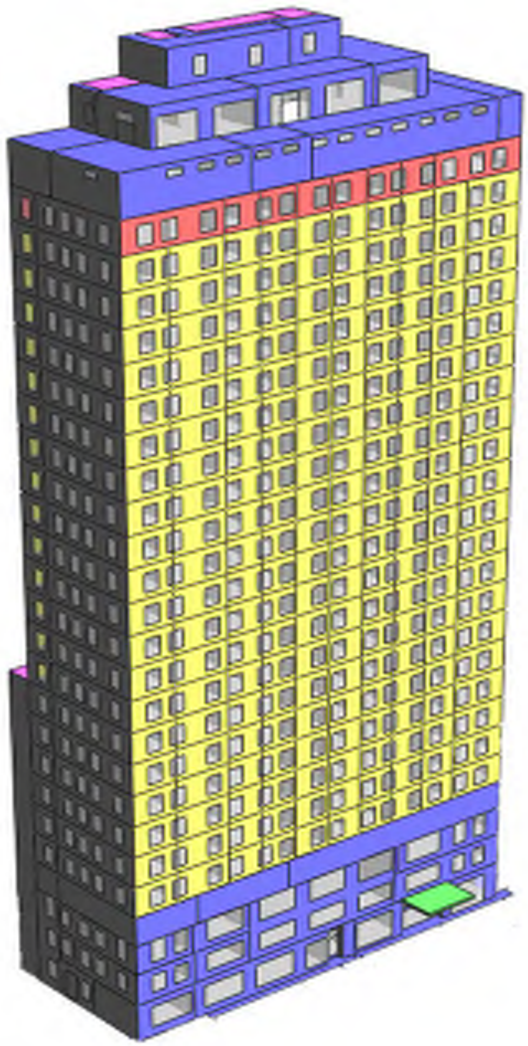
Computer Simulation Models



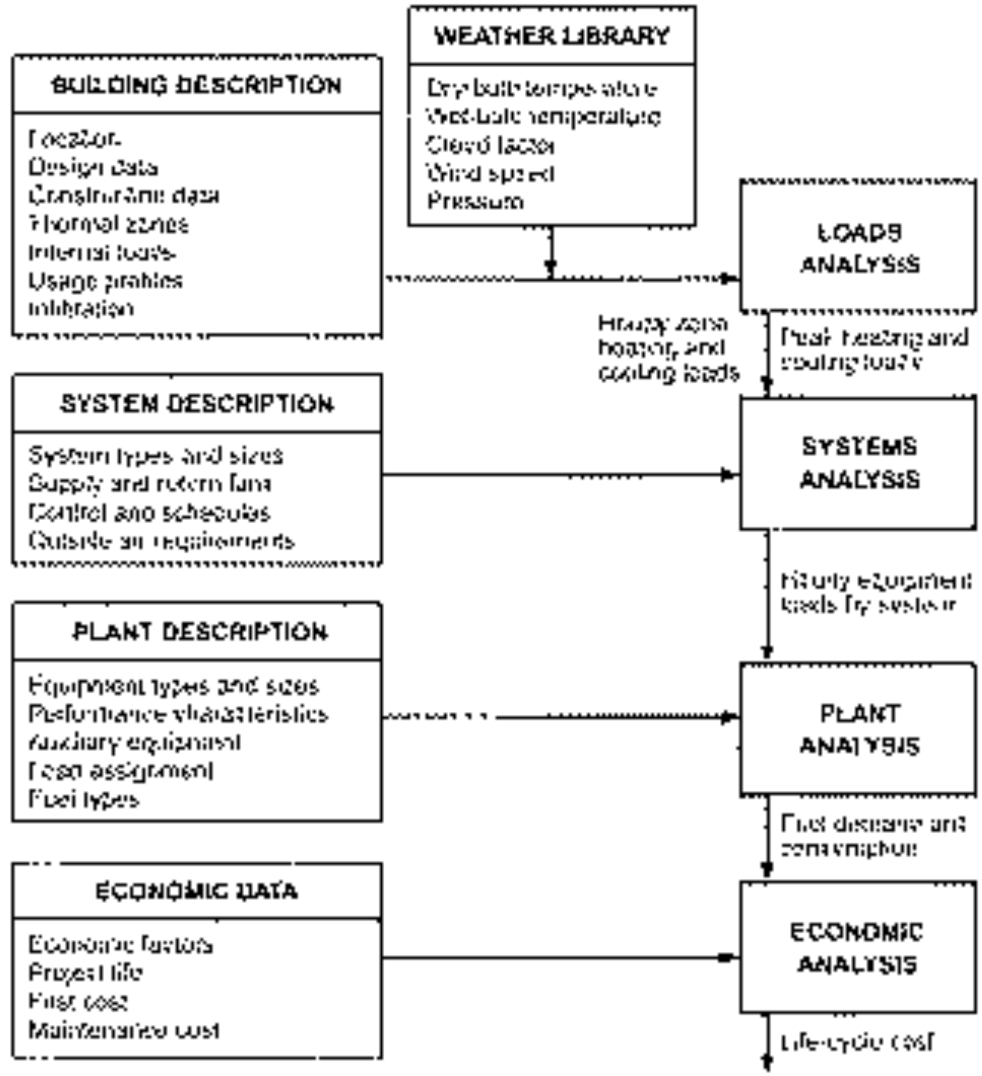
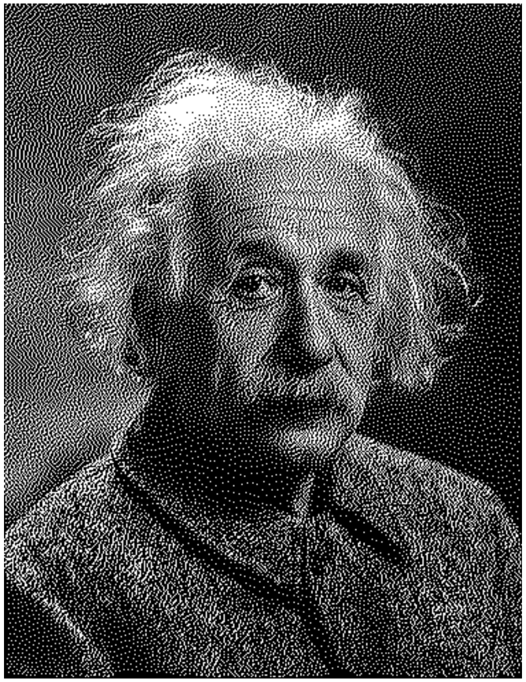


Fig. 1 Flow Chart for Building Energy Simulation Program
(Ayres and Stamper 1995)

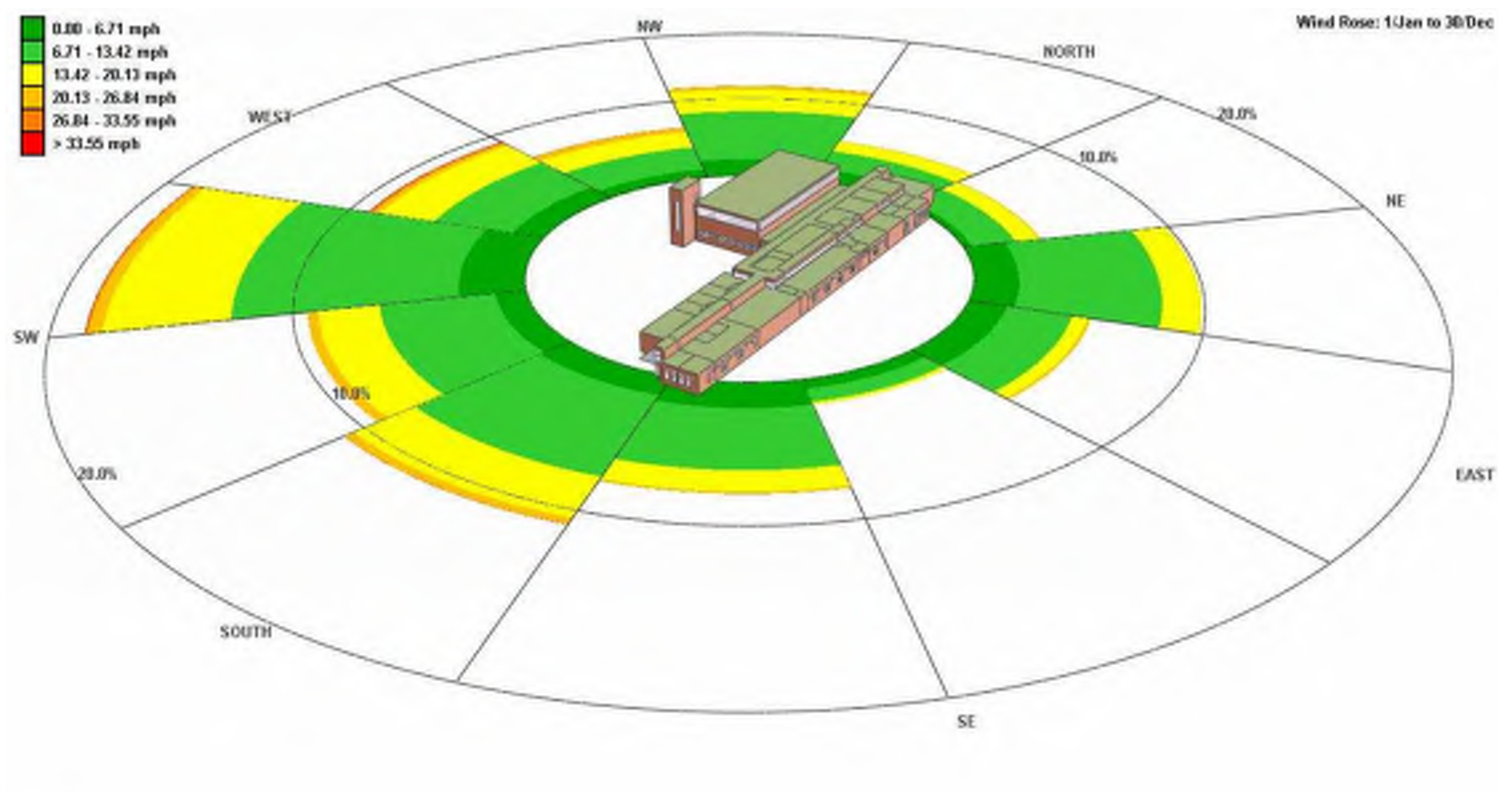
Albert Einstein

"Everything should be made as simple as possible, but not simpler"



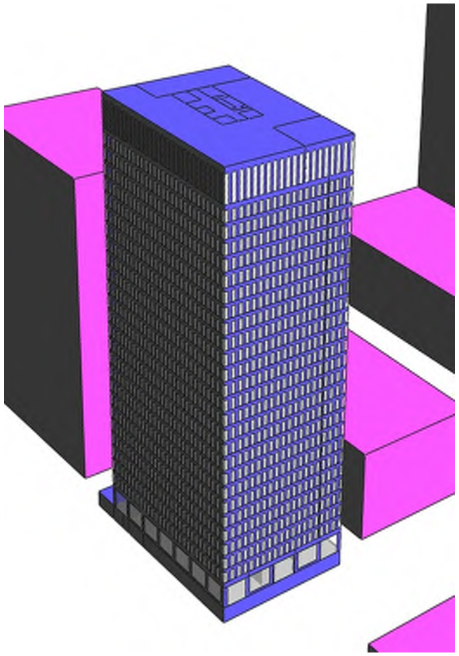
What do you want to accomplish?

- Verify a design model?
- Identify potential?



How to create a calibrated model?

- An existing building, no previous model created
- A newly built building, with design energy model created



How to create a calibrated model?

- Input variables
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  – Uncontrollable variables (e.g. weather)
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  – Physical description (e.g. thermal properties)
- Output
  – Response variables

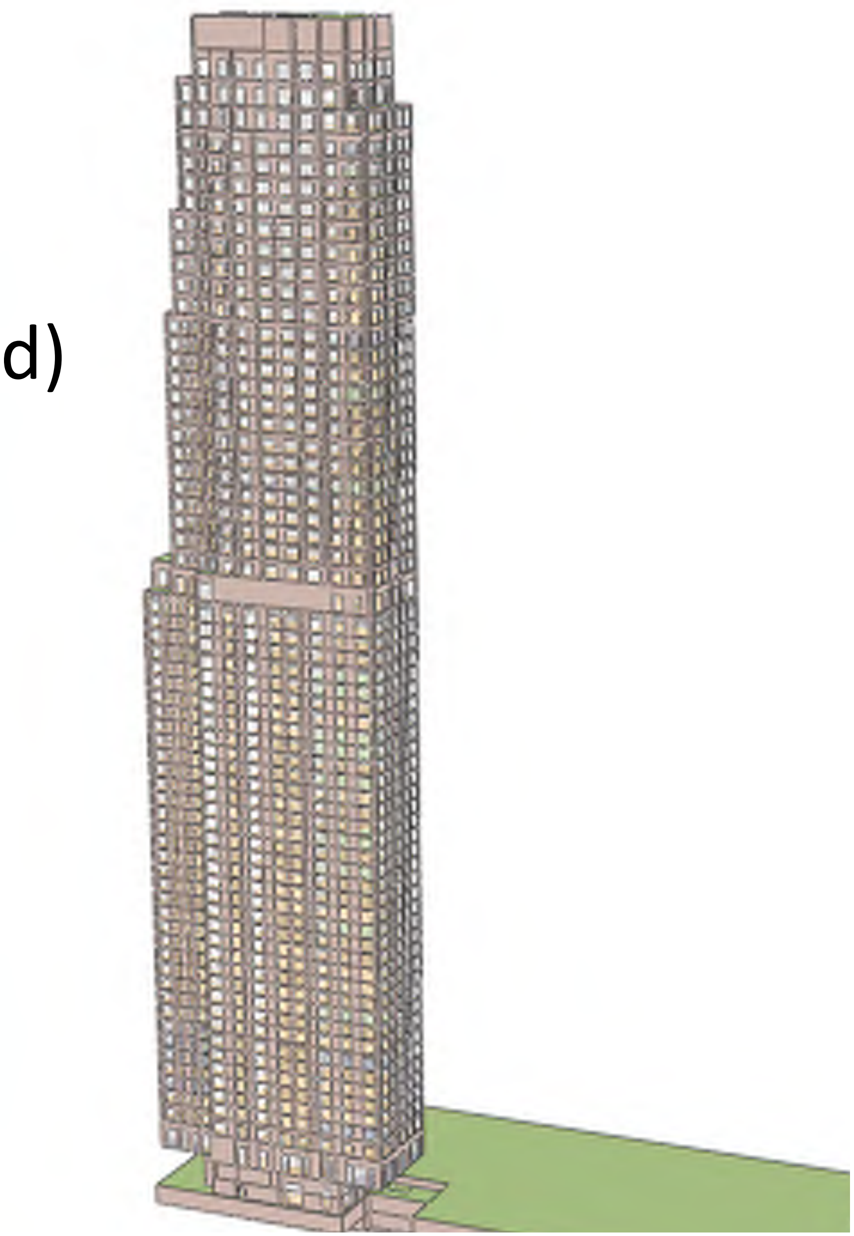
**Fundamentals Handbook 2013 – Chapter 19*

How to model an operating building?

- Building Assessment
  - Data collection
    - Nameplates
    - Schedules of operation
    - Operating setpoints
  - Spot Measurements
    - Amp draw from constant speed loads
    - Air / water flow measurements
    - Building characteristics (e.g. thermal performance)
  - Trend data
    - Variable speed equipment trending (>10 min intervals)
    - Weather!

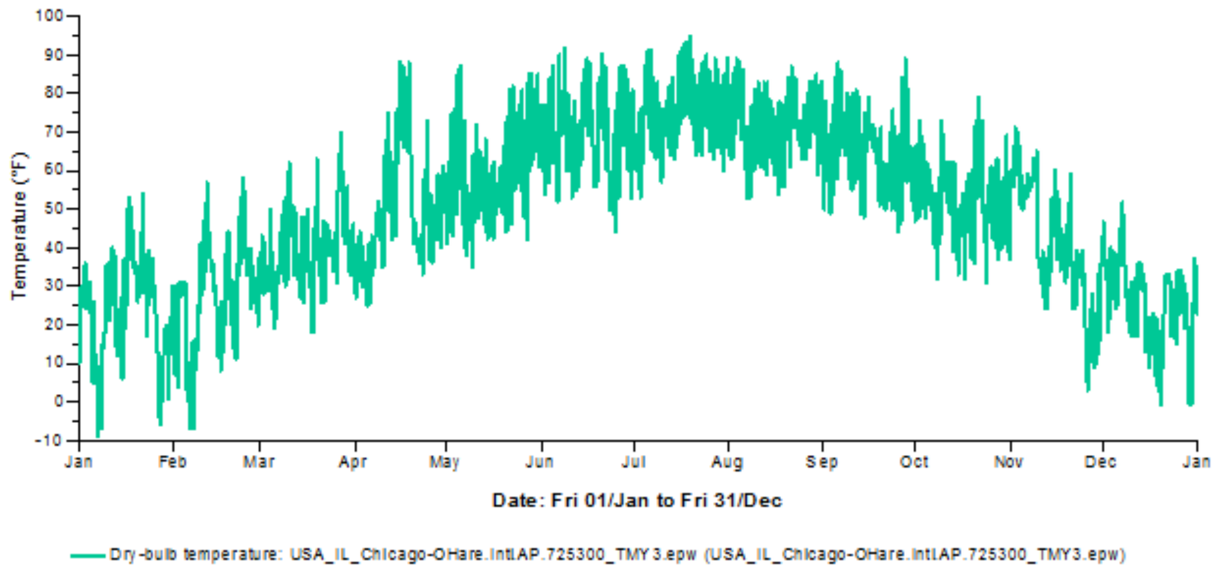
How to model an operating building

- Unknown variables
  - Infiltration
  - Occupancy (can be measured)



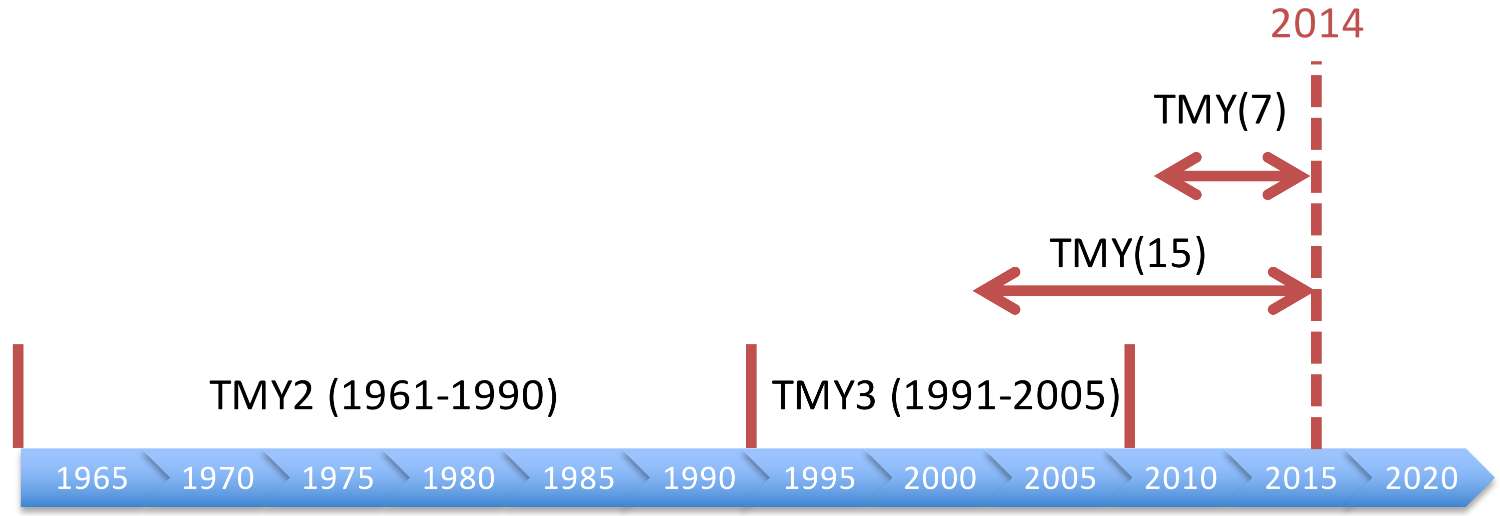
Weather (8,760)

- Dry-bulb temperature
- Wet-bulb temperature
- External dew-point temperature
- Wind speed
- Wind direction
- Direct radiation
- Diffuse radiation
- Global radiation
- Solar altitude
- Cloud cover
- Atmospheric pressure
- External relative humidity
- External moisture content

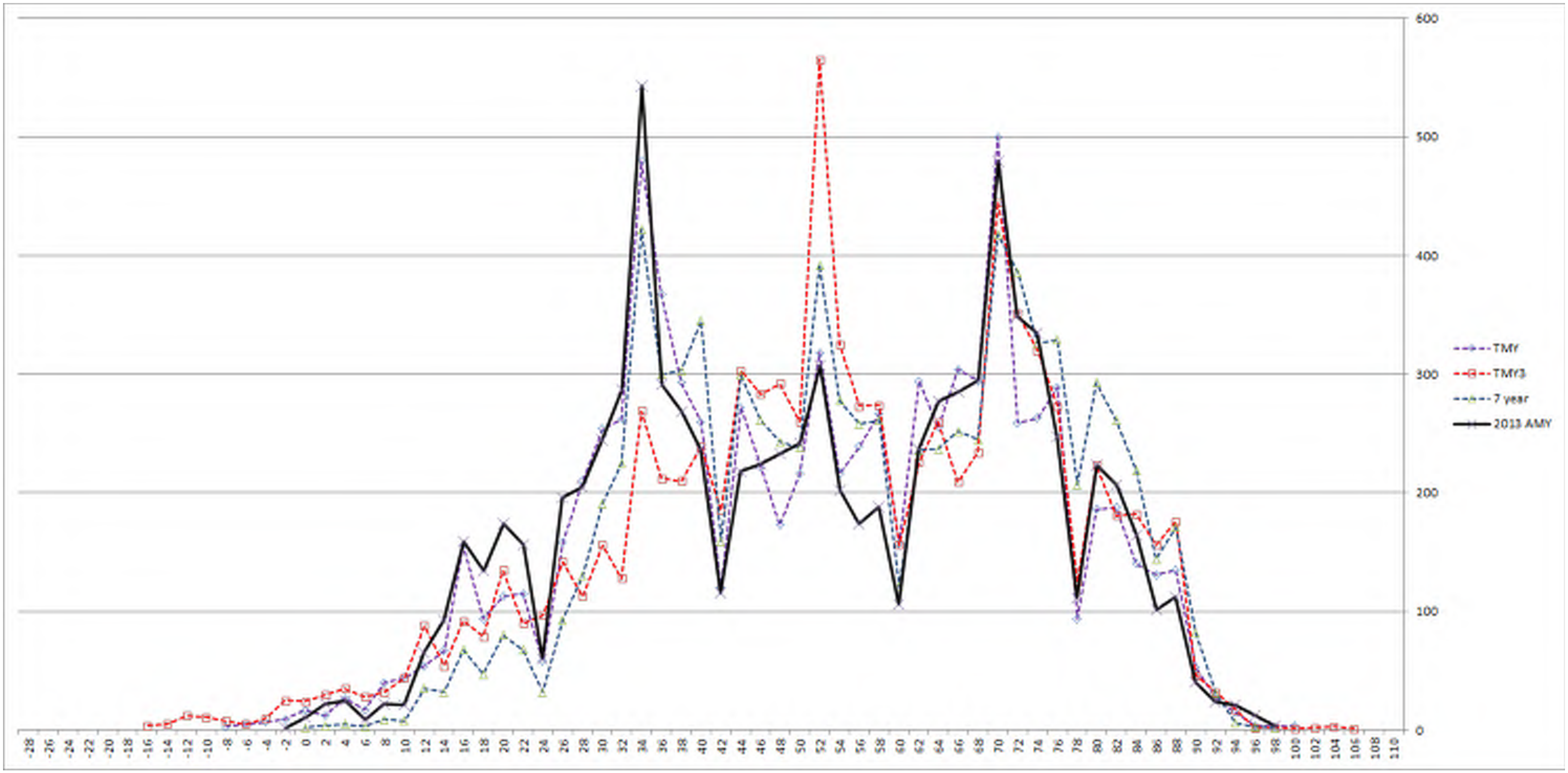


What weather file should you use?

- TMY (Typical Meteorological Year)
- TMY2 – Most Common
- TMY3
- IWEC
- CWEC
- TRY
- DSY
- TMY(7)
- TMY(15)
- AMY



TMY & Shifting Weather Data



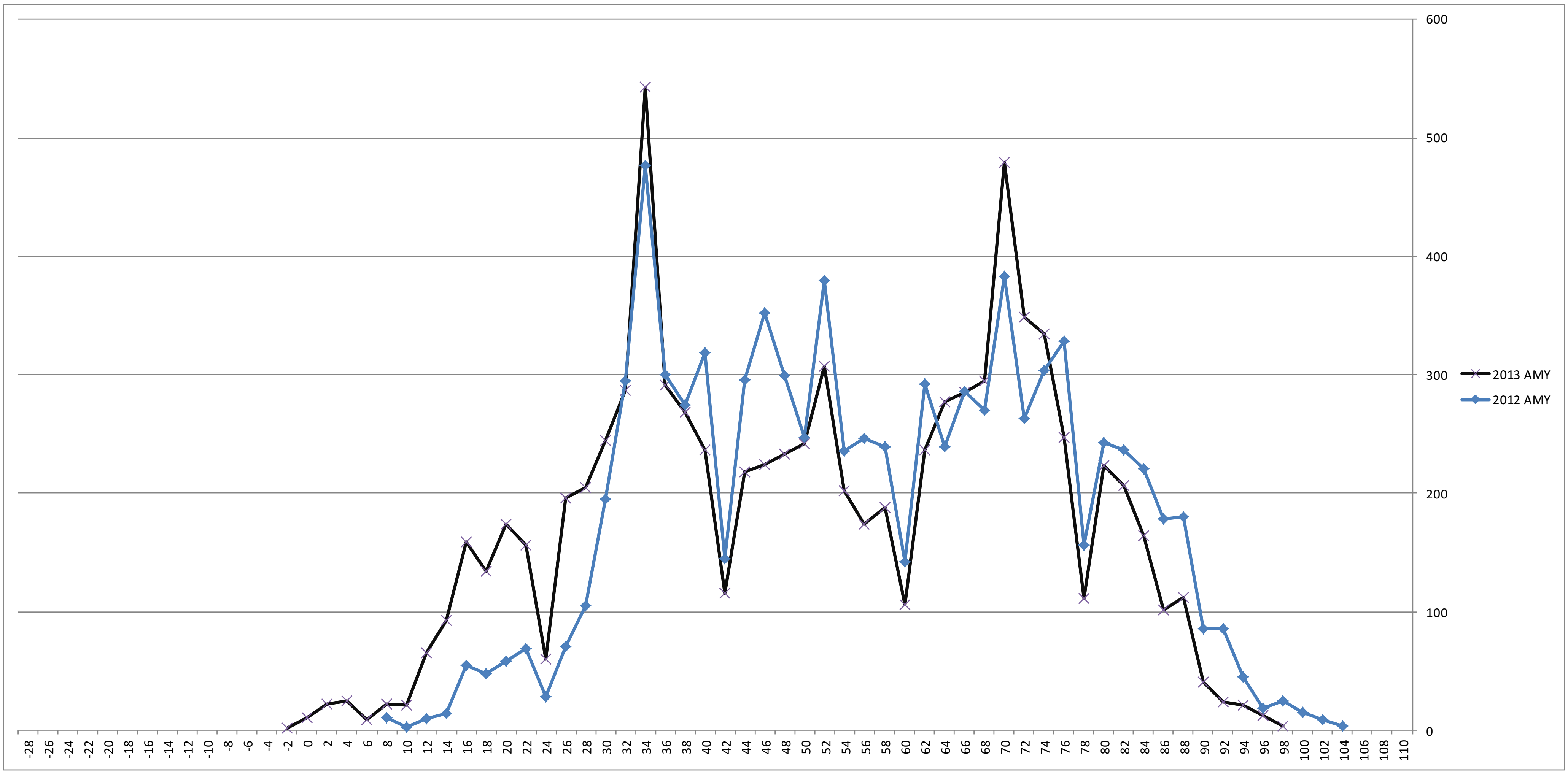
Understanding TMY

KMDW	Year(s)	Mean T	Median T	Max T	Min T	Mean h	Median h	Max h	Min h
TMY	1948-1980	50.86	51.98	98.96	-9.94	18.99	17.90	41.77	-2.07
TMY 3	1991-2005	52.49	53.60	104.00	-17.14	19.85	19.13	42.00	-3.88
7 Year	2007-2013	55.06	55.40	96.80	-0.40	20.72	19.36	46.94	0.54
2012	2012	55.70	55.40	102.20	6.80	20.48	19.36	46.94	2.16
2013	2013	50.63	51.80	96.80	-2.20	18.92	18.02	45.06	0.10

	Current kWh	Proposed kWh	kWh Savings
TMY	369,988	313,558	**56,430**
TMY 3	361,269	308,529	**52,740**
7 year	370,957	319,067	**51,890**
2012	373,992	320,868	**53,124**
2013	373,256	317,322	**55,933**

- Increasing average/median temperature
- Increasing average/median enthalpy
- No year is “typical”

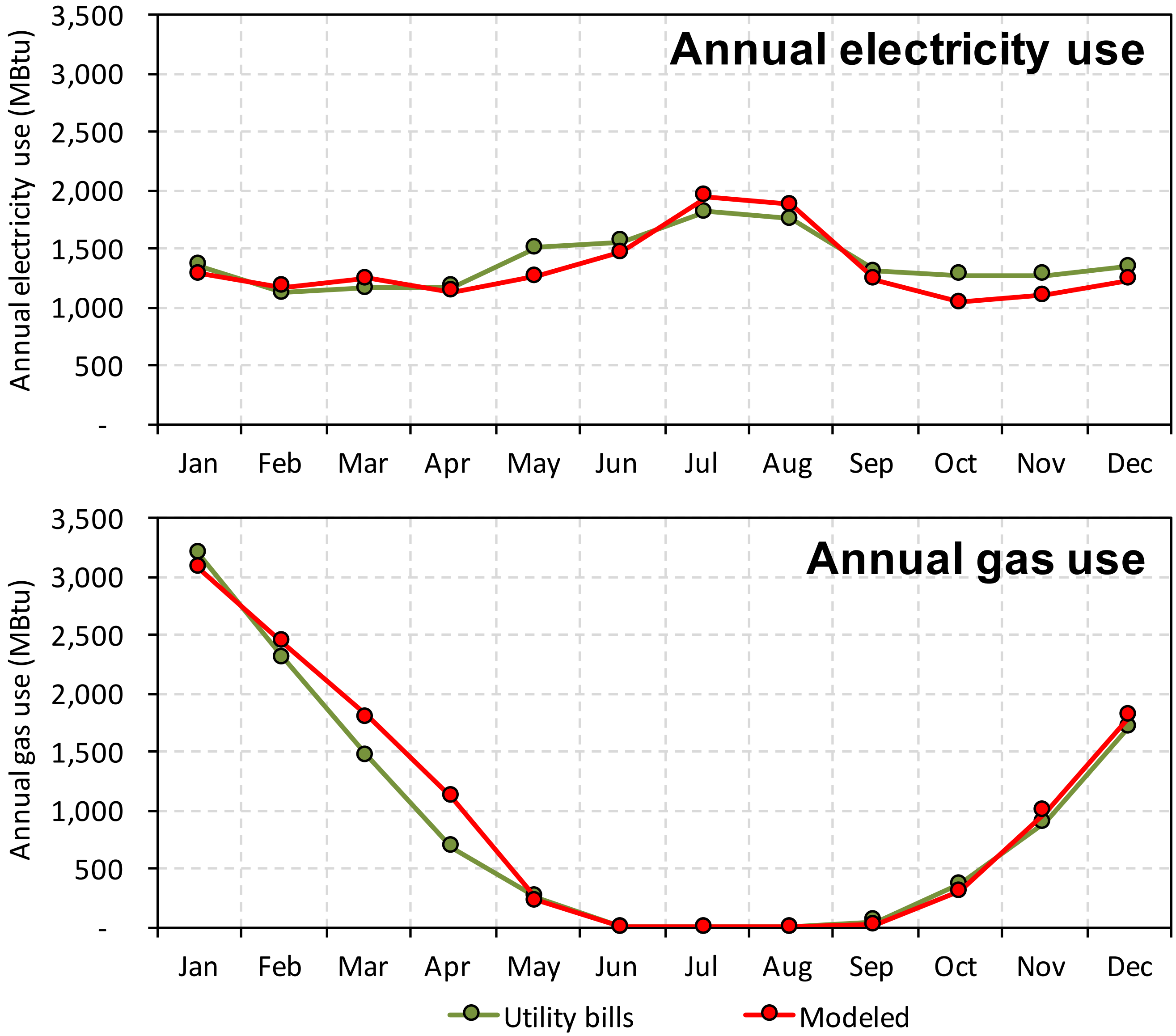
Actual Meteorological Year: 2012 vs. 2013



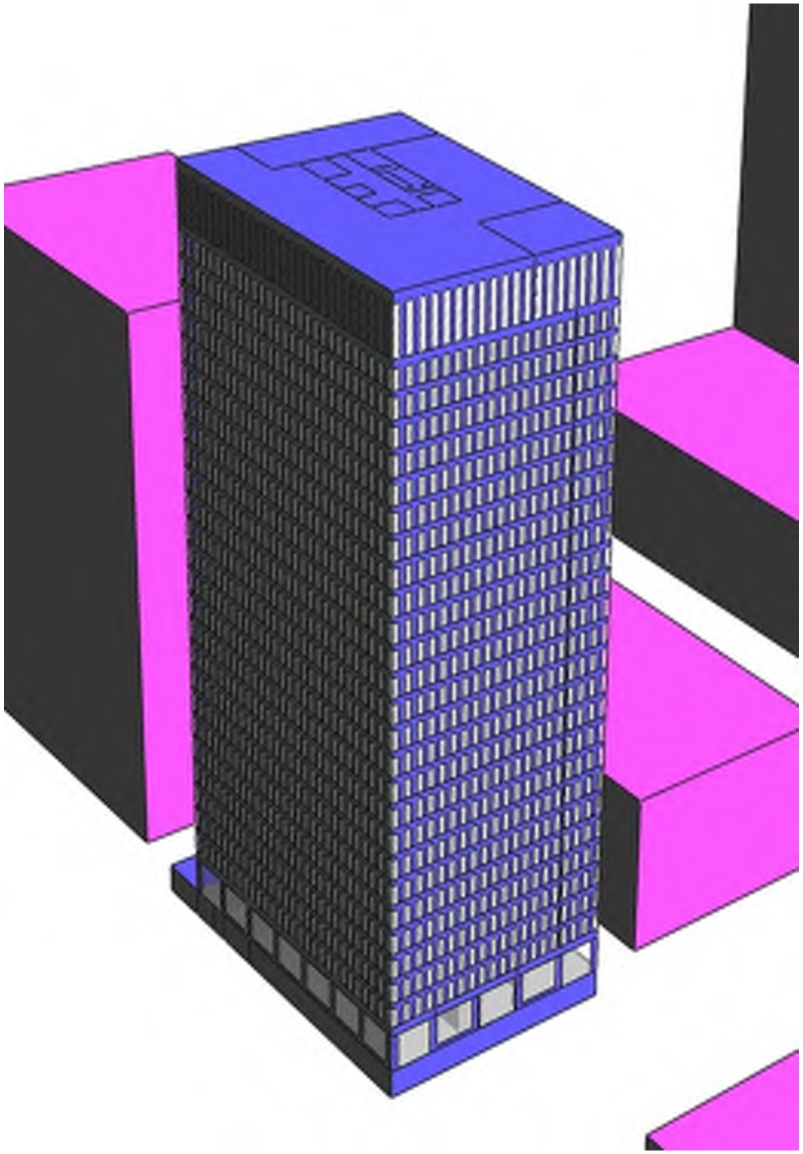
How accurate are energy models?

- ASHRAE Guideline 14-2002
- ASHRAE Standard 140-2011
- International Performance Measurement & Verification Protocol (IPMPV)
  - Normalized Mean Bias Error (NMBE)
    - 5% with Monthly Data
    - 10% with Hourly Data
  - Coefficient of Variation of the Root Mean Square Error (CVRMSE)
    - 15% with Monthly Data
    - 30% with Hourly Data

Calibrated model results



Model assumptions



Known:

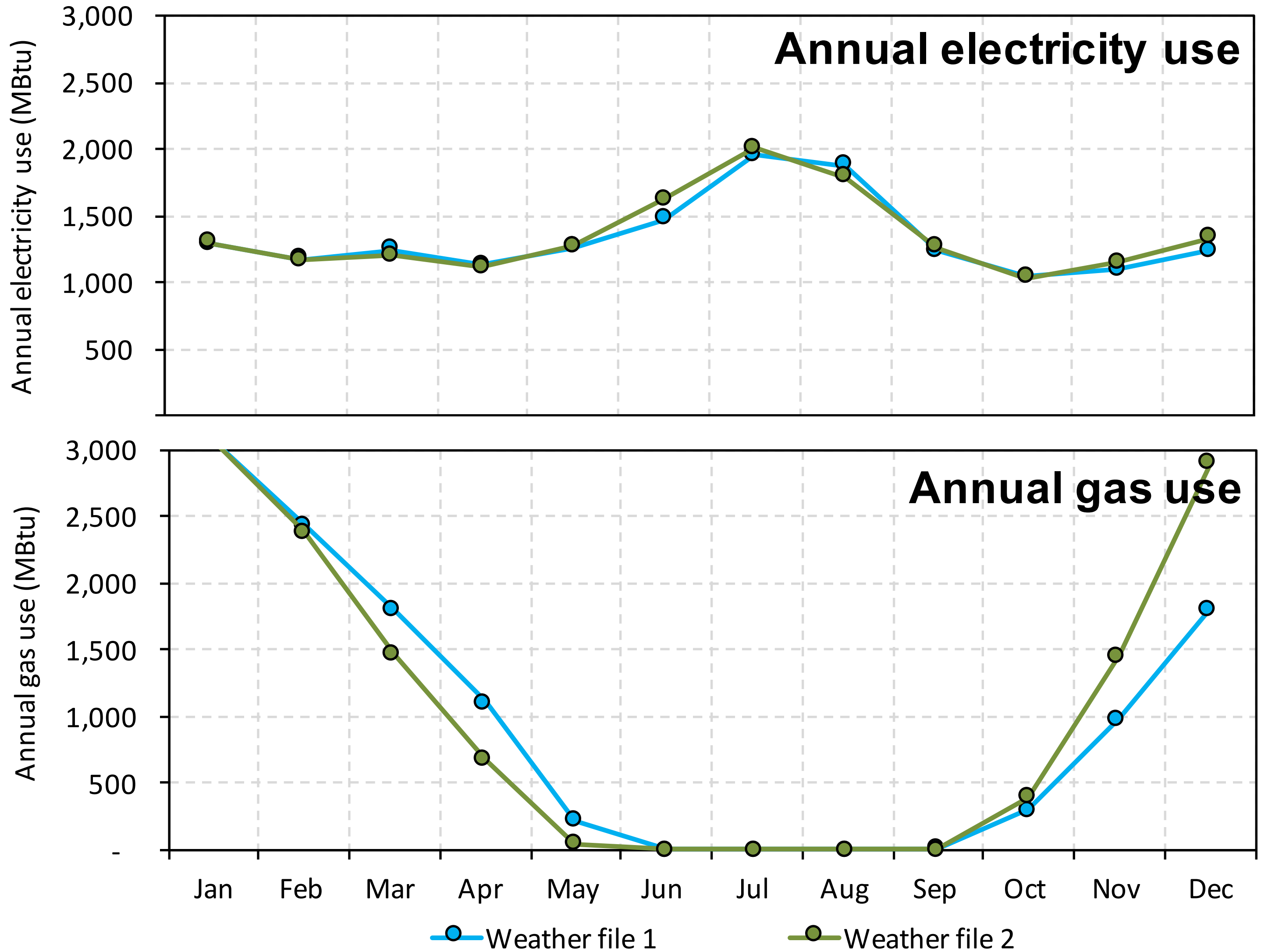
- Building context and surrounding buildings
- Building geometry
- Envelope materials
- Room temperature settings
- HVAC system components and capacities
- Spot measurements

Unknown:

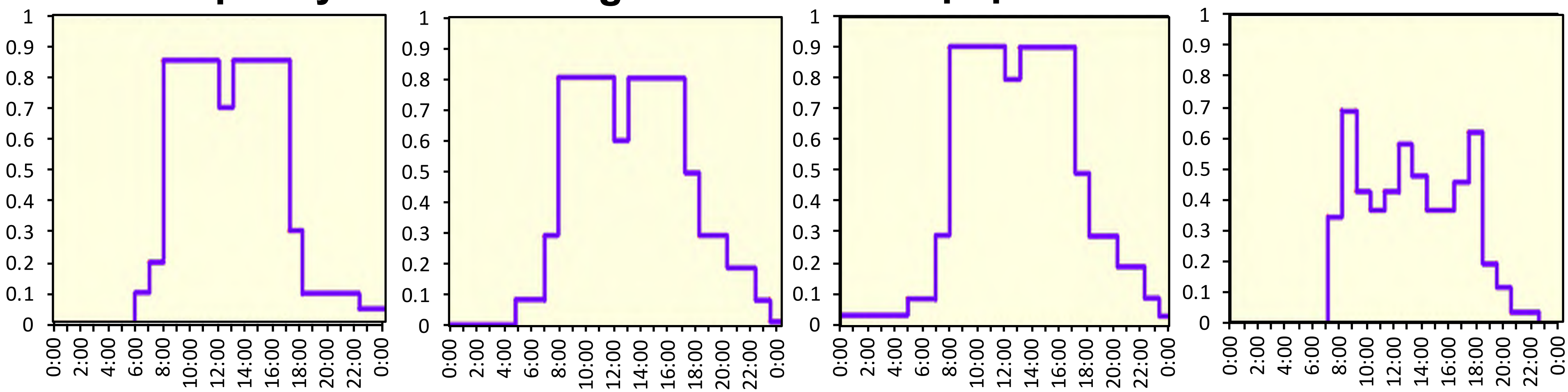
- Individual floor tenants' layouts
- Energy usage profiles (occupancy, lighting, equipment schedules)
- Weather data and microclimate
- HVAC system settings and performance
- Air infiltration rates

Importance of selecting right weather data

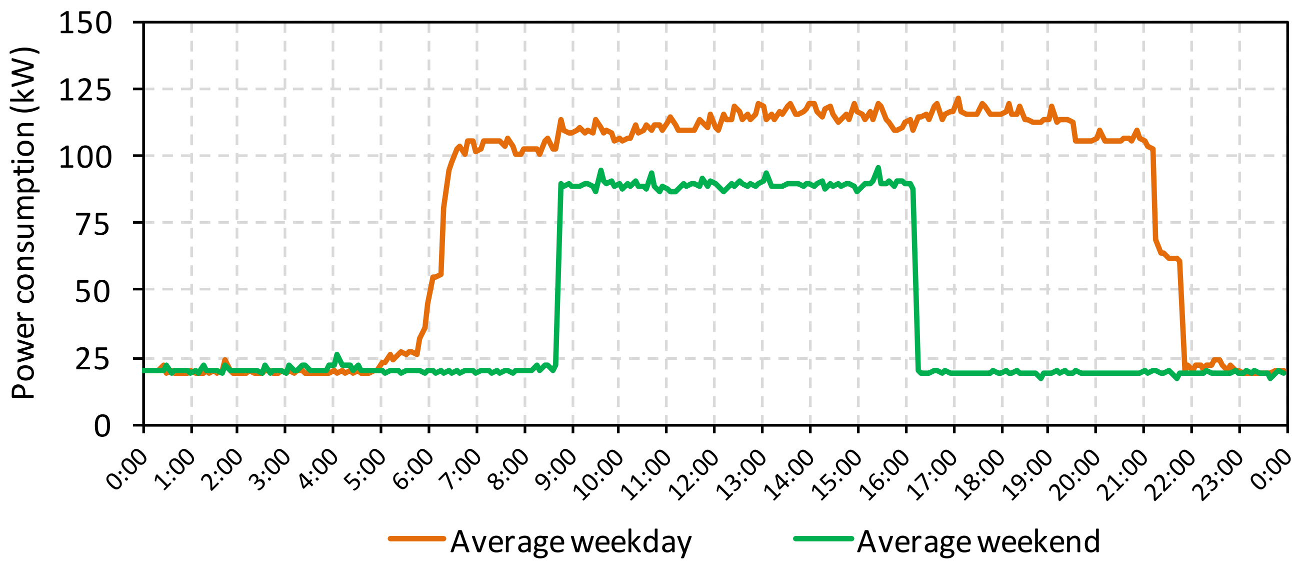
Chicago 2011 file (1) VS. Chicago TMY3 file (2)



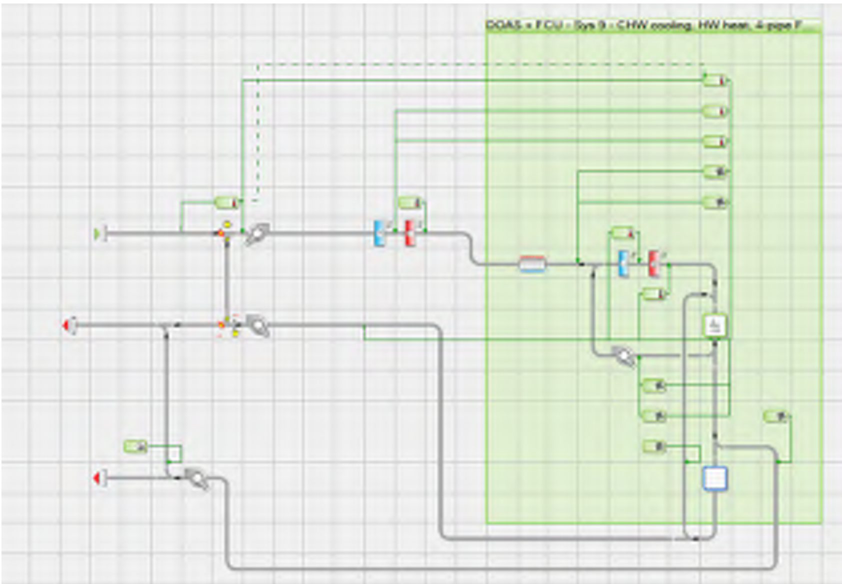
Daily energy usage profiles

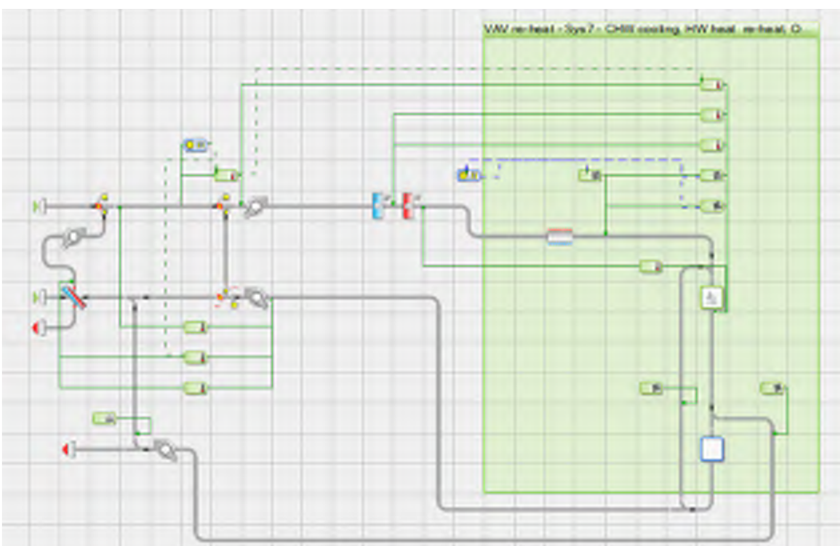


Actual daily energy use profile (from ComEd Energy Insights)



HVAC systems





- 7 HVAC systems with air handling units:
  - Serving south perimeter zones
  - Serving east, west, & north perimeter zones
  - Serving central core zones
  - 1 unit serving the main lobby
  - 1 unit serving retail zones (no information available)
- 1,200 fan coil units
- 2 steam boilers (10,000 MBH each)
- 2 chillers (500 tons each)
- 1 cooling tower

Energy savings results

	Existing	Window 1	Window 2	Window 3
Energy use				
Electricity (kBtu/year)	15,401,917	15,157,815	15,135,081	15,142,421
Gas (kBtu/year)	11,740,434	7,877,407	7,397,939	7,537,130
Total (kBtu/year)	27,142,351	23,035,221	22,533,019	22,679,551
Electricity savings (%)		2%	2%	2%
Gas savings (%)		33%	37%	36%
Total savings (%)		**15%**	**17%**	**16%**
Energy use intensity (kBtu/ft^2)	75.5	64.1	62.7	63.1
Energy cost				
Electricity ($/year)[1]	478,920	471,330	470,623	470,851
Gas ($/year)[2]	79,350	53,241	50,001	50,941
Total ($/year)	558,271	524,571	520,624	521,793
Total savings ($)		**33,699**	**37,647**	**36,478**
Total savings (%)		**6%**	**7%**	**7%**
Total savings ($/ft^2)		0.09	0.10	0.10

[1]625 N. Michigan blended electricity tariff: 0.11 $/kW-hr as of 2011

Image Credit: Walgreens, Co.

Resources

- Reference Materials:
  - ASHRAE Handbook – Fundamentals 2013
    - Chapter 19
  - ASHRAE Guideline 14-2002
  - ASHRAE Standard 55-2010
  - ASHRAE Standard 62.1-2007 / 2010
  - ASHRAE Standard 90.1-2007 / 2010 / 2013
  - ASHRAE Standard 100-2006
  - ASHRAE Standard 140-2011
  - Energy Information Administration (Average Utility Data)
  - EPA Target Finder
  - International Energy Conservation Code 2012
  - IESNA Lighting Handbook, 9th Edition
  - IPMPV
  - Building Energy Modeling – An ASHRAE Certification Study Guide
- Software:
  - DOE Approved Software
  - eQuest (Free)
  - Trane Trace 700 (30-day Trial)
  - IES<VE> (30-day Trial)
- Weather Data:
  - ENERGY PLUS Weather Files
  - Degree Days.net
  - NREL (TMY2 / TMY3)
  - Weather Analytics