TOWARDS ZERO-ENERGY BUILDINGS

Issues and Strategies

September 21, 2011

Tom Lunneberg, P.E.
Innovative Energy Solutions
Carlsbad, California

TOPICS

- What is a Zero-Energy Building?
- Energy Usage Characteristics
- Impact on Building Design Process
- Building System Strategies
- Analysis Methods
- Case Studies

WHAT IS A ZERO-ENERGY BUILDING (ZEB)?

- Definitions
  - “Zero Electricity” Building
    - Only electrical energy is considered
    - Can be either “Instantaneous” or “Annual” zero-electricity building
  - “Annual” ZEB
    - Building uses utility-supplied energy at times and exports energy at other times, but on an annual basis exports more than it consumes
  - “Instantanous” or “True” ZEB
    - Building uses no utility-supplied electricity or fossil fuels at any time (e.g. totally off the grid)

ZERO-ELECTRICITY BUILDING EXAMPLE

- New aquatic Center proposed to be a net *electrical* exporter
- Fuel cells proposed to meet electrical and partial thermal demands
- Proposed solution exports 289% of estimated electrical consumption but consumed 315,000 therms of natural gas per year

	Proposed Aquatic Center Demand	**One Fuel Cells**	**Two Fuel Cells**
Electrical Peak Demand/ Capacity	300 KW	190 KW (63%)	380 KW (127%)
Electrical Consumption/ Output	1,140,000 kWh/yr	1,650,000 kWh/yr **(144%)**	3,300,000 kWh/yr **(289%)**
Pool Heating Peak Demand/ Capacity	3,000 kBTU/hr	900 kBTU/hr (30%)	1,800 kBTU/hr (60%)
Pool Heating Consumption/ Output	220,000 th/yr	85,000 th/yr **(39%)**	160,000 th/yr **(73%)**
Fuel Cell Power Plant Consumption	---	155,000 th/yr	315,000 th/yr

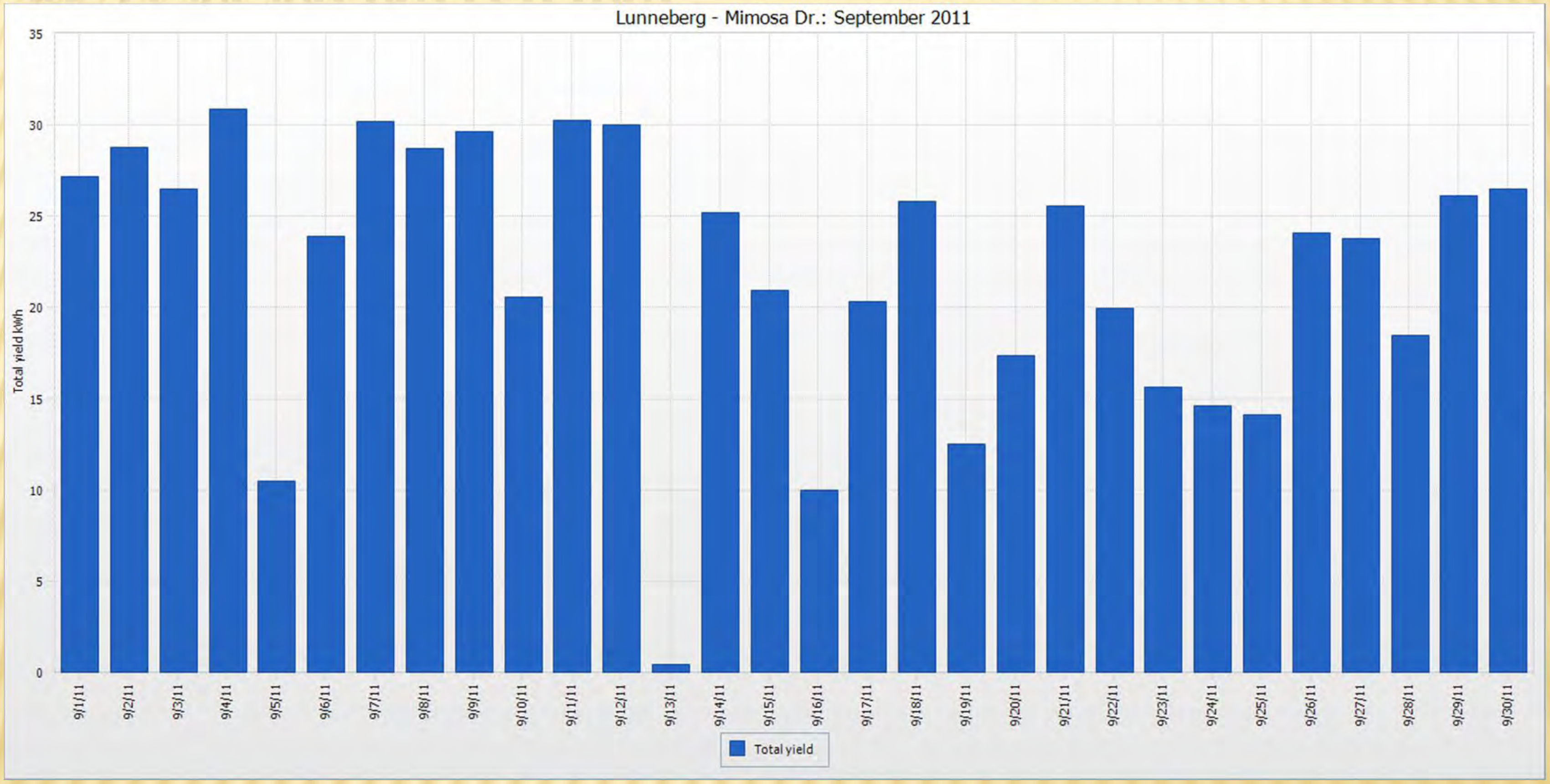
ANNUAL ZERO-ENERGY BUILDING

- Generates as much (or more) energy than it consumes
- Includes all fuels (gas and electricity)
- The grid is the battery
- Accounting issues abound
  - Basis (cost or energy)
  - Source-to-site conversion efficiency
  - Time of Use

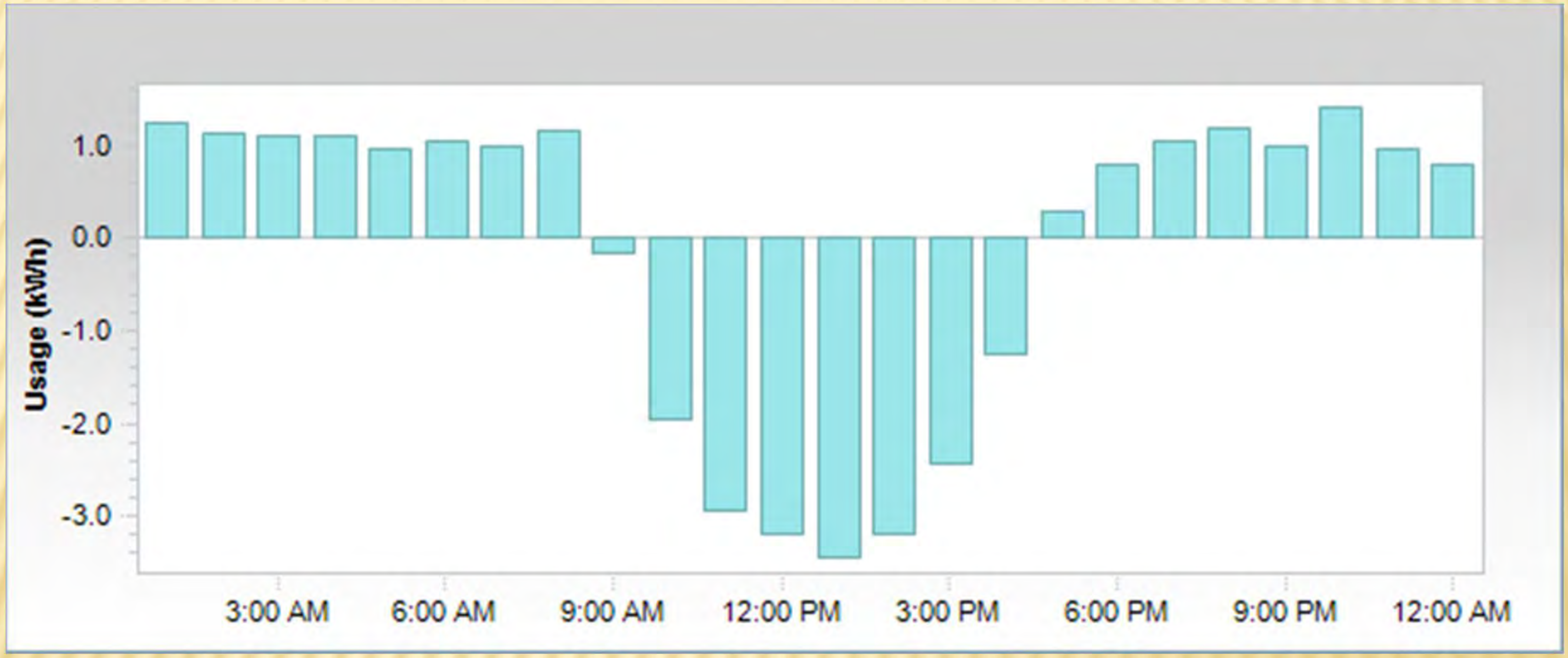
ANNUAL ZERO-ENERGY ACCOUNTING

- Some days the building generates more energy than it consumes, but…
- Other days it consumes more than it generates, so…
- Most buildings look at a 12-month period for reconciliation
- Smart metering and online access facilitate performance evaluation

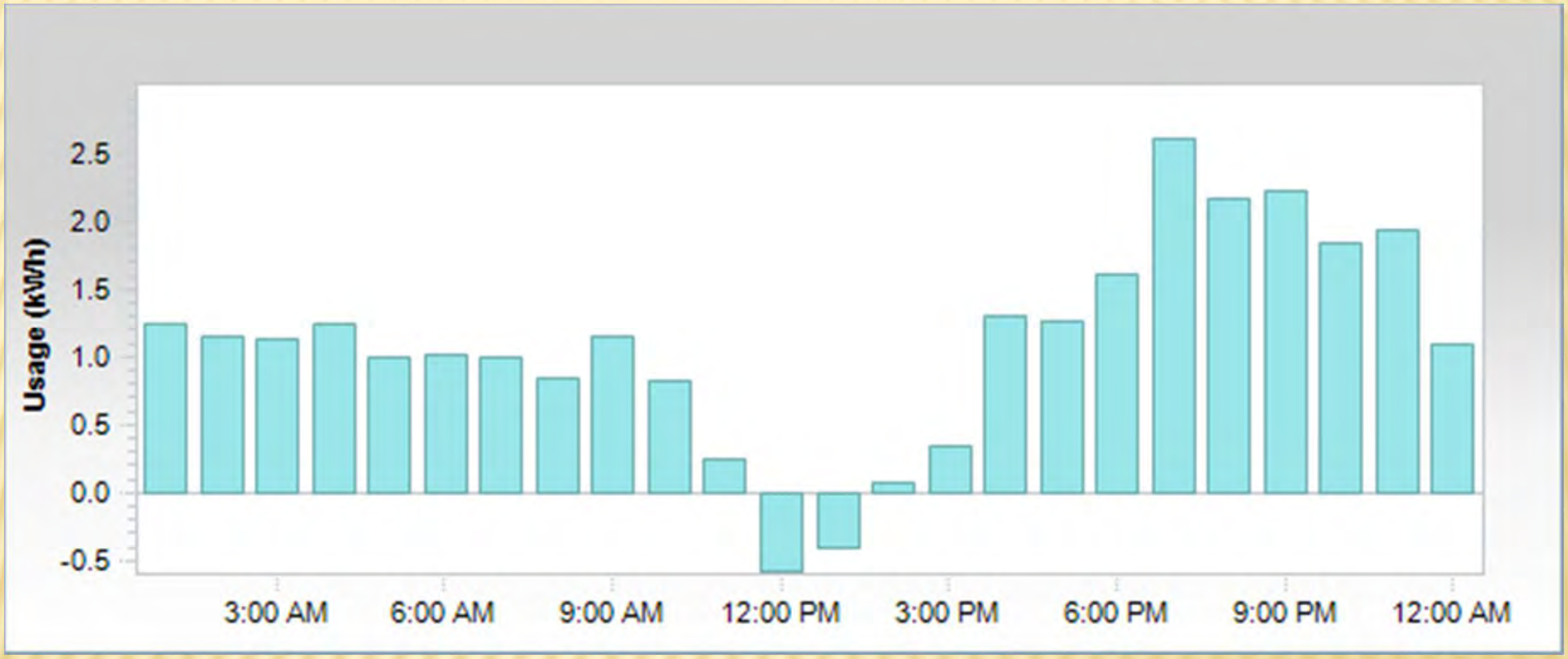
MONTHLY PV GENERATION FROM ONLINE SYSTEM MONITORING



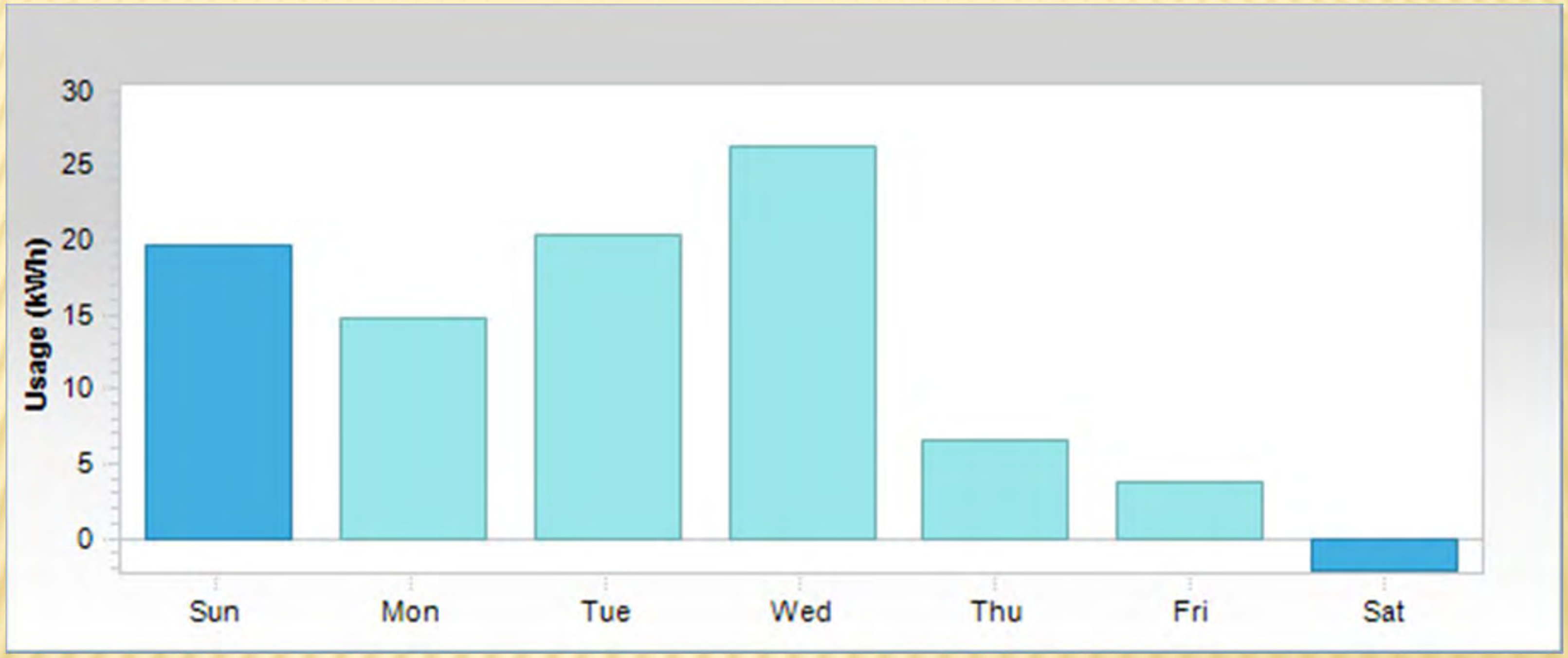
SUNNY WEEKEND DAY (CONSUMPTION + PV GENERATION)



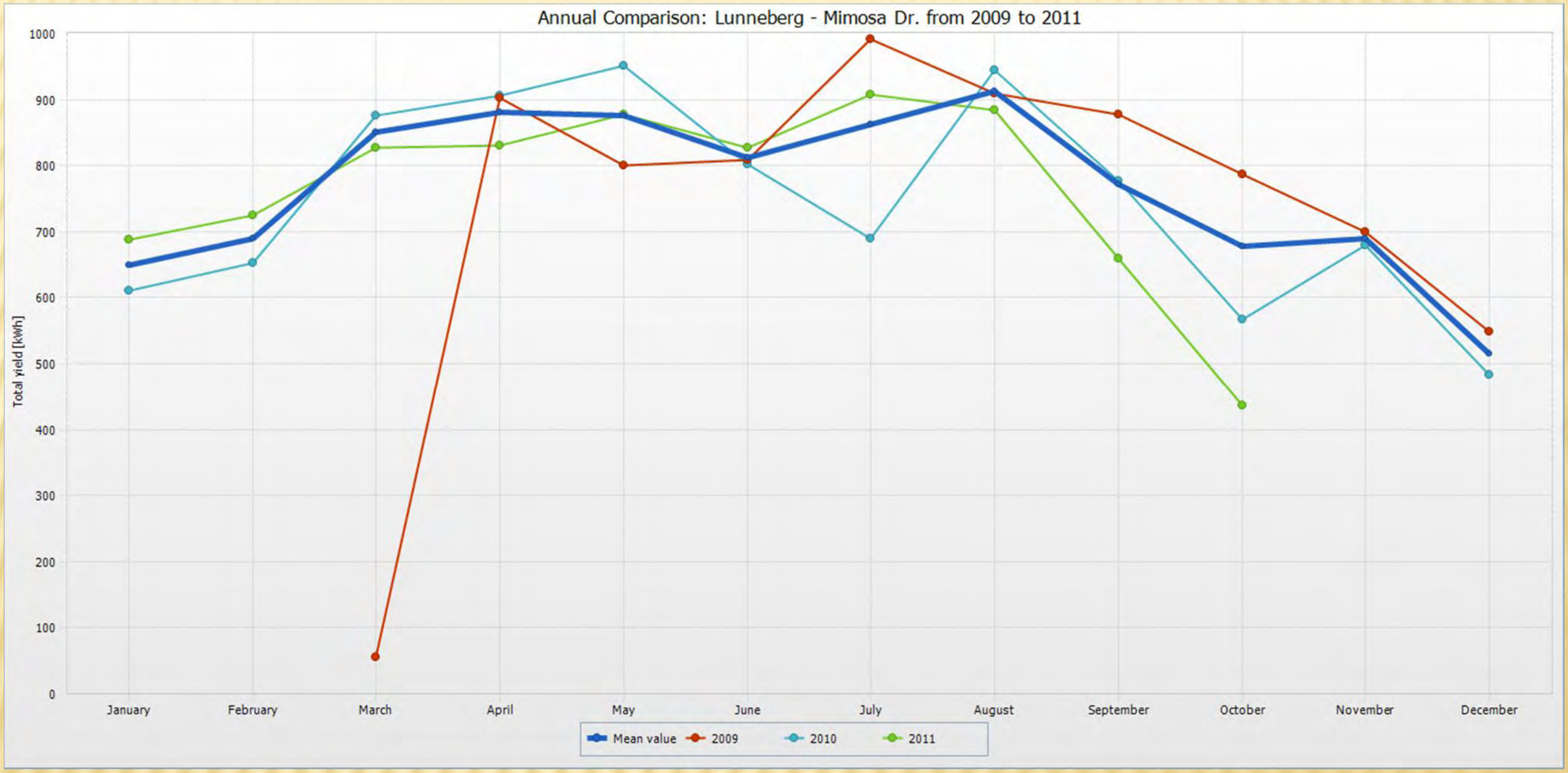
RAINY WEEK DAY (RESIDENTIAL)



NET ZERO ENERGY: SOME DAYS ARE BETTER THAN OTHERS…



SOLAR PRODUCTION



TRUE ZERO-ENERGY BUILDING

- "Off the Grid" (literally or figuratively)
- Self-sufficient in meeting energy demands
- Typically requires an energy storage system
- Building design focused on load minimization and maximizing energy output

Kaupoa Beach Village, Molokai

LA Audubon Visitor Center

ON-SITE RENEWABLE ENERGY SYSTEMS

- Wind, hydroelectric, geothermal, biomass… and *others* are all possibilities, but today…
- …we are limiting our discussion to on-site *photovoltaic* (PV) systems

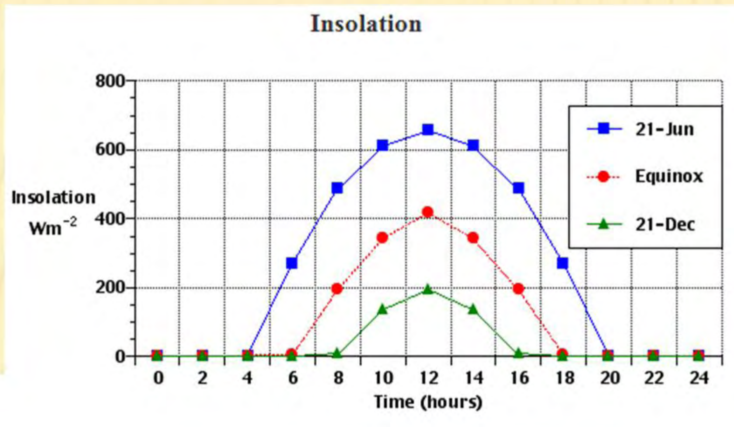
IMPACT ON BUILDING DESIGN PROCESS

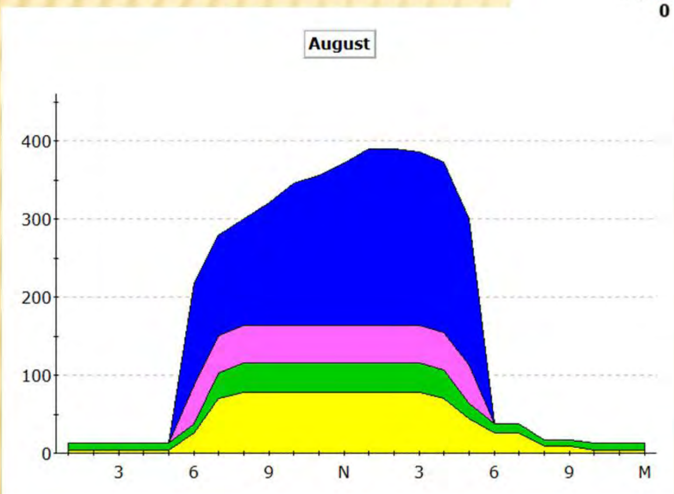
- Must create synergy between building and climate
  - Climate responsive design features
- Must create synergy between building and renewable energy systems
  - Complementary relationship between load profile and renewable energy availability
- Energy efficient design *still* makes sense!
  - High efficiency, lighting, envelope, and HVAC usually more cost effective than on-site renewables on a $/kWh saved basis

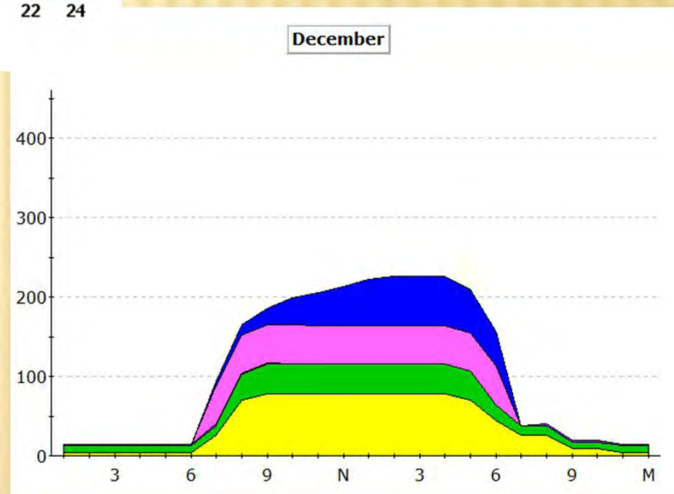
ZEB BUILDING DESIGN GOALS

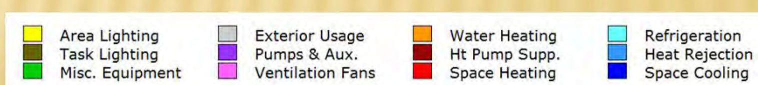
- Integrated Design Process is essential
- Minimize peak loads
  - Makes it easier to meet peak with on-site power
  - Improving HVAC efficiency an essential element
  - Maximizing use of natural light greatly reduces lighting demand in the afternoon
- Reduce/eliminate unnecessary energy use
  - Scheduling of lights, HVAC
- Use site-generated energy to meet peak loads
  - Don't use central PV to power the landscape lights!
- Zero Energy Goal (annual or instantaneous) impacts PV system configuration
  - Maximize annual or summer on-peak output?

SEASONAL DEMAND AND SOLAR VARIATION





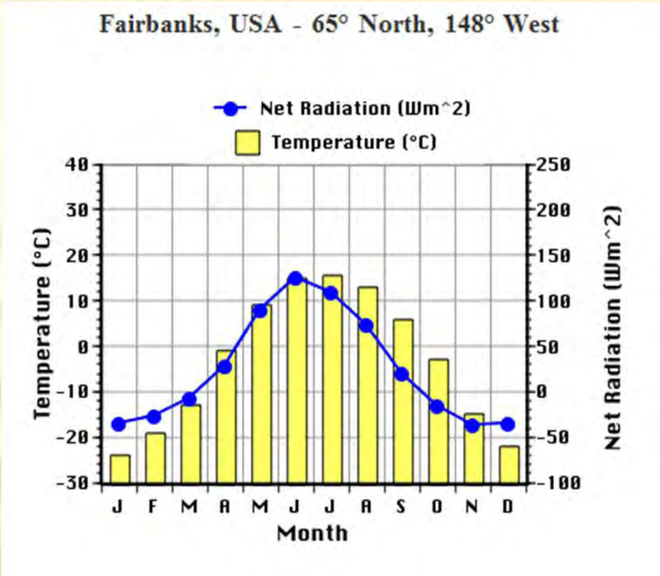


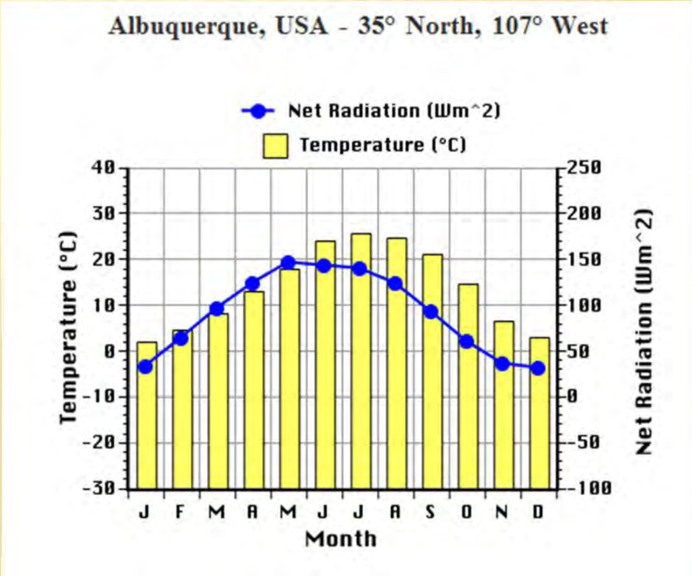


Solar Date Source: www.physicalgeography.net

SOLAR AND THERMAL VARIATION

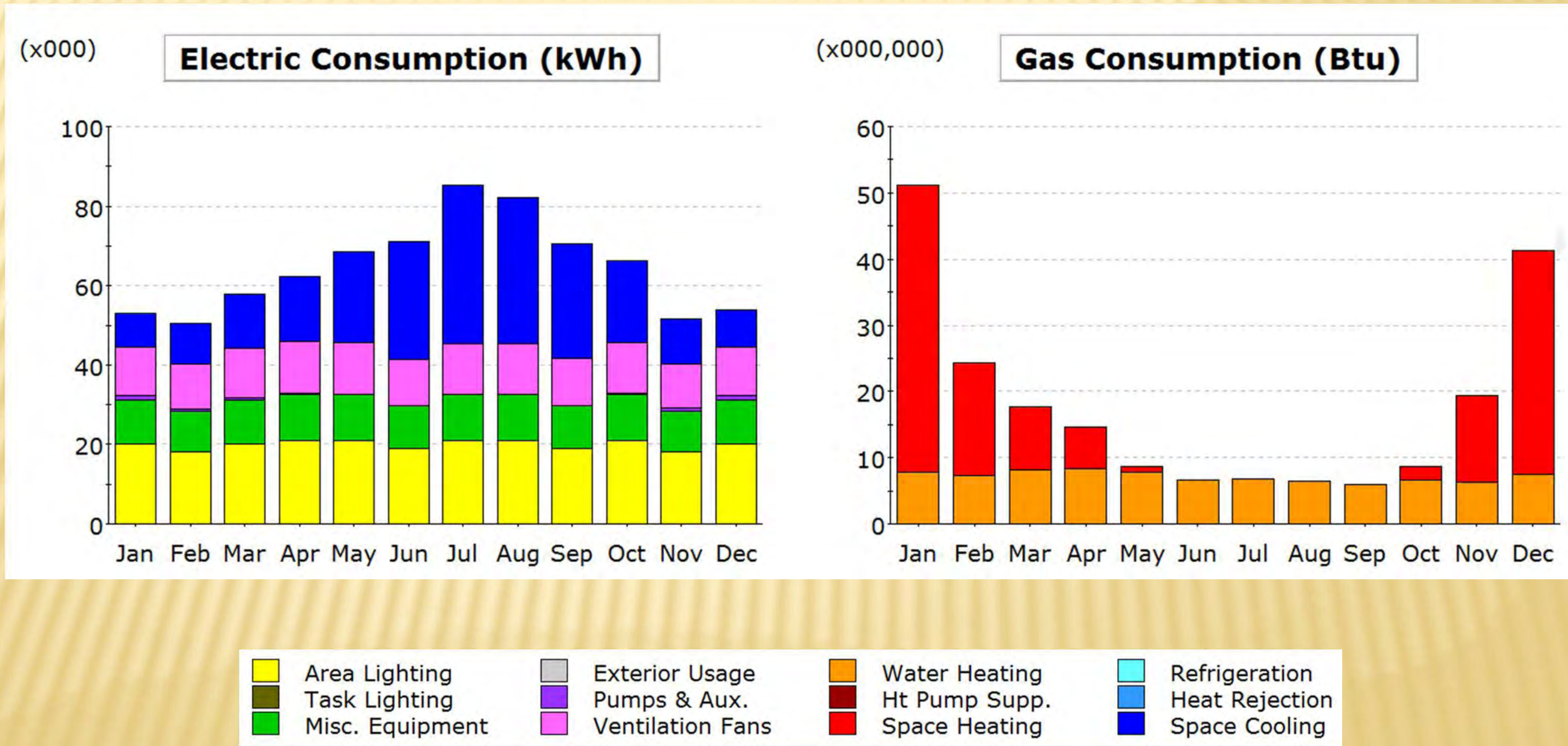
Climate and microclimate determine building thermal loads and solar availability





Source: www.physicalgeography.net

MONTHLY CONSUMPTION VARIATION

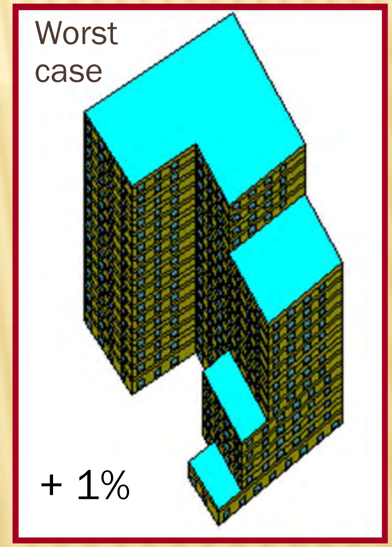


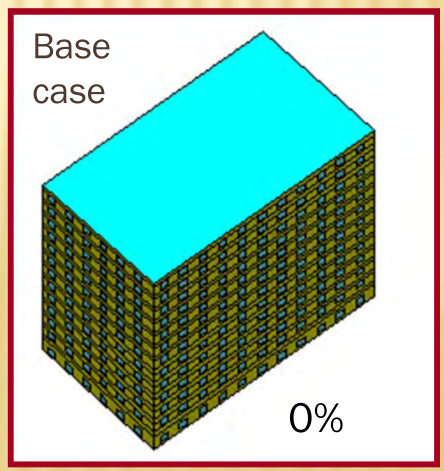
"ZEB FRIENDLY" DESIGN FEATURES

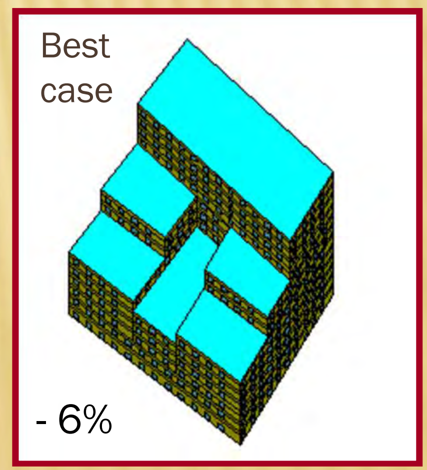
- Building form and orientation
  - Maximize availability of daylight
  - Minimize cooling loads
  - Consider roof configuration and orientation for installation of PV systems
- High efficiency lighting and daylighting
- High efficiency HVAC

FORM AND ORIENTATION IMPACT LOADS

- Different building forms have different associated solar heat gains
  - Cube-shaped building has least impact by sun due to low surface-to-volume ratio
  - Careful design of building form, and placement of glazing can significantly reduce total building energy use
- Orient longer exposures north-south
  - Reduces solar gain
  - Increases controllability of daylight







ROOF CONFIGURATION, BUILDING ORIENTATION, AND SURROUNDING IMPACT PV PERFORMANCE

MAXIMIZE DAYLIGHTING

- Separate view glass from daylight glass
- Use reduced visible light transmittance for vision glass (typ 25% to 35%)
- Use higher visible light transmittance for daylighting glass (typ 60% to 70%)
- Increase daylighting penetration into the building with light shelves on north and south facades

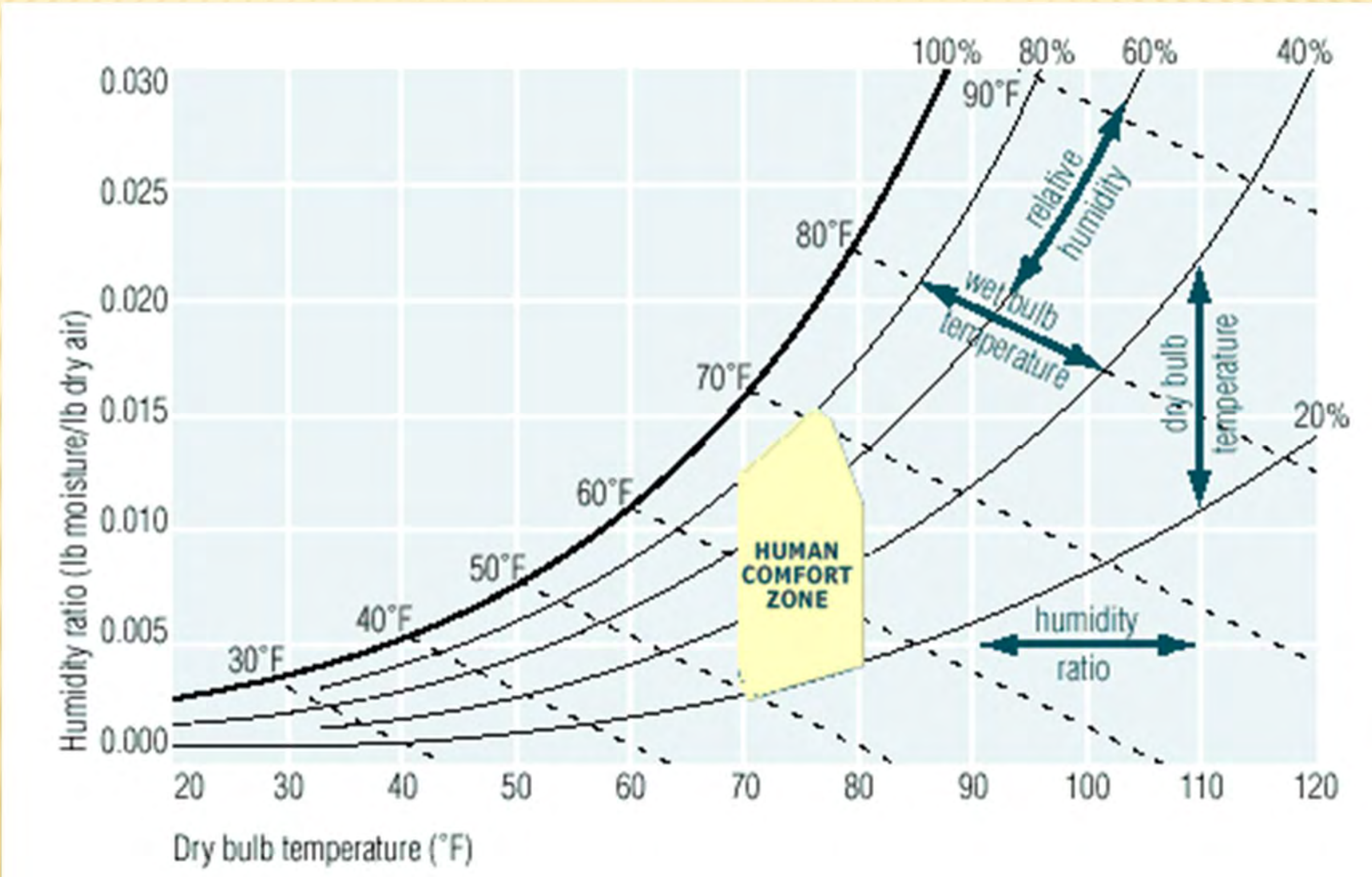
DETERMINE THE NEED FOR COOLING

- Cooling can be eliminated (or reduced significantly)
  - Through solar control
  - Through building materials
  - Through internal loads minimization
  - Through the use of operable windows and forced ventilation (especially in coastal areas)
- Benefits of eliminating cooling
  - Reduced construction cost
  - Lower maintenance costs
  - Significantly lower energy costs
- Challenge to eliminating cooling
  - Project stakeholders may not be willing to endure worst case conditions during the hours per year where comfort conditions can not be met

NATURAL VENTILATION EXPANDS THE COMFORT ENVELOPE

- Most HVAC systems designed to meet 72 – 75 deg. temperature setpoints
- Studies show occupants who have operable windows claim to be comfortable in much larger temperature ranges
- “Mixed-mode” buildings provide both natural and mechanical ventilation

EXPANDING THE HUMAN COMFORT ZONE



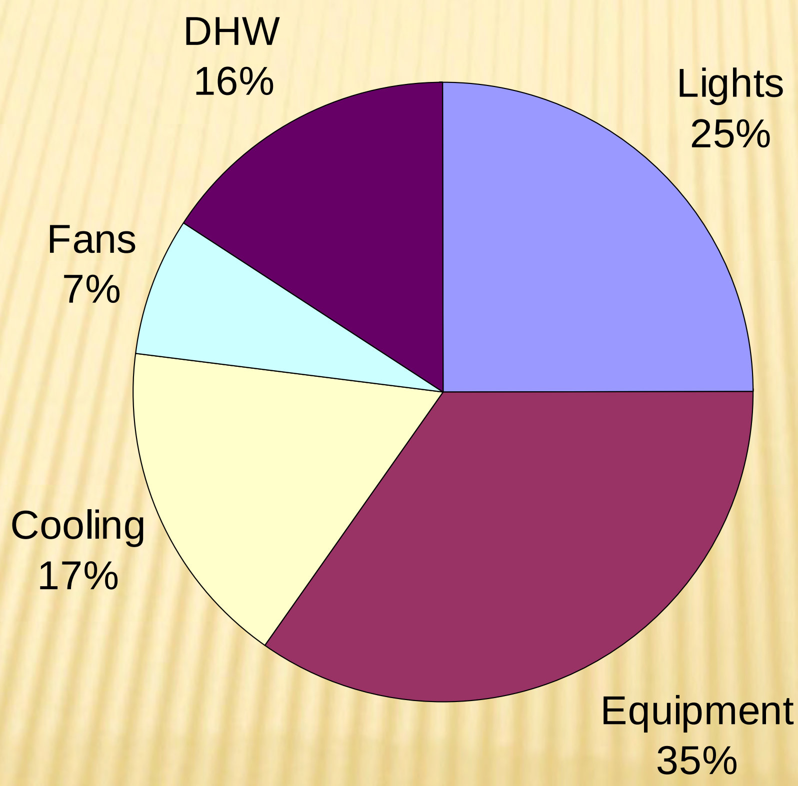
ANALYSIS METHODS

- Typically, two kinds of analysis required
  - Building energy simulation software
  - On-site renewable performance software
- Integration of these capabilities available but not frequently employed

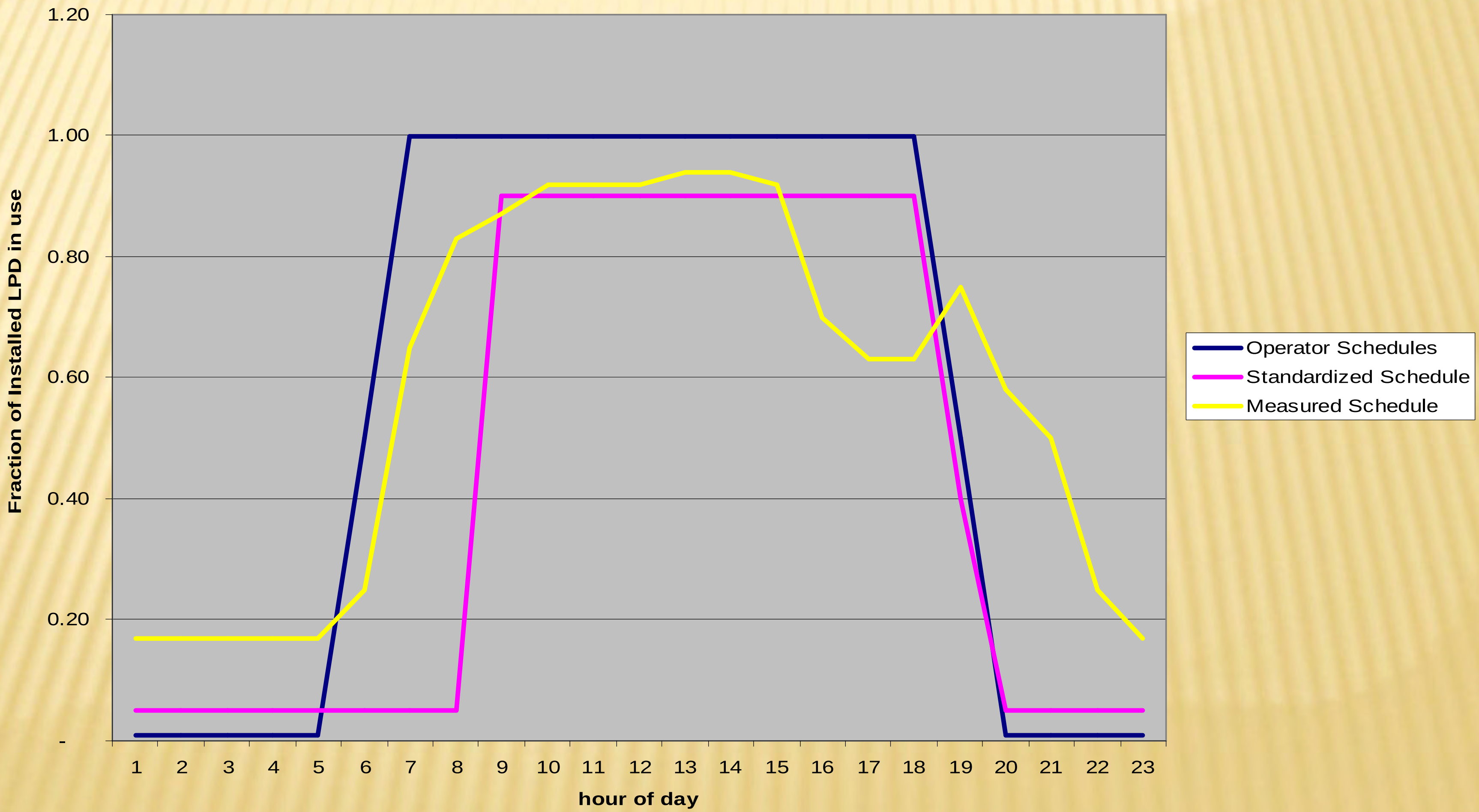
ENERGY SIMULATION SOFTWARE

- Energy Simulation
  - EnergyPro
  - eQUEST
  - Energy+
  - Others
- Must differentiate between idealized (e.g. code compliance) and actual operation of building systems
- Must account for all energy end-uses (regulated, non-regulated, interior, exterior) to provide meaningful estimate of loads and energy
- Must use realistic weather data for analysis

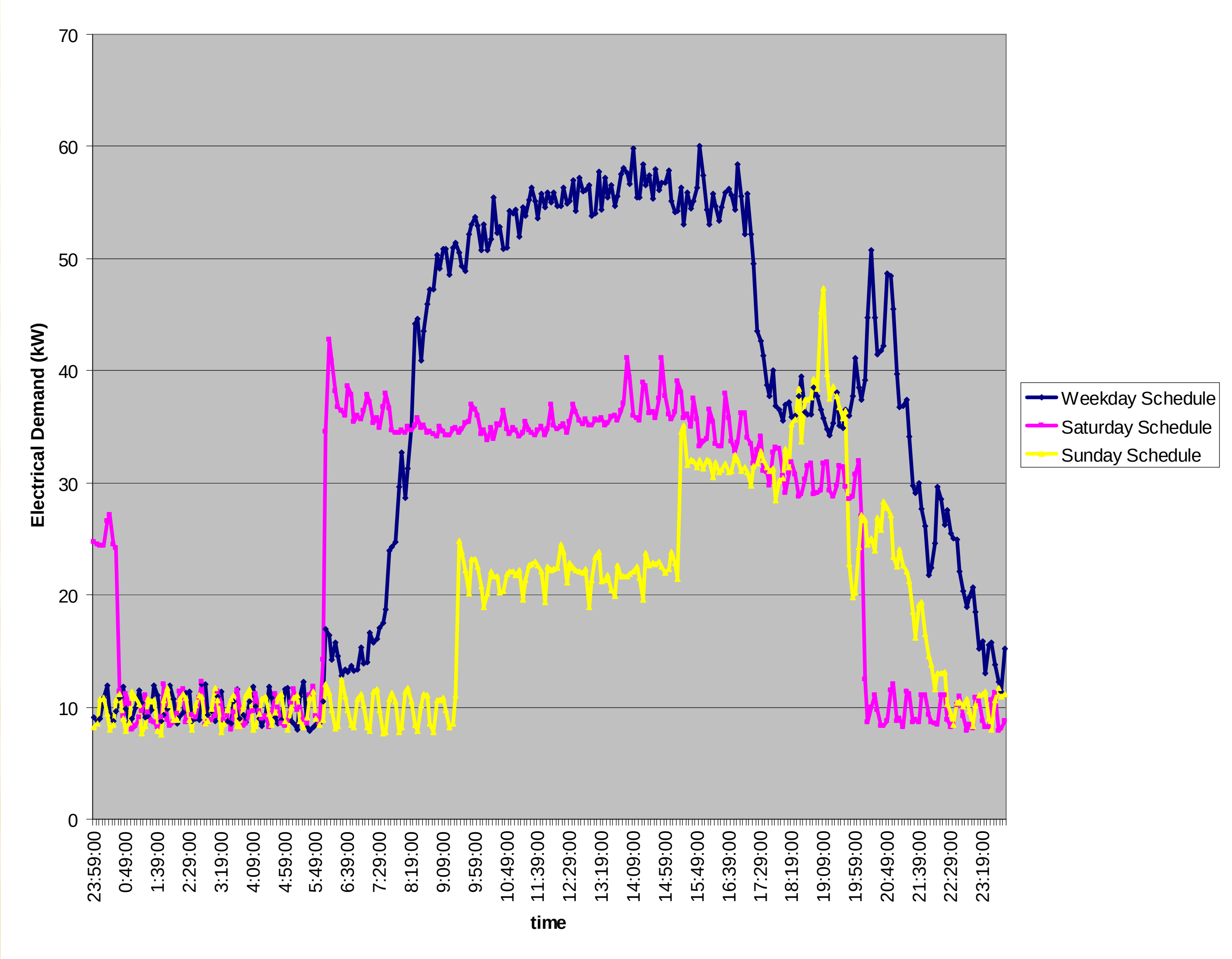
ENERGY MODELING: ‘GIGO’ PERSONIFIED



ACTUAL VS IDEALIZED SCHEDULES

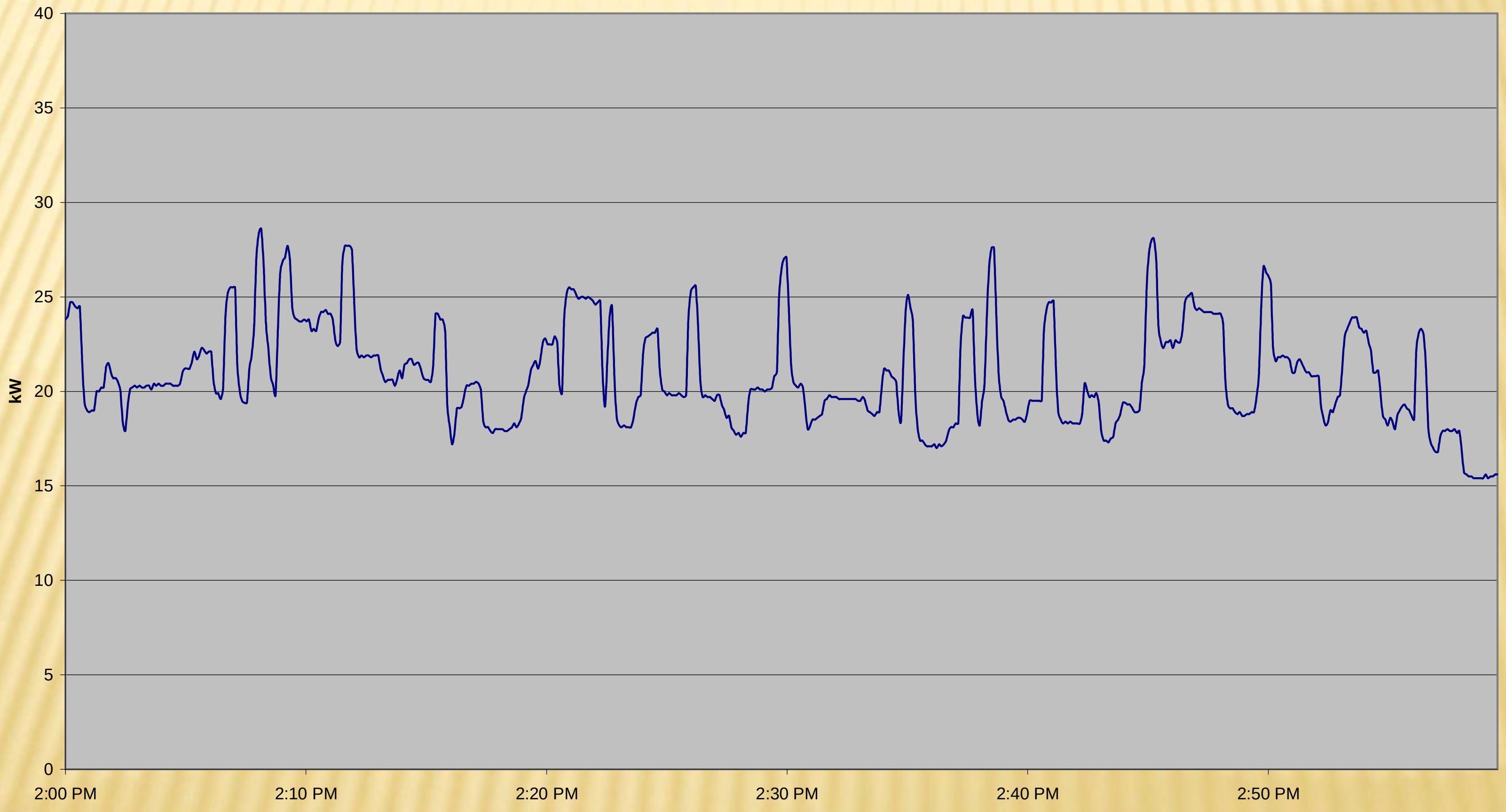


TYPICAL LIGHTING SCHEDULES



LOAD PROFILES AREN'T AS SMOOTH AS WE THINK THEY ARE

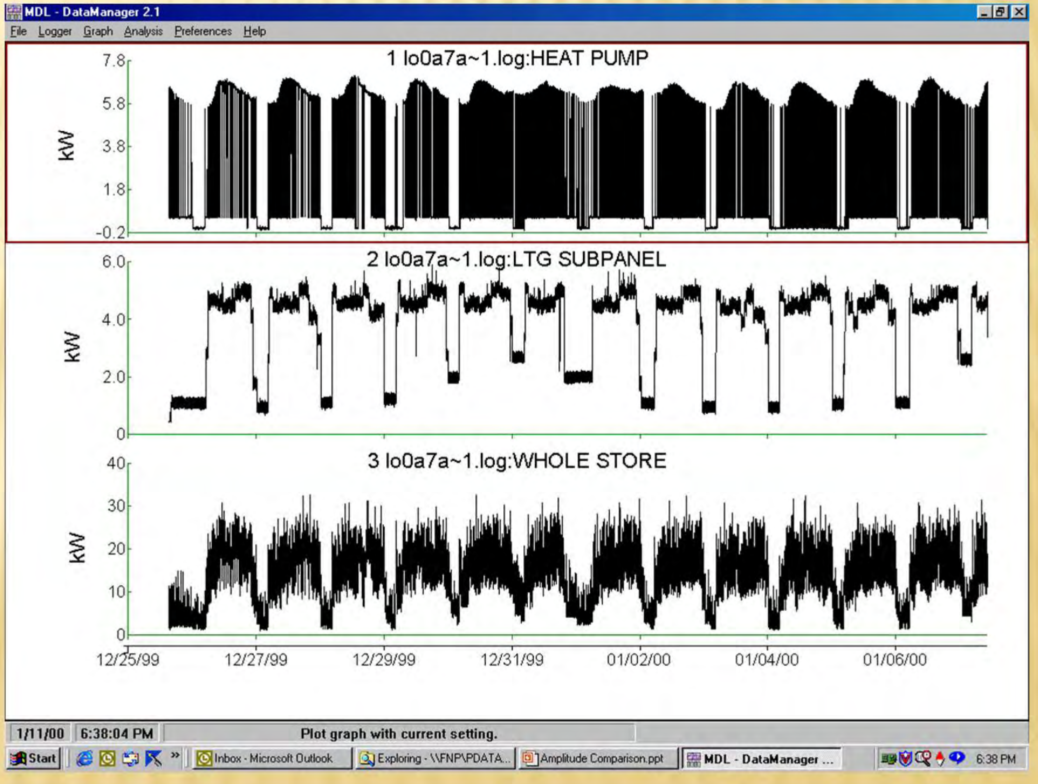
Figure 3. Whole Store Load Profile



EQUIPMENT USE PATTERNS CAN BE COMPLEX

- The sum of all equipment load profiles is the facility load profile
- Occupant behavior impacts usage
- Weather impacts usage
- Maintenance impacts usage

Logger 2; Download 2: La Jolla



'PVWATTS' PV PERFORMANCE SOFTWARE

- Developed by National Renewable Energy Laboratory
- Free online PV performance calculator
- Multiple versions available (simple and more sophisticated)
- rredc.nrel.gov/solar/calculators/PVWATTS/

PVWatts ***** AC Energy & Cost Savings *****

Cautions for Interpreting the Results

Station Identification	
City:	Los_Angeles
State:	CA
Latitude:	33.93° N
Longitude:	118.40° W
Elevation:	32 m
PV System Specifications	
DC Rating:	268.0 kW
DC to AC Derate Factor:	0.803
AC Rating:	215.2 kW
Array Type:	Fixed Tilt
Array Tilt:	33.9°
Array Azimuth:	180.0°
Energy Specifications	
Cost of Electricity:	12.0 ¢/kWh

Results

Month	Solar Radiation ($kWh/m^2/day$)	AC Energy (kWh)	Energy Value ($)
1	4.44	28069	3368.28
2	5.35	30839	3700.68
3	5.62	35392	4247.04
4	6.05	36513	4381.56
5	6.19	38342	4601.04
6	6.17	36777	4413.24
7	6.48	39655	4758.60
8	6.68	40683	4881.96
9	5.78	34036	4084.32
10	5.43	33580	4029.60
11	4.84	29342	3521.04
12	4.46	27828	3339.36
Year	5.63	411056	49326.72

Output Hourly Performance Data

About the Hourly Performance Data

Run PVWATTS v.1 for another location

Run PVWATTS v.2

Please send questions and comments regarding PVWATTS to Webmaster

PVWATTS calculates electrical energy produced by a grid-connected photovoltaic (PV) system. Researchers at the National Renewable Energy Laboratory developed PVWATTS to permit non-experts to quickly obtain performance estimates for grid-connected PV systems within the United States and its territories.

TIP FOR LEED PROJECTS TO IMPROVE EAC1 AND EAC2 PERFORMANCE

- Don’t undervalue your on-site renewable energy value by using average or “virtual” electric rate!
  - PV output is generally highest during time of day when electricity is the most expensive
  - Average $/kWh value of PV-generated energy is almost always higher than the average $/kWh for energy consumed by building
    - e.g. average PV $/kWh = $0.19 and average consumed $/kWh = $0.14
  - Unpleasantly involved spreadsheet analysis usually* necessary

CASE STUDIES

- Hunter Industries(San Marcos, CA)
- Public Works Building, NCBC Port Hueneme (Ventura County, CA)
- Solara (San Diego County, CA)
- L.A. Audubon Society Visitor Center (Los Angeles County, CA)

HUNTER INDUSTRIES

- 139,270 SF warehouse and office
- Located in San Marcos
- Many load reduction measures
- Two PV systems
- 2008 SANDEE Award Winner

LOAD REDUCTION MEASURES

- Extensive daylighting
  - 162 skylights, aligned with shelving system
  - White, reflective interior finishes and packaging materials
  - T5 HO lighting with daylight and motion control
- Reflective Roofing Material
- High efficiency HVAC
  - Evaporatively-condensed VAV packaged units
  - 28% more efficient than air-cooled equivalent

TWO PHOTOVOLTAIC SYSTEMS

- 84 kW array owned by Hunter
  - Sized to meet 100% of lighting needs for building
- 102 kW array owned by SDG&E
  - Meets remaining building loads and exports electricity onto grid

PORT HUENEME PUBLIC WORKS BUILDING

- 15,000 SF office building
  - 10,000 SF renovation of existing building
  - 5,000 SF new wing
- Designed/built 1995-2000
- AIA COTE "Top Ten Green Building"

LOAD REDUCTION MEASURES

- Building form and orientation
- Designed for daylight
- High performance glazing
- Reflective roofing material
- Operable windows
- Highly efficient interior lighting

ADVANCED MECHANICAL SYSTEMS

- Underfloor air distribution in 5,000 sf wing with high efficiency air conditioning
- No air conditioning in most of existing 10,000 sf wing
- Gas engine-powered heat pump employed as demonstration technology
- High efficiency solar hot water heating system

PV SYSTEM

- 15 kW PV array
- “Donated” to this project from a government research project
- Project was also offered (but did not accept) a hydrogen fuel cell and system to dissociate hydrogen from water using PV system

LESSONS LEARNED

- "Annual Zero Electricity" mentioned as an informal goal, *but…*
- PV system capacity was pre-determined because it was "donated", *so…*
- Load reduction and energy efficiency measures employed to greatest extent possible, *and as a result…*
- Electric meter *sometimes* runs in reverse during times of peak PV output or reduced load.

SOLARA

- 56 unit multi-family affordable housing project in Poway
- Project led by Global Green USA with funding from PIER program
- PIER Project goals
  - 25% better than T24
  - 70% energy cost reduction
  - Not more than 1 kW/DU peak demand
  - Not more than $5K/DU incremental cost after rebates
  - Most PIER projects achieved 3 of the 4 goals
- Project includes 141 kW DC PV array mounted on buildings and parking shading structures

SOLARA DESIGN FEATURES

- Buildings oriented for maximum solar performance
- Reflective roofing material
- Natural ventilation
- Efficient lighting
- Tankless water heaters
- High performance windows
- Formaldehyde-free insulation
- HFC refrigerant for AC units

SOLARA: LESSONS LEARNED

- While not a net energy exporter, electrical demand was negative for 12 consecutive months @ CAL ISO system peak
- Electrical savings do not track with cost savings in multifamily projects due to ‘per meter’ charges
- Project is a hit with residents due to low utility bills, smart design, and easy pedestrian access to basic services

“My house is really cool, because the sun does all the work.”

- Jeffrey Lopez, 8 years old
Solara Resident

Source: Union Tribune, 6/2/07

L.A. AUDUBON SOCIETY

- 5,400 SF visitor center in Debs Park (near Pasadena off 110 fwy)
- Literally ‘off the grid’ for electricity
- Site constraints led to ZEB requirement

Photos: CTG Energetics, Inc.

L.A. AUDUBON SOCIETY VISITOR CENTER

- Design features
  - "Off the Grid"
  - Form and orientation selected for maximum PV output
  - Efficient lighting system
  - Solar Thermal Powered Air Conditioning!

Photos: CTG Energetics, Inc.

OFF THE GRID

PV Array

Load Management

Absorption Chiller and Cooling Tower

Batteries storage surplus power

Photos: CTG Energetics, Inc.

CONCLUSIONS

- We have entered an exciting new era for building design
- Integrated energy design is key to a successful zero energy building
- Improved PV technology will push ZEBs further
  - Increased efficiency of panels
  - Lower cost
  - Better integration with building

QUESTIONS?