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· August 15-18, 2010 · Dallas, Texas ·
· Dallas Convention Center ·

NET ZERO ENERGY BUILDINGS (NZEB)

INTRODUCTION

- Presentation attempts to optimize energy consuming systems in an office building and to attain Net Zero Energy Buildings
- Application of passive systems and hybrid systems to minimize the energy consumption and further applications of renewable energies to attain Net Zero Energy Buildings

NET ZERO ENERGY BUILDINGS

- **Presentation Overview**
  - Definitions
  - Mandates
  - Passive Systems
  - Active-Hybrid Systems
  - Supplementing with Renewables (Solar, Wind, Geothermal, and Biofuel/Biomass)
  - Conclusion
  - Examples

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NET ZERO ENERGY BUILDINGS

- **NZEB Definitions**
  - **All the energy consumed by the building is generated within the building's site**

    (NZEB-Site)

or,

  - **All the energy consumed by the building is generated on-site and with off-site renewables**
    (Photovoltaics, Geothermal, Wind Systems, Bio-Generation)

    (NZEB-Source)

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NET ZERO ENERGY BUILDINGS

- Emerging Definitions (Semantics vs. Focus)
  - "Net Zero Energy Buildings at Site" (NZEB-Si)
  - "Net Zero Energy Buildings at Source" (NZEB-So)
  - "Carbon Neutral Buildings" (including Construction or not)
  - "Net Zero Carbon Emission Buildings"
  - "Life Cycle Net Zero Energy Buildings" (LNZEB)
  - "Net Zero Energy Buildings including Embodied Energy"

These terms mean different things to different people, often influenced by program focus, performance goals, and available information. Paraphrased from EO 13514…

"A Building Designed to Operate with All Energy Needs Met from Sources that Do Not Produce Greenhouse Gases (and Be Economically Viable)"

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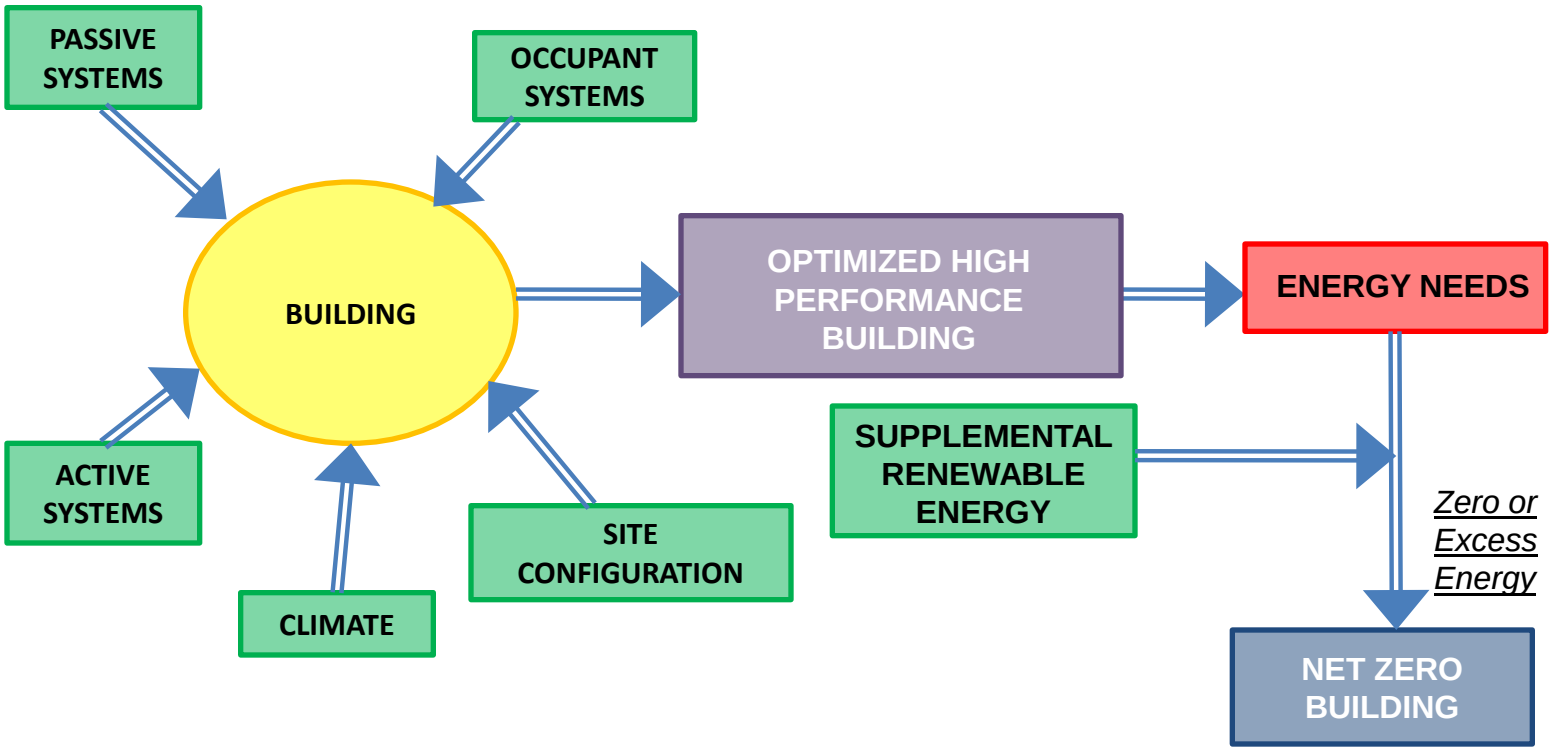
NET ZERO ENERGY BUILDINGS

- **Mandates for Current Designs (Not NZEB Based)**
  - Codes, Industry Standards *(ASHRAE Stds 90.1, 189)*
  - Legislation, Executive Orders *(EO 13514, EO 13423)*
  - Rating Systems *(e.g. LEED, others)*
  - Federal Guidelines *(DOE, "Guiding Principles," others)*
- **Mandates for the Future (NZEB Based)**
  - EISA Legislation: New Const. & Major Renovations 55% Less Fossil Fuel in 2010, 100% Less by 2030
  - EO 13514: All New Federal Buildings, Programmed in 2020 and Beyond, Must Achieve Net Zero Energy Use by 2030

NET ZERO ENERGY BUILDINGS

- **NZEB at Site - Integrated Design**
  - Discussion relates to only office buildings



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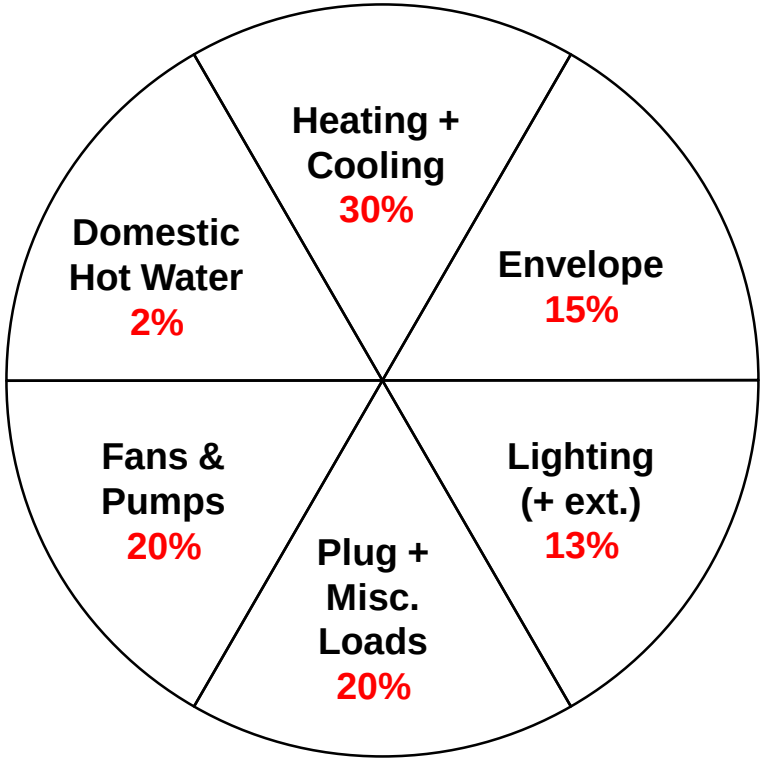
NET ZERO ENERGY BUILDINGS

- **Current Office Bldg. Energy Use Profile**

	Btu/ft2/yr
Envelope	12,000
Heating + Cooling	24,000
Domestic Hot Water	2,000
Fans & Pumps	16,000
Plug + Misc. Loads	16,000
Lighting	10,000
TOTAL	80,000



*** Average CBEC's data**

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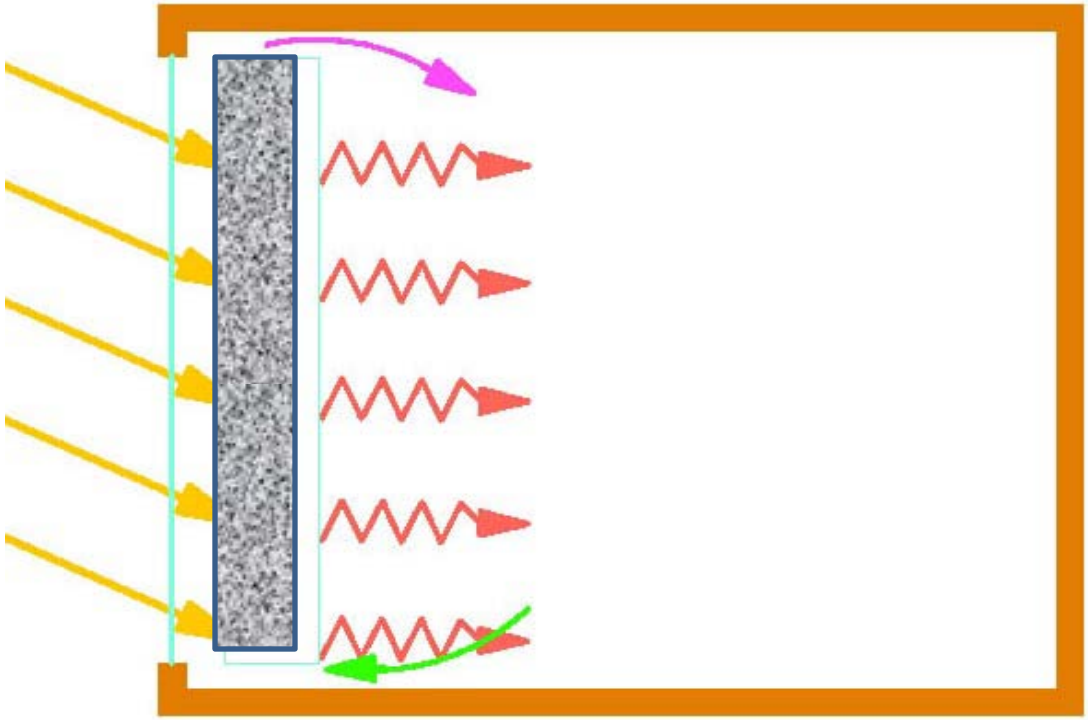
Passive Systems

NET ZERO ENERGY BUILDINGS

- **Passive Systems**
  - Trombe Walls
  - Natural Ventilation
  - Water Ponds
  - Daylighting
  - Reflective Lighting
  - Earth Berms

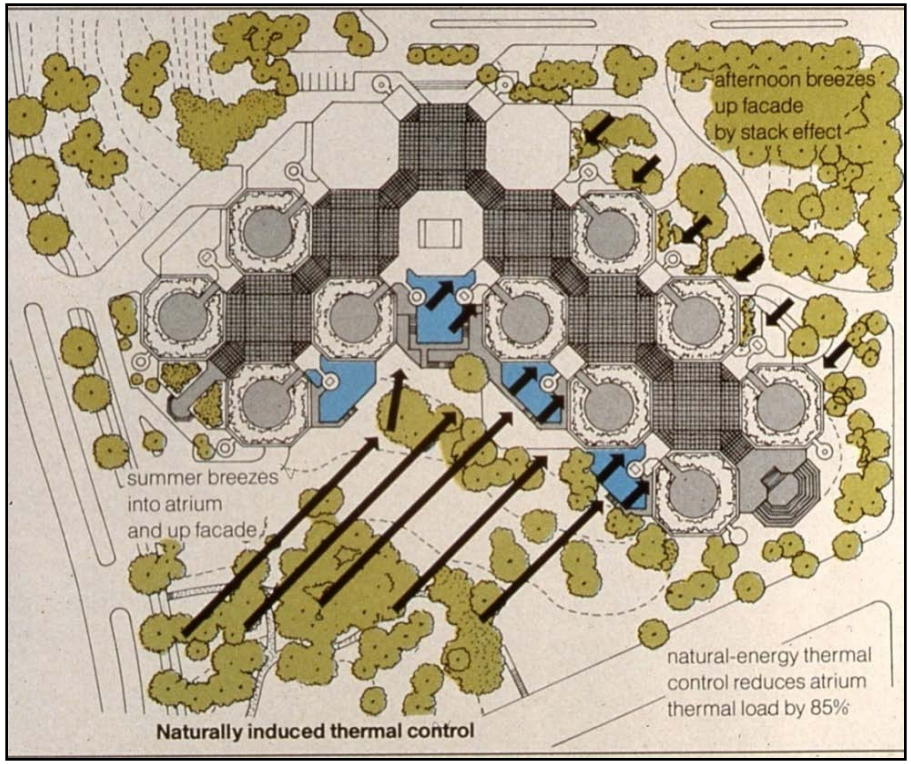
NET ZERO ENERGY BUILDINGS

- **Passive Systems**
  - Trombe Walls
    - South wall painted black
    - Rock storage
    - Air is circulated due to the pressure difference



NET ZERO ENERGY BUILDINGS

- **Passive Systems**
  - Natural Ventilation and Water Ponds
    - Water ponds in the atrium
    - South winds creating natural ventilation effect
    - Water evaporation to reduce surrounding temperature 5 F



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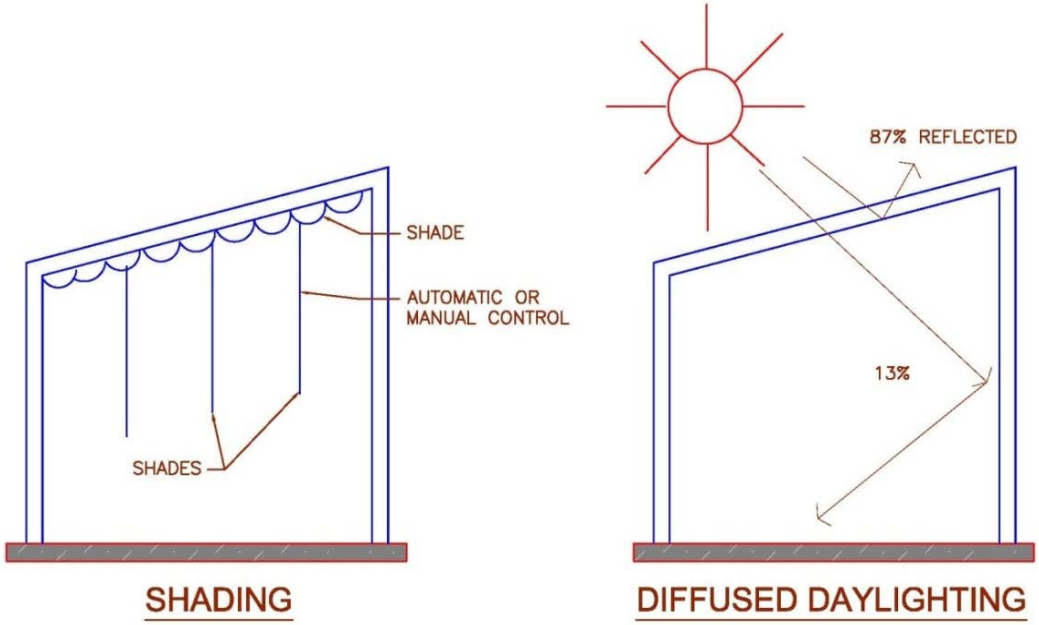
NET ZERO ENERGY BUILDINGS

- **Passive Systems**
  - Daylighting
    - Numerous Concepts
    - Shown Sky-light System Features Drop Down Deflecting Shades
    - Requires Reflective Surfaces
    - Need Light Control (e.g. Louvers)
    - Insulated Glazing for Night Losses

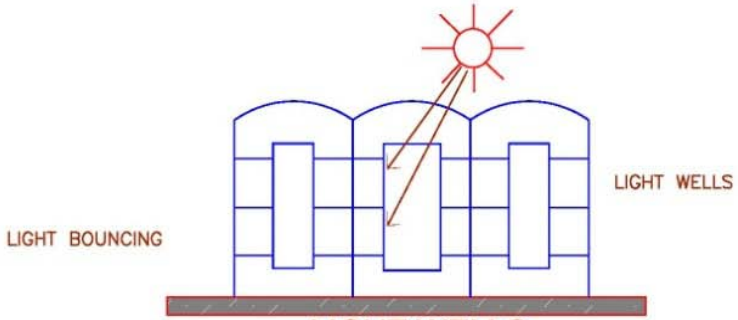


CONTROL OF DAYLIGHT & HEAT IN LARGE SPACES

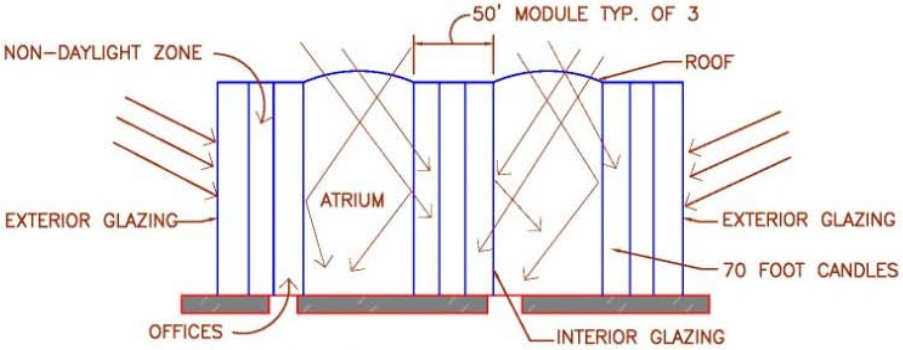
NET ZERO ENERGY BUILDINGS

- **Passive Systems**
  - **Daylighting**
    - Atrium
    - Light wells
    - Maximum 50' center modules
    - Allow diffused daylighting

NORTH DAYLIGHTING



LIGHT WELLS



50' MODULE DAYLIGHTING

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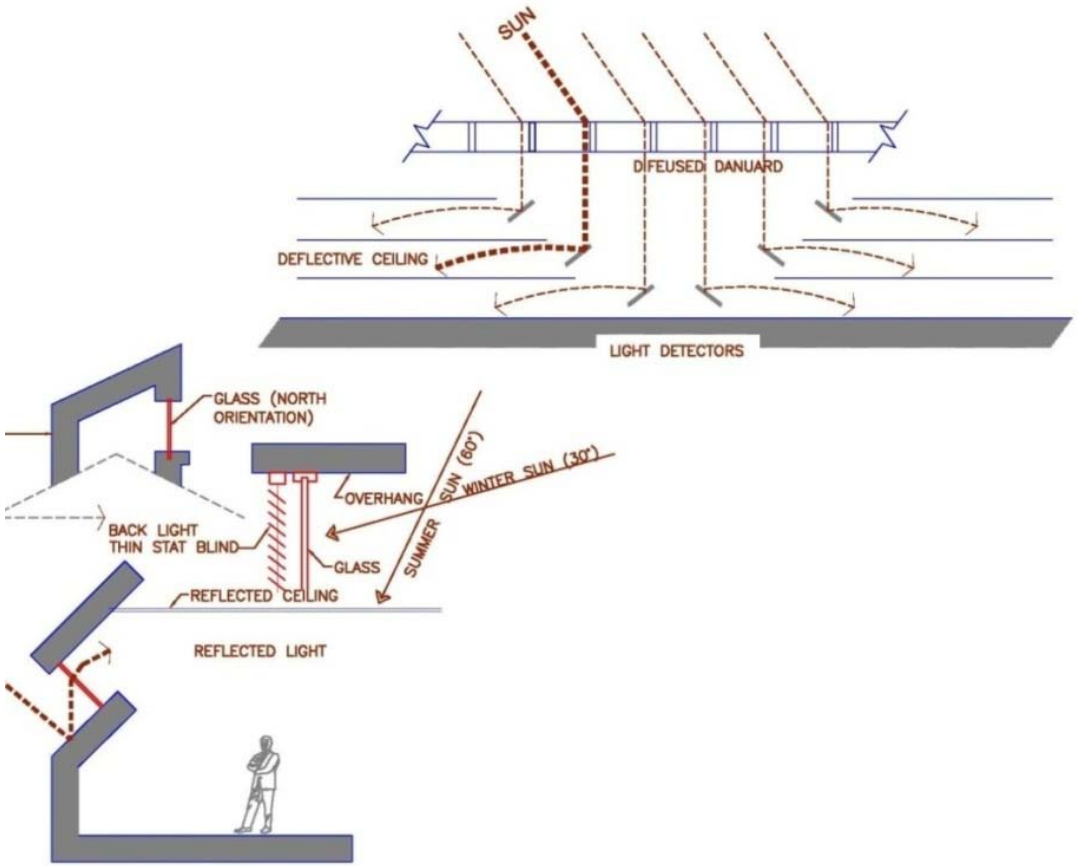
NET ZERO ENERGY BUILDINGS

- **Passive Systems**
  - Reflective Lighting
    - Over hangs
    - Solar louvers
    - Shade control
    - Reflective mirrors
    - Reflective louvers



PASSIVE DAYLIGHTING

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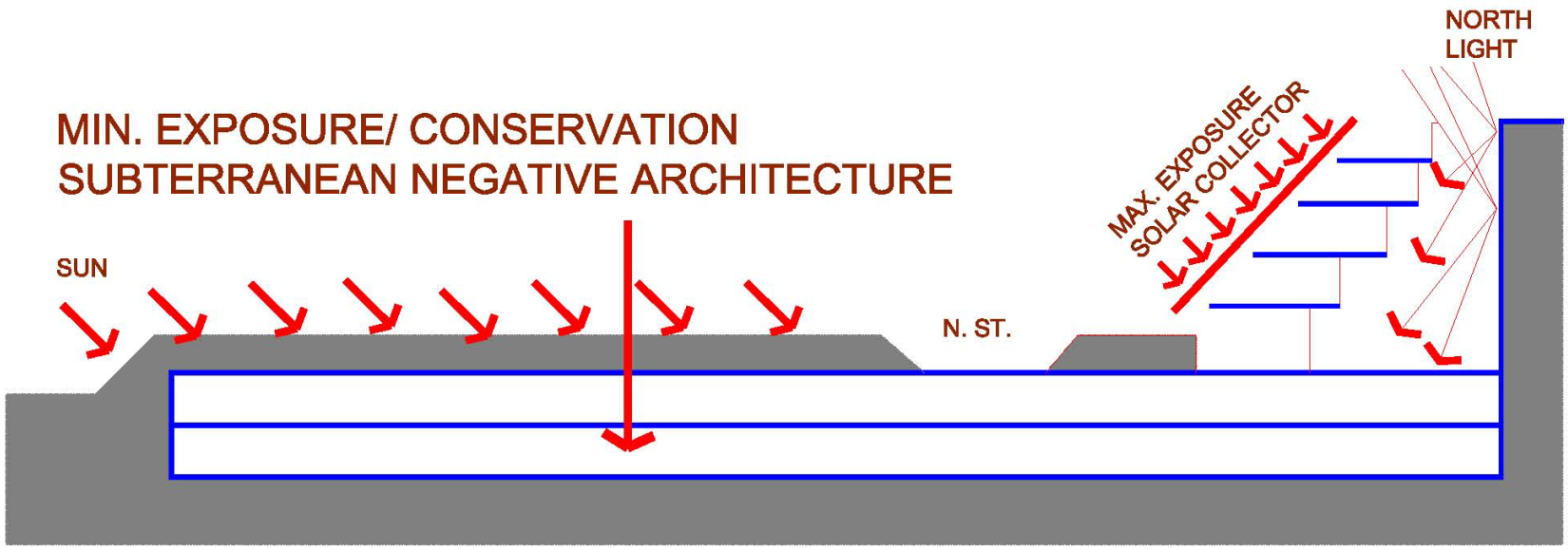
NET ZERO ENERGY BUILDINGS

- **Passive Systems**
  - Earth Berms
    - Building is significantly below grade
    - Berms and greenroof



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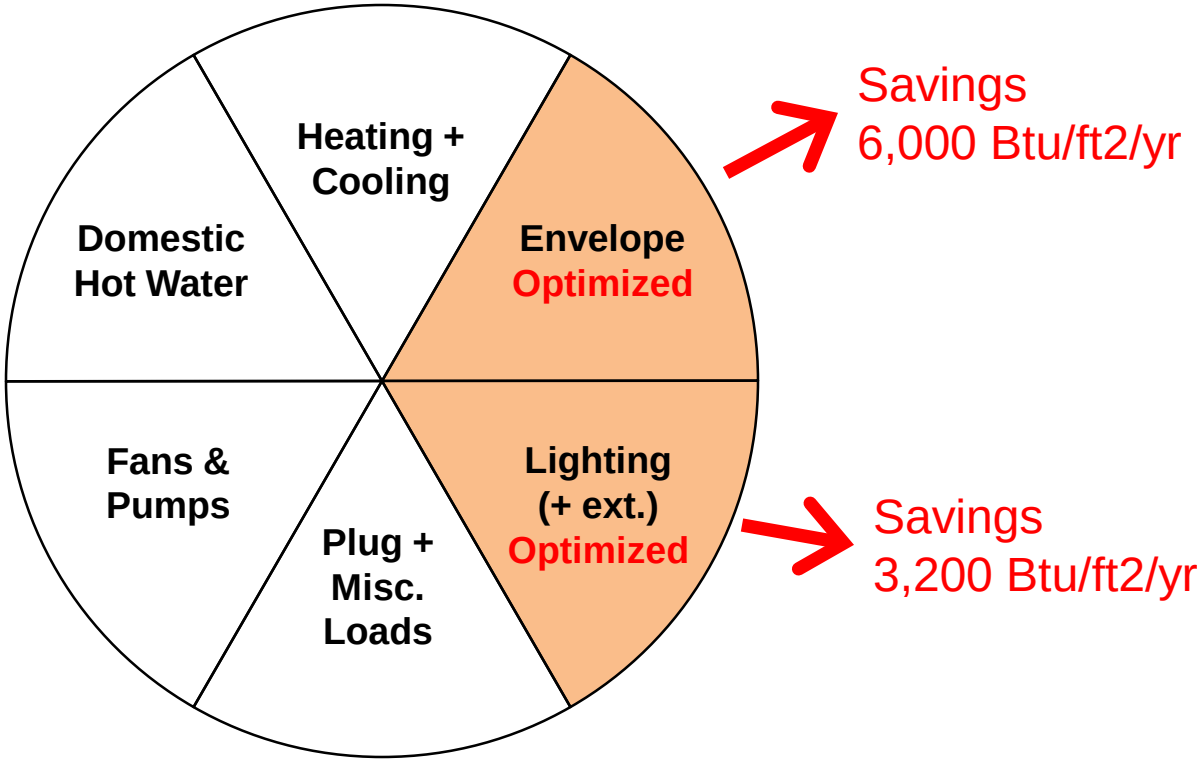
NET ZERO ENERGY BUILDINGS

- **Passive Systems**
  - Energy Consumption Optimization
    - Utilization of passive systems for the envelope and lighting can save in office building, perhaps in the order of 50% of normal envelope
    - Generally envelope loads are 15% of the total energy consumption and may vary from 12,000 BTU/ft^2/yr to 18,000 BTU/ft^2/yr
    - Application to passive systems with high performance envelope using extensive envelope systems will bring it down to 6,000 BTU/ft^2/yr to 9,000 BTU/ft^2/yr

NET ZERO ENERGY BUILDINGS

- **Office Energy Consumption Distribution**



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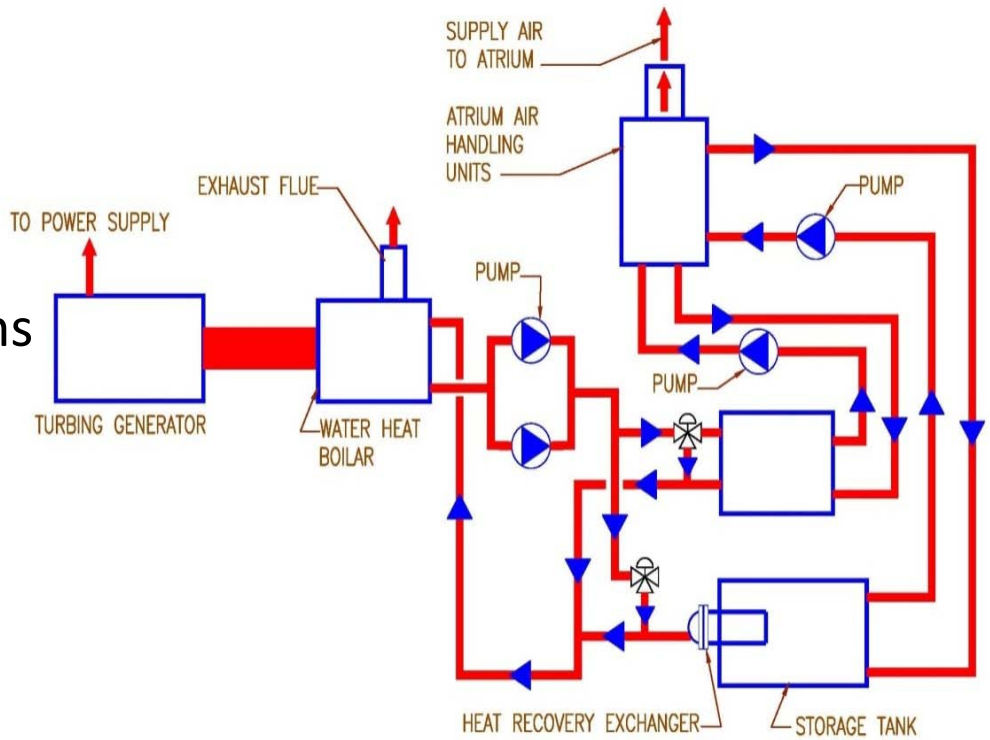
Active-Hybrid Systems

NET ZERO ENERGY BUILDINGS

- **Active-Hybrid Systems**
  - Ground-source heat pumps
  - Heat recovery systems
  - Integrated solar roof systems
  - Cooperative utility solid waste system for electric power generation
  - Methane powered turbine generator systems



TURBINE COGENERATION HEAT PUMPING

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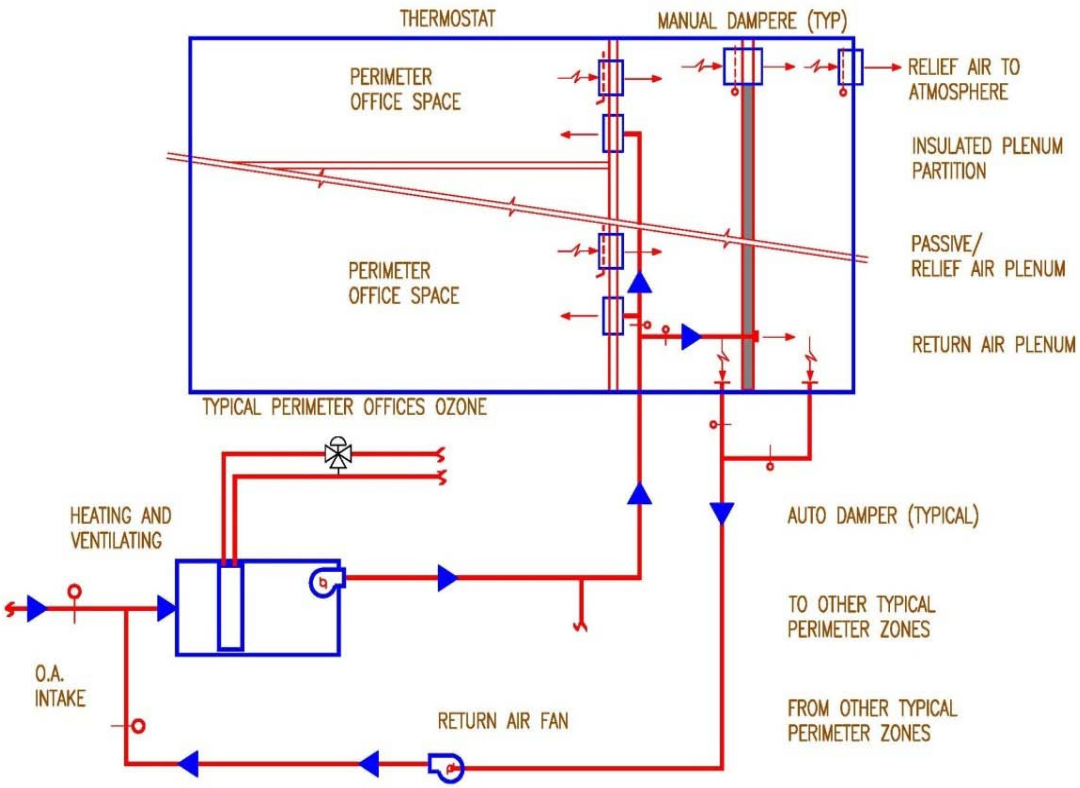
NET ZERO ENERGY BUILDINGS

- **Active-Hybrid Systems**
  - Cogeneration
  - Waste heat pumping
  - Air economizers
  - Water economizers
  - Desiccant dehumidification system
  - Evaporative cooling
  - Active/passive south wall system



ACTIVE/PASSIVE - SOUTH WALL SYSTEM

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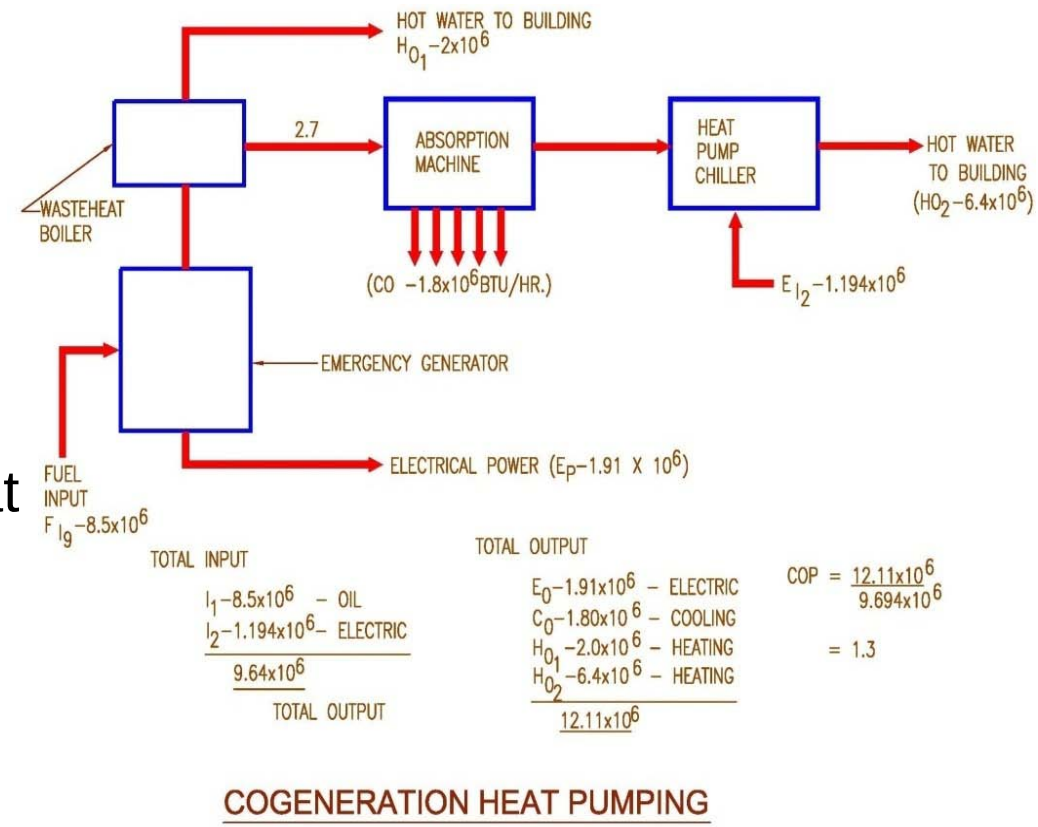
NET ZERO ENERGY BUILDINGS

- **Active-Hybrid Systems**
  - Solar desiccant dehumidification
  - Solar cooling with absorption machine
  - Low cost flat plate heat pump system
  - Power generation with PV system
  - Cogeneration heat pumping and absorption cooling



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NET ZERO ENERGY BUILDINGS

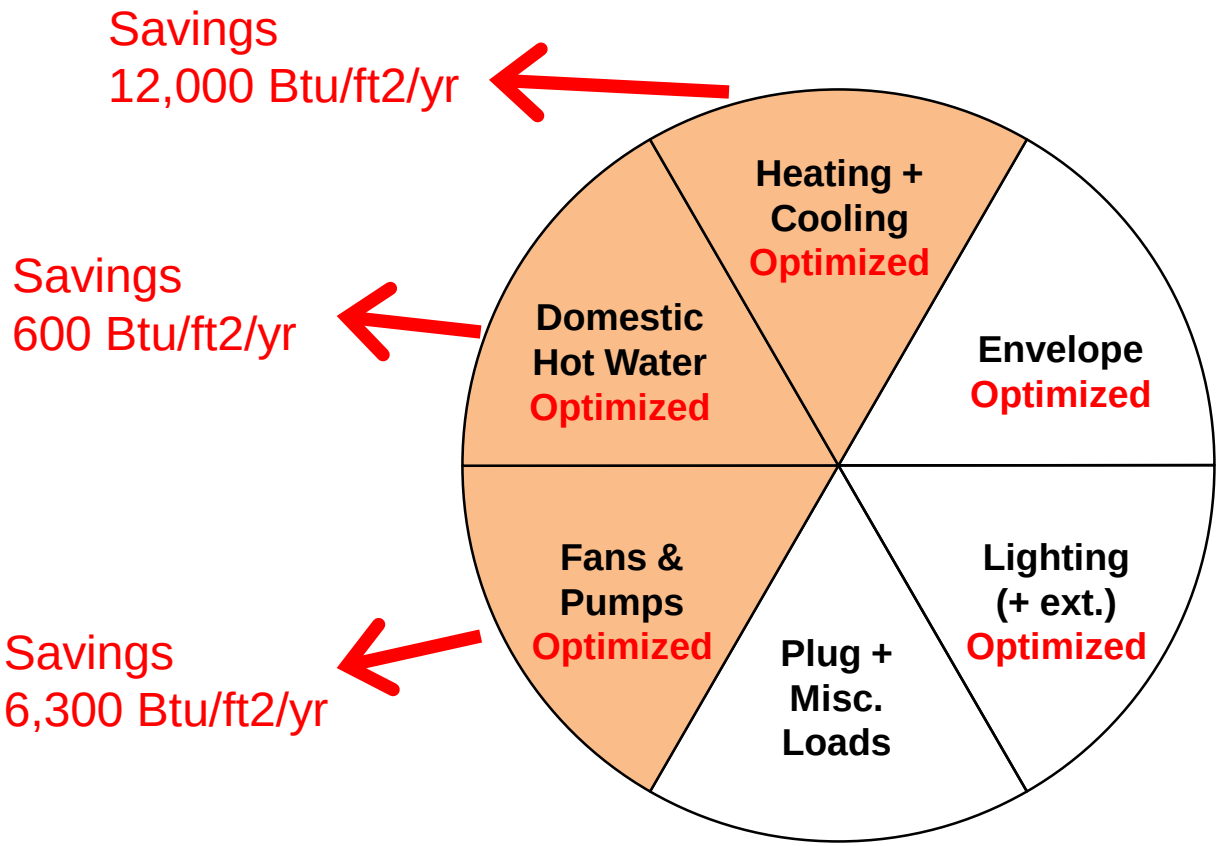
- **Active-Hybrid Systems**
  - Micro-turbines (cogeneration)
  - Fuel cells (cogeneration)
  - Incinerator boilers to power turbine generator/absorption
  - Spring water pre-cooling

NET ZERO ENERGY BUILDINGS

- **Active-Hybrid Systems**
  - Energy Consumption Optimization
    - Generally for office buildings, HVAC system energy consumption is about 30% of the total energy consumption and will be in the vicinity of 24 to 30,000 BTU/ft^2/yr
    - Application of energy saving active system or hybrid system will be in the vicinity of 50%.
    - This amounts to 12,000 BTU/ft^2/yr to 15,000 BTU/ft^2/yr

NET ZERO ENERGY BUILDINGS

- **Office Energy Consumption Distribution**



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NET ZERO ENERGY BUILDINGS

- **Computer Energy Modeling and Manual Energy Calculations**
  - Computer energy modeling has many default values and extensive flexibility that can accurately predict energy consumption at the building site – if inputs are correct
  - Performing manual calculations, using common sense approach, can often lead to the same (Go, No-Go) conclusions

NET ZERO ENERGY BUILDINGS

- **Manual Calculation Procedures**
  - Assumptions
    - Office building operation: 11 hr/day, 250 work days/yr → 2,750 hrs
    - Employee at desk: 8 hr x 250 days = 2,000 hrs
    - Lighting - 0.9 watts/ft^2
    - Receptacle Loads – 2 watts/ft^2
    - Miscellaneous Loads – 1 watt/ft^2

NET ZERO ENERGY BUILDINGS

- **Manual Calculation Procedures**
  - Lights: 2,920 hrs equivalent operation per year including emergency lighting (@ 5%) (see ASHRAE 90.1-2007 User Manual) →

$$0.9 \times 2{,}920 \times 3.412 \Rightarrow 9{,}000 \text{ Btu/ft2/yr}$$

  - Receptacle Loads: 2W/ft^2 with a load factor of 53% on work days (8 hrs at full load, 30% remaining time) →

$$2 \times 0.53 \times 24 \times 250 \times 3.412 + 0.3 \times 2 \times 24 \times (365 - 250) \times 3.412 \Rightarrow 12{,}000 \text{ Btu/ft2/yr}$$

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NET ZERO ENERGY BUILDINGS

- **Manual Calculation Procedures**
  - HVAC Distribution Systems
    - Fans (including supply, return/relief, exhaust): on the basis of 1 cfm/ft^2 supply air, using ASHRAE 90.1-2007 Appendix G that gives bhp=0.00094xCFM/ft^2, and assuming motor efficiency of 85%

$$bhp = 0.00094 \times 1 = 0.00094 \text{ HP/ft2}$$

$$Pfan = \frac{bhp \times 746}{0.85} = 0.825 \text{ W/ft2}$$

$$\text{For 3,000 hours of operation:}$$

$$0.825 \times 3{,}000 \times 3.412 \Rightarrow 8{,}500 \text{ Btu/ft2/yr}$$

NET ZERO ENERGY BUILDINGS

- **Manual Calculation Procedures**
  - **HVAC Distribution Systems**
    - **Pumps:**
      - **Chilled water pumps: 0.10 HP/ton**
      - **Hot water pumps: 0.05 HP/ton**
      - **Condenser water pumps: 0.10 HP/ton**
      - **Misc. pumps: 0.10 HP/ton**
      - **Total: 0.35 HP/ton**

$$\frac{0.35\ \text{HP/ton}}{400\ \text{ft2/ton}} = 0.001\ \text{HP/ft2}$$

$$\text{For 3,000 hours of operation:}$$

$$0.001 \times 746 \times 3{,}000 \times 3.412 \Rightarrow 7{,}700\ \text{Btu/ft2/yr}$$

NET ZERO ENERGY BUILDINGS

- **Cooling and Heating Energy:**
  - Cooling/heating energy by chiller, boilers, and any other primary source.
    - Typical cooling load: 30 Btu/hr/ft^2
    - Typical heating load: 30 Btu/hr/ft^2
  - CBECS Data (2003):
    - Typical cooling energy (inc. envelope): 8,000 Btu/ft^2/yr
    - Typical heating energy (inc. envelope): 28,000 Btu/ft^2/yr
  - Typical cooling+heating energy: 36,000 Btu/ft^2/yr, depending upon climate zone, this may vary substantially.
  - Due to active-hybrid system applications, reduce this to 18,000 BTU/ft^2/yr

NET ZERO ENERGY BUILDINGS

- **Miscellaneous loads: elevators, vending machines, drinking fountains … Assuming:**
  - 1 W/ft^2
  - full-load equivalent operating time of 4 hr on weekdays
  - full-load equivalent operating time of 1 h on week-ends and holidays

$$(1\times 4\times 250\times 3.412)+(1\times 1\times 115\times 3.412)=3{,}800\ \text{Btu/ft2/yr}$$

NET ZERO ENERGY BUILDINGS

- Exterior lighting: assuming 0.1 W/ft^2 of floor area in operation 12 hrs/day

$$0.1 \times 12 \times 365 \times 3.412 = 1{,}500 \text{ Btu/ft2/yr}$$

- Domestic hot water: 1 occ/100 ft^2, giving 0.01 occ/ft^2, with 80% efficiency for water heater, 1 gal/occ/day on average (see ASHRAE_HVAC Handbook), supply at 120F from 55F

$$\frac{0.01 \times 8.31 \times 1 \times (120 - 55) \times 250}{0.80} = 1{,}700 \text{ Btu/ft2/yr}$$

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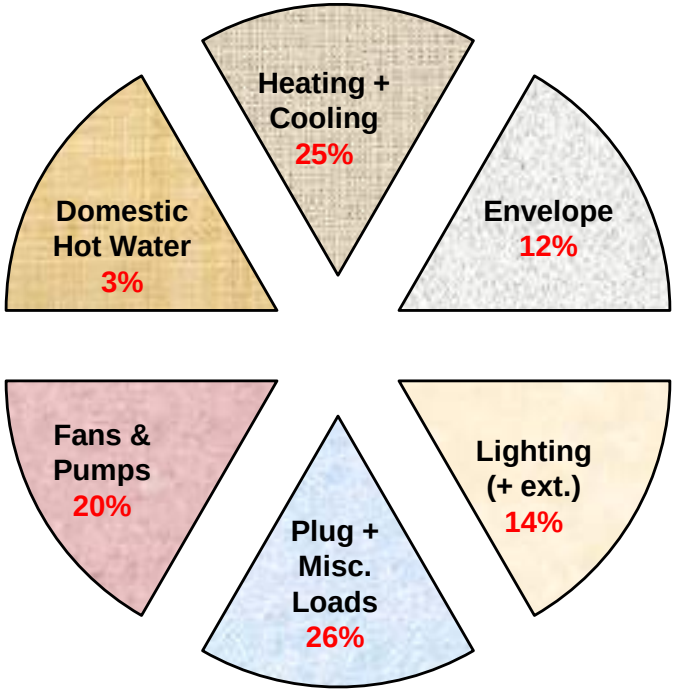
NET ZERO ENERGY BUILDINGS

- **Energy Consumption Optimization Summary:**
  - Receptacle + Misc. Loads: 12,600 Btu/ft^2/yr
  - Fans + Pumps: 9,700 Btu/ft^2/yr
  - DHW: 1,400 Btu/ft^2/yr
  - Heating + Cooling: 12,000 Btu/ft^2/yr
  - Envelope: 6,000 Btu/ft^2/yr
  - Lighting: 6,800 Btu/ft^2/yr
  - **Total: 48,500 Btu/ft^2/yr**



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NET ZERO ENERGY BUILDINGS

- **Supplemental Renewable Energy**
  - If the site is urban and not possible to install renewable energy systems such as PV, solar collectors or wind, use other alternatives
  - If roof or land area is available to use PV's or biomass/biofuel, use a combination of these renewables
  - Utilize ground source heat pump (GSHP)
  - Solid waste incinerator to generate steam to drive a steam turbine to generate electricity and feed into the process loads
  - Purchase green power to offset remaining energy consumption

NET ZERO ENERGY BUILDINGS

- **Renewables Available in the Industry**
  - Flat plate collector - PV
  - Solar integrated ground source heat pump
  - Concentrated PV collectors
  - Concentrated high temperature hot water collector system
  - Wind energy
  - Geo-thermal system at 300 F and above
  - Biomass
  - Biofuel

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NET ZERO ENERGY BUILDINGS

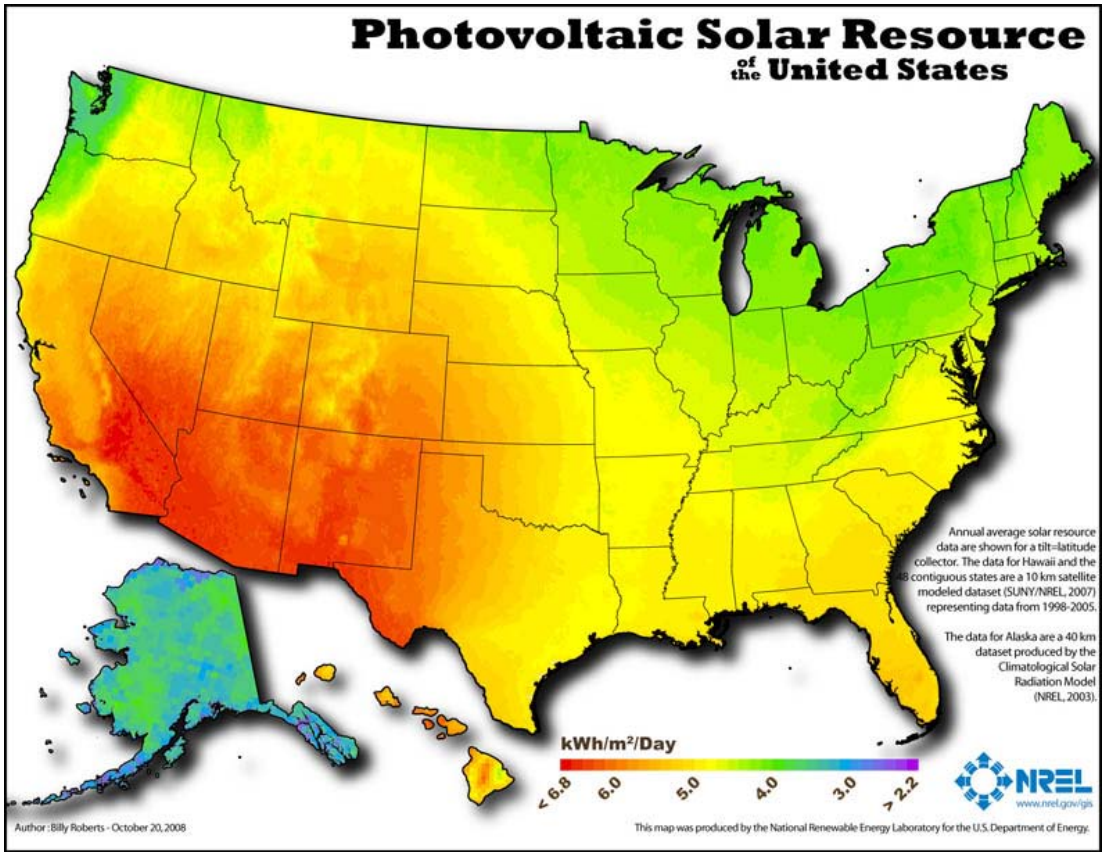
- **Approach to Net Zero:**
  - Photovoltaics: 44,800 Btu/ft^2 of PV/yr
  - Geothermal (GSHP) saves 50% to 70% of typical heating+cooling energy
  - Solid waste: assume 1 lb of waste per occupant, 1 occ/100 ft^2, calorific value of municipal waste ≈ 3000 Btu/lb (compare to natural gas at 21,000 Btu/lb)

$$0.01 \times 3{,}000 \times 250 = 7{,}500 \text{ Btu/ft2/yr}$$

  - Green purchase for remaining balance

NET ZERO ENERGY BUILDINGS

- **Photovoltaics:**
  - 44,800 Btu/ft^2 of PV/yr, based on the national average of 5 kWh/m^2/day



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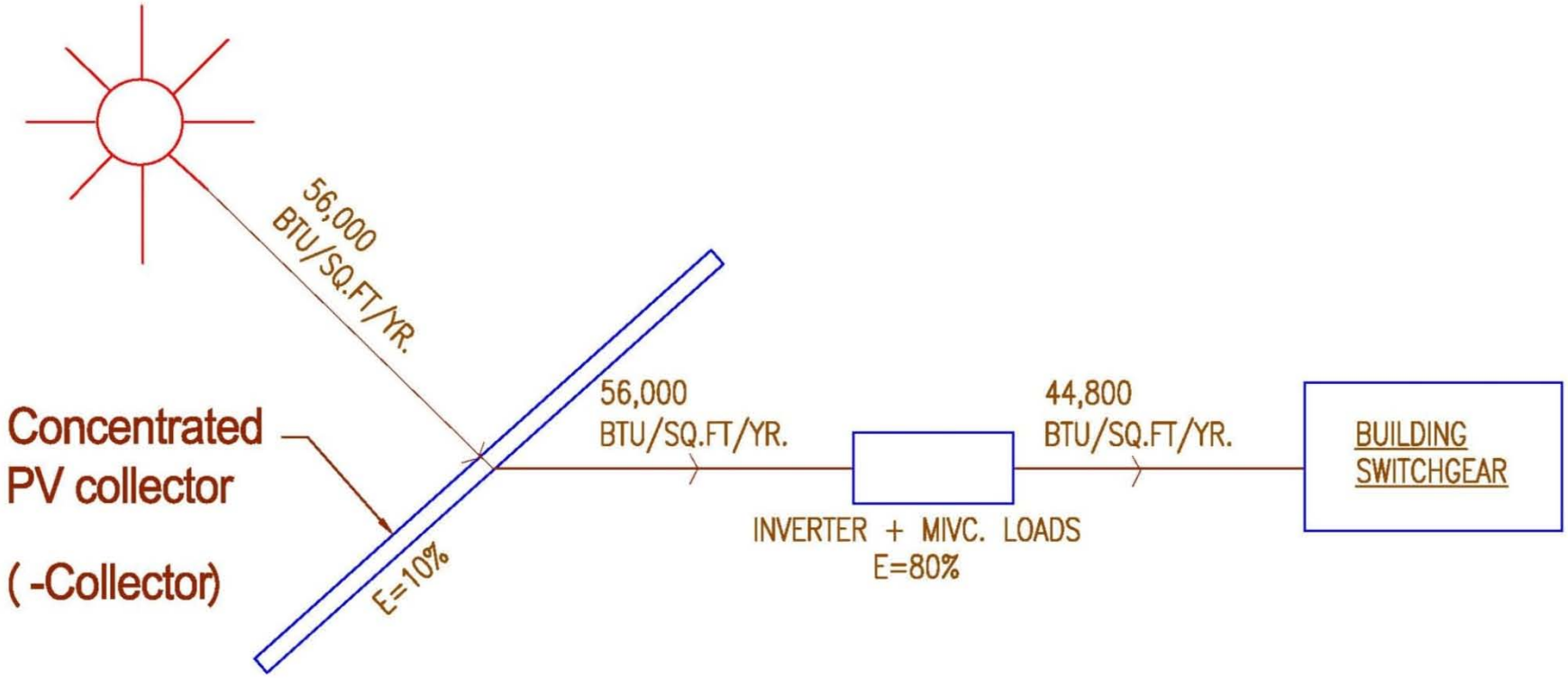
NET ZERO ENERGY BUILDINGS

- **PV – Electric Power Generation**



PV – ELECTRIC POWER GENERATION

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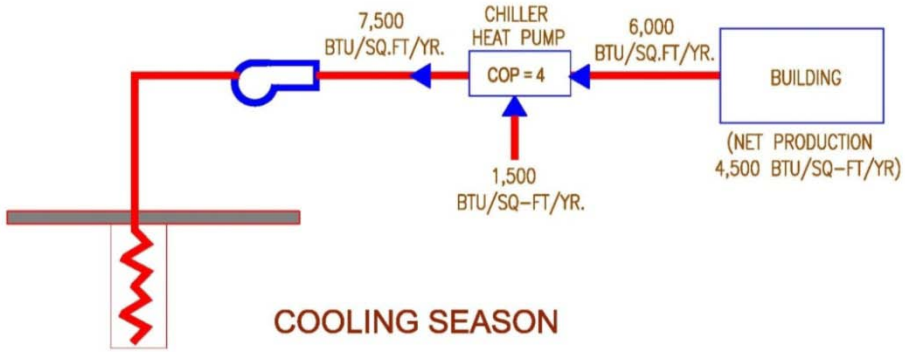
NET ZERO ENERGY BUILDINGS

- **Ground Source Heat Pump:**
  - Geothermal (GSHP): assume heating COP = 3 and cooling COP = 4

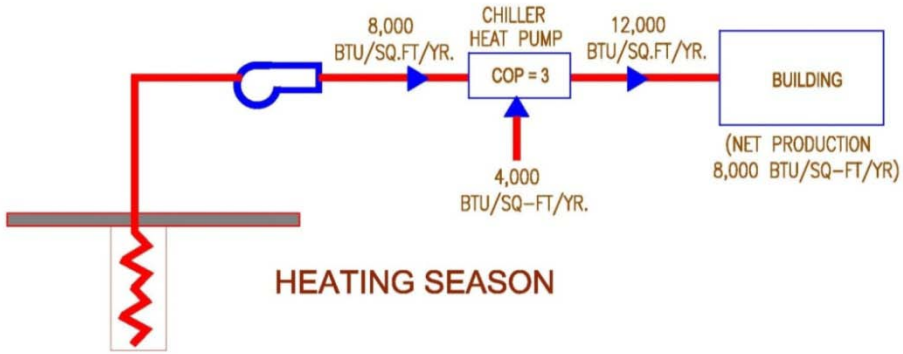
$$\text{Net Input} = \frac{6{,}000}{COP}$$

$$\text{Net Input} = 1{,}500$$



$$\text{Net Input} = \frac{12{,}000}{COP}$$

$$\text{Net Input} = 4{,}000$$



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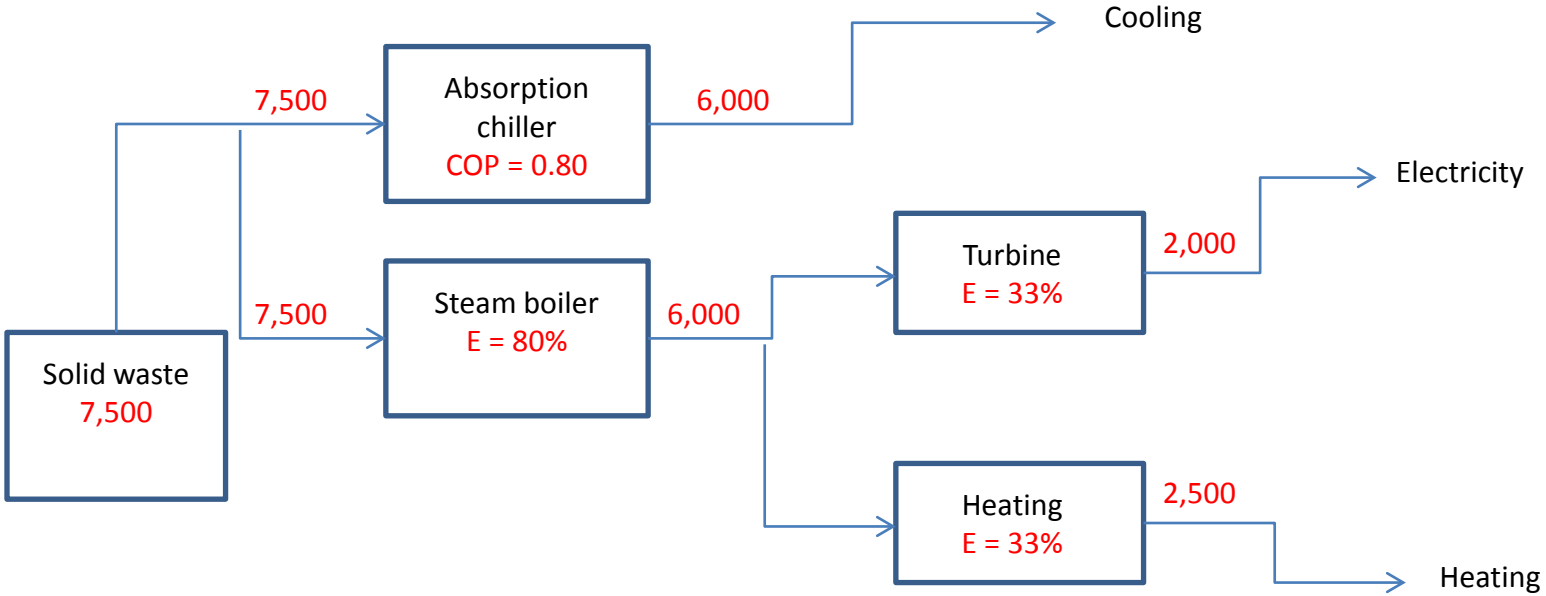
NET ZERO ENERGY BUILDINGS

- Solid Waste: assume 1 lb of waste per occupant per day, 1 occ/100 ft^2/day, calorific value of municipal waste ≈ 3,000 Btu/lb (compare to natural gas at 21,000 Btu/lb)

$$0.01 \times 3{,}000 \times 250 \text{ days} = 7{,}500 \text{ Btu/ft2/yr}$$



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NET ZERO ENERGY BUILDINGS

- **Renewables Production Summary**

SYSTEM	NET PRODUCTION	UNITS
Photovoltaics	44,800	Btu/ft^2 of PV/yr
Geothermal	12,500	Btu/ft^2 of floor area/yr
Solid Waste - Cooling	6,000	Btu/ft^2 of floor area/yr
OR Solid Waste – Heating and Electricity	2,000 electricity + 2,500 heating	Btu/ft^2 of floor area/yr

  - If feasible, any of the combinations makes it possible to approach net zero.
  - If any of the combinations are not possible for some reason, purchase “green power!”

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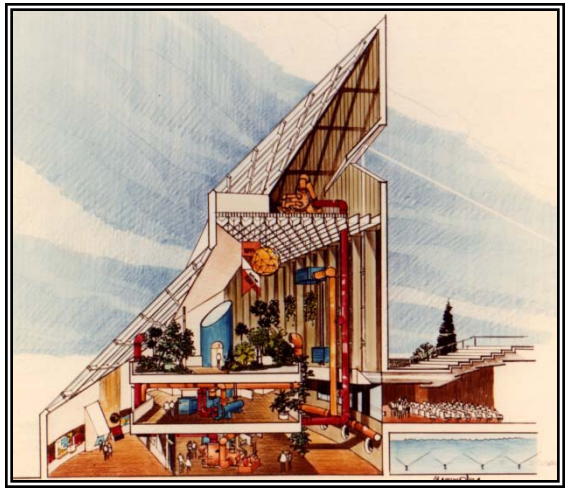
Conclusion

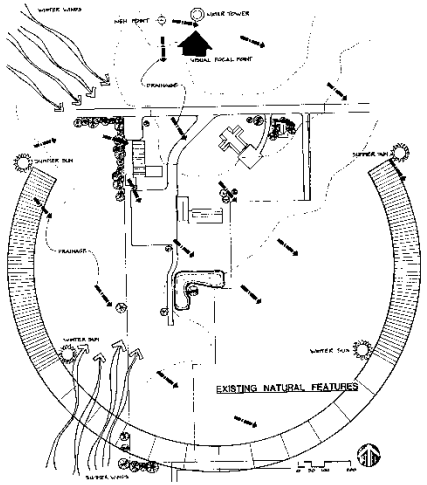
- Many definitions for net-zero energy buildings: keys remain:
  - Aggressive energy use optimization of passive and hybrid systems may save 20 to 25% of energy consumption against ASHRAE 90.1, ASHRAE 189.1 or CBEC's data.
- Is it worth spending a substantial amount of initial cost to save a small amount of energy in the envelope systems?
- Energy modeling may not give you accurate results all the time!!!
- Optimization cannot be accomplished at least this time for plug loads
- Maximum potential energy consumption at the building site will be between 35 to 50,000 BTU/ft^2/yr, that can be achieved in any climate
- For NZEB this amount has to be offset by renewables

Can It Be Done?

NET ZERO ENERGY BUILDINGS

- Example: **Jordan College**
  Grand Rapids, MI
  - Natural Wind Flow
  - Intensive Landscaping
  - Thermal Mass
  - Micro Turbines
  - Wind Power
  - Variable Speed Pumping
  - Wood Burning System
  - Central Chilled Water Storage
  - Grey Water Recycling
  - Photovoltaics
  - Natural Water Ponds





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NET ZERO ENERGY BUILDINGS

- Example: **State Office Building Sacramento, CA**
  - Building Area: 220,000 ft^2
  - Sustainable Design Features:
    - Solid Desiccant Dehumidification
    - Earth Berms
    - Concentrated Solar Collectors
    - Reflective Lighting
    - Maximum Daylighting
    - Light Wells And Light Corridors
    - Recycled Materials
    - Daylighting Models
    - Ice Storage Tank
    - High Temperature Storage Tank
    - 350ºf High Temperature Solar Collectors
    - Variable Speed Pumps
    - Direct Digital Controls
    - Concentrated Solar Collectors

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NET ZERO ENERGY BUILDINGS

- Example: **Department of Energy National Labs, Oak Ridge, TN**
  - Solar Silo Configuration to Store Low-Grade Heat
  - Integrated Storage Tank at Main Entry
  - Low Temperature Desiccant Cooling
  - Low Cost Flat Plate Collectors
  - Daylighting
  - Diffused Lighting
  - Shading
  - Passive Heat Collection
  - Ground Water Heat Pumping
  - Solar Pond

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NET ZERO ENERGY BUILDINGS

- Example: **Audubon Center at Debs Park**
  - City: Los Angeles, California
  - Total Energy Use: 17.1 kBtu/ft^2/yr
  - Renewable Energy Supply: 17.1 kBtu/ft^2/yr
  - Building Area: 5,000 ft^2

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NET ZERO ENERGY BUILDINGS

- Example: **The Aldo Leopold Foundation**
  - City: Baraboo, Wisconsin
  - Total Energy Use: 19.4 kBtu/ft^2/yr
  - Renewable Energy Supply: 21.3 kBtu/ft^2/yr
  - Building Area: 13,400 ft^2

NET ZERO ENERGY BUILDINGS

- Example: **Hudson Valley Clean Energy Office & Shop**
  - City: Rhinebeck, NY
  - Total Energy Use: 9.9 kBtu/ft^2/yr
  - Renewable Energy Supply: 10.5 kBtu/ft^2/yr
  - Building Area: 5,400 ft^2

NET ZERO ENERGY BUILDINGS

- Example: **Science Museum of Minnesota**
  - City: St. Paul, Minnesota
  - Total Energy Use: 22.5 kBtu/ft^2/yr
  - Renewable Energy Supply: 32.4 kBtu/ft^2/yr

NET ZERO ENERGY BUILDINGS

- Example: **Lewis Center for Environmental Studies**
  - City: Oberlin, Ohio
  - Total Energy Use: 32.1 kBtu/ft^2/yr
  - Renewable Energy Supply: 36.5 kBtu/ft^2/yr
  - Building Area: 13,600 ft^2

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