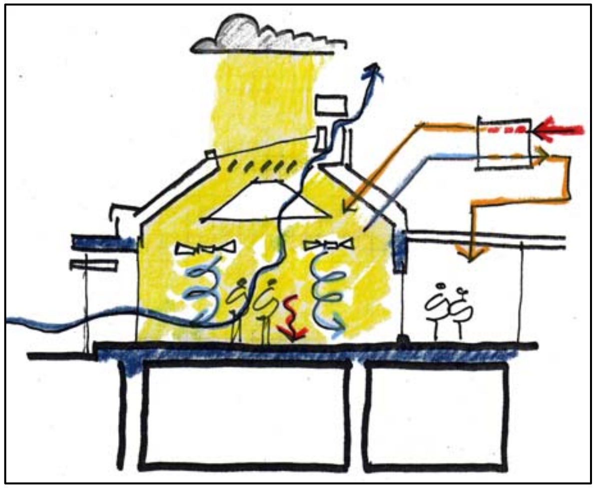
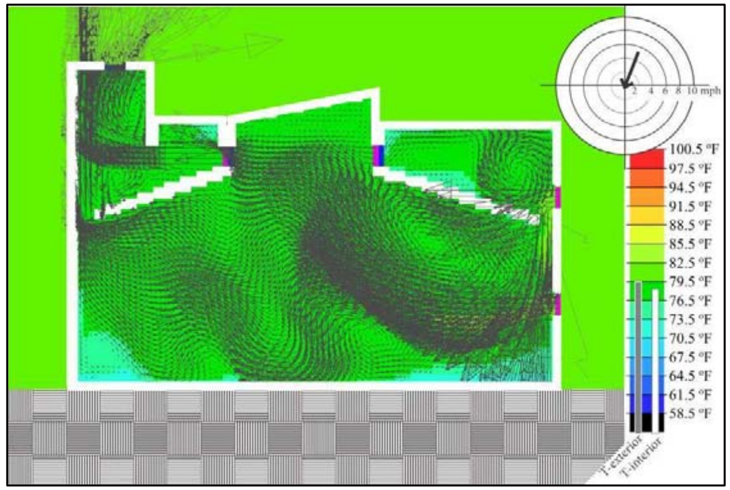
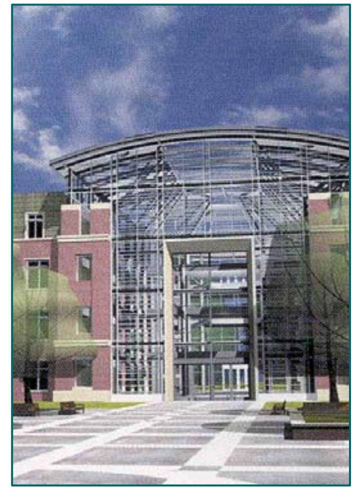






PassivHaus Principles
Applied to Non-residential Buildings

Design Implications for Ultra-low Energy Thresholds:

Lighting, Fans & Pumps, Miscellaneous Loads, and Service Water Heating

Non-residential Buildings

What are they?

Offices

K-12 schools

Higher education

Theaters

Churches

Hospitals

Restaurants

Recreation facilities

Warehouses

Supermarkets

Fueling stations

To name a few ….

Non-residential Buildings

How to characterize?

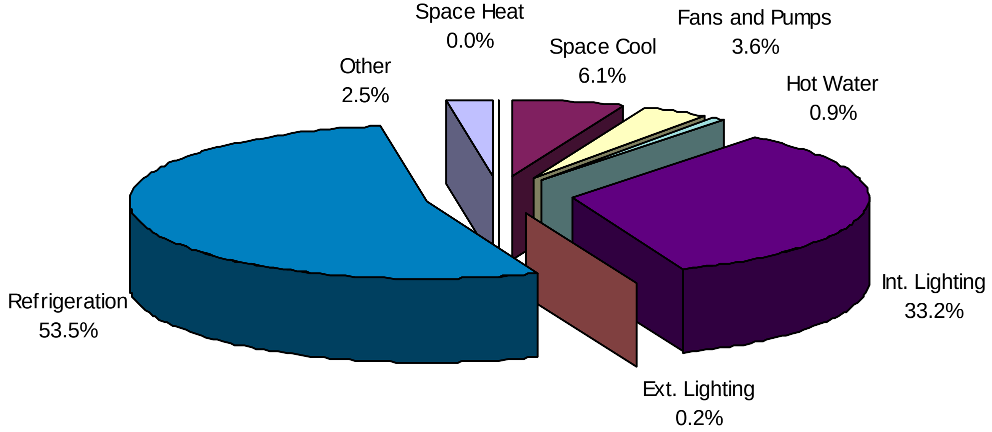
Energy Use Intensity (EUI)

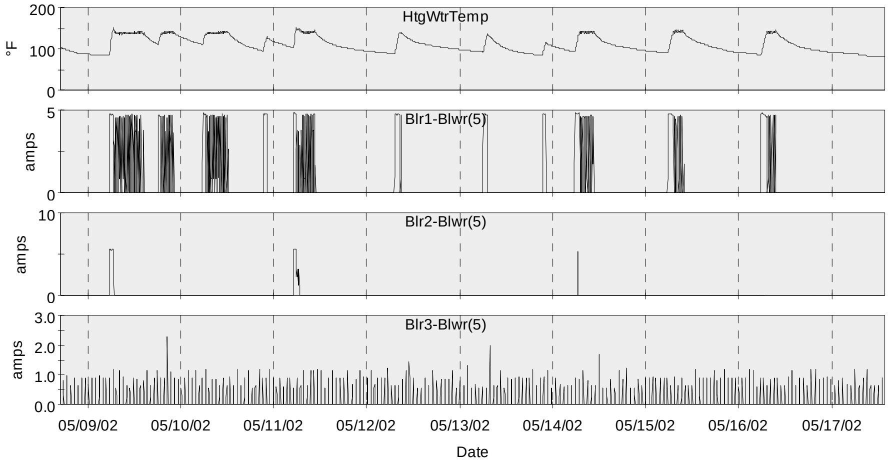
Energy End Use Splits

Use and Load Patterns

HVAC System Types & Controls

Energy Codes in Play





Energy Use Intensity & Energy End Uses

PassivHaus Limit: 14 kBtu/SF

Heating: 4.75 kBtu/SF allocation

Cooling: ????

Lighting: ????

Fans & pumps: ????

Miscellaneous: ????

Service hot water: ????

How are the designs for the systems in these end use categories different in PassivHaus projects?

To Get Started: Make End Energy Budget Allocations

PassivHaus Limit: 14 kBtu/SF

Heating: 4.75 kBtu/SF allocation

Cooling: 0 (no mechanical cooling)

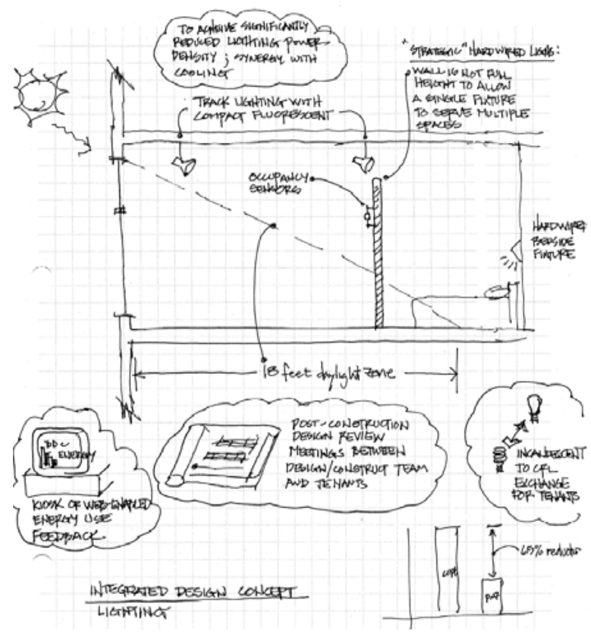
Lighting: 2.8 kBtu/SF 30% of remaining budget

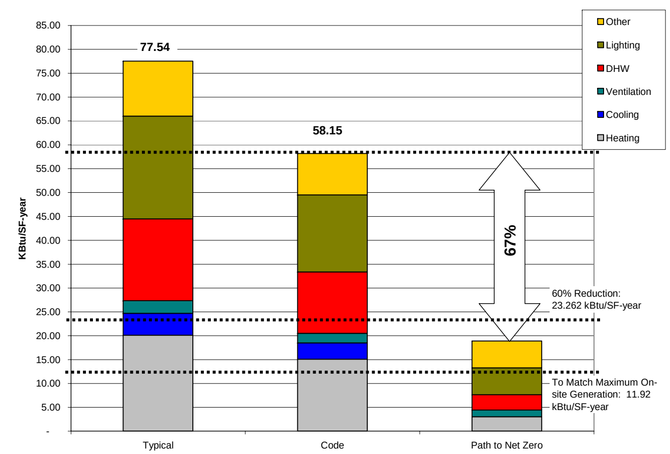
Fans & pumps: 2.8 kBtu/SF 30% of remaining budget

Miscellaneous: 2.8 kBtu/SF 30% of remaining budget

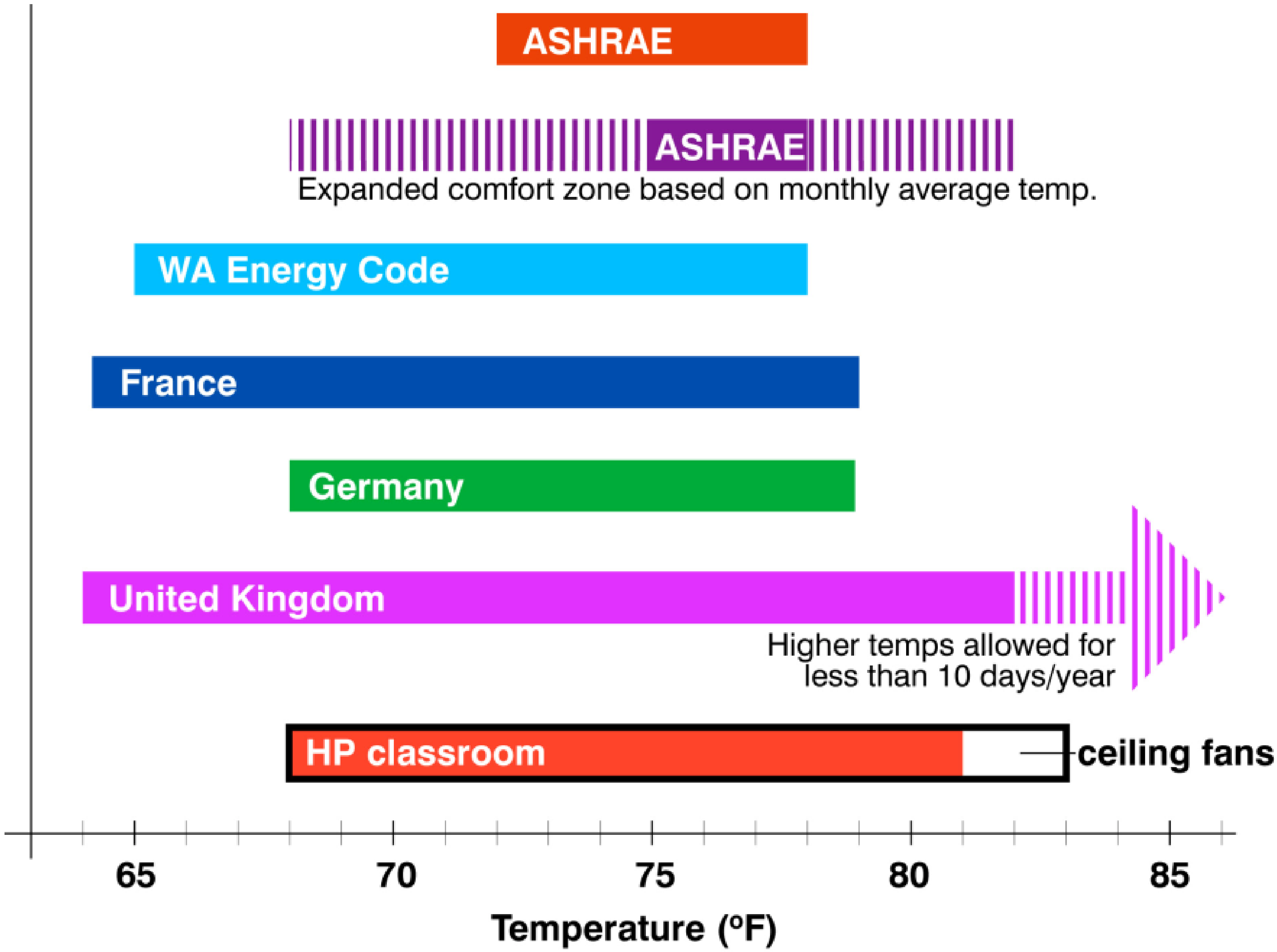
Service hot water: 0.9 kBtu/SF 10% of remaining budget

Then test the allocations to understand design implications (we'll use office buildings as our context)

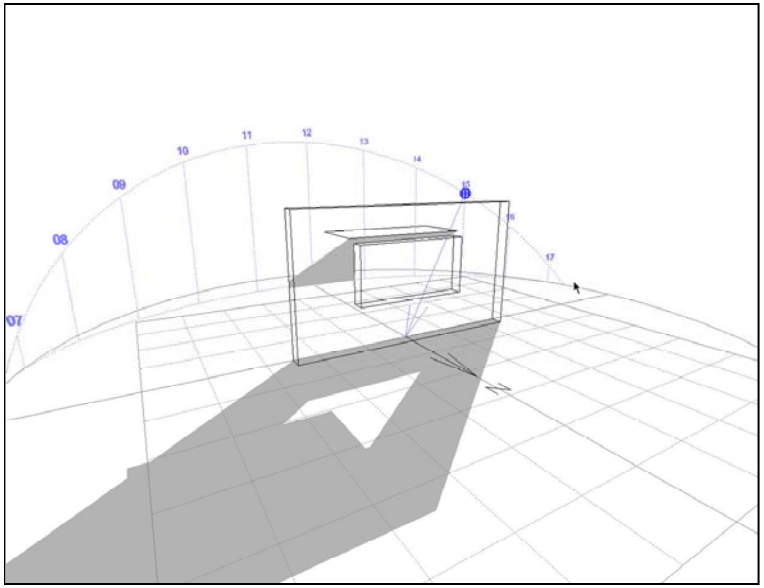




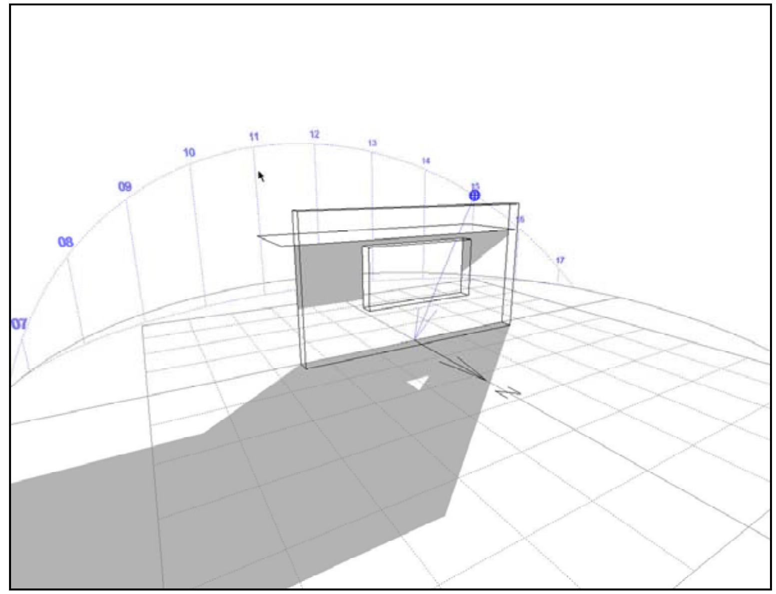
A Few Comments on Cooling: Understanding Thermal Comfort



Cooling: Controlling Solar Gain

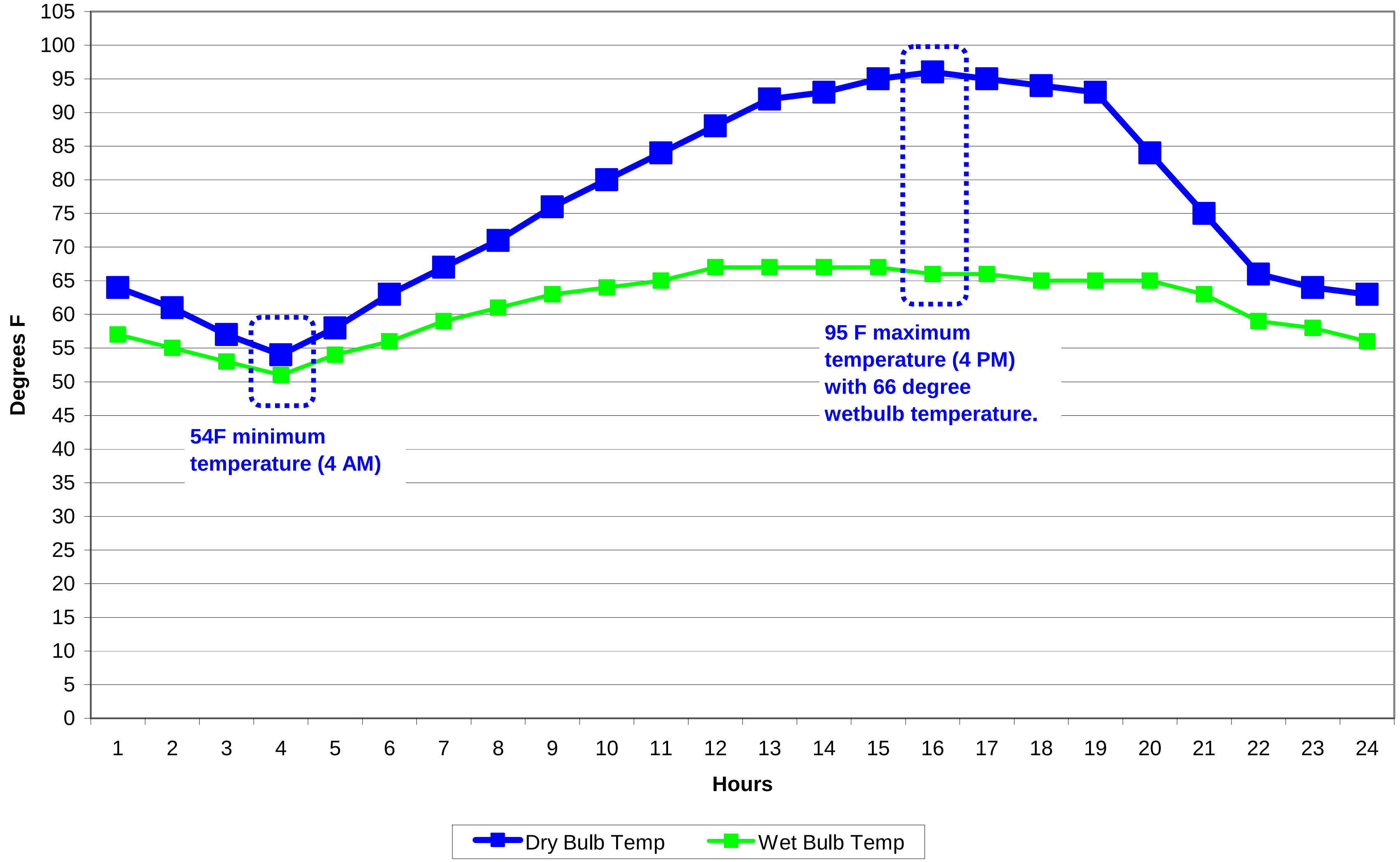


3’11” overhang, window width



5’6” overhang, extends 5’0” to either side of window

Cooling: Climate-Responsive Passive Cooling Concepts



Lighting: Ultra-efficient Office Example

Select Effective Design Criteria

- Low horizontal illuminance (10 to 20 fc)
- Principles of non-uniform illumination
- Comprehensive daylighting (DF=2)
- Ambient-task thinking

Lighting Power Density (LPD): = 0.33 w/sf

Most Efficient Light Sources

- 20 fc and 60 lumens/watt (delivered to visual task plane)
- Premium T8 linear fluorescent in nice fixture

End Use EUI: 2.3 kBtu/SF

(UNDER ALLOCATION BY 0.5 kBtu/SF)

Use Only When Needed

- At 2043 hours/year (equivalent full load hours per year)
- Occupancy sensors and daylighting controls
- Full occupancy weekdays ; Half occupancy weekends

Lighting: Typical Modern Office Example

Design Criteria

- Horizontal illuminance (35 to 50 fc)
- Principles of non-uniform illumination
- Daylighting (DF=2)
- Task lighting supplemental but not contributory

Lighting Power Density (LPD): = 0.8 w/sf

Most Efficient Light Sources

- Design 20% lower than code budget

Use Only When Needed

- At 2043 hours/year (equivalent full load hours per year)
- Occupancy sensors and daylighting controls
- Full occupancy weekdays ; Half occupancy weekends

End Use EUI: 5.6 kBtu/SF

(OVER ALLOCATION BY 2.8 kBtu/SF)

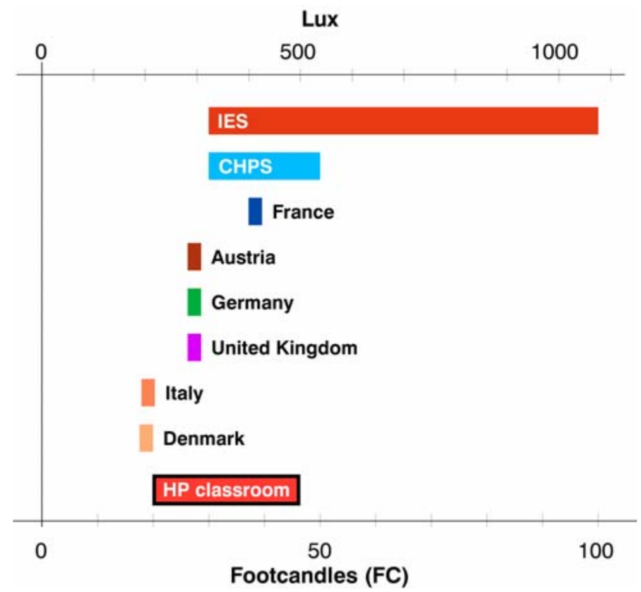
Lighting: Effective Design Criteria

Horizontal Illuminance

Footcandles: Lumens / SF on horizontal visual task plane (i.e. desktop)

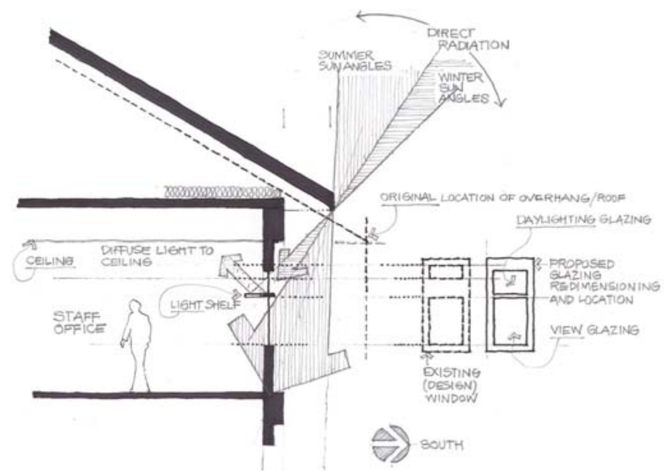
Only one of many design criteria but often elevated to prime importance

Daylight and electric light criteria should be similar



Principles of Non-uniform Illumination

Notion that we only need design illuminance in locations where visual task are performed and it is okay to have variability



Daylighting

Controlled introduction of sunlight to accomplish visual tasks without using electric lighting

Ambient-Task Concepts

Design of “layered” light systems where local visual task zones are illuminated with dedicated “task” lighting systems

Lighting: High Efficacy Sources

Linear Fluorescent

T8 and T5 lamps
Electronic ballasts / dimming capability
80 to 100 lumens per watt

Compact Fluorescent

Hardwired and screw-in
Electronic ballasts / dimming capability
50 to 65 lumens per watt

White LED

Downlights, linear, etc.
50 to 70 lumens per watt

Metal Halide

Pulse start, ceramic metal haldie
60 to 80 lumens per watt

Lighting: Effective Controls

Manual

- Multiple switch legs to allow occupant tuning of light levels
- Strategic switch placement to encourage daylighting awareness
- Convenient and logical locations that create intuitive control feedback
- Dimming switches

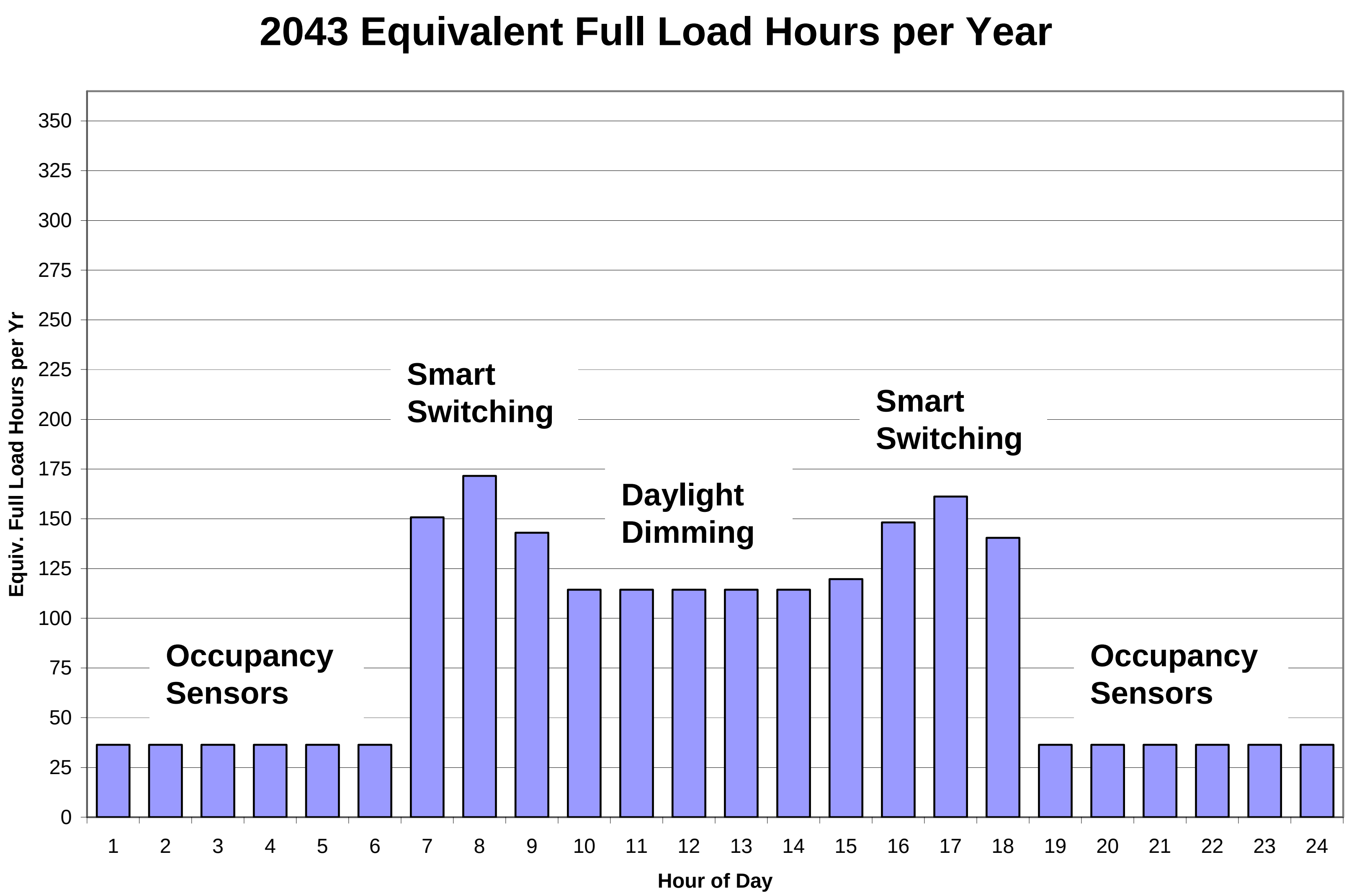
Occupancy Sensors

- Line voltage wall switches, primarily passive infrared sensing
- Low voltage systems, using multiple sensing technologies
- Understand effect of time delay

Light Level Sensing

- Simple on-off photocells
- Dimming controls – open loop (senses “exterior” light levels
- Dimming controls – closed loop (senses “interior” light levels

Lighting: Effective Controls



Lighting: Performance Summary

Circuited Load: 0.3 to 0.5 w/SF

Effective design criteria
Best in class light sources

Hours of Operation: Less than 2100 equivalent full load hours/year

Daylighting
Automatic controls with tight time delay
Excellent occupant awareness

Fans and Pumps

Design for Minimum Work

- Ventilation air only
- If hydronic heating, specify high temperature differentials to minimum flow rate
- Minimize pressure requirements

Office: 0.15 cfm/SF at no greater than 2" wc total static pressure (supply & exhaust)

Use most efficient fans and pumps

- Maximize mechanical efficiencies (fan wheels, centrifugal pump impellers)
- Maximize electrical motor efficiencies

35% combined mech/elec efficiency = 0.1 watt/SF of ventilated office space

(fan power limit of 0.00077 kW/cfm = 0.116 watt/SF of ventilated office space)

Design for variable flow / variable speed

- Variable flow operation (modulating 2-way valves or dampers)
- Variable speed drives
- Electronically commutated motors

At 75% speed, power draw ~50% of full load

Fans and Pumps Example

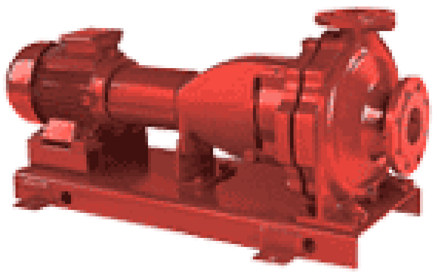
Ventilation

$$\text{BHP} = \frac{\text{Air flow, cfm} \times \text{static pressure, in. wc}}{6356 \times \text{Efficiency}_{mech}}$$

0.15 cfm/SF x 2” wc / 6356 / 35% combined efficiency (0.00066 kW/cfm): 0.1 w/sf

Run continuously at 75% average speed: 1.50 kBtu/SF-year

Run continuously at full speed: 3.0 kBtu/SF-year



Pumps

$$\text{BHP} = \frac{\text{Water flow, gpm} \times \text{head, ft. wc}}{3960 \times \text{Efficiency}_{mech}}$$

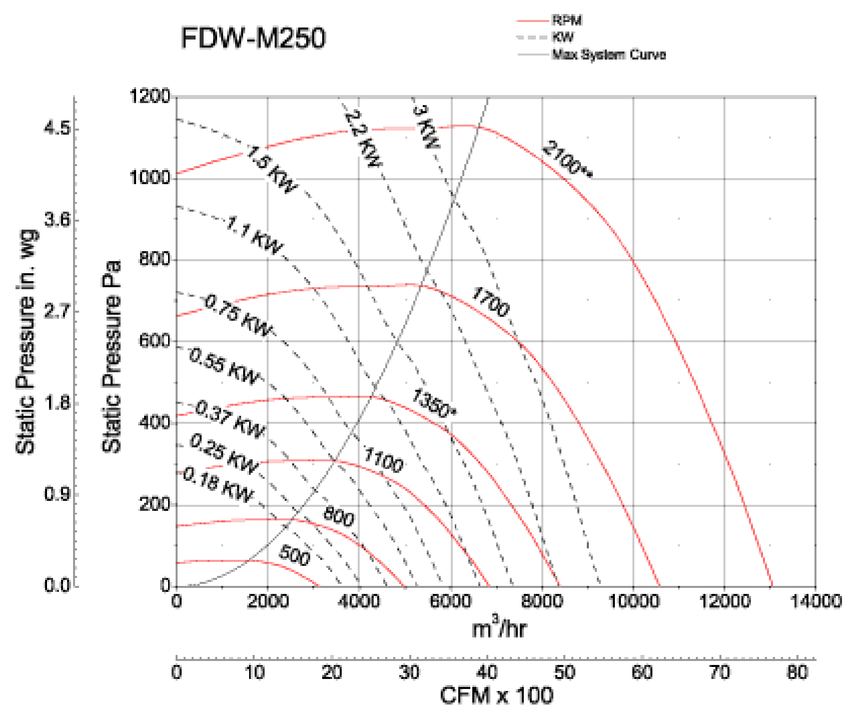
0.00025 gpm/SF x 25 feet / 3960 / 35% combined efficiency: 0.0034 w/sf

Fans Example (Conventional Office)

Ventilation: Air flow established by peak cooling load

0.75 cfm/SF x 5” wc / 6356 / 58% combined efficiency: 0.76 w/sf

Run 3,500 hours/yr at 75% average speed: 4.54 kBtu/SF-year



Fans and Pumps: Variable Flow / Variable Speed

Relationships (Affinity Laws)

$BHP_2 = BHP_1 \times (N_2 / N_1)^3$

$kW_2 = kW_1 \times (N_2 / N_1)^3$

$CFM_2 / CFM_1 = N_2 / N_1$

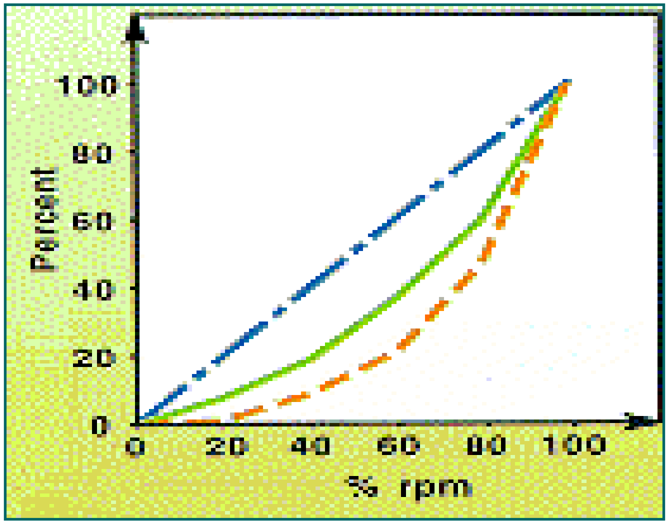
$Flow_2 / Flow_1 = N_2 / N_1$

$H_2 / H_1 = (N_2 / N_1)^2$

BHP = Brake Horse Power

N = Speed, RPM

H = Pressure



Applications

Fan control

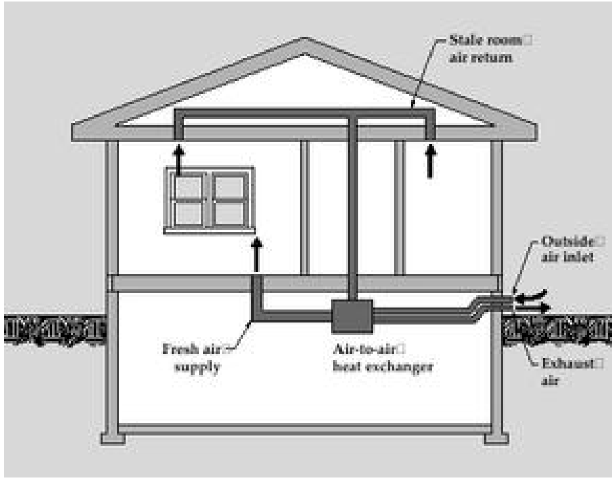
Pump control

Process motor control

Fans and Pumps: Performance Summary

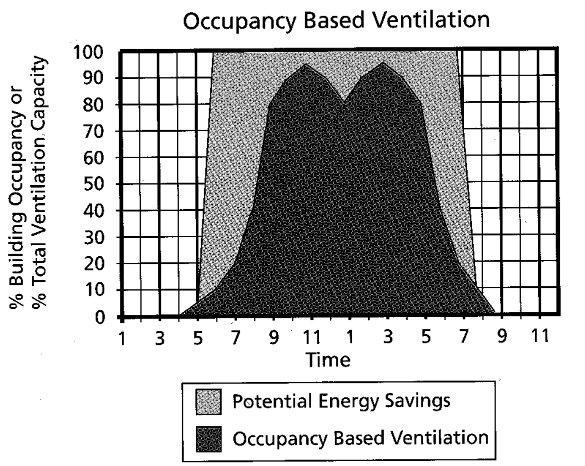
Connected Load: 0.1 to 0.2 w/SF

Air flow for ventilation only
Maximize combined efficiency
Minimize pressure drops



Hours of Operation: Less than 3500 hours/year (equivalent full load)

Variable flow / variable speed
Demand controlled ventilation for spaces with high occupancy density



Plug Loads

Minimize connected load

Less than or equal to lighting (0.3 to 0.5 w/sf)

Use only when needed

At 2000 hours/year (2.3 kBtu/SF-year)

Conventional office

Connected load: 1.0 w/sf
Operating hours: 3250 EqFLHrs/Yr
EUI: 11.1 kBtu/SF

Plug Loads: Minimize Connected Load

Information Technology

Laptops
Thin client systems
LCD monitors (avoid multiple screens)
Shared printers

Elevators and Lifts

Traction elevators
Useable stairs

Appliances

Energy Star +

Other

Avoid vending machines
Pay attention to phantom loads
Consider energy information systems

Plug Loads: Use Only When Needed

Manual

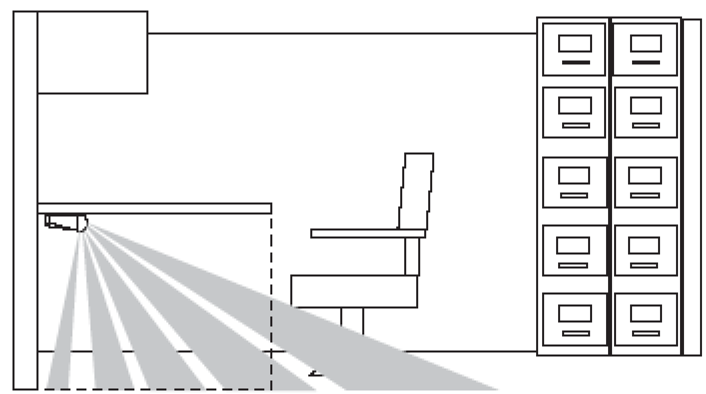
Switched outlets
Accessible plug strips

Automatic Control

Occupancy sensor controlled plug strips
Equipment with effective “sleep” modes

Phantom Load Control

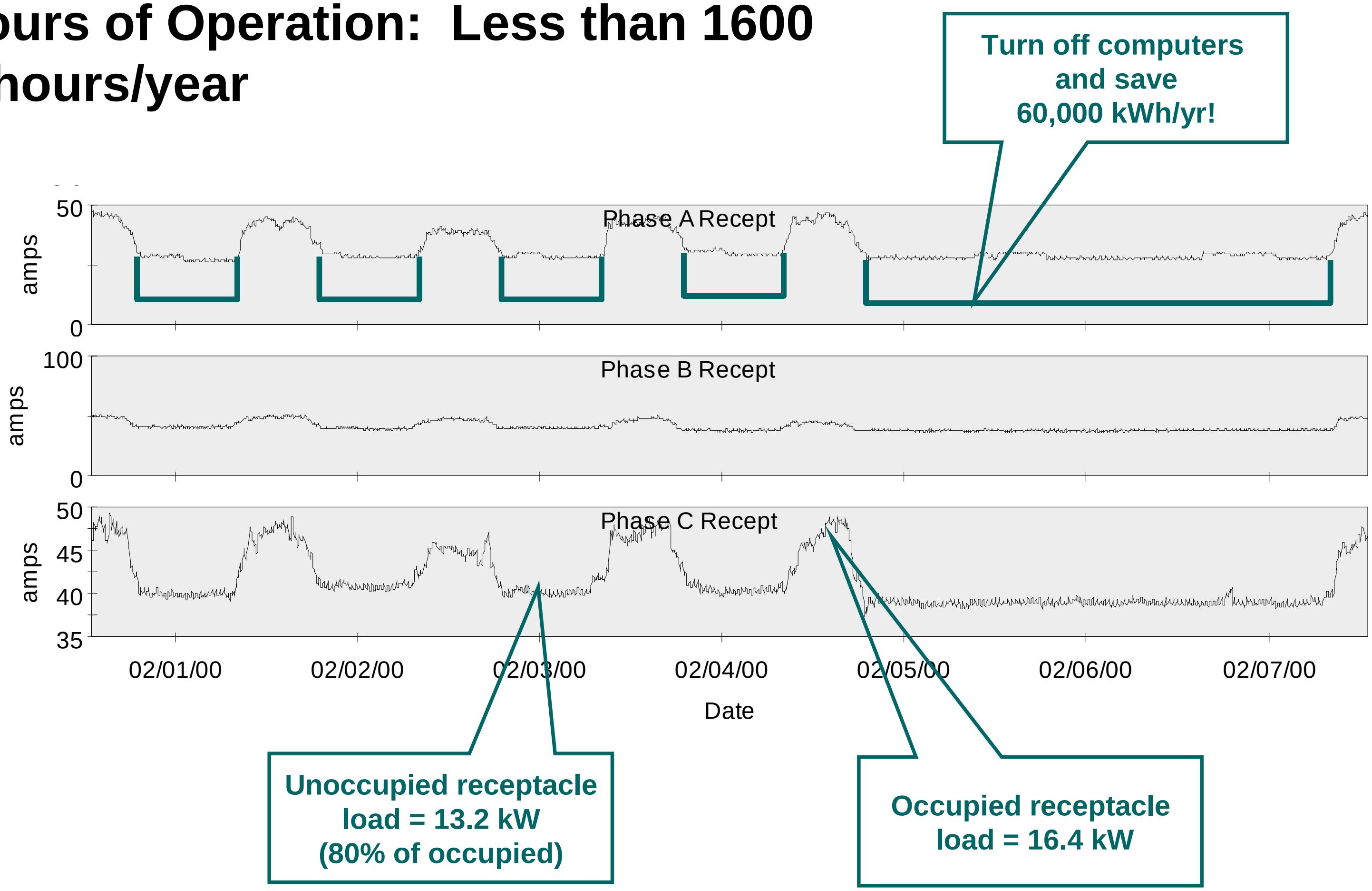
Occupancy awareness



Plug Loads: Performance Summary

Connected Load: 0.3 to 0.5 w/SF

Hours of Operation: Less than 1600 hours/year



This is 7400 equivalent full load hours per year

Service Water Heating

Minimize Water Heating Load

Peak loads minimized with low flow plumbing
Eliminate “parasitic” loads / losses
Minimize setpoint

Use maximum efficiency sources

Solar thermal
Biomass
Heat pumping
Condensing natural gas
Tankless electric resistance

Office: 2 gal/person per day of 110 deg F water; no unoccupied period losses

Tankless electric resistance: 0.31 kWh/SF (1 kBtu/SF)

Solar thermal integration: Solar fraction of 0.50 >> 0.5 kBtu/SF

Service Water Heating: Minimize Loads

Low flow plumbing

- Low flow faucets and appliances
- 1.5 gpm shower heads

Eliminate losses

- Minimize or eliminate storage
- Super-insulation tank and piping
- Avoid re-circulation (or at least aggressively control)
- Avoid natural draft gas-fired heaters

Minimize setpoints

- Cold water only fixtures
- Setpoints between 110F and 120F
- Storage tank turnover to address legionella

Service Water Heating: Use Maximum Efficiency Sources

Solar

- Size for solar fraction of 1.0 during peak solar resource period
- Annual fraction of at least 0.50

Biomass / Fossil Fuel

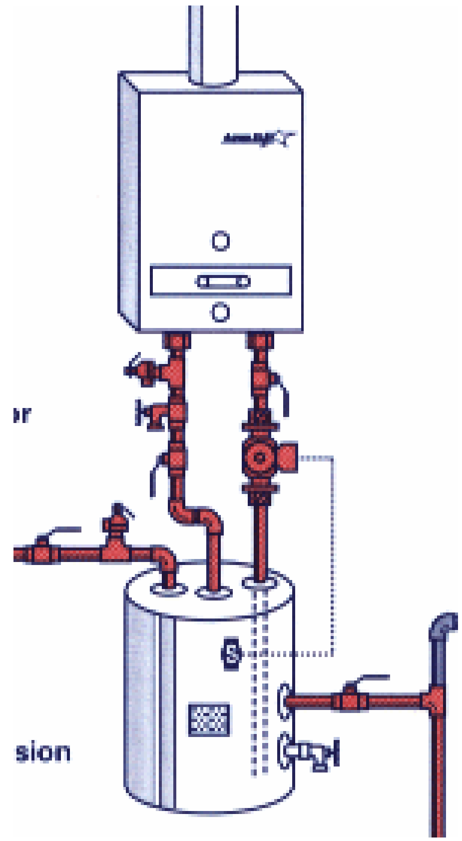
- Use controlled combustion
- Avoid natural draft

Heat Pumping

- Heat pump water heater can recover heat
- Ground-coupled heat pumping

Tankless Electric

- Small point of use
- Demand initiated tankless

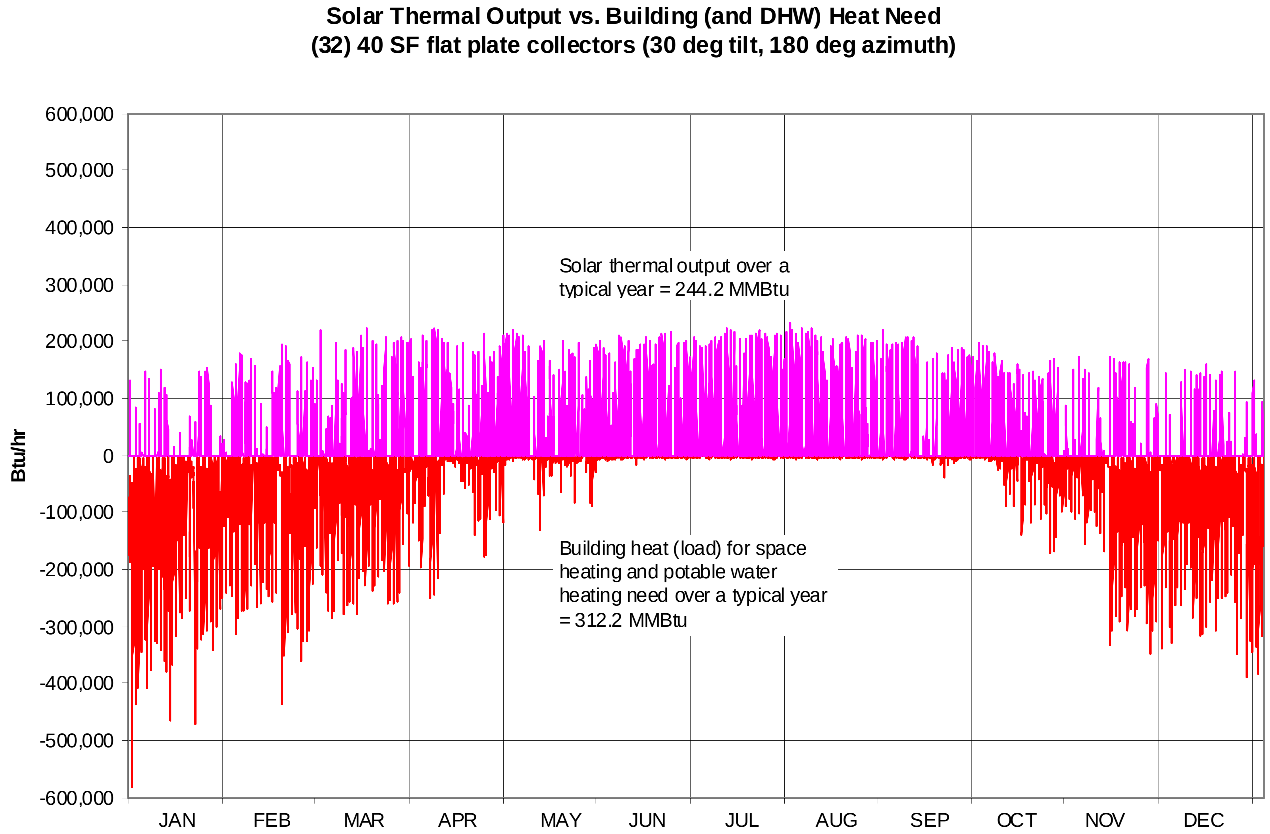


Service Water Heating: Performance Summary

Effective Use: 0.007 gal/SF (offices)

Supply Water Setpoint: 115 deg F

Solar: Seriously consider



Overall Performance of Our Example

End Use	Target kBtu/SF	Example kBtu/SF
Heating	4.25	4.25
Cooling	0	0
Lighting	2.8	2.3
Fans/Pumps	2.8	3
Plugs	2.8	2.3
DHW	0.9	1
Total	**9.3**	**8.6**

PassivHaus Thinking: Navigating the Culture of Design

Cooling

Will have to overcome serious obstacles associated with accepting “effective” thermal comfort criteria

Lighting

Will have to overcome serious obstacles associated with accepting “effective” design criteria

Fans and Pumps

Can no longer build conventional U.S. HVAC systems
No simultaneous heating/cooling
Will have to overcome huge market inertia of the HVAC industry

Plug Loads

Occupant outreach and engagement is required
This will be the most challenging end use
Solution is not necessarily technical

Service Water Heating

Will need to redefine how and why commercial buildings need potable hot water
For high use occupancies, will need to integrate solar thermal systems