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

Expanded comfort zone based on monthly average temp.

- ASHRAE
- WA Energy Code
- France
- Germany
- United Kingdom

Higher temps allowed for less than 10 days/year

- HP classroom
- Ceiling fans

Temperature (°F)

65  70  75  80  85
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

- **54°F minimum temperature (4 AM)**
- **95°F maximum temperature (4 PM) with 66 degree wetbulb temperature.**
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

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

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 Power Density (LPD): = 0.33 w/sf

End Use EUI: 2.3 kBtu/SF
(UNDER ALLOCATION BY 0.5 kBtu/SF)
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

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

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

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 halide
- 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

2043 Equivalent Full Load Hours per Year

- Smart Switching
- Daylight Dimming
- Occupancy Sensors

Hour of Day
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

Use most efficient fans and pumps
- Maximize mechanical efficiencies (fan wheels, centrifugal pump impellers)
- Maximize electrical motor efficiencies

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

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

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)

At 75% speed, power draw ~50% of full load
Fans and Pumps Example

Ventilation

\[
\text{BHP} = \text{Air flow, cfm x static pressure, in. wc} \times \text{Efficiency}_{\text{mech}} \\
6356 \times \frac{0.15 \text{ cfm/SF} \times 2” \text{ wc}}{6356} / 35\% \text{ combined efficiency} \times (0.00066 \text{ kW/cfm}) = 0.1 \text{ w/sf}
\]

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

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

Pumps

\[
\text{BHP} = \text{Water flow, gpm x head, ft. wc} \times \text{Efficiency}_{\text{mech}} \\
3960 \times \frac{0.00025 \text{ gpm/SF} \times 25 \text{ feet}}{3960} / 35\% \text{ combined efficiency} = 0.0034 \text{ w/sf}
\]
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

FDW-M250
Fans and Pumps: Variable Flow / Variable Speed

Relationships (Affinity Laws)

\[ BHP_2 = BHP_1 \times \left( \frac{N_2}{N_1} \right)^3 \]
\[ kW_2 = kW_1 \times \left( \frac{N_2}{N_1} \right)^3 \]
\[ CFM_2 / CFM_1 = \frac{N_2}{N_1} \]
\[ Flow_2 / Flow_1 = \frac{N_2}{N_1} \]
\[ H_2 / H_1 = \left( \frac{N_2}{N_1} \right)^2 \]

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

- Turn off computers and save 60,000 kWh/yr!

Unoccupied receptacle load = 13.2 kW (80% of occupied)

Occupied receptacle load = 16.4 kW

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

Solar Thermal Output vs. Building (and DHW) Heat Need
(32) 40 SF flat plate collectors (30 deg tilt, 180 deg azimuth)

Solar thermal output over a typical year = 244.2 MMBtu

Building heat (load) for space heating and potable water heating need over a typical year = 312.2 MMBtu
## Overall Performance of Our Example

<table>
<thead>
<tr>
<th>End Use</th>
<th>Target kBtu/SF</th>
<th>Example kBtu/SF</th>
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<tbody>
<tr>
<td>Heating</td>
<td>4.25</td>
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<tr>
<td>Cooling</td>
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<td>0</td>
</tr>
<tr>
<td>Lighting</td>
<td>2.8</td>
<td>2.3</td>
</tr>
<tr>
<td>Fans/Pumps</td>
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<td>3</td>
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<tr>
<td>Plugs</td>
<td>2.8</td>
<td>2.3</td>
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<tr>
<td>DHW</td>
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<td>1</td>
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<tr>
<td><strong>Total</strong></td>
<td><strong>9.3</strong></td>
<td><strong>8.6</strong></td>
</tr>
</tbody>
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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