Re-Arch: The Initiative for Renewable Energy in Architecture

Best Practices in Daylighting & Passive Systems for Smaller Commercial Buildings

Thomas Brown, Architect, LEED-AP

Project Team:
University of Minnesota College of Design (CDes)
Midwest Renewable Energy Society (MRES)
Center for Sustainable Building Research (CSBR)
Midwest Renewable Energy Association (MREA)
American Institute of Architects Minnesota (AIA MN)
Green Institute


Funded in part by the Minnesota Pollution Control Agency (MPCA)
• Passive Solar
  – Tools
• Passive Solar
  – Sun Angle

• Source: LOF-Sun-Angle-Calculator-cover.jpg
• Passive Solar
  – Sun Angle
  – sbse.org/resources/sac

Source: SBSE-LOF-sun-angle-calculator-order-website-1.jpg
• Passive Solar
  – Sun Angle

• Source: Solar-Card-Design-Works-1.jpg
• Passive Solar Design
  – Guidelines

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- Passive Solar Design
  - Guidelines
  - Mid-month Sun Angles – 12 noon

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  – Guidelines  
  – Summer Shading Sun Angles – April to August

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• Passive Solar
  – Shading
    • Overhangs

Designing Overhangs
Overhangs control the solar heating season, that is, the beginning and end of the period of solar gain through south-facing glazing. Fixed overhangs should be designed so there is a separation between the top of the window and the underside of the projecting surface, as shown in figure 3-17. This feature, combined with the length of the overhang, allows the low-angled winter sun (angle A in the drawing) to penetrate the interior, while blocking the high-angled summer sun (angle B) from gaining entrance at the end of the heating season. To determine the length of the overhang projection, use the following formula:

\[ \text{length of projection (L)} = \frac{\text{height of window opening (H)}}{F \text{ factor}} \]

In this equation, the F factor is a number that varies with the latitude. It is determined from table 3-2. For example, suppose you are building a home in Wisconsin at 44° north latitude. Suppose your windows are 6 feet high. To determine the overhang, you would simply divide 6 feet by the F factor, which in this case is 2 to 2.7. As you can see, F factors are expressed in a range, which allows some design flexibility. If you want more sunlight, use the larger number in the range. Knowing your heating requirements (heating degree days) and solar availability (average daily solar radiation by season) will assist you in making this determination.

F Factor Used to Determine Length of Overhang Projection in All Passive Solar Designs

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• Source: Chiras-Solar-House-7c-overhangs.jpg
• Passive Solar
  – Shading
  • Overhangs

**Fig. E-56.** An example showing how roof overhang geometry can be modified to provide desired summer shading and winter solar gain. The 90° allowances shown extend the desired effects over a ten-week season.
• Passive Solar
  – Shading
    • Overhang Example
    • Summer Solstice
    • April-August
    • Spring-Fall Equinox
    • Winter Solstice
    • Stevens Point, WI
Passive Solar

- Shading
  - Overhang Example
  - Summer Solstice
  - April-August
  - Spring-Fall Equinox
  - Winter Solstice
  - Stevens Point, WI

Stevens Point, WI -- 7' View + 2' Transom = 9' Glazing
• Passive Solar
  – Web Tools
• Passive Solar
  – Web Tools
  – builditsolar.com
• Passive Solar
  – Web Tools
  – builditsolar.com

Source: Build-it-Solar-website-solar-resources-2.jpg
• Passive Solar
  – Web Tools
  – builditsolar.com

Source: Build-it-Solar-website-solar-site-analysis-1.jpg
• Passive Solar
  – Web Tools
  – susdesign.com

**design tools**

*sustainable by design* provides a suite of shareware design tools on sustainable energy topics:

- **SunAngle**
  our premier tool for solar angle calculations

- **SunPosition**
  calculates a time series of basic solar angle data

- **Sol Path**
  visualization of the path of the sun across the sky

- **Window Overhang Design**
  visualization of window overhang performance

- **Window Heat Gain**
  calculation of monthly heat gain through windows

- **CFL Economics**
  compares economics of CFL vs incandescent lamps

• Source: Sustainable-by-Design-website-Design-Tools-1.jpg
• Passive Solar
  – Web Tools
  – susdesign.com

Source: Sustainable-by-Design-website-SolPath-45-6-21.jpg
• Passive Solar
  - Web Tools
  - susdesign.com

• Source: Sustainable-by-Design-website-Sun-Angle-45-90.jpg
• Passive Solar
  – Web Tools
  – susdesign.com

• Source: Sustainable-by-Design-website-Window-Heat-Gain-1.jpg
• Passive Solar
  – Web Tools
  – Solardat.uoregon.edu/
    SolarChartProgram

**Sun path chart program**
This program creates sun path charts in Cartesian coordinates for: (1) "typical" dates of each month (i.e., days receiving about the mean amount of solar radiation for a day in the given month); (2) dates spaced about 30 days apart, from one solstice to the next; or (3) a single date you specify. You can select whether hours are plotted using local standard time or solar time. In addition, there are a number of options available to allow you to alter the chart's appearance.

Resulting charts are displayed in your Web browser window, and they are meant to be printed out. Two formats are currently available: PDF (Adobe) and PNG (a standard international graphics format).

The create sun path charts in polar coordinates go to the [polar sun path charts](#) Web page. For more information, visit our Web page [about using sun charts](#).
• Passive Solar
  – Web Tools
  – Solardat.uoregon.edu/SolarChartProgram

Source: U-Oregon-Solar-Sun-Path-Chart-website-2.jpg
• **Passive Solar**
  – Web Tools
  – Solardat.uoregon.edu/SolarChartProgram

- Source: U-Oregon-Solar-Sun-Path-Chart-Mpls-MN-6-21.jpg
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  – Solardat.uoregon.edu/SolarChartProgram

Source: U-Oregon-Solar-Calculator-website-1.jpg
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  - Solardat.uoregon.edu/SolarChartProgram
• Passive Solar
  – Web Tools
  – Archiphysics.com

• Source: ArchiPhysics-Website-1.jpg
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  – Web Tools
  – ArchiPhysics.com

• Source: ArchiPhysics-website-Passive-1.jpg
• Passive Solar
  – Web Tools
  – advancedbuildings.org

• Source: Canada-Advanced-Buildings-website-1.jpg
• Passive Solar
  – Web Tools
  – wbdg.org

Source: WBDG-website-Passive-Solar-1.jpg
• Passive Solar
  – Web Tools
  – eere.energy.gov
• Passive Solar
  – Web Tools
  – greenbuilder.com

Passive Solar Guidelines

1.0 Passive Solar Design Introduction

Solar energy is a silent form of energy that powers our planet and is essential for our survival. Some of the natural processes that can be harnessed through building design to manage the energy flow include passive solar design, which focuses on utilizing the sun's energy to heat or cool the building. This involves designing the building to maximize the amount of solar energy that can be absorbed and stored within the building's envelope.

Efficient passive solar design strategies include:

- **Passive solar systems**
  - The building should be oriented to minimize heat loss.
  - The building envelope should be designed to retain heat and minimize heat loss.
  - The building should be designed to maximize the amount of solar energy that can be absorbed and stored within the building's envelope.
  - The building should be designed to minimize the amount of heat that is lost through the envelope.

Source: GreenBuilder-website-passive-1.jpg
• Passive Solar
  – Web Tools
  – nrel.gov
- Passive Solar
  - Web Tools
  - retscreen.net

Source: Retscreen-website-Tools-1.jpg
• Passive Solar
  – Guidelines - Rules of Thumb

General

• In winter, the sun rises in the southeast and sets in the southwest, with a low noontime sun angle of about 23 degrees in December. The low angle allows good solar penetration.

• In summer, the sun rises in the northeast and sets in the northwest, with a high noontime sun angle of about 69 degrees in June. The high angle allows good summer shading with overhangs.

• The sun is in the same position in spring and fall. In spring, the west sun is sometimes welcome, in fall it often is not.

• The west afternoon sun is not of value in the winter and can be a liability in the summer, presenting a cooling and shading problem.
• Passive Solar
  – Guidelines - Rules of Thumb

**Building Construction**

- Avoid standard truss or rafter framing, where exterior overhang soffits are tight to the top of the windows.
- Use raised-heel energy trusses, where the exterior soffit is at or near the interior ceiling height.
- For conventional stick-built framing, set rafters on a plate on top of ceiling joists, instead of on wall top plate.
• Passive Solar
  – Guidelines - Rules of Thumb

**Building Shape**

- Elongated shape along east-west axis
- Easier to shade south-facing glazing
- Less exposure to summer sun in east and west
• Passive Solar
  – Guidelines - Rules of Thumb

Building Orientation

• Elongated building axis facing south
• Up to 30 degrees east or west of south acceptable
• Southeast orientation provides earlier winter warm-up
• Southeast orientation lessens summer cooling load from west sun
Passive Solar

Guidelines - Rules of Thumb

Glazing Type

- Use clear or low-e gas-filled insulating glazing
- Use higher Solar Heat Gain Coefficient (SHGC) on south-facing glazing, or use clear south-facing glazing
- Use lower SHGC on east, west & north-facing glazing
- Avoid un-shaded overhead glazing
- Use high clerestory or transom windows, instead of skylights, to increase daylight penetration & facilitate shading
- Minimize large expanses of west-facing windows and glazing
• Passive Solar
  – Guidelines - Rules of Thumb

**Glazing Area**

- Allocate 50% of the overall glazing to walls within 30 degrees of south
- Allocate 50% or less of window area to the north, east and west faces
- Provide 10-15% of floor area in south-facing glazing
  - Less glazing if building constructed of lightweight materials
  - More glazing if building constructed of heavier materials
- Limit east or west-facing glazing to less than 5% of floor area
• Passive Solar
  – Guidelines - Rules of Thumb

**Shading**

- For south-facing glazing provide exterior overhangs
- A higher, longer overhang provides better winter sun penetration and summer shading.
- For south-facing gable end roofs, provide a skirt overhang at base of gable.
- For east or west-facing windows, use hip roof overhangs or provide a skirt overhang across the base of gable-end roofs
- For east or west-facing windows, consider vertical wings or fins
- For north-facing glazing provide fins or no shading
- Avoid overhangs tight to top of glazing.
### Thermal Mass

- High-mass buildings provide thermal fly-wheel effect and respond slowly to temperature spikes and dips
- Surface area of thermal mass is more important than thickness
- Provide 3-4 sq ft of thermal mass for each 1 sq ft of south-facing glazing for areas exposed to direct sunlight
- Provide 9-12 sq ft of thermal mass for each 1 sq ft of south-facing glazing for remote areas not exposed to direct sunlight
- Incorporate heavier materials into construction wherever possible
  - Concrete slabs, ceramic tile, stone, pavers
  - Thicker or multi-layer gypsum board, thin-coat plaster
  - Masonry veneer, CMU partition walls
• Passive Ventilation
• Passive Ventilation
  – Belvedere
• **Passive Ventilation**
  – **Cross-ventilation**
  – **Opening area**

![Diagram of Passive Ventilation](Sun-Wind-Light-Brown-DeKay-p242a.jpg)

<table>
<thead>
<tr>
<th>window height as a fraction of wall height</th>
<th>1/3</th>
<th>1/3</th>
<th>1/3</th>
</tr>
</thead>
<tbody>
<tr>
<td>window width as a fraction of wall width</td>
<td>1/3</td>
<td>2/3</td>
<td>3/3</td>
</tr>
<tr>
<td>single opening</td>
<td>12-14%</td>
<td>13-17%</td>
<td>16-23%</td>
</tr>
<tr>
<td>two openings in the same wall</td>
<td>---</td>
<td>22%</td>
<td>23%</td>
</tr>
<tr>
<td>two openings in adjacent walls</td>
<td>37-45%</td>
<td>37-45%</td>
<td>40-51%</td>
</tr>
<tr>
<td>two openings in opposite walls</td>
<td>35-42%</td>
<td>37-51%</td>
<td>47-65%</td>
</tr>
</tbody>
</table>

*Average Interior Air Velocity as a Percentage of the Exterior Wind Velocity range = wind 45° to perpendicular to opening*
• Passive Ventilation
  – Cross-ventilation

• Source: Sun-Wind-Light-Brown-DeKay-p242b.jpg
• Passive Ventilation
  – Cross-ventilation

Source: Sun-Wind-Light-Brown-DeKay-p149.jpg
• Passive Ventilation
  – Wing walls

Recommended Wing Wall Dimensions
Adapted from Chandra et al. (1986, p. 37).

\[ P = 0.5 \, W - 1.0 \, W \]
• Passive Ventilation
  – Solar Chimney
  • Stack Effect
  • Exterior Sunshades

Source: Window-System-High-Performance-Bldgs-Carmody-Selkowitz-BRE-Env-Bldg-UK-1.jpg
• **Passive Ventilation**
  – Solar-induced
  • Stack Effect
• Passive Ventilation
  – Double-Skin Envelope
    • Thermal Chimney
    • Stack Effect

Figure 3-67. Double-envelope system in heat extraction mode where ventilated cavity air is exhausted to the outside

Figure 3-68. Double-envelope system in heat recovery mode where ventilated cavity air is recirculated to the building

• Source:  Window-System-High-Performance-Bldgs-Carmody-Selkowitz-Double-Envelope-1a.jpg
• Passive Ventilation
  – Earth tubes
  – Passive cooling
Passive Ventilation

- Calculations

Ventilation

Even the best designed solar rooms will require ventilation at times of too much heat or humidity or too little carbon dioxide. Ventilation should be able to replace all of the room’s air up to six times each hour.

Natural ventilation is preferred to energy-consuming mechanical ventilation. The greatest amount of ventilation occurs when the exhaust vents are positioned as high as possible and the intake vents as low as possible. Air flow rates and, in turn necessary vent sizes, can be estimated. The velocity of the air, in feet per minute is approximately

\[ V = \frac{n(T_0 - T_f)}{T_f - 460} \]

where

- \( n \) = the height between the intake vent and exhaust vent,
- \( T_0 \) = the temperature at the outlet vent, and
- \( T_f \) = the temperature at the intake vent.

For example, if the outdoor temperature at the intake vent is 85°F, the temperature at the outlet vent is 100°F, and the height is 10 feet,

then the velocity is

\[ V = \frac{10(100 - 85)}{85 + 460} \]

\[ = 255 \text{ cubic feet per minute (255 cf/min).} \]

For solar rooms that taper at the top (as in lean-tos), smaller values should be used. Air can carry 0.018 Btu per cubic foot for each degree it increases in temperature (0.018 Btu cf-°F). The amount of heat exhausted through one square foot of vent each hour is, therefore

\[ (255 \text{ cf/min}) \times (100^\circ - 85^\circ) \times (0.018 \text{ Btu/cf-°F}) \times 60 \text{ min} = 4131 \text{ Btu.} \]

A representative value for solar heat gain through glass is 200 Btu per square foot each hour. Therefore, each square foot of vent can accommodate 20 square feet of glass.

Solar rooms must sometimes be ventilated in midwinter, when heat from the bright sunlight builds up too quickly to be dissipated through the house or absorbed by thermal mass. Just be sure that such vents are sealed tightly on winter nights, and on cold sunless days.

Determining Ventilation Air Flow

In stack-effect ventilation, air flow is maximized by the height of the stack and the temperature of air in the stack. Air flow is proportional to the inlet area and to the square root of the height times the average temperature difference, as follows:

\[ Q = 540A \sqrt{n(T_1 - T_2)} \]

where

- \( Q \) = the rate of air flow, in cubic feet per hour;
- \( A \) = the area of the inlets, in square feet;
- \( n \) = the height between inlets and outlets, in feet;
- \( T_1 \) = the average temperature of the air in the “chimney,” and
- \( T_2 \) = the average temperature of the return air (normally just the outside temperature).

It is better to add heat (presumably using a passive air-heating collector) at the bottom of the chimney or stack than at the top. In this way the entire column of air in the chimney is hot, creating the desired buoyancy to cause the air to flow.

If outlet sizes are appreciably different from inlet sizes, the above expression must be adjusted according to the following ratios:

<table>
<thead>
<tr>
<th>Area of Outlets</th>
<th>Value to be substituted for 540 in above expression</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>745</td>
</tr>
<tr>
<td>4</td>
<td>740</td>
</tr>
<tr>
<td>3</td>
<td>730</td>
</tr>
<tr>
<td>2</td>
<td>680</td>
</tr>
<tr>
<td>1</td>
<td>640</td>
</tr>
<tr>
<td>½</td>
<td>465</td>
</tr>
<tr>
<td>¼</td>
<td>340</td>
</tr>
<tr>
<td>1/16</td>
<td>185</td>
</tr>
</tbody>
</table>

This information is from Design with Climate by Victor Olgyay, Princeton University Press.

Don’t forget this one, either:

\[ Q = 540A \sqrt{(T_f - T_s)} \]

Source: Passive-Solar-Anderson-Wells-Ventilation-3.jpg
• Passive Ventilation
  – Calculations

Source: Sun-Wind-Light-Brown-DeKay-p187a.jpg
• Passive Ventilation
  – Example
Passive Ventilation

- Guidelines

**General**

- Natural ventilation can be induced or augmented by passive solar strategies and/or with mechanical-assisted ventilation to create a “mixed-mode” strategy. ASHRAE Standard 55 incorporates hybrid ventilation models.
- Double-skin facades work best with mixed-mode ventilation, utilizing passive solar chimney effect in the daytime to induce cross-ventilation, and nighttime venting to induce passive cooling.
- Single-side high-opening ventilated spaces are effective to a depth of 2x the room height.
- Single-side high and low-opening ventilated spaces are effective to a depth of 2.5 x the room height.
- Double-sided or cross-ventilated spaces are effective to a depth of 5x the room height.

- Source: gaia.lbl.gov/hpbf
• Passive Ventilation
  – Guidelines

### Building Configuration

- Consider a narrow footprint perpendicular to prevailing breezes
- Take advantage of ceiling or building height to create “stack effect”
- Allow heat to rise and stratify, by careful placement of air returns
- Consider inducing stack effect with “solar chimney” elements
- Provide low inlet and high outlet venting
- Consider “double-skin” building shell at exterior walls
- Combine “ventilation” elements with “daylighting” elements
- Avoid high partitions to prevent obstruction of airflow

• Source: gaia.lbl.gov/hpbf
• Passive Ventilation
  – Guidelines

**Window Orientation**

- Orient operable windows to prevailing winds
- Consider protruding elements, such as fins or wing walls, to catch and re-direct breezes
- Provide lower openings oriented to prevailing breezes and higher openings on the downwind or “lee” side of the building

• Source: gaia.lbl.gov/hpbf
• Passive Ventilation
  – Guidelines

**Window Configuration**

• Choose window opening or hinging configurations to maximize airflow from different directions
• Consider center-hinged “butterfly” joining of multiple-ganged casement windows, to avoid self-blocking
• Consider high clerestories, in combination with low inlet openings

• Source: gaia.lbl.gov/hpbf
• Passive Ventilation
  
  – Guidelines

Mechanically-assisted Ventilation

• Consider mechanically-induced ventilation to supplement natural stack effect or cross-ventilation
• Locate whole-house-type fan units in remote locations to minimize noise
• Provide low openings to allow cooler make-up air to enter building

• Source: gaia.lbl.gov/hpbf
• Passive Ventilation
  – Guidelines

Earth Cooling

• Configurations
  • Open-loop inlets
  • Closed-loop ground-coupled heat-exchanger
  • Combination
• Provide adequate cross-section area to minimize airflow resistance
• Provide positive drainage and condensate removal to prevent mold growth or other air stream contamination
• Break