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Passive Solar Design Overview – Part 2 in a Series

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This is Part 2 in a series on passive solar by Oil Drum reader Will Stewart. Passive solar is one of many practices attempting to increase the percentage of our baseline energy use we receive from renewable flows as opposed to fossil stocks.

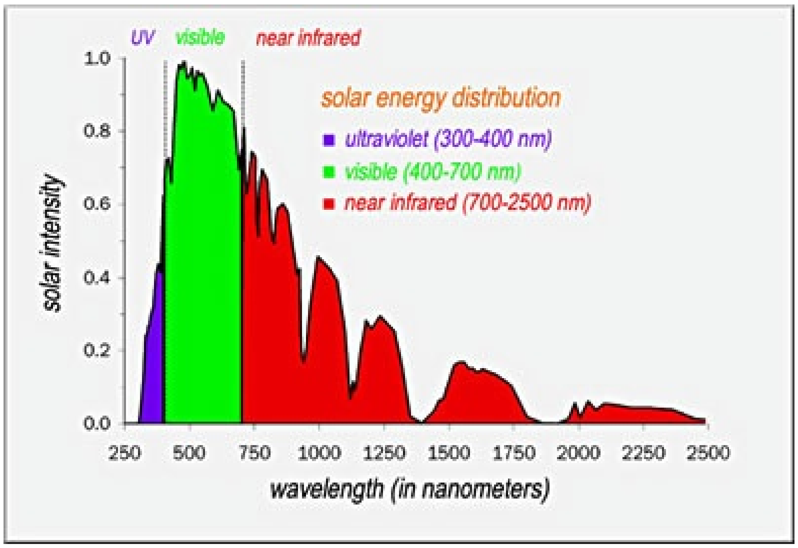
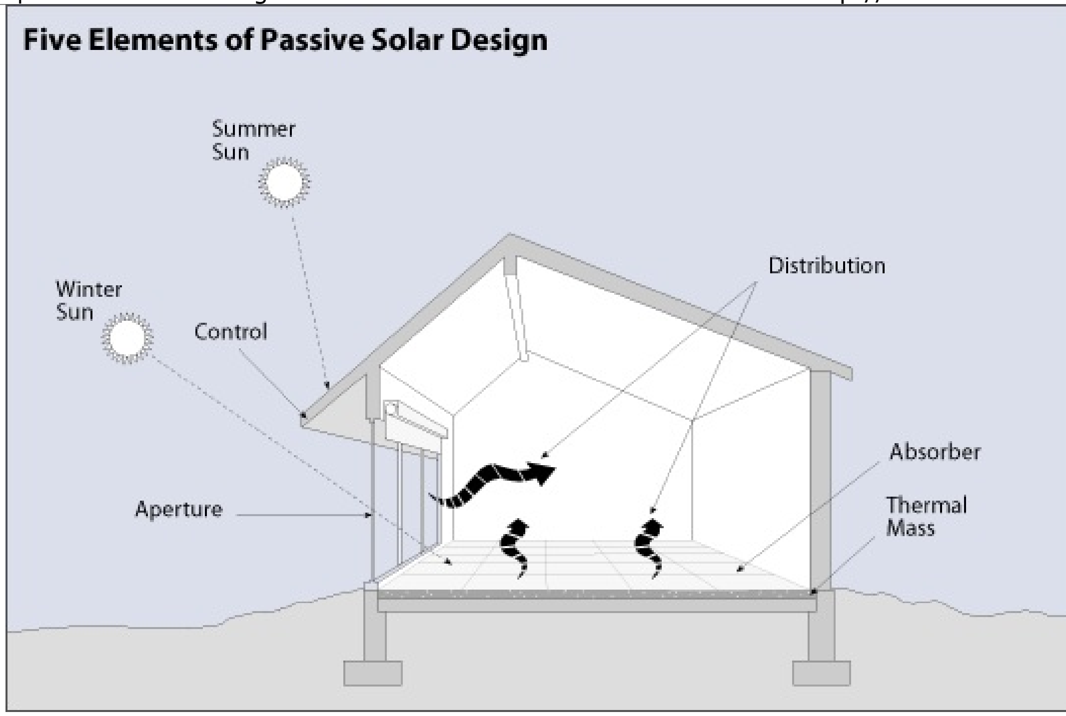


Figure 6 - Solar Intensity at Sea Level by Wavelength

Passive Solar Design Overview – Part 2

In Part 1 of this series, we looked at the three main architectural styles of passive solar design (Direct Gain, Indirect Gain, and Isolated Gain), as well as the first of the five design aspects, *Aperture*. This article will address the next design aspect, *Absorber*, at an overview level, beginning with a short introduction in heat transfer basics, so that the reader understands the fundamentals of *building heat gain and loss*, all of which are as equally important for renovation as they are for new construction.



Heat Transfer Basics

Heat can be transferred from one mass to another by;

1. *Conduction:* Transfer of heat energy resulting from differences in temperature between contacting adjacent bodies or adjacent parts of a body (i.e., put your hand on a warm stove). Heat travels through walls via conduction.
2. *Convection:* The natural tendency for a gas or liquid to rise when it comes in contact with a warmer surface (i.e., gliders and soaring birds seek rising thermals over sun-drenched land surfaces). For example, interior air will convect upwards from warm thermal mass areas and downwards alongside cool window or wall surfaces.
3. *Radiation:*
When one object warms a cooler non-contacting object (i.e., what you feel on your face as you sit in front of a fire or on a sunny beach). Hotter objects will transfer heat to cooler objects within direct line of sight. A person standing near a warm thermal storage mass will feel more comfortable than standing near a poorly insulated wall or window.

Figure 5 shows how these heat transfer types are experienced by windows (and walls, except for transmitted radiation).

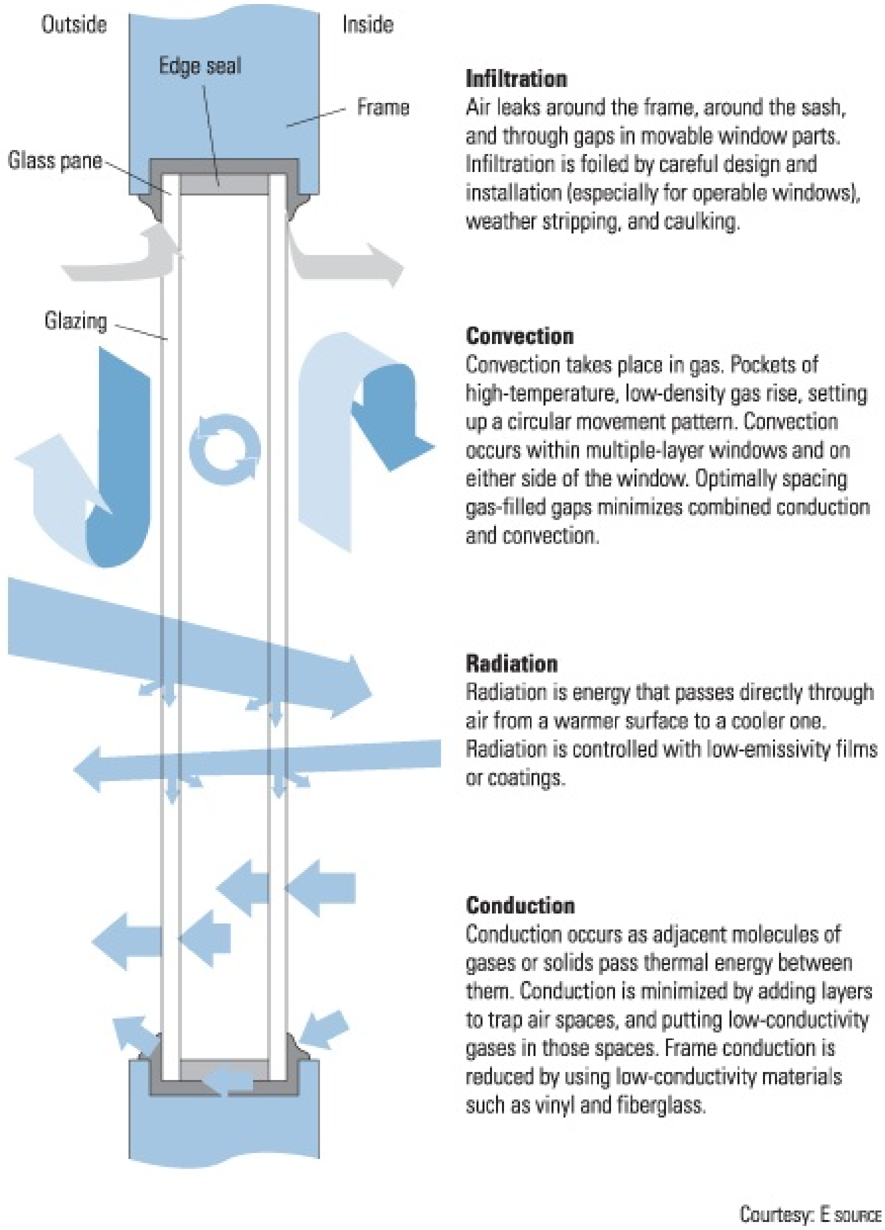


Figure 5 - Heat Transfer by Conduction, Convection, Radiation, and Infiltration

Building Heat Losses

We need to have a short primer in thermodynamics (don't worry, this will be relatively simple). First, we have to discuss units of heat. In the English system used by the US, a British Thermal Unit (**BTU**) is the amount of heat energy needed to raise the temperature of one pound of water by one degree F. In the SI system (rest of the world), **joules** and **kilowatt-hours** are the measure of heat energy (1055 j = 1 BTU and 1 kilowatt-hour = 3412 BTUs).

Next, we look at heat energy used over time. If we burn a bunsen burner for one hour (assuming no heat loss), raising the temperature of 1 pound of water 20 degrees, then the heat energy rate is 20 BTU/hour.

In order to determine how much solar heat input and thermal storage we will need, we must understand the heat losses of the building under design;

$Q_{loss} = (\Sigma(UA)_n + C_v)(t_i - t_o)$

where:
Q_{loss} = BTU/hr or kW
U = 1/R-value (*conduction*, see R-values of common materials)
A = area (ft_2 or m_2)
n = exterior building surfaces (all walls, windows, ceilings, floors)
C_v = infiltration losses (see Architect's Handbook) [1]
t_i = desired indoor temperature
t_o = outdoor temperature, normally the coldest in the 97.5 percentile (2.5% of the time is colder)

Building Heat Gains

Now that we know how much heat is being lost by a building, we can determine how much heat we need to collect. From Part 1, we understood how much energy could be received by our aperture. Let's size our aperture now (with rough calculations) to balance out the losses;

$Q_{gain} = (\Sigma((Q_{insolation} + Q_{diffuse} + Q_{reflected})A)_n SHGC + Q_{other}$

where:
Q_{gain} = BTU/day or kWh/day
$Q_{insolation}$ = BTU/ft_2/day or kWh/m_2/day from table in Part 1
$Q_{diffuse}$ = (normally a part of the empirical insolation data, more at NREL)
$Q_{reflected}$ = insolation energy x surface reflectivity (rough estimate, more at NREL)
n = each window facing the equator (cooling calculations must account for east and west windows)
SHGC = Solar Heat Gain Coefficient
Q_{other} = Heat from people and various powered devices inside the insulated shell [2]

So in order for our building to have sufficient heat input, **the daily gains must equal the hourly losses over a 24 hour period**, on average, centered around the desired temperature. On cloudy days, the deficit is made up by extra thermal mass (see below), backup heating, or increasing layers of thermal underwear. Note that backup heating could be an active solar heating system with a small collector array and a large storage tank that collects and stores heat on sunny days for use on cloudy days.

An important point to note: the higher the R-value and lower the area of the walls and windows, the less energy is lost through them, hence less sunlight (windows) and thermal mass are needed to achieve and maintain the desired temperature range. That's why superinsulation techniques (e.g., R-50 strawbale walls, minimal thermal-bridging wall components) and space efficiency are commonplace in passive solar design (compared to 6" R-19 walls or 4" R-13 walls, for example). Strawbale walls have far lower embodied energy than concrete, so are highly attractive from an EROEI standpoint. Due to its significant breadth, the subject of energy efficient building techniques will be the subject of another article.

Absorber

The absorber in a passive solar implementation is the surface that receives the sunlight (direct or reflected), converting the visible light and infrared spectrum energy into heat. Figure 6 shows the light spectrum energy density that penetrates the atmosphere. Note that the most intense radiation comes from the visible light spectrum between 400 and 700 nm, though substantial amounts are also available in the infrared spectrum (if not substantially blocked by low-E glass).

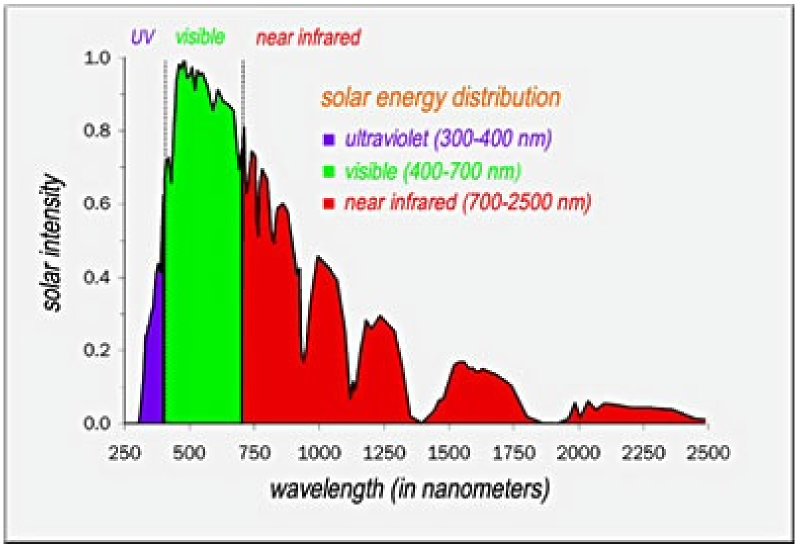


Figure 6 - Solar Intensity at Sea Level by Wavelength

Hence, an appropriate absorber in a passive solar design will convert as much of this impinging spectral energy into heat as possible. The measure of how well the absorber captures the radiant energy is referred to as the *absorptivity*. The higher the absorptivity, the less energy is reflected away (see Table 1 for properties of common materials).

Once the sun's energy is captured by the absorber, it can also be re-radiated in the infrared spectrum to cooler objects; the measure of this re-radiation is called *emissivity*. For direct gain homes where a thermal storage floor is heated, emissivity is not much of a concern, as the heat is radiated into the room (if the people or objects in the room are cooler). In situations where the absorbing surface faces external surfaces with little insulating value (i.e., windows), the re-radiation loss is a reduction in energy efficiency and should be minimized as much as possible. Some materials or treatments have much higher absorptivity values than emissivity values; these are called *selective*, and are also used quite frequently in solar thermal collectors for hot water and active solar heating. Many materials have varying values of absorptivity and emissivity depending on the temperature and spectral wavelength, so the values listed are averaged out for the integral of the solar intensity by spectrum shown in figure 6. See this list for more materials.

Table 1 - Absorptivity and Emissivity of Common Materials[3][4]

Material	Absorptivity	Emissivity
White tile/stone/paint	0.30 - 0.50	0.85 - 0.95

Unfinished concrete	0.65	0.87
Red brick/stone/paint	0.65 - 0.80	0.85 - 0.95
Flat black paint	0.96	0.87
Copper Oxide	0.90	0.17
Black nickel	0.90	0.08
Black chrome-coated copper foil	0.95	0.11

In Part 3, we'll cover how to select and size thermal mass in order to even out the swings in outside temperature and internal solar gain. Future articles in the series will be devoted to distribution, controls, renovation, design tools, green building standards, case studies, and more.

References:
1. David Kent Ballast, Architect's Handbook of Formulas, Tables, and Mathematical Calculations, Prentice Hall, 1988
2. Kissock, J, Internal Heat Gains and Design Heating & Cooling Loads, University of Dayton Lecture
3. Michael J. Crosbie, The Passive Solar Design and Construction Handbook, John Wiley and Sons, 1998
4. John Little, Randall Thomas, Design with Energy: The Conservation and Use of Energy in Buildings, Cambridge University Press, 1984