The Oil Drum: Campfire

Discussions about Energy and Our Future

Passive Solar Design Overview - Part 5: Distribution, Ventilation, and Cooling

Posted by Nate Hagens on September 24, 2009 - 10:22am in The Oil Drum: Campfire
Topic: Alternative energy
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This is a guest post from Will Stewart, a Systems Engineer in the energy industry.

In this final article in the passive solar design overview series (see Parts 1, 2, 3, and 4), we will cover the techniques used to avoid hot and cold spots in a passive solar building, how to provide fresh air, and how to provide cooling (in many situations).

Wind directed HRV cowlings at BedZed

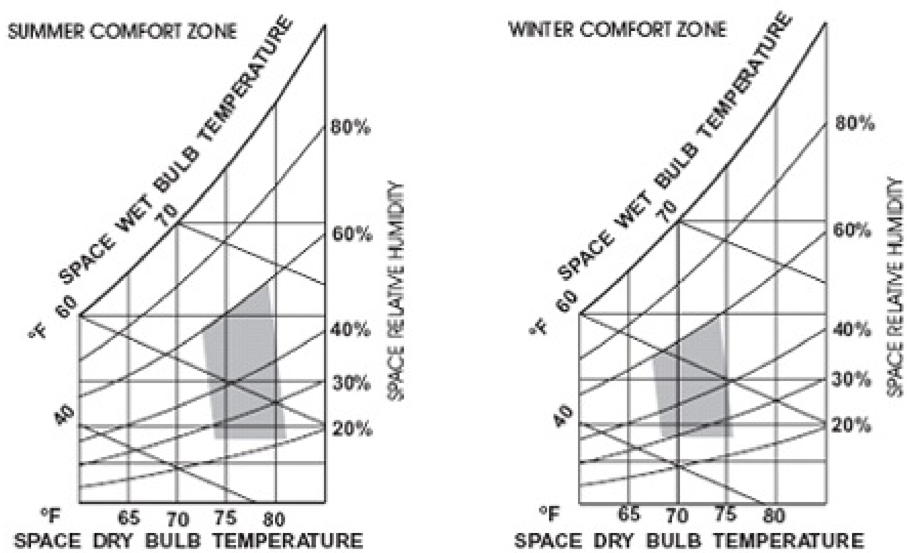
The first aspect we must address is the needs of the building occupants. While we may strive for ideal conditions as often as possible, a zero net energy home might not be required by its owners to always fit the mold of a typical power-intensive HVAC design. To understand how we need to distribute the heat from the building's thermal masses, we need to understand how the human body interacts with the conditioned space, and how to define comfort.

Comfort

In simple terms, the human body is considered to have obtained thermal comfort when a body's heat loss equals its heat gain.

More specifically, the American Society of Heating, Refrigeration, and Air-Conditioning Engineers (ASHRAE) devised a simple chart showing the upper and lower bounds of temperature and humidity by for what it defines as human comfort zones, taking into consideration differing clothing levels by season.

ASHRAE Comfort Zones



Other factors are also important, such as metabolic rate, clothing insulation, radiant temperature of other masses or heat sources, and air speed.

The body exchanges, in a typical scenario [17]:

- 62% of it's body heat via radiation,
- 15% by evaporation,
- 10% by convection,
- 10% by respiration and
- 3% by conduction.

Note that during the US Energy Crisis in the 1970's, Jimmy Carter sat in front of a fire with a sweater on, asking Americans to set their thermostats to 65 degrees F in the winter time, outside of the ASHRAE comfort zone. As we experience other such shortfalls in supply in the future, expect the BAU comfort zones to be questioned and expanded to fit the situation at hand.

Distribution

Capturing and storing solar thermal energy is not enough; how do we ensure its dispersal when and where we need it? There are two types of heat transfer related to passive solar heat distribution; *convection* and *radiation*.

- **Convection**:

  Simply put, warm air rises. Any thermal storage element that is warmer than the surrounding air will heat the air closest to it, causing that air to rise. There are extensive calculations necessary to determine convection heat transfer with precision, but for our purposes, an approximation will suffice;

$Q = h\,A\,(Ts - Ta)$

where;

Q = heat transferred

h = convection parameter (approximations assuming laminar flow)

Horizontal surface: $h = 0.27\,(\Delta T / A)^{0.25}$

Vertical surface: $h = 0.29\,(\Delta T / A)^{0.25}$

A = area

Ts = surface temperature

Ta = ambient (indoor) temperature

- **Radiation**:
  If a thermal storage element is warmer than nearby objects within line of sight, the element will transfer heat in the infrared wavelengths. The energy emitted via radiation from an object warmed by the sun (i.e., thermal storage wall, masonry floor) can be calculated with this formula;

$Q = \varepsilon\,\sigma\,A\,T^4$

where;

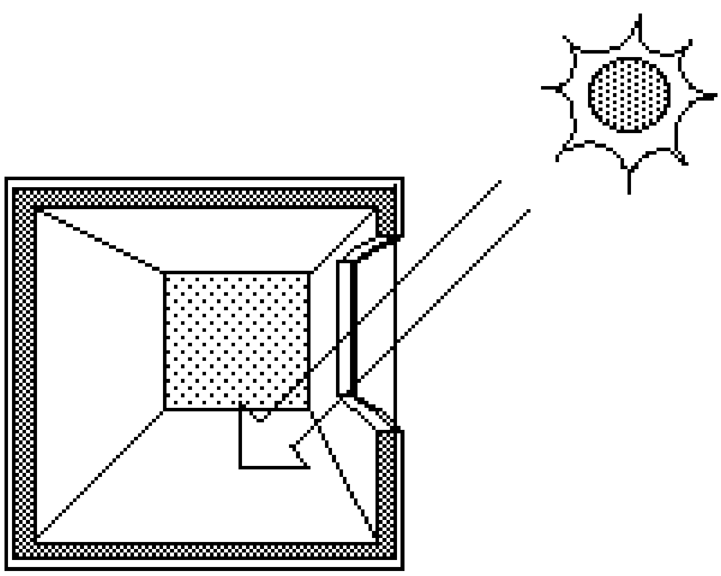
ε = surface emissivity (See Part 2 of this series and additional values in this list).

σ = Stephan Boltzmann constant, $5.7 \times 10^{-8}\ W/m^2/K^4$

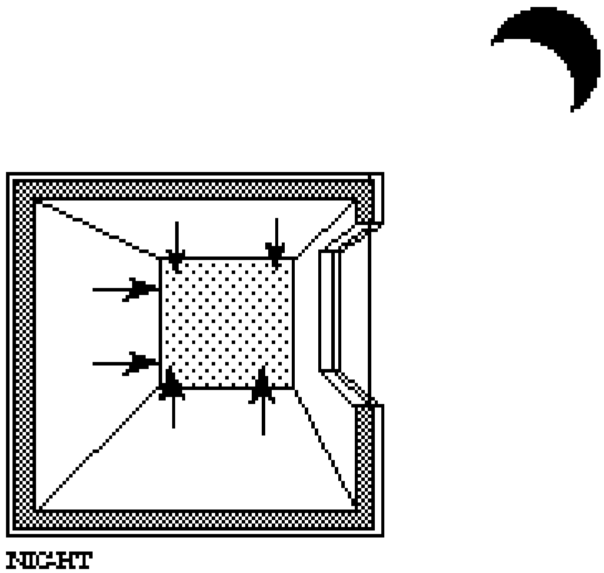
T = absolute temperature K (°C + 272)

Direct Gain:

Part of our answer here depends upon the depth of the heated space, and the location and conductivity of the thermal mass; if a house is too deep (north to south), then the polar-facing side can be cooler than the area warmed by the thermal mass. The heat is convected up from the warmed masonry floor, allowing one to walk about in stocking feet in the winter.

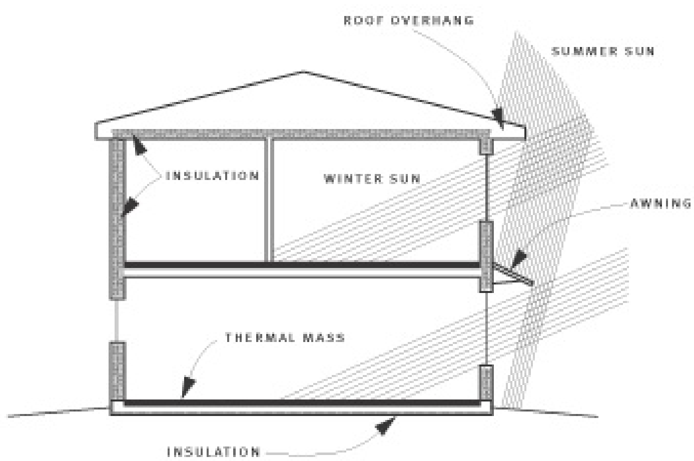


DAY



Heat transfer from direct gain thermal mass (Graphic courtesy of [greenbuilder.com]())

Interior design of direct gain buildings that utilize thermal mass can take advantage of the depth the winter sun can penetrate into the occupied space, which reaches the maximum depth on December 21st. Rooms or portions of larger rooms on the polar-facing side of the building where the sun does not directly heat the thermal mass are candidates for utility rooms, closets, bathrooms, and other rooms where occupancy is infrequent and/or of short duration.



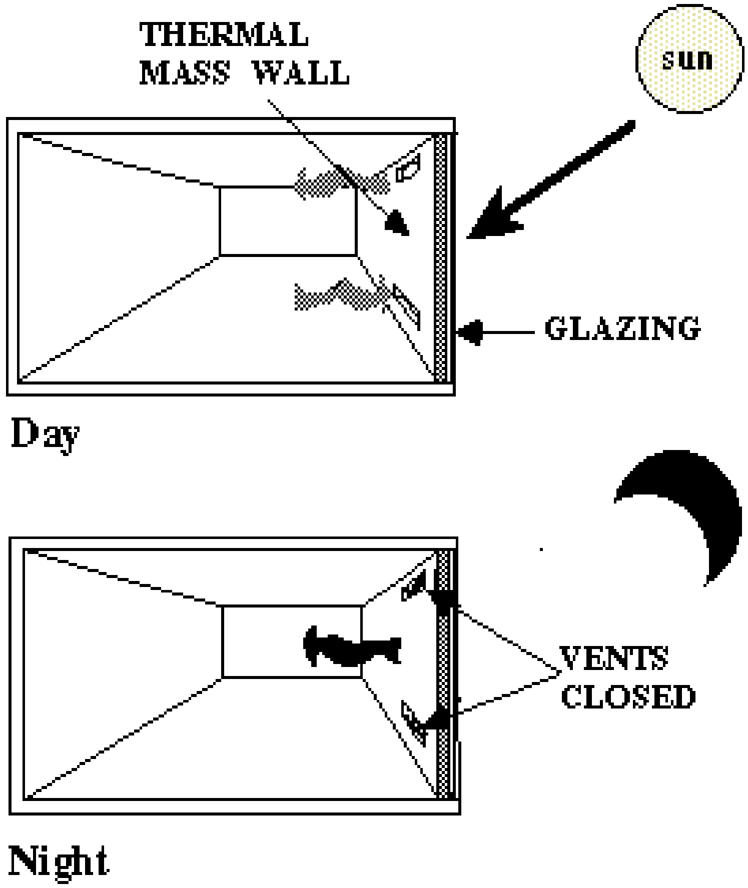
Direct Gain heat transfer (Graphic courtesy of [RecycleWorks]())

Indirect Gain:

Trombe walls distribute heat in two manners;

- By convection of warmed air back into the top of the room during the daytime, and
- by thermal radiation from the trombe wall mass, primarily at night

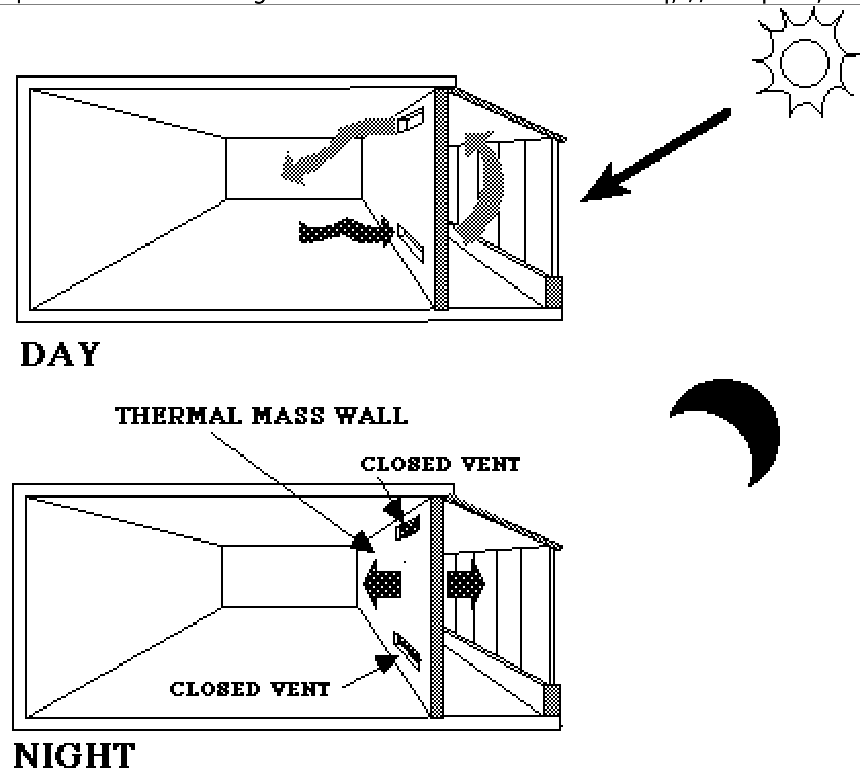
In designs that take advantage of trombe walls, we clearly see that during the night, objects close to the trombe wall will be warmer than those further away. Such considerations play a major role in the interior design and living space layout of homes utilizing this technique. Unless a storage mass with a period of at least one day is factored in (see Part 3), trombe walls would not be suitable to office or other work spaces that are only occupied during the day.



Trombe wall heat distribution

Isolated Gain:

Isolated gain designs are very similar to Trombe walls with respect to heat (or cooling) distribution.



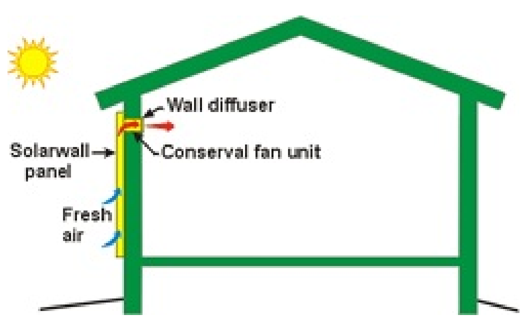
Isolated Gain

Ventilation

An occupied space requires a minimal amount of circulation and fresh air to avoid the sense of staleness. During pleasant weather, the most obvious approach would be to simply open the windows (except for offices without operable windows). During heating (and cooling) weather, there are several ways to accomplish bringing in fresh air, including;

Passive Solar Pre-Heat

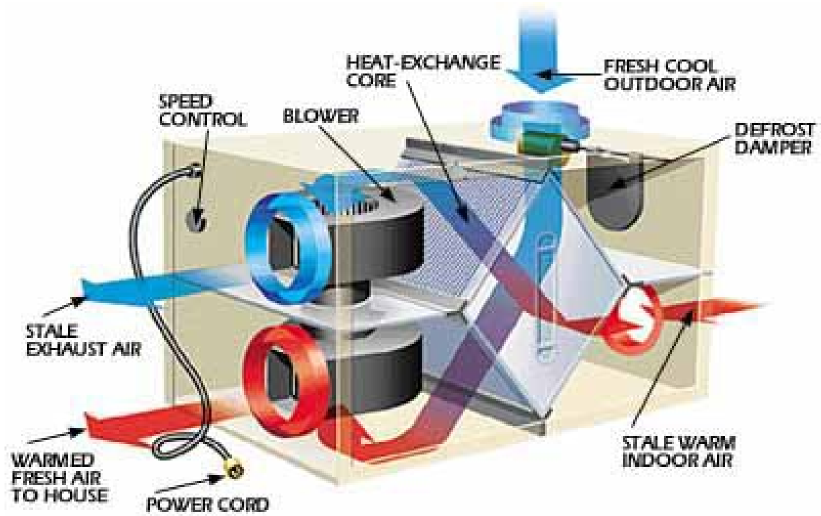
Fresh air can be brought in through a passive solar panel on sunny days via the thermosiphon effect (i.e., warm air rises). To avoid unwanted infiltration, the opening should be sealed during non-sunny hours. Fans may be used to control the flow rate.Very cold locations and/or those with marginal solar resources may not be viable candidates for this approach. Air that is expelled from the house is normally at the desired temperature, and the heat energy in that air is lost to the outside.



Passive Solar Pre-heater

Heat recovery ventilator (HRV)

Heat recovery ventilators are (normally) powered ventilators and are considered active technology when such, though are often employed in passive solar buildings and are a key element in [Passive Houses](). High efficiency is important, and they are often only turned on a scheduled basis, when CO2 levels reach a threshold, or when indoor humidity is excessive. HRVs exchange the heat energy from stale warm inside air with fresh cold outside air, warming the incoming fresh outside air with outgoing warm inside air. Confused? Just take look at the picture below, and note that HRVs capture the indoor heat energy before it is exhausted to the outside;



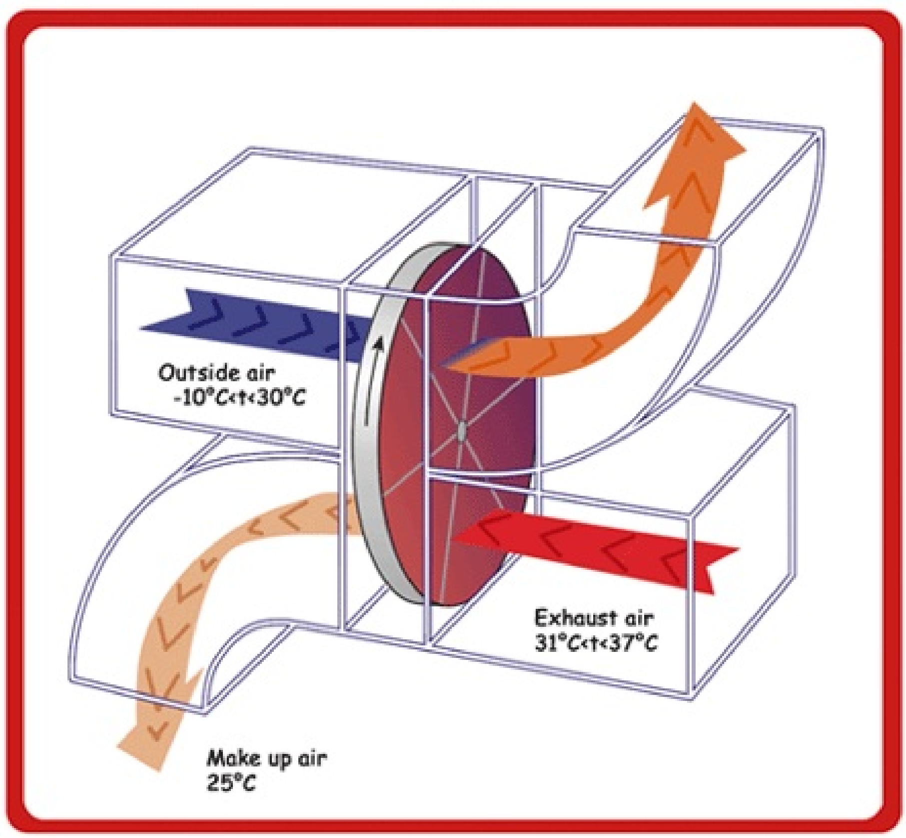
Heat Recovery Ventilator

A new non-powered twist to HRVs was made at the London Beddington Zero Energy Development (dubbed "BedZed"). Wind is used as the motivating force, steering a rotating wind vane ventilator on the roof. The fresh air intake is on the windward side, and the stale air exhaust is on the leeward side. While the wind speed determines the overall air change rate, manual damper controls can be employed to moderate the ventilation rate on high wind days.

Wind directed HRV cowlings at [BedZed]()

Energy recovery ventilator (ERV)

These are very similar to HRVs, except that they also account for differences in humidity, capturing latent heat energy that might otherwise be lost. The moisture capture is often implemented through the use of a rotating dessicant wheel, which absorbs the humidity from one air stream, and releases it into the other air stream as the wheel turns. This helps to maintain humidity levels in winter time, and often keeps humidity out in summer, though high humidity climates can often overwhelm the dessicant wheel capacity.



A diagram of a rotary heat exchanger, or "heat wheel" (From Uptime Technology BV)

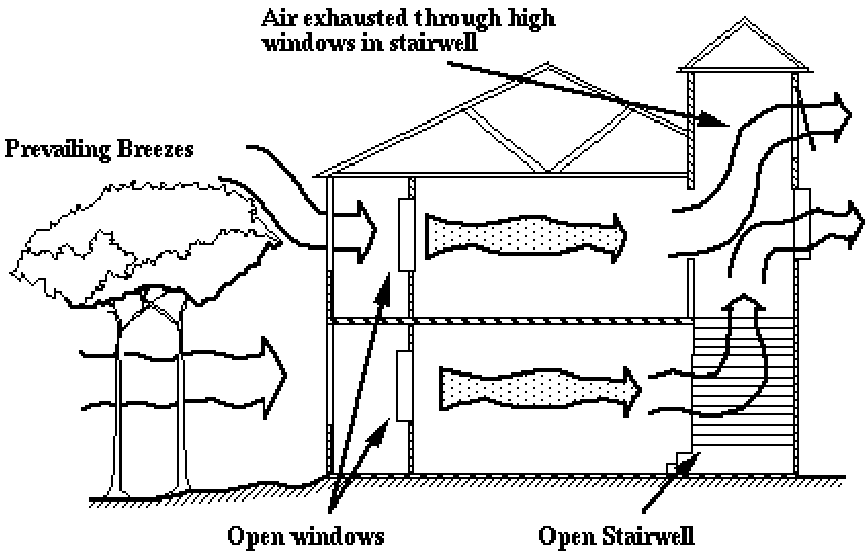
Energy Recovery Ventilator

Cooling

There are a number of approaches and variations concerning summer ventilation in passive solar design; in this overview, we will briefly examine two techniques that are applicable in low to moderate humidity environments.

Solar Chimney

Air rises when it is warmed. Some designs incorporate an elevated component in a building, often as a cupola or a stairway with an extended height ceiling. The solar chimney is a collecting point for warm air, which it dissipates through its vents or a high window. One step further is the use of a vertical passageway from different floors to the elevated compontent, so that the warmer air from each floor can rise through up in a chimney effect. Taking it yet one step further, painting a vertical exhaust element black would absorb the sun's energy, heating the air further, and creating a stronger updraft.



Solar Chimney (Graphic courtesy of Greenbuilder.com)

Night Flush

In areas where cooling season nighttime temperatures are lower than approximately 65F (for at least some portion of the season) and humidity levels are low to moderate, a night flush can be employed by opening windows and exposing internal thermal mass to lower ambient temperatures, reducing the temperature of the thermal mass. This has the effect of rejecting heat accumulated during the previous day. When morning comes, the windows are closed when the ambient temperature rises above that of the thermal mass, with the thermal mass helping to moderate the temperature swing throughout the day (if enough thermal mass has be utilized). One drawback of this approach in residences is the potential for sleeping occupants to be warm upon repose, then chilled during the early morning hours. Commercial office and retail buildings, on the other hand, do not have this issue.

A number of commercial buildings have been designed and constructed utilizing the night flush approach, some examples of which include;

- Fraunhofer Institute for Solar Energy Systems Office
- Social Services Administration Teleservice Center
- US Federal Building, San Francisco (see video)
- Caltrans District 3 Headquarters
- Sokol Blosser Winery Barrel Aging Cellar

US Federal Building, San Francisco (night flush windows open)

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