PDHonline Course E280 (2 PDH)

Passive Solar & Low Energy Cooling Strategies

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Passive Solar & Low Energy Cooling Strategies

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COURSE CONTENT

1. Introduction

The major strategies for passive solar and low energy cooling are i) reduction of external heat gain, ii) reduction of internal heat generation, iii) providing ventilation, and iv) use of low-energy cooling methods. Each of these topics will be discussed in the following sections.

2. Reduction of External Heat Gain

The amount of heat entering a building from outside can be reduced by i) insulating, caulking & weather stripping, ii) shading, iii) reflective films & coatings, and iv) radiant barriers. Each of these methods will now be described and discussed briefly.

a) INSULATING, CAULKING & WEATHER STRIPPING is useful to reduce cooling requirements and cost, just as it is useful to reduce heating requirements and cost. Caulking and weather stripping helps to reduce heat gain into the building by reducing flow of air conditioned air out of and/or hot air into the building through cracks and gaps in the buildings structure. Adequate insulation reduces the amount of heat flow into the building by conduction through the roof and walls.

b) SHADING is useful for keeping the sun from shining directly into windows, and also for reducing direct sunlight onto the rest of the building. Several means of providing shading are available, including: landscaping, roof overhangs, awnings, exterior shadescreens, exterior shutters and shades, and interior shades. Each of these will now be expanded upon briefly.

Landscaping can be an effective and pleasant means of providing shading for a house. It can block out the hot summer sun, encourage sunlight to enter the house in the winter, deflect cold winter winds, and channel breezes for cooling in summer. Trees to the east and west of the house will provide summer shading.

These trees will be most effective if they shade east and west facing windows, but shading the walls and roof is helpful as well. The south side of the house would typically be left relatively clear in order to allow solar heating in the winter. Trees to the north of the house do not provide direct shade for the house, but reduce the temperature of the air surrounding the house.

Roof Overhangs are a simple architectural feature which can be used on the south side of the house to block direct sunlight from windows in the summer without reducing the available sunlight in winter. This is possible because (in the northern hemisphere) the sun is higher in the sky in the summer, and thus blocked by the roof overhang, but it is lower in the sky in the winter, allowing direct sunlight to pass beneath the overhang. This is illustrated in Figure 1 below. Overhangs do not work as effectively for east or west facing windows, because the sun is low in the sky in the east in the morning and in the west in the evening, even in the summertime.

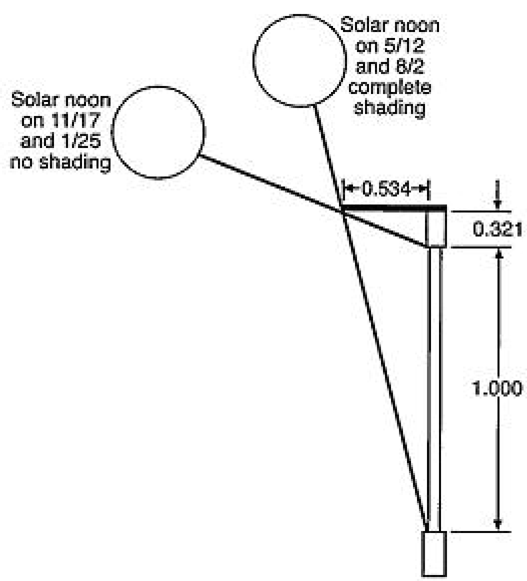

Figure 1. Shading Geometery and Sun Positions for 40^{o} North Latitude

Figure 1 came from reference #4 for this course, *Solar Radiation Data Manual for Buildings*, published by the National Renewable Energy Laboratory (NREL), and available for free download at the website: http://www.nrel.gov/docs/legosti/old/7904.pdf . This publication provides a lot of data useful for passive solar heating for 239 locations in the United States and its territories. One of the items of information it contains is recommended roof overhang dimensions to provide summertime shading and wintertime sunlight for south-facing windows at each of the 239 locations. Three examples from *Solar Radiation Data Manual for Buildings*, are given in Figure 2. The recommended overhang dimensions are shown for Albuquerque, NM (latitude: 35.05^o N), St. Louis, MO (latitude: 38.75^o N) and International Falls, MN (48.57^o N). As shown in the diagram, as one goes farther north, the sun is lower in the sky, and the recommended overhang is greater.

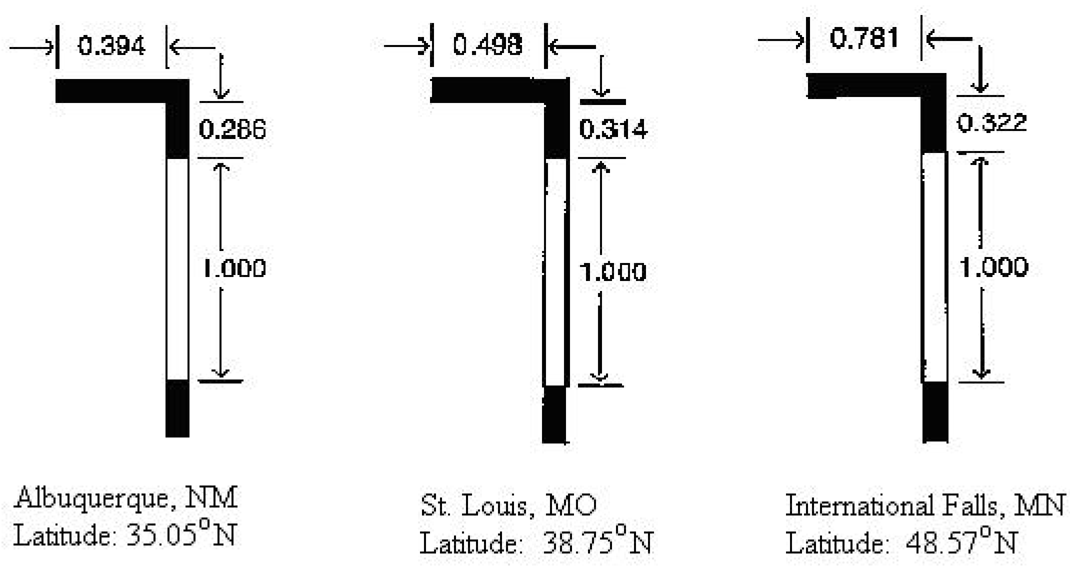

Figure 2. Roof Overhang Recommendations from NREL Publication

Example #1: Using information from the publication, *Solar Radiation Data Manual for Buildings*, find the following dimensions for design of roof overhang shading of a south-facing window in Albuquerque, New Mexico: For a window of 24" vertical height, find the vertical distance for the top of the window below the roof overhang and the horizontal distance that the roof overhang should extend beyond the wall, so that the window will be completely shaded at solar noon on 5/12 and 8/2, and will have no shading at solar noon on 11/17 and 1/25.

Solution: As shown in figure 2 above (The Albuquerque, NM portion is from page 148 in *Solar Radiation Data Manual for Buildings*), the distance of the top of the window below the overhang should be 0.286 times the vertical height of the window, and the horizontal distance of the overhang beyond the wall should be 0.394 times the vertical window height. Thus:

Dist. from top of window to overhang = 0.286*2 feet = **0.572 ft,** and

Horiz. dist. overhang extends beyond wall = 0.394*2 feet = **0.788 ft.**

These results are shown in Figure 3, below.

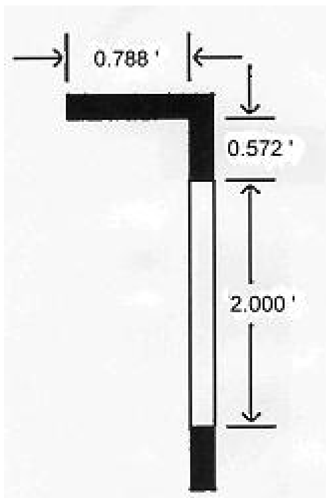

Fig. 3. Solution to Example #1

Awnings serve the same general function as a roof overhang, but are somewhat more flexible. Lightweight materials such as aluminum, canvas, acrylic or polyvinyl laminate are often used, making it possible for them to be used over windows without the need for extra support. Awnings work well on east and west walls, especially if they extend below the top of the window to increase their shading effectiveness. They may have open or closed sides. Awnings without sides work well for east and west windows, but for south windows, awnings with sides give better shade from early morning and late afternoon sun. Awnings should have a vent at the top or open sides to avoid trapping heat beneath the awning next to the window. Light colors are better, in order to avoid absorbing heat from the sunlight. Awnings on south windows should be retractable or removable in winter in order to make use of passive solar heating.

Exterior Shade Screens are made of thick fiberglass mesh, which absorbs the sunlight. They are effective against diffuse and reflected, as well as direct sunlight. Hence they can block up to 70 percent of all incoming sunlight. Most varieties of exterior shade screens can also serve as insect screening, so they allow natural ventilation better than some other shading options which block air flow. Shade screens may be ordered to size or purchased by the roll and installed by the homeowner. They should be removed in the winter in order to allow full sunlight to enter the window then for heating.

Exterior Shutters and Shades are another option for shading. Either hinged shutters or rolling blind type shades will provide window shading, but they typically will obscure the view from the window, block daylighting, and may block air flow. Exterior shutters may be operated manually or automatically. Automatic controls are more costly and difficult to maintain, but don't depend upon the diligence of someone to operate them manually.

Interior Shades are not as effective as exterior shading, because they cannot block the heat until it has already entered the building, but they can still be used as a supplement to exterior shading or where other shading options are not available. Use of draperies or curtains which are made of tightly woven, opaque material of a light or reflective color, makes them most useful. The tighter the curtain fits to the window, the better its ability to trap heat and prevent it from entering the rest of the house.

c) <u>REFLECTIVE FILMS AND COATINGS</u>: Reflective coatings which adhere to glass can block up to 85 percent of incoming sunlight. Some coatings are applied seasonally, while others are permanently affixed to the glass surface. Permanent films or coatings are not appropriate for south windows in passive solar homes, since they would block wanted heat from entering in the winter heating season. They would be practical, however, for unshaded east or west windows. Window films are not recommended for windows that receive partial shading, because the film absorbs sunlight and will cause the glass to heat unevenly and possibly crack.

d) <u>RADIANT BARRIERS</u> may be useful for roofs that are unshaded. A radiant barrier is a layer of aluminum foil placed in an airspace between a heat-radiating suface (the roof of your house) and a heat-absorbing surface (the insulation on the floor of your attic). It reduces the heat entering your house in two ways. Its shiny surface reflects most of the radiant heat striking it and it will emit very little heat itself. Radiant barriers come in many different forms: single-sided or double-sided foils, foil-faced insulation, and multilayered foil systems with air spaces. Installation instructions should be available from the dealer or manufacturer.

3. Reduction of Internal Heat Generation

Not all of the heat in a home in summer comes from the sun. Much of it comes from the occupants of the house and the appliances they use. Appliances and their use have an effect on internal heat generation in a house. Choosing energy-efficient appliances throughout the house, from large appliances like refrigerators down to something as small as light bulbs will be helpful. The less efficient an appliance is, the more waste heat it generates. Thus, use of inefficient appliances runs up costs in two ways, the cost of additional energy to operate the appliance and the extra cost of cooling due to the waste heat generated. Energy-guide labels and energy star certification can be used to help in choosing major appliances. For lighting, there is no reason not to replace incandescent light bulbs with compact fluorescent bulbs (CFLs). The initial cost of CFLs has been coming down, although they remain higher than incandescent bulbs, but they last about 10 times as long and the electricity requirement for the same amount of light is only about one fourth as much for CFLs. Also, since CFLs are more efficient, they produce less waste heat.

Kitchen and laundry appliances produce heat, in some cases by design. Substituting alternatives that produce less heat, or scheduling their use for the cooler morning and evening hours, however, can minimize their effect on the cooling load for the house. In the kitchen, a microwave oven or a smaller toaster oven can be used rather than the large oven, whenever possible. Serving cold dishes in summer is a good idea because lunch and dinner time occur during the hottest part of the day. Cooking dishes in the evening to be served later (either cold or reheated in the microwave) shifts the added heat of cooking away from the already warm dinner hour. Grilling foods outdoors generates heat outside instead of in the house. When cooking on the stovetop, be sure to cover pots and pans. Less energy will be needed to cook the foods, and less heat and humidity will be put into the house. If boiling in an open pot is necessary, be sure to turn on the kitchen exhaust fan, so that it can help to remove the humidity introduced by the steam.

When doing laundry, wash only full loads and use cold water whenever possible. It will save the energy needed to heat the water and lessen the addition of warm, moist air into your laundry room. If the schedules of family members permit, a "solar clothes dryer" (clothes line) can be used instead of an electric or gas clothes dryer, since they produce large amounts of heat. Moving laundry tasks to morning or evening is helpful also.

4. Ventilation

Movement of air, or ventilation, can do a great deal toward achieving a cool home. Ventilation helps in two ways: i) removing heat from the house, and ii) providing air movement within the house to cool its occupants. There are several means of accomplishing ventilation, both natural and mechanical, which will be discussed here briefly. Though mechanical means are not strictly passive, they are a much less energy-intensive method of achieving a cool home than air conditioning.

Natural Ventilation, or relying on summer breezes to generate air movement within the house, is the simplest of passive cooling strategies. Since wind speed and direction are variable, however, it can be rather unreliable. Careful selection of windows and their positioning can help enhance natural ventilation. In planning the layout of windows in a house, it is important to remember that there must be both an air inlet and exit for natural ventilation to take place effectively. In other words, windows on both the windward and leeward side of the house need to be open to promote air flow. If there is no exit for the air, the house will become pressurized by incoming air, and then little additional air will come in. Pathways for airflow within the house also need to be left open. For example, if the door to a room on the windward side of the house is normally left closed, the room will quickly become pressurized and not continue to draw in air to cool itself and the rest of the house. Trees are helpful for providing shading to the house, especially windows, however, the trees should not block air flow through the windows if natural ventilation will be used. Low branches should be removed to provide a pathway for airflow, as illustrated in the two figures below.

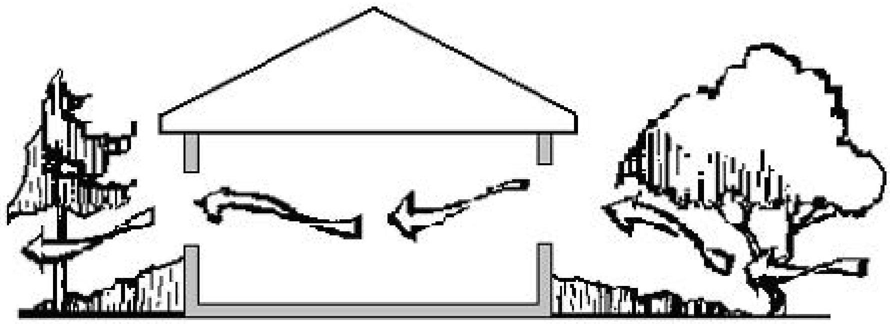

Figure 4. Trees Provide Shade and do not Block Air Flow

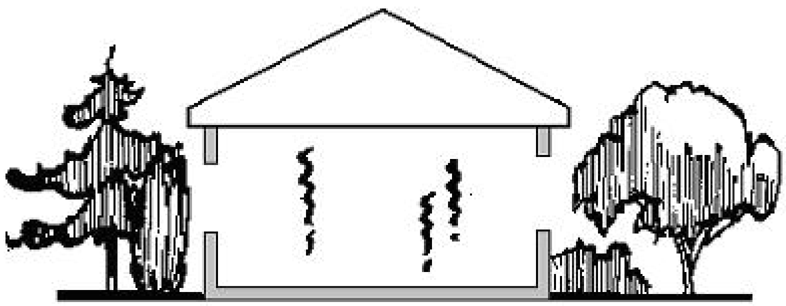

Figure 5. Trees Block Air Flow Through House

Since hot air has a lower density and rises, it is helpful to have a high outlet for air flow, so that natural convection* aids in causing the air flow. Some examples are shown in figure 6 below.

***NOTE**: Natural convection (also called free convection) is the movement of a fluid due to decreased density of a heated portion of the fluid. That is, as a portion of a fluid is heated, its density decreases and it rises. This will cause movement of other portions of a fluid mass as well. In the air flow examples shown in Figure 6, the buoyancy of the heated air takes it to the top of the interior space leading it to an outlet, and enhancing the natural ventilation rate.

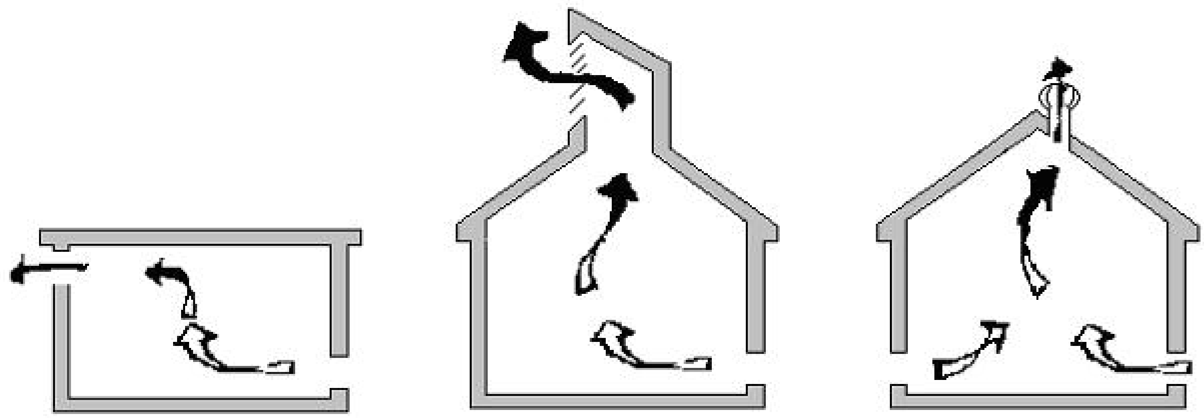

Figure 6. Air Flow Patterns Using Natural Convection

A **Solar Chimney** makes use of natural convection to increase natural ventilation rates even more than the air flow configurations shown in Figure 6. As shown in Figures 7 and 8, using solar energy to heat air in a vertical plenum, causes upward air flow in the plenum and draws air out of the living space.

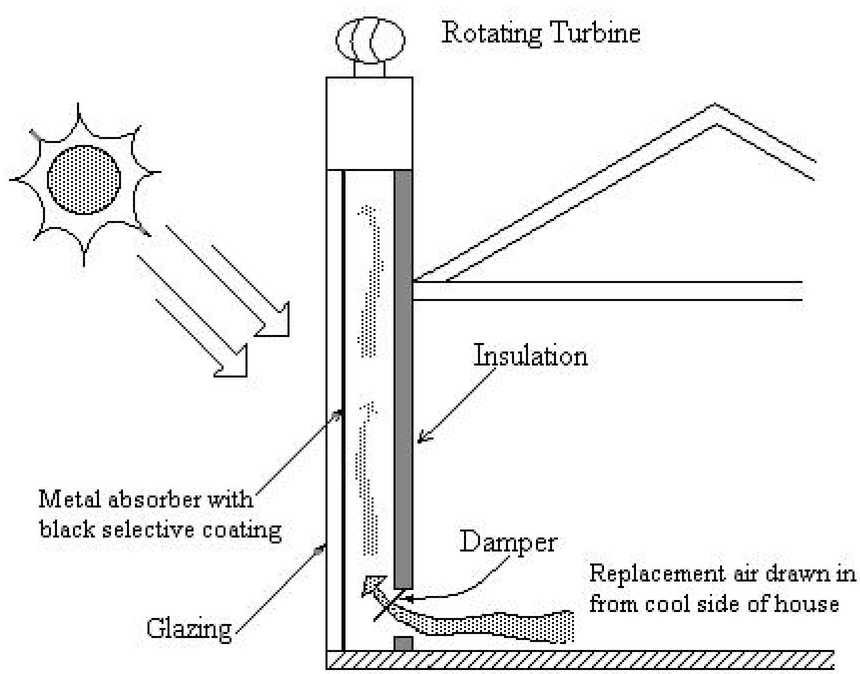

Figure 7. Solar Chimney

Figure 7 is a solar chimney design to be used only for enhanced ventilation. Figure 8 is a convective loop, passive solar collector, that can be used for heating during the heating season and enhanced ventilation during the cooling season.

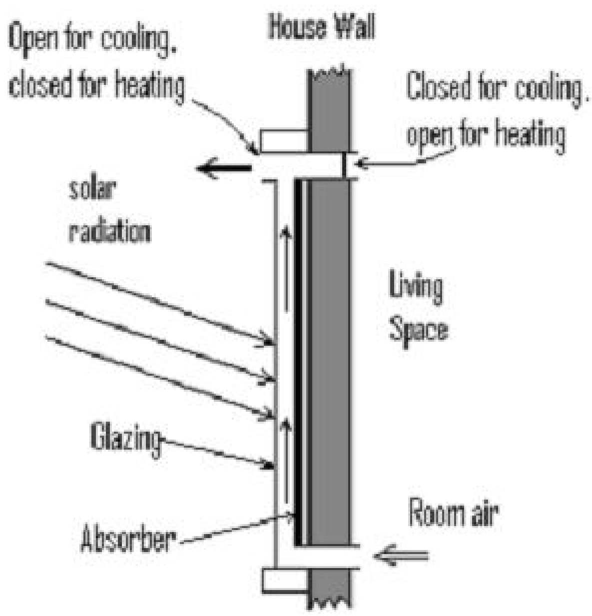

Figure 8. Vertical Convective Loop Collector used as Solar Chimney for Cooling

The rate of air flow due to stack effect (solar chimney) ventilation, is affected by the stack height, the temperature difference between the heated air and return air, and the inlet and outlet areas. For equal inlet and outlet areas, the air flow rate can be estimated from the following equation:

$$Q = 540 A \sqrt{h(T_1 - T_2)} \qquad (1)$$

Where: Q = rate of air flow, cubic feet per hour

A = area of inlets, square feet

h = the height between inlets and outlets, feet

T_1 = average temperature of air in the “chimney”, ^oF

T_2 = average temperature of return air, ^oF

If inlet and outlet areas are different, then the constant in equation (1) should be changed as follows:

Area of Outlets / Area of Inlets	Value to be substituted for 540 in equation (1)
5	745
4	740
3	720
2	680
1	540
3/4	455
1/2	340
1/4	185

Example #2: Estimate the air flow rate through a convective loop, passive solar collector used as a solar chimney, as shown in Figure 8, with a height of 8 feet, air temperature of 150 ^oF in the collector, air temperature of 76 ^oF in the house, and one square foot openings for both inlet and outlet.

Solution: Substituting values into equation (1) gives:

$$Q = 540(1)\,[\,8(150 - 76)]^{1/2} = 13{,}139 \text{ cfh} = \underline{\mathbf{219\ cfm}}$$

Whole House Fans can be used to bring in outdoor air for cooling even when no breezes are blowing. They remove hot air from near the ceilings and typically exhaust it out through a vent in the attic, while bringing in cooler air from outside. A general rule of thumb for sizing whole house fans is that the fan should be able to provide between 0.5 and 1 air changes per minute.

Example #3: What size (cubic feet per minute) would be needed for a whole house fan for a 1500 square foot house with 8 foot ceilings?

Solution: The air volume in the house is 1500 x 8 = 12,000 ft^3. The fan should move 0.5 to 1 times this volume per minute or **6,000 to 12,000 cfm.**

Ceiling Fans don't remove hot air as whole house fans do, but they provide localized breezes, which blow past a person's body and help it to lose heat more efficiently. This gives the perception that the temperature is about 4^{o} F cooler than it actually is. Thus, in a house with appropriately located ceiling fans, the air conditioner setting may be raised 2 to 6 degrees above what would otherwise be considered comfortable.

Attic and Roof Ventilation is needed to provide adequate ventilation between the roof and the insulation in the attic all year around. In winter, it helps prevent moisture buildup, which could damage the insulation and other building materials. In summer, it reduces roof and ceiling temperatures, thus saving on cooling costs, and lengthening the life of the roof. Several types of attic/roof ventilators are available, including ridge, gable, soffit, static mushroom, and turbines, as well as electric powered fan ventilators.

5. Low Energy Cooling Methods

Three low energy cooling methods will be considered here: i) **earth tubes**, ii) **radiative cooling,** and iii) **evaporative cooling**.

a) **Earth tubes** can be used to cool the air coming into the house for ventilation in the cooling season, as illustrated in Figure 9. The warm outside air gives up heat to the cooler surrounding earth and is thus cooled before entering the house. The same earth tube could be used to preheat air coming into the house in the heating season. The ground several feet down remains cooler than the outside air in the summer and warmer than the outside air in the winter.

There is information about earth tubes from several sources at the Build It Solar website at: http://www.builditsolar.com/Projects/Cooling/passive_cooling.htm. Earth tubes are not widely used in the United States, although they are more prevalent in Europe. They do not work well in hot, humid climates. They are best for hot dry climates, as in the southwestern U.S. A fan may be used to increase the flow rate of air through the earth tube, or a solar chimney could be coupled with an earth tube to draw air into the house through the tube. The tube should be sloped slightly away from the house, to prevent buildup of condensed water in the tube.

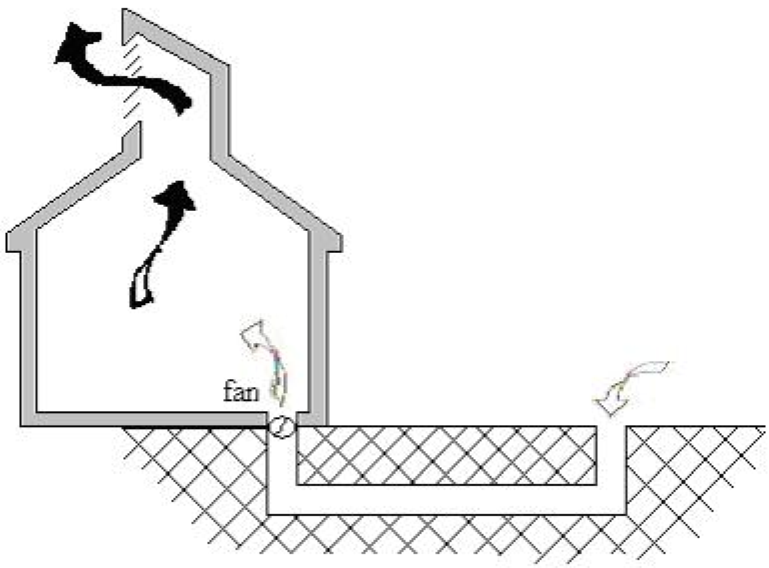

Figure 9. Earth Tube Cooling of Incoming Air for Ventilation

b) **Radiative Cooling**

A thermal storage roof or roof pond system, which may be used for passive solar heating, can also be used for radiative cooling in the summer. For heating, retractable insulating panels cover the roof at night and remain open to the sun during the daytime. For cooling the reverse strategy is used, as shown in Figure 10. The thermal storage roof pond is left open at night and gives off heat by radiation to the night sky and convection to the surrounding air. During the daytime, insulating panels cover the roof and it absorbs heat from the living space. This type of system works best in regions with low humidity and clear summer nights. Nighttime cloud cover will reduce the cooling performance. Roof pond systems should have an unobstructed view of the sky directly overhead. Adjacent trees, walls and other buildings can interfere with nighttime radiation of heat from the pond and can radiate heat to the pond at night.

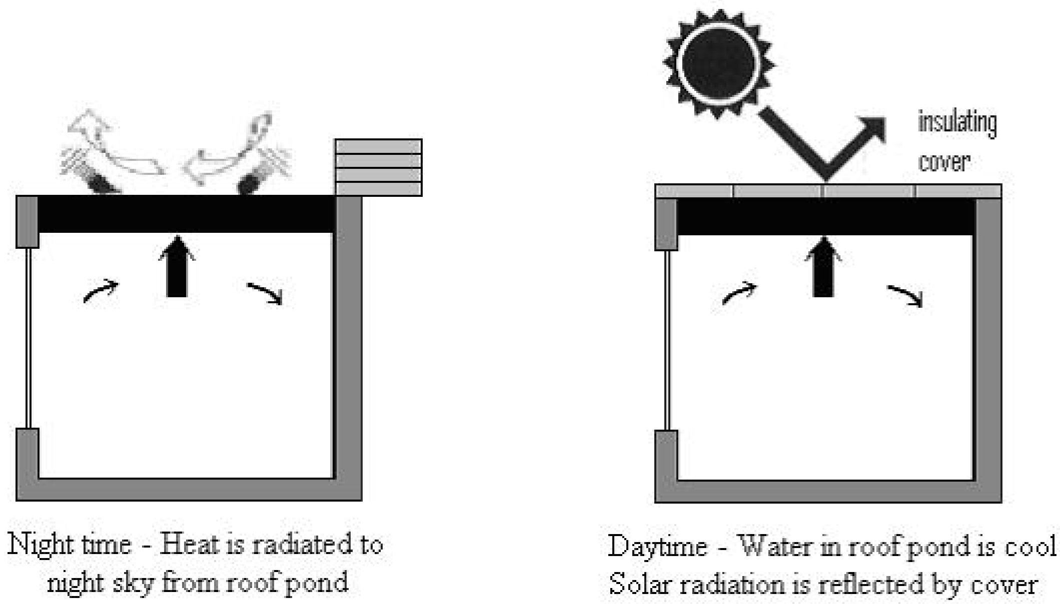

Figure 10. Radiative Cooling with a Roof Pond System

c) **Evaporative Cooling**

Evaporative cooling is based on the principle that water absorbs heat from its surroundings when it evaporates. In fact it absorbs about 1000 Btu per pound of water evaporated. Cooling of the skin by evaporating perspiration, is an example that most people are familiar with. Low humidity in the air and air movement past the skin both enhance the cooling.

Evaporative coolers (also known as "swamp coolers") are a proven technology, which has long been used in the arid southwest as a lower cost alternative to refrigerated air conditioning. Figure 11 shows the general configuration of this type of cooling system. Dry, warm outside air is drawn through a moist pad, which is kept saturated by a small water pump, as shown in Figure 11. This type of system will not work well where atmospheric humidity is high.

A roof top sprinkler can be used as shown in figure 12 to enhance radiative cooling from a metal roof at night. The excess water runoff into the gutter can be captured for reuse.

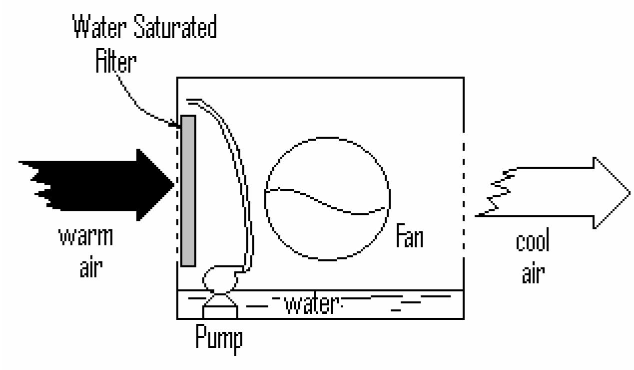

Figure 11. General Configuration of an Evaporative Cooling System

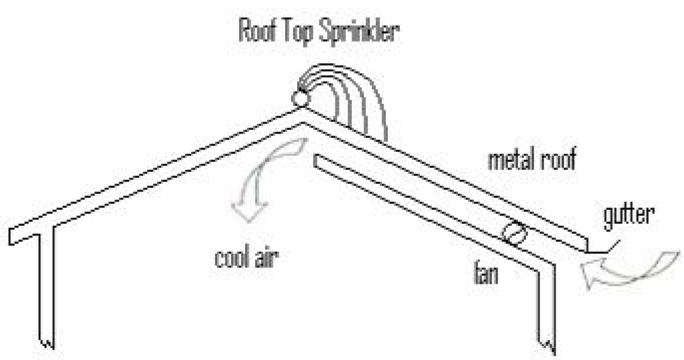

Figure 12. Roof Top Sprinkler System

6. Summary

The main strategies for passive solar and low energy cooling of a building are i) reduction of external heat gain, ii) reduction of internal heat generation, iii) provision of ventilation, and iv) use of low energy cooling alternatives. External heat gain can be minimized through the use of proper shading, especially for south facing windows and use of good insulation and weather stripping to minimize heat infiltration and transmission into the building. Use of energy efficient appliances, and sensible use of appliances that give off excess heat, during the cooling season, can help to reduce internal heat generation. Natural or augmented ventilation can help to bring cooler air into the building and to make the living space feel more comfortable. Earth tubes, radiative cooling and evaporative cooling are three possible methods for low energy cooling. All three of them work best in locations with low atmospheric humidity.

7. References

1. Goswami, D. Y., Krieth, Frank, and Kreider, Jan F., *Principles of Solar Engineering*, Philadelphia: Taylor & Francis, 2000.

2. Anderson, Bruce & Wells, Malcolm, *Passive Solar Energy: The Homeowners Guide to Natural Heating and Cooling,* Andover MA: Brickhouse Publishing Co., 1981 (available for free download at the website given below:) http://www.builditsolar.com/Projects/SolarHomes/PasSolEnergyBk/PSEbook.htm

Websites:

1. Passive Solar Heating & Cooling – Arizona Solar Center http://www.azsolarcenter.com/technology/pas-3.html

2. North Carolina Solar Center, Passive Cooling Information http://www.ncsc.ncsu.edu/information_resources/factsheets/13coolng.pdf

3. Solar DIY Space Cooling Information and Projects http://www.builditsolar.com/Projects/Cooling/passive_cooling.htm

4. NREL, *Solar Radiation Data Manual for Buildings* (Provides much solar radiation data, including recommended design for roof overhang shading of south-facing windows for 239 stations in the United States and its territories.) http://www.nrel.gov/docs/legosti/old/7904.pdf .

