Energy Efficiency Features of the Meherana Meadow Cottage

by Greg Dunn

Meherana's Meadow Cottage, besides meeting an urgent need for indoor meeting space and winter lodging at Meherana, has also been designed and constructed to be a model of energy efficiency. It is also completely off-grid electrically, though that was not so much an explicit original design objective as a practical imperative. In this article you'll learn of the Cottage's many innovative design features. If you find yourself building a house sometime in the near future, we hope this article will give you some great ideas for improving its energy efficiency, too!

Meadow Cottage with Rooftop Solar Panels

Design Team for the Meadow Cottage

Chris Pearson served as the primary designer and construction manager for the 1760 sq ft Meadow Cottage. Chris has been studying energy efficient design for many years, and making practical application of what he learned at every step of the way. Chris was assisted by many people at various stages in the construction of the house, but in particular by Ralph Brown, Michael Comerford, Ben Leet, Paul Williams, and Jim Wilson.

Electrical Controls

Electrical System

Power lines bring electricity from the PG&E grid to Meherana, connecting at a power pole near the Old Sahavas Kitchen. Any service from there must either be supplied by the consumer, or strung (or laid in the ground) by PG&E at the consumer's expense. PG&E estimated their price to run above-ground electrical service to the Meadow Cottage at $35-40 thousand; the more desirable underground cabling would have run twice that amount.

Battery Bank

Instead, Meherana is using a solar photovoltaic system with a backup propane-powered generator. All electricity for the house will come from a bank of batteries kept charged either by the photovoltaic panels on the cottage roof, or when necessary, by the backup generator. The equipment and materials for this system, which has a maximum load of 60 amperes, were obtained at a total cost of about $12 thousand; the labor to install it was volunteer. There will also, of course,

Propane-Powered Backup Generator and Tank

be no bills for electricity – ever! – although any necessary maintenance on the system will be at Meherana's expense. In particular, the system's storage batteries have an expected life of six to eight years, when they will have to be replaced at a cost of $2-3 thousand. Even so, the decision to go with the off-grid system was a slam dunk from a financial viewpoint.

The propane-powered *Generac* electrical generator was specifically designed to work as a backup charging source in a solar photovoltaic system. It starts automatically whenever the charge on the batteries drops below a certain level, indicating that the electrical demand inside the cottage has exceeded the photovoltaic panels' collective capacity to keep up. This generator requires about one gallon of propane per hour when running at its maximum output capacity, and the propane tank holds enough propane -- 500 gallons -- to keep the generator running at full output continuously for twenty 24-hour days. The need to do anything approaching that, however, should never arise, since the solar panels provide electrical output year-round, even on cloudy days (never more, of course, than on a sunny summer day!), and since the cottage will rarely require the sustained maximum output of the battery bank.

HEAT TRANSFER 101

Before we explore further the energy efficiency features of the Cottage, it will be valuable to take a moment to review the different ways in which heat is transferred between physical entities. Maximizing the energy efficiency of a house mostly involves dealing successfully with various forms of heat and energy transfer between the house's interior and the external environment.

During hot periods, you want to minimize the amount of heat and radiant energy (rays from the sun) that gets *into* the house; and you want to exhaust excess heat inside the house as efficiently as possible to the outside environment. Conversely, during the winter you want to let in as much radiant energy (in the form of solar rays) as possible, since that radiant energy will be absorbed by materials in the house and converted to heat. You also want to minimize the amount of heat that escapes *from* the house.

Heat can move between two different material bodies in several ways. *Convective* heat transfer (or simply, "convection") occurs by means of the movement of a liquid or gas. It's what happens, for example, when a cold wind blows against the exterior walls of a heated house. The molecules, atoms, and sub-atomic particles of that cold air collide with similar particles in the warmer wall and energy moves from the latter to the former.

The second mode by which heat is transferred among the various areas and materials inside a house is called *conduction*. Conduction occurs when heat travels within a body, or between two bodies in contact with one another, not as a result of relative motion between the two bodies but instead via microscopic diffusion and collisions of particles such as molecules, atoms, and electroncs. For example, heat can pass out of a house via conduction through its foundation into the cooler earth on which that foundation rests. It's the same mechanism that occurs when you grab the hot handle of an iron skillet!

The third mode of heat transfer to consider is *radiant* heat transfer (or "radiation"). This is what happens when rays of energy travel from the sun through the windows of a house into its interior, where they are absorbed by the interior materials (walls, furniture, people, and etc.). Much of the energy that enters a house in this way is of a higher frequency than would place it in the spectrum that would be considered heat; but when this higher frequency energy is absorbed by objects inside the house, it gets *converted* to heat.

Nature seeks temperature equilibrium, and wants the temperature between any two adjacent bodies or substances to be equal. The greater the difference in their temperatures, the faster will be the transference of heat from the warmer body to the cooler one. Just how long it takes for two bodies to reach temperature equilibrium depends upon how effective the materials they're made of are at moving energy.

Materials that facilitate the rapid movement of heat within or across them are known as good *conductors*. Most metals are good conductors, with metals such as gold, copper, and aluminum being especially willing conduits of heat (and other forms of energy such as electricity). Poor conductors include empty space, styrofoam, rubber, plastics, and fiberglass (which is a mixture of plastic and glass in a soft, spongy weave.)

Although you can't stop the transfer of heat from a warmer body to a cooler one, you can slow it down by placing a layer of poorly conductive material between the two. A potholder will keep the heat in a hot iron skillet from burning your hand. A thermos bottle keeps your coffee hot or your lemonade cold by interposing a layer of airless space between the bottle's contents and the external environment. A layer of fiberglass insulation in your hot attic will slow down the movement of heat from that attic into your cooler house (or out of your warmer one).

Ventilation System for the Meadow Cottage Attic

House designers pay particular attention to the upper part of a house when designing for energy efficiency, for two main reasons:

1. The house's roof is exposed orthogonally to a large amount of incoming radiant solar energy; and
2. Hot air travels upward (with moving air being a powerful mechanism for heat transfer).

In the summer, a typical attic can rise to temperatures 40 degrees higher than the ambient (outside) temperature, as the combined result of radiant energy absorption and heat transfer – accelerated by air moving against the house's ceiling – from the house interior. The sun's rays penetrate the roof and either get converted into heat after being absorbed by materials inside the attic, or get converted by the materials of the roof itself, whence the collecting energy is then conducted and convected into the attic space. The warmest air from the house interior rises to the ceiling and tranfers heat to it as it flows against it.

Nature (or more specifically, its thermodynamic aspect) wants the temperature in the attic, the temperature inside the adjacent house, and the outdoor temperature all to be the same. But the absorption of radiant energy by the attic space (in particular) on a hot day will throw these three spaces into a disequilibrium that nature will immediately begin working to resolve. If the outdoor air temperature is 100 degrees, the temperature of the attic space is 140 degrees, and the temperature of the house interior is 75 degrees, then heat needs to -- and will! -- flow from the attic into both the surrounding air and the house below. The tendency of hot air to move upward will contribute to making the outdoors a desirable destination for that excess heat– that part we like! – but unfortunately, the large temperature difference between the attic space and the house interior will tend to move the heat downward into the house!

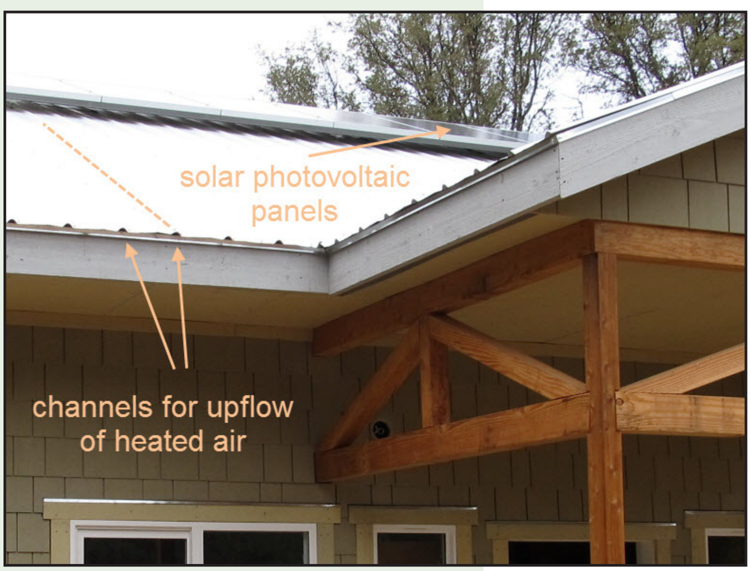
How can we design a house to reduce that heat transfer from the attic to the house inteior? Well, there are two main ways. The first is to put a heat transfer barrier – insulation – between the attic and the house. Insulation consists of a layer of material that is a poor conductor of heat. When you separate two regions of different temperature by a layer of insulation, you don't stop the flow of heat between the two, but you can slow it down, in the same way that a good thermos bottle will allow you to keep a quart of tea hot for several hours, but not forever. If you can slow down the rate at which heat from the attic moves down into the house interior, you simultaneously provide time for a greater share of the excess attic heat to be exhausted to the outside air.

The other way to reduce heat transfer from the attic to the house is to keep the attic as cool as possible. The greater the temperature difference between the attic and the house interior, the higher will be the rate at which heat moves from one to the other. Now you don't, of course, need the attic to be at a human-comfortable 75 degrees, and you certainly wouldn't want to pay for an air conditioner to keep it at that temperature. So instead what you do is

a) keep as much energy as possible from getting into the attic to begin with, and

b) make it as easy as possible for heat to leave the attic via convection into the (lower-temperature) ambient air.

Objective (a) is accomplished in the Meadow Cottage via the following mechanisms:

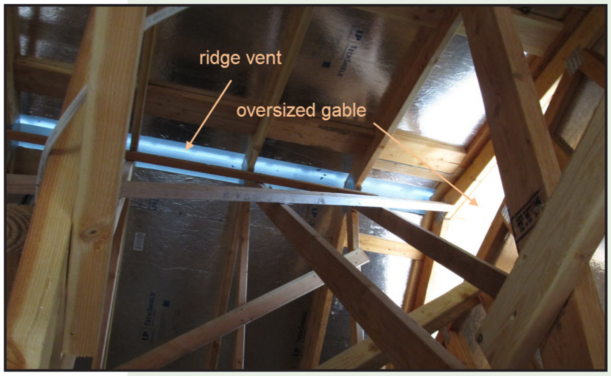


Corrugated White Metal Roof

- a metal roof painted white which very effectively reflects radiant heat hitting the roof in the form of the sun's rays;
- corrugations in the metal roofing layer that permit heat that builds up in the metal to be convected away by the natural upward flow of the ambient air. The panels of roofing material are not joined at the crest, but instead are separated there by an air gap that permits warmed-up air from the corrugations to exit into the atmosphere. The gap is covered by a metal cover that prevents rain from passing the exterior roof surface.
- the substrate for the metal roof is thermal OSB (oriented strand board, a material similar to particle board). It's "thermal" because it) has one side covered in radiation-resistant aluminum foil. The foil side is placed face down (against the attic interior), and the combination of the foil layer and the air behind it form a second major barrier to the absorption of energy from the sun's rays. The foil skin on the OSB can reduce radiant energy absorption by as much as 40% over bare OSB or plywood!

Objective (b) is accomplished via the following mechanisms:

- a venting system consisting of (1) a ridge vent that runs the entire length of the roof crest; (2) oversized gable vents at the ends of the roof; and (3) a continuous soffet vent that runs the entire length of the house on the underside of the roof at its extremities. Air primarily comes into the attic via the continuous soffet and primarily moves out via the ridge vent. The gable vents, like large open windows, allow air to move in either direction, as needed.



Ridge Vent and Oversized Gable Vent

The ridge vent, like the ends of the metal roofing material, is covered by the full-house-length metal cover, so no water gets either to the roofing substrate (the foil-covered OSB) or past it into the attic.

Continuous Soffet Vent and Deep Horizontal Roof Overhang

Now, note that the design features of the roof and attic that prevent absorption of radiant heat and maximize heat transfer away from the attic work *for* you in summer, but *against* you in winter. In winter you'd love to have all the radiant energy input you could get. Well, you can't have everything, at least not until somebody invents a paint that goes from white to black as the temperature drops (which will probably be any day now). The good news is that, while the dynamics of energy transfer contribute to raise attic temperatures far above the ambient temperature in summer, the reverse is not true: attics do not get colder in winter than the ambient temperature. So the biggest temperature difference that you have to worry about in winter is that between the outdoor temperature and your desired indoor temperature; whereas in summer it's between the desired indoor temperature and the temperature in the superheated attic! So if you have to choose between optimizing your design for the summer circumstances or the winter ones, you choose the former. At least that's true in an area with summers as long and hot, and winters as relatively mild, as Mariposa!

Insulating the House

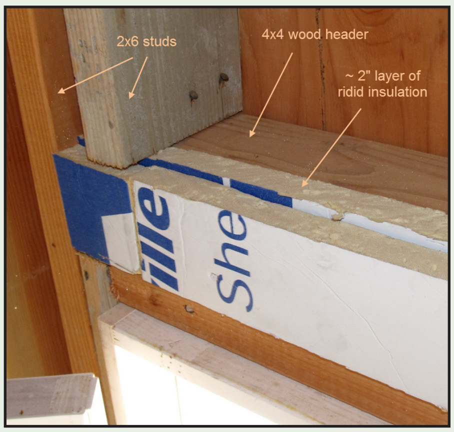
In addition to the ventilation features just discussed, the Meadow Cottage attic has a layer of R-38 fiberglass insulation on its floor. (The R value is a measure of the resistance of a material to heat flow.) The use of R-38 insulation in an attic is conventional in the Mariposa area; however, in the Meadow Cottage the raised-heel roof trusses used to support the roof – discussed in more detail later in this article – permit the R-38 insulation layer to extend fully to the edges of the attic, instead of tapering down to a thinner layer as the roof line descends to the attic floor.

As already discussed, heat transfer through the attic and roof is the biggest problem to be counteracted in the design of a house. However, a great deal of heat also enters and escapes through the vertical wall and window surfaces of a house, so you certainly can't afford to ignore that problem, either.

Wall Studs 2x6 on 24-inch Centers

In the past, most houses were constructed with 2x4 wall studs. The 3-1/2" of space created by a standard 2x4 stud only permits fiberglass insulation with an R-13 value to be used. Nowadays it is increasing common to see 2x6 wall studs used in the exterior walls of a house; and this is what the Meadow Cottage uses. These create a 5-1/2" space that can be stuffed with fiberglass insulation. This thicker insulation has an R-19 value, thereby slowing the rate of heat transfer between the inside of the house and the environment.

FR-19 Fiberglass Insulation



Rigid Insulation in Door Header

A second advantage of using 2x6's is that, being thicker than 2x4's, they are also stronger, so that you don't need as many of them to hold up a roof. 2x4's are traditionally placed 16" apart; with 2x6's, you can increase the space between studs to 24". This provides an additional advantage from the viewpoint of insulation, because wood itself is a very poor insulator -- which is to say it is a reasonable good conductor of heat -- and the less of it you have connecting the interior of the house to the exterior, the better. With 2x6's you have only 2/3 as many breaks in the fiberglass insulation as you must have when using 2x4's.

The use of 2x6's provides still another advantage from the viewpoint of insulation. The "headers" above doors and windows are traditionally made of poorly insulating wood, typically in the form of 4x4s. These headers must bear the load from the weight of the roof and transfer it to the vertical studs on either side of the door or window opening. Since the 3-1/2" thickness of a 4x4 is adequate to satisfy the header's load-bearing function; and since a 4x4 leaves two inches in the width of a 2x6 wall stud available, that extra 2" can be filled with a material that insulates far better than wood. In the Meadow Cottage, Chris has used a material called "rigid insulation" for this purpose. While more expensive than fiberglass insulation, it also provides a greater barrier to heat transfer than fiberglass insulation of the same thickness.

Rigid insulation is also used in other areas, such as the upper portion of the Great Room side walls. Structural boards needed in that area prevent the use of a full thickness of R-19 fiberglass insulation.

Another heat transfer detail that is addressed in the Meadow Cottage is conduction from the interior walls through the exterior walls. In a conventional house, this unwanted heat transfer is facilitated by the direct wood-to-wood contact between internal walls and external walls. In the Meadow Cottage, there is a 4-inch gap between the interior and exterior walls, permitting insulation to be placed between the two.

The floor of the Meadow Cottage has the standard R-19 insulation as required in the Mariposa County zone. Heat transfer through the floor is a relatively minor problem except in very cold climates.

Rigid Insulation and Thermostat OSB on High Walls and Attic Ceiling

Gap Between Interior and Exterior Walls

Heat Transfer Through Windows

Dual-Pane Windows with Radiant-Energy-Blocking Coating

Most of you are probably familiar with dual-pane windows by now: these use a layer of air (or ideally, the absence of air) trapped between two panes of glass as a thermal insulator. Like fiberglass, still air (and especially rarified air, the closer to a vacuum the better) creates a very effective barrier to convective heat transfer. (As a bonus, it creates a very effective barrier to sound transfer as well, making it a Godsend in the crowded, noisy city – or anywhere where dogs are howling, cats are yowling, coyotes are yipping, or noisy machines are running.)

The Meadow Cottage, of course, uses dual-pane windows throughout. On all sides but the south one, the windows also have a coating that impedes the transfer of radiant energy – important when the sun is shining directly or indirectly into the window. Uncoated windows were selected for the south side of the house so as, during the winter season when the sun is low in the sky, to permit radiant energy to pass into the house, where it will be absorbed by the materials inside the house and converted into the longer-wavelength heat waves. During the summer, extra-wide roof overhangs – discussed more elsewhere – shade the windows from the direct rays of the higher-in-the-sky sun. A gable over the front doorway area, and a planned awning on the west side of the house will provide still more summertime shade.

Energy Management Benefits of Raised-Heel Roof Trusses

Raised-Heel Roof Truss

The roof of the Meadow Cottage sits atop roof trusses slightly but significantly different in design from the conventional ones. A conventional roof truss is shaped like a triangle, resulting in (a) minimal vertical space for insulation around the edges of the attic, and (b) roof overhangs that are limited in how wide they can be by the fact that the wider they are, the lower they hang down at the outer edge.

A raised-heel roof truss, by contrast, is shaped like a triangle with the bottom two corners trimmed off. This leaves, at each of those "trimmed corners", ample vertical room at the edges of the attic for insulation, so that the thick R-38 attic insulation can extend all the way to those edges, instead of tapering down to nothing. It also raises the height of the entire roof by 18", so that the roof overhang can extend farther out from the house (providing shade) without the roof edge becoming excessively low.These benefits of the raised-heel roof truss have been fully exploited in the Meadow Cottage.

Managing Heat Transfer Through the Ducting

In a conventional house, the ducting that distributes hot air from the furnace for heating and cool air from the air conditioner for cooling is placed in the house's attic or under the floor. Building codes only require insulating it to R-8, so a significant amount of heat transfer occurs between the ducts and their environment. Whatever goes there is lost to the interior space you're trying to make comfortable.

In the Meadow Cottage, all ductwork is inside the conditioned space. The large-diameter ducting behind the main air-return vent (in the ceiling of the Great

Main Air-Return Duct (concealed, but still in the conditioned space)

Duct Into Bedroom

Air-Return Vent and Duct (Great Room)

Room) is in an enclosed cavity between the bottom of the attic (10 feet from the house's floor) and a drywall dropped ceiling 8 feet off the floor in the house's central hallway. The ceiling above this duct is insulated with R-38 fiberglass, while the dropped ceiling below it is simple uninsulated drywall; therefore, the major part of heat exchanged between the duct and its environment stays inside the conditioned space of the house interior.

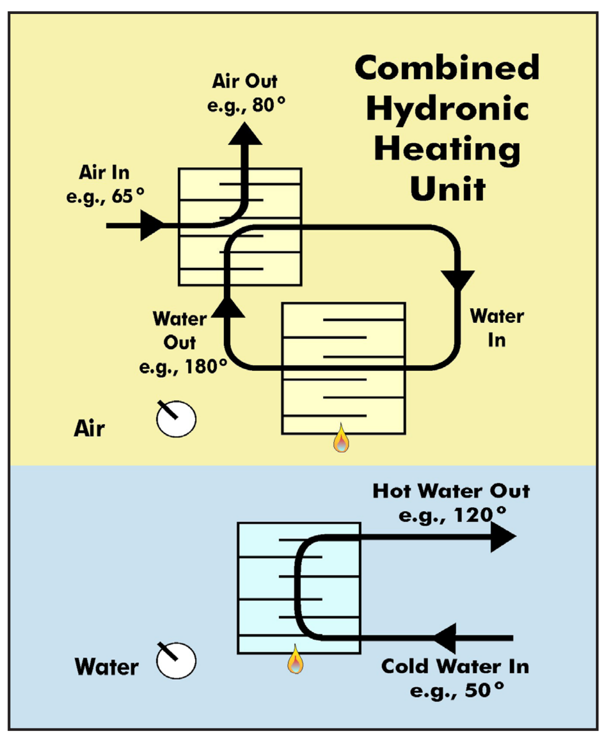
Ducts in the bedrooms, Great Room, and Kitchen are exposed below those rooms' ceilings. A relatively attractive -- or perhaps we could say, more conservatively, "not too unsightly" -- style of solid metal ducting that can be painted is used for this purpose. This can fairly be considered a compromise of esthetics in exchange for energy efficiency, but the more enthusiastic admirer will find it hip and trendy. And why not?

The one component of the air movement ducting that is *not* in the conditioned space of the house is a plenum chamber above the air return vent in the Great Room. This chamber lives in the attic and will accordingly be heavily insulated.

Heating the House's Air and Water

In place of a conventional furnace and conventional hot water heater, the Meadow Cottage will employ a propane-powered, ultra-high-efficiency "combined hydronic" heating system.

This system encompasses three separate heat exchangers. One works as in a tankless water heater, where water is heated instantly, on demand, in a small chamber, for use via hot water faucets in sinks, showers, and tubs. The two others are part of a subsystem for heating air. The first of the two in this pair is a boiler that heats water to 180 degrees (compared to the ~120 degrees used directly by house occupants for washing and rinsing). The water thus heated to 180 degrees is then routed in a closed loop into the second heat exchanger of the pair, where the energy in the heated water is transferred to moving air which is



Combined Hydronic Heating Unit (Functional Sketch)

Site for Combined Hydronic Heating System and Energy-Recovery Ventilator

Duct Into Great Room and Site for Wood-Burning Stove

then circulated into the house to warm its occupants. Tankless water heaters cost less to operate than conventional tanked ones because that big tank of hot water on the latter continuously loses heat to its cooler environment. The furnace in the combined hydronic unit is also much more efficient than a conventional one. This is because greater yield is obtained by heating water with a flame and then air with the heated water than by heating the air directly with a flame. Putting both systems in a single housing provides an additional efficiency, as all of the heating components contribute to keep each other warm!

Meherana has an ample supply of wood that can be used for heating -- mostly dense, high-yield oak. Accordingly, the Great Room of the House will include a modern wood-burning stove. Heated air from the stove will rise and flow naturally toward the air-return vent in that room, whence it will be whisked into the central ducting system and distributed throughout the house. It will in many cases provide all the heat the house needs.

Hard-Setting Foam to Seal Pipe Hole

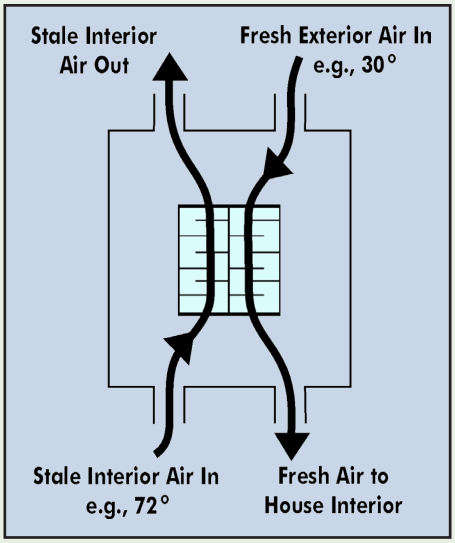
Sealing the House Against Air Leaks

A convential house is riddled with somewhat random air leaks where conditioned air from the interior is exchanged for unconditioned air from the out-of-doors. These leaks may help to satisfy the occupants' need for fresh air with an appropriate balanced of oxygen and carbon dioxide, but in the process they allow large amounts of energy to be wasted as ambient air at an undesirable temperature mixes with conditioned air from the house interior.

Hole for Electrical Wire (to be sealed)

In the Meadow Cottage, air leaks have been kept to an absolute minimum. Cracks and seams have been rigorously caulked – including seams around all doors and windows, and the seam between the floor and the exterior walls. Wall sheeting has been not just nailed, but also glued, to the wall studs to block even tiny amounts of air from moving between the studs and the exterior walls. Every hole bored for wires and pipes in the framing inside the house has been sealed with hard-setting foam to prevent heat exchange between the interior of the house and the attic or crawl space.

Caulking at Floor Sill



Heat Recovery Ventilator (Functional Sketch)

Air-Return Pathway

Air-Return Pathway (detail)

Site for Swamp Cooler Entry Point

Importing Fresh Air from Outside the House

When you seal a house against air leaks as tightly as the Meadow Cottage is being sealed, you have to provide another mechanism for importing fresh air. the Meadow Cottage will obtain fresh air by way of a heat recovery ventilator. This ventilator transfers heat between stale outbound interior air and fresh inbound air from the out-of-doors before the former is cast out of the house or the latter brought in. This is accomplished in yet another heat exchanger. The ventilator is tied into the central ducting system at a plenum chamber in the house's machine room, and uses the fan in the main ducting system to help it distribute the fresh air it imports to the rest of house. Using a control on the ventilator, an operator can dial whatever amount of air exchange he needs or wants; for example, he could specify that he wants the entire air volume of the house turned over three times per hour.

Return Air Pathways Permit Air to Exit Rooms with Closed Doors

In order to faciltate air flow to rooms with closed doors -- important both for the distribution of fresh air and the maintenance of constant temperature throughout the house -- air-return pathways are being installed above the doors. These special vents feature a honeycomb matrix made of a cardboard-like fiber that allows air to flow freely, but muffles light and sound.

Natural Air Conditioning

The Meadow Cottage will include a whole-house fan with an intake vent in the Great Room near the ceiling on a side wall. This can be turned on in the evening or night when exterior air is cooler than the interior of the house to cool the house down using unconditioned – but fresh and cool – outdoor air. The fan chosen for this purpose is an especially quiet belt-driven model . (The belt drive permits the motor that powers the fan to be located away from the opening where the fan and its noise directly impacts the interior of the house.)

Swamp Cooler

With all the energy efficiency features of the Meadow Cottage, it seems likely that occupants will feel only relatively rarely the need for supplementary air conditioning. Nevertheless, a swamp cooler unit with dedicated ducting will be integrated into the house for summertime cooling. Swamp coolers are more efficient than conventional air conditioners and work particularly well in hot, dry climates such as that which the Mariposa area experiences during the summer.

The swamp cooler will be located behind the house near the machine room.

Summary of Energy Features

We conclude this article with a summary of the energy-efficiency-related design and construction features of the Meadow Cottage that we've discussed. Use it as a checklist or a design feature tickler for your next house!

- Corrugated metal roof - air flow passages exhaust heated air out gap in the rooftop
- White color of metal roof - most reflective of radiant heat
- Foil-coated radiant energy reflective OSB substrate used for interior layer of roof
- Extra-large gables and full-length ridge vent permit hot air to exhaust; continuous soffet vent along attic floor provides low-resistance passive air intake to support the upward air flow
- Raised-heel roof trusses permit R-38 insulation layer all the way to the edges of the attic; they also facilitate an extra-wide horizontal roof overhang to block summer sun rays
- R-38 insulation in attic; 6" exterior walls with R-19 insulation
- Exterior wall studs on 24" inch (rather than 16") centers reduce interior- to exterior wood contact and provide greater insulation area on the exterior walls
- Extra rigid insulation around door and window headers
- All cable and pipe holes sealed to prevent air communication with attic and crawl space
- Solar panels and batteries permit off-grid operation - backup propane-powered generator
- Overhang on south side blocks summer afternoon sun
- Double-pane windows resistant to convective heat transfer
    - uncoated on south side to permit greater passage of radiant energy during winter months when the sun is low in the sky (and therefore not blocked by the roof overhang)
    - coated elsewhere to resist transfer of radiant energy
- 6" gap between internal and external walls to permit insulation rather than wood-to-wood contact
- Very quiet whole-house fan permits cooling with ambient air during sleeping hours
- Virtually all HVAC ducting is in the conditioned space so that heat transferred through the surface of the ducts is not lost to the house's interior
- Ducting plenum in attic is heavily insulated
- Very efficient combined hydronic air and water heater provides maximum heating from the propane used
- Integrated energy recovery ventilator provides fresh air with minimum unwanted loss or gain of heat from the house interior to the outside environment; return-air pathways inside house permit excellent air circulation between rooms with closed doors, without accompanying unwanted sharing of noise and light
- Wood-burning stove in Great Room permits use of abundant available free wood; house air circulation system distributes heat from the stove throughout the house
- Swamp cooler available if needed for efficient cooling of house

P.O. Box 1997 • Mariposa CA 95338 • Mariposa, California USA • www.meherana.org