Chapter 4
Solar Requirements: Site, Orientation and Design

Every hour the sun beams onto Earth more than enough energy to satisfy global energy needs for an entire year. - National Geographic

Opening Questions:

What is critical about site selection for sustainable housing?
Can I live sustainably in a house on a wooded lot with shading?
What is important about orienting houses to capture solar energy?
How do passive and active solar systems complement each other?
Where (why) does passive solar make sense and how is it achieved?
What is the clear message for developers vis-a-vis sustainable housing?
What is the clear message for local zoning in promoting sustainable housing?
What is the message for builders/architects/homeowners striving for sustainability?

Data and Analysis:

The opening quote of this chapter offers another perspective on the incredible power of the sun, and yet too many new homes are built in the U.S. without sufficient consideration of its presence and potential. The previous chapter offered a convincing argument--both economic and ecological--for harnessing the energy of the sun to power homes with *active* systems, primarily with onsite solar PV. In this chapter we introduce the broad parameters of *passive* solar to heat indoor space in colder climates and then consider site, orientation, and design features to optimize solar capture for both active and passive systems. Thermal solar (heating water) is also discussed briefly. In addition to site decisions on individual properties by a builder and homeowner, this issue raises questions for developers, local governments, and public and social policy. The focus is on new construction and development, though the basic principles may be applied--to the extent possible--to existing and renovation projects.

Passive solar is not needed, or wanted, in warm climates where there is little or no heating demand. In regions where air conditioning is used for most or all of the year, homes should be designed to block as much passive solar heat gain as possible. Shading windows from direct sunlight, while allowing indirect but natural light into the building, can be achieved with intentional design of orientation, location of windows, and roof overhangs. The designer will consider the latitude of the home, which reveals the moving angle of the sun throughout the year, to optimize placement of windows and shading. Ideally, houses in warm climates will minimize glazing on east and west sides where solar heat gain is less controllable by designed shading.

Solar heat gain is not only desired in colder climates, but it can be a powerful method to aid indoor warming in the winter. Passive heat gain also adds little to no cost to construction when its principles are considered and adopted from the design stage. The Energy Systems chapter provides more specific analysis on the science, materials and practicality of passive capture and storage, but for now it should be noted that the objective of passive solar is to capture and use the sun's energy for only part of the year; this highlights one important distinction with active solar systems, which aim to capture energy throughout the year.

Passive solar capture occurs when the sun shines directly on indoor surfaces that absorb the energy and convert it to heat. The benefit inside the home is achieved when heat radiates from energized surfaces to the surrounding air, thereby heating space. In the northern hemisphere, this is designed on the south side of buildings so that maximum solar heat is gained in the winter when the sun travels in a lower arc across the southern sky, providing more direct sunlight into south-facing windows. Roof eaves, awnings, or other overhangs can be specifically designed, then, to block the sun's rays during warmer months when indoor heating is unwanted (see Figure 3.1).

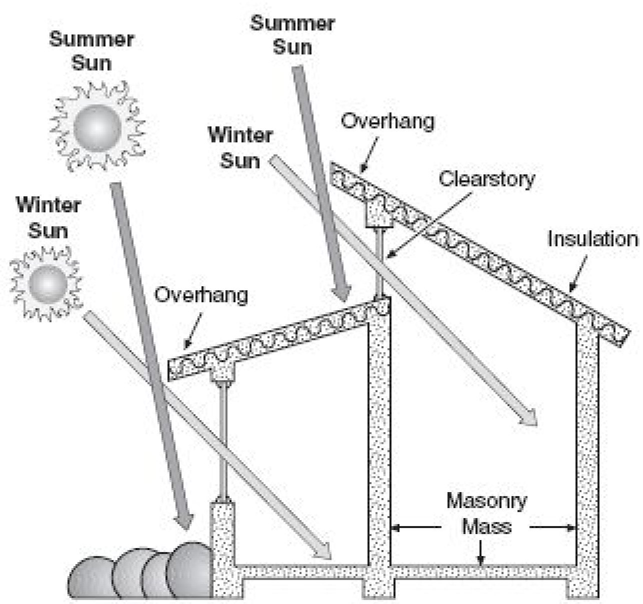
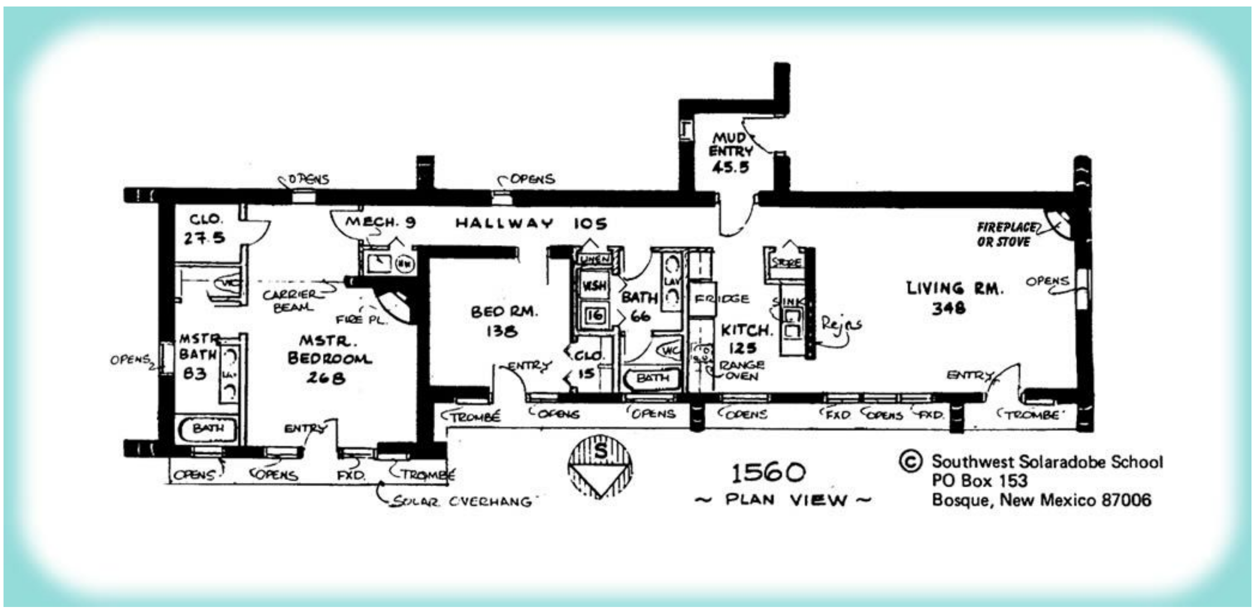


Figure 3.1: passive solar design

Windows on east and west elevations also allow for passive solar heat gain, but these introduce inefficiencies. First, most wall systems within which windows are placed, are far superior to glass as a thermal insulator; windows, therefore, become weak links in the overall building envelope. Even the best windows will not achieve the insulation value of the most basic and simple wall system; this results in larger energy losses through windows than through walls. Another weak point introduced by windows in any location is the challenge to seal them effectively against adjacent wall structures. Since heat loss and air leakage through and around windows occurs all the time, and since east and west windows may absorb passive heat gain for only a few hours each day, the losses from a weaker thermal barrier will in most cases overwhelm any benefits from solar heat gain; this is the case with windows on all but southern exposures. Additionally, east and west facing windows cannot be effectively shaded during warm seasons when solar heat gain is unwanted; solar heat gain through east and west windows during warm seasons may require more energy to offset those gains with air conditioning.

Windows on the north side of buildings in cold climates in the U.S. do not allow for any passive solar gain in the winter when it might be desired. Additionally, north-facing windows bear the brunt of prevailing winter winds, which makes them most susceptible to cold air infiltration. Ideally, a cold-climate home in the northern hemisphere would be designed with no glass facing north, most of the windows on the south side, and only a few or no windows east and west (see example building plan in Fig. 3.2).



The physical and surrounding conditions of each particular building lot may make it impossible or impractical to design and orient a house ideally for solar capture, and this points to the importance of site selection and zoning design. However, if there are no serious or unmitigated constraints, a narrow and long footprint on an east-west axis (as shown in Fig. 3.2) provides:

1. Maximum capacity for passive solar heat gain (for winter space heating).
2. Sufficient natural light from primarily south-facing glass, without windows to the north.
3. Relatively short walls on east and west, negating or minimizing need for windows there.
4. Least expensive roof design to maximize capacity for roof-mounted active solar PV; the default roof design for this floor plan is a two-pitch roof with the ridge running on the

central east-west axis. The south-facing roof pitch effectively accommodates solar modules for an active PV system.

Windows need to be carefully selected for their location on the house and directional orientation. The National Fenestration Rating Council (NFRC) requires window manufacturers to test and display energy performance ratings on their products; in addition to a label displayed on each unit, this information is available in product catalogs when pricing and selecting windows. There are typically four or five ratings for windows; visible transmittance, air leakage, and condensation resistance are important and should be considered in brand and model selection, but it is the ratings of U-Factor and solar heat gain coefficient that are critical for orientation. U-factor measures the effectiveness in resisting heat loss through the window; this is similar to R-value ratings in other building components, however the scale is inverse, meaning that lower U-factor ratings are better insulators. In fact, U-factor ratings are the reciprocal of R-value; dividing the U-factor into 1 provides an equivalent R-value, and from that simple calculation it is clear that even the best windows (lowest U-factor) are insulation weak points in almost any wall system. U-factor ratings commonly fall between 0.07 and 1.20 (NFRC, 2017), or equivalent R-values of between 14.3 and 0.83, respectively. Solar heat gain coefficient (SHGC) measures the effectiveness in resisting unwanted heat gain. SHGC is expressed as a fraction, between 0 and 1, and a lower number means more resistance to unwanted heat gain through the glass. Lower numbers are better for east, west, and north (if any) windows, but if looking for passive solar heat gain, higher numbers will perform better on south-facing glass. Further complicating window selection for passive solar design is that U-factor and SHGC are inversely related; if a lower U-factor rating is desired, it will necessarily compromise some solar heat gain potential. Working with a knowledgeable architect or energy modeler is advised for making the most effective window selections.

The ideal orientation for the solar side of the house is true south; this is to achieve the most effective benefit from both heat gain and shading in a passive solar design. The further east or west of true south that the solar side is oriented, less passive heat will be gained when it is wanted, and less effective shading will occur in swing seasons (between winter and summer), risking overheating and higher energy use for air conditioning. The orientation for active solar is also to the south, though precision to true south is not as critical. In fact, in many locations an active solar array can be oriented as much as ten degrees east or west of true south with minimal impact on overall PV performance. The orientation for maximum active solar power generation will depend on the unique specifications of each array, as well as local weather patterns. We recommend using a calculator, such as PV Watts from the National Renewable Energy Laboratory (NREL), to find expected energy output unique to each array, location and orientation, but if designing for both active and passive solar, perfect true south is the ideal orientation for the combined needs.

Homeowners and builders can select land and lots for suitable sites for utilizing both passive and active solar, but the largest impact will come from developers, community associations, and public policy that encourage planning that allows or mandates orientation ideal for solar. When developers partition roads, lots, and utilities for a new housing tract, choices about design are sometimes dictated by topography, but in many cases the layout could include factors that promote sustainable homes. The layout that works best for solar capture on individual homes constructs access roads east and west, with rectangular-shaped building lots, and the broader side adjacent to the street. Lots on the north side of the access road will have primary views through ample south-facing windows, across a front lawn toward the street. Homes on the other side of the street will have primary views across a back lawn; this consistent orientation to the south also aids privacy between houses. Setbacks from the street could also encourage preferences for this layout, with narrower setbacks for lots south of streets and deeper setbacks for homes to the north (see Figure 3.3). Developers could take these steps on their own, but a more powerful approach would be for public policy to adjust local zoning requirements in the direction of encouraging developers, builders, and homeowners.

[insert development plan/map as Figure 3.3]

Currently, the economics of development favor an approach opposite of the ideal noted above; developers prefer allocating less street frontage to residential lots that are deeper than they are wide. This allows the developer to sell more lots to offset their infrastructure investments in roads and utilities. Recognizing that these public works also have a negative ecological impact, finding efficiencies with those resources is also important. If lots with narrow frontage and greater depth are designed into the development layout, then a road system that runs north and south is ideal, and certain design elements and covenants are needed to encourage solar homes. For example, banning or limiting north-facing windows will free homeowners to design their homes with openings to the south, without concerns for compromised privacy. Maximum elevations for structures and trees would avoid the possibility of shading a neighbor's passive or active solar capture zones. See Figure 3.4 for example of possible regulations.

[insert development plan/map as Figure 3.4]

Decisions to design a passive and active solar home have long-term consequences, and in many cases require long-term investment; homeowners are not likely to take steps toward harnessing the power of the sun unless they are assured of the protection of that investment. A good practice on any lot is to place the garage on the north side of the building as a cold wind buffer and privacy screen; a covenant requiring garages to be on the north side of homes in developments mitigates many of these challenges (see Figure 3.5).

[insert development plan/map as Figure 3.5]

Both passive and active solar are viable in almost every region of the United States, though in different magnitudes. These are proven technologies already, and continued falling prices for active systems now make both approaches economically advantageous. Passive solar capture places many more restrictions on design and many more requirements to achieve maximum effectiveness. If these seem sufficiently challenging, or they add resources or cost to the project, it may no longer be imperative to stretch for a pure passive system. This is because solar PV has fallen in price so dramatically as to change the calculus on priorities. For example, dismissing passive approaches in favor of a larger PV system to achieve net zero energy without solar heat gain assist, is likely cost-effective if too many modifications or sacrifices are necessary to shape design for effective passive capture. On the other hand, if the circumstances of the lot and house easily accommodate passive approaches, it can add energy to the overall household portfolio, with little cost or sacrifice. Homeowners want windows for natural light anyway, and if these can be designed primarily on the south side of a true south orientation, then it is well worth adding passive solar. The issue of thermal mass with passive solar is discussed in the energy chapter.

Until recently, thermal solar systems (heating water) offered a stronger economic return to homeowners than active PV systems. However, the combination of falling prices on PV and the complexity and long-term maintenance concerns with thermal solar now firmly favor PV. Rather than heating water directly, solar PV turns the sun’s energy into electricity, which then heats water in a conventional electric water heater. It is now less costly to harness and use the energy of the sun than from fossil fuel-derived energy distributed to American homes through most utility grids, and the gap is predicted to widen still further in the future in favor of renewables (WorldWatch Institute, 2017). In addition to these economic incentives, implementing these more sustainable systems is a critical response to our ecological challenges. Planning for, and designing, both passive and active systems into new home construction would be significant, but it starts with suitable orientation on a site that also protects the solar investments.

Some Americans dream of living in a house tucked into a forest or among tall shade trees; can a sustainable house be managed in that kind of environment? It depends. If the woodsy homeowner is willing to spurn all modern conveniences and the usual amenities of the American residence, such as electricity, water, or energy from fossil fuels, they might come close to achieving operational sustainability, though with no surplus offsets for embodied energy and environmental impact from construction and decommissioning. Trees around the north, east, and west sides of a house are helpful from an energy standpoint, as long as they do not shade a solar PV array, preferably on a south-facing roof pitch. Trees or other organic growth to the north help block the prevailing winter wind, and on east and west sides block solar heat gain when it is unwanted. Trees to the south obviously block the sun from active and passive capture zones, and if solar is the only viable source of renewable onsite energy, a house in the woods could achieve sustainability only by removing trees and other potential shading on the south side.

External design elements for maximum solar capture require a minimally-interrupted roof plane, facing south, and pitched close to local latitude. To achieve optimal (or nearly) solar PV production, the house should be designed beginning with the roof, and from the roof down. As mentioned above, a residence with the long axis on an east-west orientation will naturally and least expensively provide ideal conditions for both active and passive solar capture. Other orientations and lot restrictions can work, but it will require more creative design, as illustrated with the case study house (below). Interior room design and space allocation is important for the passive solar home. It has already been noted that positioning a garage or carport (if necessary) on the north side of the residence helps from both energy and privacy perspectives. Within the conditioned envelope, common living spaces (living, dining, kitchen, etc.) work better on the south side of the house where natural light is most valued from glazing that should be predominantly oriented toward the south. The common spaces also lend better to passive solar capture, and the radiant heat available during late afternoons and evenings in colder months is most valued in these common areas. Most users generally prefer less natural light in bedrooms and bathrooms, and they are better located toward the north side of the building where lower levels of natural light could be achieved from limited (and preferably small) windows facing east and/or west.

Case Study:

The case study house was constructed on a hillside, just west of a ridge running SSW to NNE (see Figure 3.6 below). The natural topography suggested an orientation of the long axis of the house perpendicular to the fall line of the hill (or parallel to the ridge) to avoid higher construction costs with excavation and/or excessive foundation work in any other layout. Remember that for reasons outlined earlier in this chapter, optimal passive solar heat gain, and adequate active solar capture, occurs most naturally when the long axis of a house is oriented east and west; that was unfortunately impractical on the case study lot. To address these challenges, the basic shape and orientation of the roof was designed first, assuming the long axis of the house would run mostly north and south, along the natural contour lines of the hill. This required that the ridge line of the roof needed to span across the short axis of the house rather than what is more commonly done, spanning across the long axis. While this design was more costly to construct, it was an accommodation considered viable in the interest of long-term financial return on solar energy generation, and to achieve operational sustainability. This design also naturally provided a vaulted ceiling in the common living spaces (living, dining, and kitchen), which gives the perception of larger space with a smaller footprint (see Figure 3.7 below). The south facing roof was extended beyond the west exterior wall to add sufficient space for the solar PV array, to provide deeper shading of some west-facing windows, and also to shade an outdoor deck constructed on the SW corner of the house.

[insert Figure 3.6: top-down and topographical map of lot, house, and orientation]

[insert Figure 3.7: image of interior that captures vaulted ceiling and common spaces]

Even though the long axis of the case study house needed to be perpendicular to south for practical lot and building requirements, we still found ways to design for both active and passive solar capture. Due to the steep natural grade (east to west), it made sense to design a lower floor that would be fully below grade on the east side, while fully exposed on the west; often referred to as a walkout basement. Common living spaces were placed on the south side of the house where daytime natural light is most valued from glazing predominantly to the south. The common spaces also lend better to passive solar capture, and the radiant heat available during late afternoons and evenings in colder months is most valued in these common areas. Additionally, shading to block unwanted solar heat gain in the summer and swing seasons was achieved with the roof overhang of the south pitch (for the upper floor), and a deck walkway shading lower floor glass. Most users generally prefer less natural light in bedrooms and bathrooms anyway, and they were located on the north side of the building envelope with fewer and smaller east and west windows. Finally, an unfinished (and unconditioned) garage was placed on the NW corner of the house envelope as a further buffer to the winter wind.

[insert image of southern elevation]

For passive solar heat gain capture and storage, a trombe wall was constructed just inside the building envelope next to large south-facing windows (see figure 3.8). This thick masonry wall was designed to be practical (as a heat sink), functional (as seating), and an aesthetic feature (attractive stone facing). The wall was painted flat black on the south side to maximize absorption of the sun’s energy in winter months. A ducted central air system can be used to distribute passive heat to other rooms in the house by operating the circulation fan. Outside of heating seasons, the large masonry mass continues to act as a heat sink and modulates indoor temperatures, while fully shaded from direct sunlight.

[insert image(s) of trombe wall]

There is an adjacent residential lot to the south, and since there is no control over the type and height of trees on that property that could possibly shade active or passive solar, the case house was placed as far north as possible to reduce potential for conflicts; it was set on the northern setback line. Finally, the natural contour lines on the lot were about 15 degrees from true south. We rotated the orientation of the house from a squared-up position with the lot (and contours) to improve solar capture; this set the long axis of the house, and direction of both passive and active systems, to nine degrees west of true south (189°). The unique nature of weather patterns at the case study location actually provides maximum PV production at 189°; furthermore, setting just west of a hillside ridge to the east, with near maximum distance to the western horizon, meant that more solar energy would be gained by an orientation a little west of true south. The tradeoff is an orientation that is not perfect for passive solar heat gain. Roof overhang geometry for passive solar heat gain and shading were selected for the specific latitude of the case house, and for true south (180°). The decision to orient at 189° emerged later when the foundation was established in line with the site realities after excavation. The result is more unwanted solar heat gain during afternoon hours in two swing season months (September and April). During the swing seasons, days can vary in temperature and insolation, such that some days solar heat gain is welcome and other days it is unwanted. The homeowner uses a temporary cardboard shield to shade the trombe wall when extra solar heat gain is unwelcome (see Figure 3.X).

[insert image of area between south wall and south property/tree line (probably from east)]

Summary and Conclusions:

Unless or until other clean and renewable energies render solar PV obsolete (and nothing like that is foreseen as of 2019), site selection is foundational to designing and building sustainable housing. The site must accommodate unrestricted solar PV capture, which means clear site lines from (ideally) a south-facing roof pitch, of adequate size to mount solar modules to meet 100%+ of annual household energy needs. Furthermore, in cold climates with significant heating loads, passive solar approaches could be added at no extra cost if designed from the outset. Active solar PV is highest priority, and if there are complications or sacrifices necessary in making passive solar work, it can be forgone in favor of a slightly larger PV array. Given the importance of the sun's energy, a typical American home built in a thick forest will not be sustainable, unless clearing on the south side provides clear and direct access of the sun to solar capture zones in or on the house.

Orientation of the house is important as well, and sites that naturally have true south exposure, or allow flexibility to rotate the building within setbacks, will provide a foundation necessary to design for solar capture and sustainable living. Passive solar can complement active systems in the winter when shorter days and fewer hours of sunlight result in lower solar energy production; this often coincides with heavier household energy demands due to heating and greater use of lighting. However, passive solar is not necessary to achieve sustainable housing, whereas active PV is required. The colder the climate, and number of heating days endured, the more it makes sense to design passive solar systems. Even then, an energy modeler will be crucial to ensure that net gains are being achieved from heat transfer into and out of the house through southern glazing.

Builders, architects, and homeowners can all take steps necessary to build a sustainable home through careful site selection, orientation, and design of the building. While that moves the needle toward sustainability on a small scale, large scale impacts will come from developers and zoning policies that encourage, incentivize, or require building lot characteristics that set them out as shovel-ready for active, and possibly passive, solar designs. Layout of access streets and building lots is critical, as is covenants to protect solar investments and privacy with passive designs, such as shading restrictions and north-side window restrictions.

Many community and residential development covenants include orientation requirements that do not allow this level of flexibility. In light of our global sustainability crisis, we suggest advocating for a variance, where necessary, in the interest of maximizing solar (or other renewable) energy. We also advocate petitioning for the following additions to community and development covenants:

1. No windows on north side of houses
2. If garage or carport, position on north side of house
3. Tree (and other structure) height limits to avoid shading solar investments

[insert IMAGE of site from above...possible gis or google earth view?]

Dos and Don’ts:

Dos related to site, orientation and design for solar

1. Identify a building lot that ideally allows the long axis of the home to face true south.
2. Advocate for variances where zoning requirements or community covenants impinge on orientation of building for optimal (or close to maximum) capture of solar energy.
3. Advocate for zoning policies and community covenants that promote and encourage solar energy capture, such as no north windows and height restrictions for trees or other structures that could shade solar capture zones.
4. Consider thermal mass to capture, store, and radiate the sun’s energy in passive designs; this is further analyzed in the energy chapter.
5. If small windows are placed in east and west walls, consider deep overhangs for more effective and controllable shading to minimize unwanted heat.

Don’ts related to site, orientation and design for solar

1. Don’t build a new house on a lot that cannot gain any onsite renewable energy.
2. Don’t be dissuaded from building on a lot that is not ideal for solar capture; design may solve the problem (as in the case study house) or seek variances where necessary.
3. Don’t place windows in north-facing walls, or severely limit northern glazing.

Chapter notes:

NFRC (2017), *What does the NFRC label tell you?: lindow label*, National Fenestration Ratings Council, URL: http://www.nfrc.org/?gclid=CIbRp6vwjdMCFRuBswodkOIP3A

National Geographic (2017), *Solar Energy: Here’s what you need to know about the warming planet, how it’s affecting us, and what’s at stake*, URL: http://environment.nationalgeographic.com/environment/global-warming/solar-power-profile/

National Renewable Energy Laboratories (2017), *PVWatts Calculator*, URL: http://pvwatts.nrel.gov/pvwatts.php

WorldWatch Institute (2017), *Energy Agency Predicts High Prices in Future*, February 8, 2017, URL: http://www.worldwatch.org/node/5936