Passive Solar Design Guidelines for Northern New Mexico

Compiled by Ben Luce for the NMSEA
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History & Acknowledgements: These guidelines are largely based on talks given and materials published by Dr. J. Douglas Balcomb, formerly the head of passive solar research at Los Alamos National Laboratory, currently with the National Renewable Energy Laboratory in Golden, Colorado. Dr. Balcomb is credited with playing a major role establishing the scientific reputation of passive solar design over the past three decades, and developing many analytical tools for passive design. This compilation of guidelines began after Dr. Balcomb lectured on passive solar design in Los Alamos following the Cerro Grande Fire, at the invitation of Ben Luce, and with support from the Waste Technology and Management Division at Los Alamos National Laboratory. NMSEA would also like to thank passive solar specialists Don Neeper, Karlis Viceps, Mark Chalom and Anne Dunning for extensive discussions that influenced this document. Specific information on window ratings was derived from Carmody, Selkowitz, and Heschong, 1996 (see the references). The section on "Variations: Straw Bale and Adobe Construction" is based on discussions with New Mexico designer/builder Tony Perry and architect/builder Mark Chalom, who specialize in these particular approaches, respectively.
Note: The explicit guidelines given below are highlighted in *bold-italic* font for your convenience.

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Overall Cost Balancing

The information in this section was determined in a comprehensive study of cost tradeoffs carried out by Balcomb et al (see Balcomb, 1986, and the references therein). With respect to passive solar design, there are three types of cost that need to be balanced to achieve the minimum overall life-cycle cost:

1. The **initial cost** of conservation - insulation, high quality windows, etc.
2. The **initial cost** of solar - extra window area on the south side, extra masonry inside (for thermal mass), etc.
3. The **long term costs** of heating and cooling over a nominal time scale, say 25 years.

General guidelines for achieving the best balance among these are as follows:

Minimum total life-cycle cost (solar+conservation+heating+cooling) occurs when the initial costs (solar+conservation alone) are approximately $8000-$10,000 for a 1500 square foot house in the climate of Northern New Mexico.

At this minimum, the costs of conservation and solar are roughly equal, say, $4000-$6000 apiece.

If the total initial investment is under $4000, the balance should favor conservation.

Why is there a minimum? The minimum exists because if the initial investment is too small, the long term heating and cooling costs will be unacceptably high, and if the initial investment is too high, the initial investment will itself exceed the long-term savings in heating and cooling costs. *Note, however, that this argument, and the specific numbers quoted above, assume that an unexpectedly drastic increase in fuel costs doesn't occur.* Moreover, although there is a minimum, the overall curve is a fairly flat around the minimum, especially in the direction towards increasing the initial costs. That is, increasing (or slightly decreasing) these initial costs has little impact on increasing the total life-cycle cost. Unfortunately, this flatness is almost always used to justify investing less than the optimal amount initially. This property should be used to argue the following instead:

It is better to over-invest in solar and conservation initially, because some over-investment provides:

- *Better insurance against unexpectedly sharp increases in heating and cooling costs.*
- *Lower environmental impacts*
- *Improved comfort*
- *Improved ability to function during power and/or fuel outages.*
- *Lower life-cycle cost on the very long time scale.*

Right Orientation

The building should be roughly rectangular, with the longest axis running roughly east to west, such that the largest face points roughly towards "true south". In central northern New Mexico, true south is approximately 12.5 degrees east of magnetic south.

The south-facing side can be up to plus or minus 15 degrees true south without incurring a significant penalty to performance.

Large, exposed west-facing walls should especially be avoided.

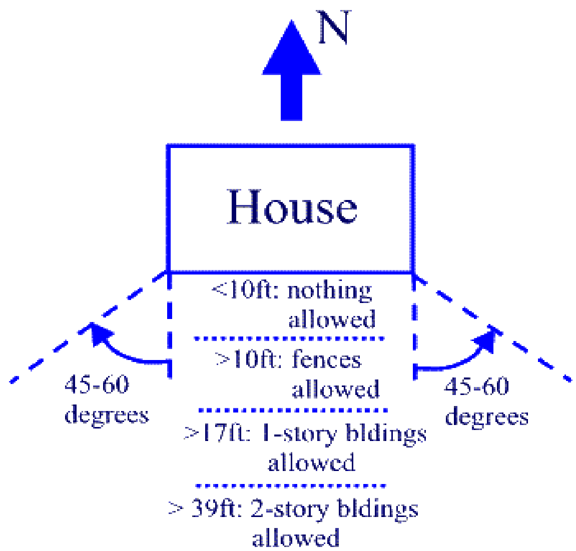
External Obstructions to Solar Gain

The basic goal of winter solar access is to allow unobstructed sunlight on the south side from 9 am to 3 pm in the winter months.

As a general rule of thumb, this means that obstructions, such as trees, other houses, etc, should be absent from within 60 degrees horizontally from due south from both south corners of the house if possible, and minimally from within 45 degrees (see the diagram below). Absence of obstructions means:

- *There should be no obstructions whatsoever with 10 feet of the south side within these angles.*
- *There can be fences outside of 10 feet.*
- *There can be 1-story buildings outside of 17 feet.*
- *There can be 2-story buildings outside of 39 feet.*

The above information on obstructions is summarized by the following diagram:

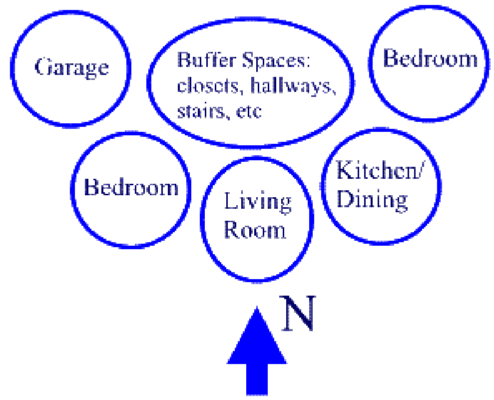


If questions remain about obstructions, suncharts, which show the vertical and horizontal angles of the sun at each month and hour of the year, can be used to verify the absence of obstructions, and also to determine the shading creating be what obstructions remain at various times of the year and day. One simply graphs the outline of the horizon, as seen from the south side of the house, directly on the sunchart. Suncharts can be obtained from many solar energy books and organizations.

Trees: Contrary to a persistent but misguided belief, deciduous trees on the south side should be avoided if at all possible. Deciduous trees on the east and west, however, can be very advantageous. They will tend to allow some additional heating from the east and west into late spring (because they haven't yet fully leafed out), when heat is still needed in substantial amounts but southern solar gain is diminished (peak seasons in Northern New Mexico tend to lag the equinoxes and solstices by about six weeks). Likewise, deciduous trees will keep their leaves well into fall, and so help shade the east and western windows at this time when you don't want heating.

Right Internal Layout

Layout of rooms should take advantage of morning sunlight for the kitchen, and possibly a bedroom, winter sunlight for the living room, and make use of buffer spaces and garages as additional northern and western shielding, as the following diagram suggests:



A sunspace might be added with advantage in front of the living room.

Minimum Levels of Insulation

The following contains specific recommendations regarding insulation for the climate of Northern New Mexico, which is moderately cold, yet sunny. These minimize the life-cycle cost under the assumption of moderate to strongly rising fuel costs. These should be viewed as the minimum values one should use, especially if one is as or more interested in reducing fuel usage for environmental reasons, rather than cost. Values for other areas, and the methodology used to obtain these, can be easily determined using the information in Balcomb, 1986 (see references).
R-Values: (The R factor stands for "Thermal resistance coefficient", and is a measure of how well a material insulates. The higher the R-value, the better the insulation. R-values referenced below have units of square feet-hour-degree Fahrenheit/BTU).

- *Walls: 21*
- *Ceiling : 34* (including air-space of the attic)
- *Perimeter: 15* (Perimeter refers to insulation added below grade to the outside of foundation walls and under the outer 2 ft of a slab, or, if the floor is built over a crawl space, the floor insulation value or at least the perimeter insulation for the stem wall down to the footings)
- *Walls for a heated basement: 16* (down to 4 ft below grade), *8* (from 4 ft down to top of footings). Use these values for bermed walls as well. It is recommended that slab floors of heated basements (only) or the main floor be insulated.

Air Leakage

Leakage area should not exceed but be slightly less than 88 square inches (for a 1500 square foot house), corresponding to a typical rate of about 1/4-1/3 air changes per hour. A more general formula is that the infiltration should be slightly less than about .0065 times the volume of the house in cubic feet.
So-called "blower door" tests, which are offered by various firms and agencies, are highly recommended as a way to measure air infiltration.
These tests should be done after the vapor barrier is installed but *before* sheetrock is installed, so that leaks can be corrected early. Leaks tend to occur along the bottom and top of the vapor barrier. Another common major source of leaks are light fixtures in the ceilings. Sheetrock can be used for vapor seal, but must be done carefully. Pressure generated by thermal stratification ("stack effect") in the air is the dominant factor forcing air leakage (more than wind by far on average) and can drive substantial leakage.

One does not want to get below about 1/4-1/3 air change per hour due to humidity problems (due to human breath, showers, etc), and buildup of toxic chemicals (formaldehyde from new carpets, for example - of course, better to use carpets and other products designed to avoid toxic emissions altogether!).
Sound insulation is a major benefit of minimizing air leakage.

Ducts and Air Flow Strategies

Avoid running ducts above the ceiling insulation.
Running ducts above the ceiling insulation can result in large losses of heat or cool air. Better to run them under the floor or slightly lowered ceiling in some parts of the house.
Or don't use ducts at all! Central air conditioning is not generally needed in the climate of Northern New Mexico, especially in a well designed passive solar home, and wood stoves are often adequate in well designed passive solar homes for supplemental heat. Radiant floor heating (that is, hot water pipes under a masonry floor) is also great way to provide supplemental heat. In addition, these integrate well with active solar hot water, because the floor water delivery temperature is low (around 110 degree Fahrenheit), and therefore compatible with relatively low temperature of solar hot water (150 degrees - which is low relative to capability of a boiler).
In a well designed house, natural convective loops through doorways generally provide adequately for distribution of heat. Special openings, vents, and fans, are therefore not recommended, because, in the words of Doug Balcomb, they are usually just "solving a problem that doesn't exist in the first place".
It should be kept in mind, however, that convective loops will have difficulty heating north rooms without direct solar gain which lie at lower elevations than south rooms (the returning cool air along the floor cannot ascend easily on its way back to the south rooms). Where such a situation is unavoidable, radiant floor systems, for example, work well to supplement the heat in these rooms. Conversely, effective passive solar heating of northern rooms at slightly higher elevations is possible with a well thought out design that allows for convective loops to pass through the room.
Additional airflow information appears under the section on Sunspaces below.

Window Sizing

Recommended Net Glazing (Window) Areas:

Orientation	***Percent of total floor area***
East	*4*
North	*4*
West	*2*
South	*7-12 (depending on whether additional thermal mass is present. See later sections)*

As indicated above, the area of south-glazing depends crucially on the amount of "thermal mass". The term "thermal mass" refers to matter inside the thermal envelope of the home that is capable of storing heat. Thermal mass is very important for a number of reasons: In a passive solar home, it is used to store heat for cold nights. In any house, it can absorb heat during the day, thereby helping to keep the house cool during the day.
The usual sheet-rock, studs, furniture, etc of a house represent a certain baseline amount of thermal mass.
To avoid overheating in a conventional house, i.e. a house without additional thermal mass, direct gain (south-facing windows) should not exceed 7% of floor area.

A house that has 7% direct gain is sometimes called a "sun-tempered" house: solar heat on a clear winter day with 7% direct gain into a sun-tempered house is usually just about adequate to fulfill daytime heating needs.

Even if adequate additional thermal mass is added to the house, for example, by adding internal masonry walls or floors with masonry thicker than an inch, then <u>*direct gain*</u> *(south-facing windows) can be up to but should not exceed* <u>*12%*</u> *of the total floor area. Requirements for "adequate additional thermal mass" is defined below in later sections.*

This limit is imposed mainly to avoid excessive glare and damage to carpets and other items. For those interested in maximum solar savings fractions, however, it may be worthwhile to use more solar gain, both direct and indirect. Also see the sections on Variations: Straw Bale and Adobe Construction and Windows for further situations that merit variations.

If adequate additional thermal mass is added to the house, additional <u>*indirect gain*</u> *(e.g. Trombe walls) may also be added with glazing area up to but not exceeding* <u>*8%*</u> *of the total floor area. Total solar gain area for a house with added thermal mass can therefore be up to but not exceed 20% of total floor area.*

Window Types

Look for windows which bear the standard rating label of the National Fenestration Council: These labels report three numbers which characterize a window's overall performance (that is, the performance of the entire window unit) under standard (and tough) conditions. These values are:

- **U-factor:** Conductivity of the window to heat loss (including conduction losses and *far* infrared, that is, nonsolar, radiation).
- **Solar Heat Gain Coefficient (SHGC):** Transmissivity of the window to the *entire* spectrum of sunlight (both visible and *near* infrared).
- **Visible Transmittance (VT):** Transmissivity of the window to the *visible* part of the spectrum of sunlight (excluding the near infrared part of the solar spectrum).
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Low-E (low emissivity) double-glazed windows should be used for all windows, and the U-value of these windows should be no greater than about .37 BTU/hr-ft^2*-F.*

If it can be obtained, so-called "High Transmission" low-E glazing should be used on the south-facing side. This type of glazing will have a high Solar Heat Gain Coefficient (SHGC) relative to the low U-factor, which should still be kept small.

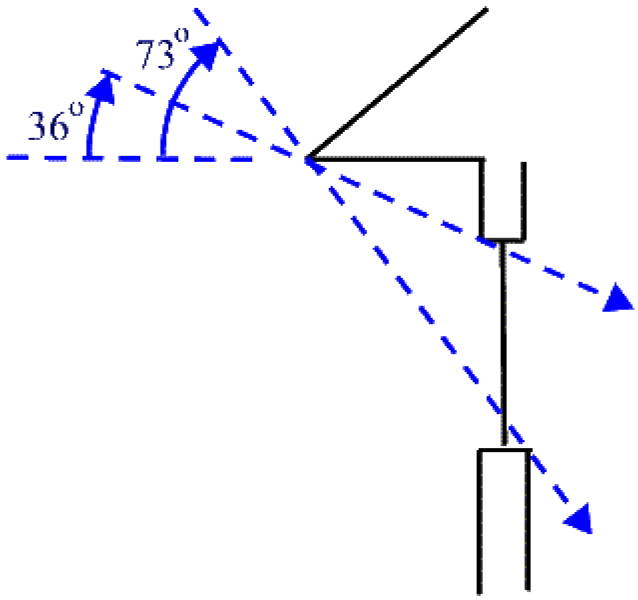
If SHGC < .74 (.74 being the value of SHGC for clear double glazing), the designer may want to consider increasing the area of the south glazing above the percentages given above by a factor of 1+ (.74 - SHGC), to compensate for loss of solar gain by a low value of SHGC. This is especially permissible if VT is also significantly less than .81 (the value for clear double glazing), so that glare and radiation damage will not be unduly increased.

The use of so-called "Selective Transmission" low-E glazing should be considered for non-south glazing, especially if one wants to increase the size of east and west windows above the percentages recommended above (say, also by a factor of 1+ (.74 - SHGC)). This type of glazing has a relatively high Visible Transmission Coefficient, so that views are maintained, yet a relatively small Solar Heat Gain Coefficient - that is, the glazing blocks both the near infrared (the invisible part of sunlight) and the far infrared, yet transmits the visible part of sunlight.

Skylights are fine but should be no more than a few percent of the floor area. Clerestories (south facing preferably), which are vertical windows in the roof, are a better idea. The use of "sunbenders", which are adjustable reflectors that are mounted over skylights to block summer sun and reflect winter sun down into the skylight, can be used to effectively retrofit skylights into clerestories. The use of sunpipes, that is, vertical light-guiding tubes in the ceiling, should also be considered in place of skylights. These often have reasonable insulating effect, yet do a good job of providing and diffusing sunlight.

Window Shading

Overhangs are strongly encouraged for south-facing windows and trombe walls in Northern New Mexico. The following overhang angles were suggested by J. Douglas Balcomb. These angles have been adjusted by five degrees or so for the climate of Northern New Mexico, such that they provide six weeks of full solar gain on either side of the winter solstice (as opposed to just on the winter solstice), and a full six weeks of shade on either side of the summer solstice (as opposed to just on the summer solstice). This adjustment is appropriate for sunny, cold climates. Note that an overhang of these dimensions is located at a significantly higher position above the window and is significantly larger than an overhang which only provide full effect on the solstices.



Right Amount and Placement of Thermal Mass

Thermal mass must be placed inside the thermal envelope to function as heat storage.
The simplest rule of thumb is that thermal mass area should have an area of 6-8 times the (uncovered) surface area of the direct gain glass area.
Thermal mass effectiveness increases proportionally to thickness up to about 4 inches. After that, effectiveness doesn't increase as significantly. So concentrate on getting the surface area, not excessive thickness.
Contrary to common belief, it is not important to have the bulk of the mass in the direct gain path - so don't worry about trying to arrange for this. Rather, strive to have thermal mass in LINE OF SIGHT of sunlit surfaces.
Once light enters the structure, reflection and thermal radiation will transmit energy from the sunlit surfaces to other thermal mass surfaces *which are in line of sight* of the sunlit surfaces. Convection of warmed air will also transfer energy between surfaces to a lesser extent. Floor area, for example, which is not directly sunlit nor in line of site of any other surface which is (for example a wall behind a clerestory) will not function very effectively as thermal mass with respect to sunlit floor area because it is not in line of sight with sunlit floor areas.
Beyond the factor of six rule of thumb above, a more accurate procedure for adding thermal mass beyond the baseline of 7%, that takes into account some of these considerations, is as follows:

- An additional 1.0 ft^2 of direct-gain glazing may be added for every 5.5 ft^2 of uncovered, sunlit mass floor. The maximum floor mass that can be considered as "sunlit" may be estimated as about 1.5 times the south window area.

- An additional 1.0 ft^2 of direct gain glazing may be added for every 40 ft^2 of thermal mass in the floor of the room, but not in the sun.
- An additional 1.0 ft^2 of direct-gain glazing may be added for each 8.3 ft^2 of thermal mass placed in the wall or ceiling of the room in line of sight with the sunlit surfaces. This figure is referenced to a thermal mass density of about 150 lbs per ft^3. The area should be increased to 20 ft^2 for a density of 100 lbs per ft^3, to 20 ft^2 for 75 lbs per ft^3, and to 30 ft^2 for 50 lbs per ft^3.

Note that, as the following rules of thumb imply, it is not advisable to color all thermal mass surfaces darkly.

Right Color of Thermal Mass

- *In general, wall and ceiling thermal mass surfaces should be light-colored, while floors should be dark. Note that making the floor dark helps keep the floor warm and easier to clean.*
- *Sunlit portions of the floor should be dark as well, to help store heat at a low level.*
- *Massive internal partition walls tend to function better than massive exterior walls, since both sides of the wall can participate in heat storage.*
- *If less than half the walls are massive, then the massive walls should be dark colored.*
- *Walls lit by clerestories are best painted white, such that they reflect the light to other thermal mass surfaces, such as the floor. If the wall becomes too hot, a thermal-siphon airflow can be set up that effectively heats the air and overheats the space. Note that this is different from the rule for sunlit floor areas above.*
- *Non-massive walls and other objects as well, should be light colored to maximize reflection of light onto massive surfaces.*
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Indirect Gain (Trombe Walls)

Indirect gain devices, such as trombe walls and water walls, are effective ways of adding additional solar gain, especially for nighttime heating.

Trombe walls (pronounced "Trom") is a south-facing, dark colored, thermal mass wall with glazing, usually built of heavy masonry, but sometimes using water or phase-change materials. Sunlight is absorbed directly into the wall, to be released into the room over a relatively long time (i.e. at night).

Both aesthetically and thermally, Trombe walls work out best if integrated well with south-facing windows. For example, it works well to have windows between trombe walls (for a single room for example), or to have a low lying trombe wall with a window above it, or to have a trombe wall aligned with a partition wall between to rooms with direct gain.

The outside surface of the mass wall should have an absorptance greater than 0.92. To achieve this, as special "selective surface" may be applied. Use of selective surface will increase the efficiency of the wall by approximately 30% in Los Alamos (up to 60% in more northerly climates). The only selective surface source we are currently aware of is: MTI Solar Inc., 220 Churchill Ave. Somerset, NJ 08873. Phone: (732) 246-1000

The selective surface is a copper foil (for high conductivity) with glue on the back, with a chrome coating (for low emissivity at subvisible wavelengths), and a further coating of copper oxide (which is black and provides the high absorptivity at visible wavelengths).

Selective surface should be applied very carefully to achieve 100% adhesian to the mass wall. MTI Solar, listed above, gives some good advice for doing this.

If a selective surface is used, single glazing is adequate for the trombe wall. Without selective surface, double glazing should be used.

The space between the glass and the mass wall should be between 1 and 3 inches. Spacing greater than 3 inches results in excessive thermal convection in the space which reduces the thermal storage.
Trombe walls should not be vented, that is, there should be no openings from the glazed side to the interior.
Although once popular, vented Trombe walls have proven to be ineffective, mostly because they deliver too much heat during the day. Venting probably stems from Felix Trombe's use of vents in his first wall, which needed vents because its was otherwise too thick (two feet!) to allow for adequate thermal conduction. Vents not only don't work well, but they tend to get filled with toys, dust, insects, and other unwanted objects.
Avoid using wood on the outside of the Trombe wall - this is a very intense area and the wood will degrade too quickly.
The Santa Fe company Brother Sun (505-471-5157) sells a framing system called "Sure Seal" that holds trombe wall glazing well while letting the glass expand and contract without losing the seal.
High heat capacity, high conductivity, materials are preferable for mass wall part of the trombe wall. These quantities are usually well correlated with density. In general it is not usually advisable to make the wall much more than 12 inches thick. Recommended thickness of the wall depends somewhat on density according to the following table:

Material	*Density (lb/ft^3)*	*Thickness (inches)*
Concrete	*140*	*8-24*
Concrete Block	*130*	*7-18*
Clay Brick	*120*	*7-16*
Ltwt. Concrete Block	*110*	*6-12*
Adobe	*100*	*6-12*

Sunspaces

Locate sunspaces on the south side. If you have overhead glass, it works well to have glass with a low Solar Heat Gain Coefficient (say, under .6) to prevent overheating in the summer.
The thermal mass should have an area at least 3 times that of the glazing. Note that this is less than the factor of six rule of thumb for thermal mass located inside a house. This is because the temperature in the sunspace is allowed to swing substantially more than the house (typically thirty degrees during the winter).
You don't need to insulate the sunspace from the rest of the house. In fact, you want to encourage a natural convective airflow into the house via natural architectural openings. Having some <u>operable</u> doors and windows provide ideal pathway, both in terms of air flow and people-friendly control. Having a massive, un-insulated wall between the house and the greenhouse will also allow some transfer via conduction.
Having special openings for venting air between the greenhouse and the house is not recommended, simply because doors and windows are adequate.
The total opening between the sunspace and the house should be 15% of the sunspace glazing.

Variations: Straw Bale and Adobe Construction

Straw Bale and adobe construction differ significantly from stick frame construction in several ways with respect to passive solar design. Straw Bale houses tend to have extremely high insulation values (R-values of around 40-50 for the walls), and are sometimes short on thermal mass. Adobe Construction, on the other hand, tends to have extremely large thermal mass, but is usually somewhat short on insulation (a modern adobe wall in New Mexico has a typical R-value of about 15). These represent two ends of a spectrum, where stick-frame construction lies in the middle.

In general, straw bale houses may function best with LESS solar gain than the guidelines above suggest, especially if they are short on thermal mass. This lower solar gain is compensated for by the extremely large insulation of the walls, assuming these insulation levels are truly achieved (e.g. the bales are packed tightly enough, window area is not excessive, and air infiltration is sufficiently controlled).
Adobe houses may function best with significantly MORE solar gain than the guidelines suggest. This greater solar gain is compensated for by the extremely large thermal mass, and the extra energy stored is needed to compensate the typically smaller levels of insulation.
In both cases, it is still useful to have the thermal performance of the house design evaluated, say, with a program such as the Energy-10 software (see below). Straw bale buildings are likely to be especially sensitive to changes in window glazing areas because for straw bale the greatest losses of heat at night will occur through the windows. Moreover, if thermal mass is low, it will be easy to overheat the house with too much solar gain.

Construction Details Resource

A good resource for construction details is the Energy Efficient Building Association (EEBA) Builder's Guide. Call 952-881-1098, or see www.eeba.org. The guide is $45+shipping & handling. The correct book for Northern New Mexico is the "Cold Climate" version.
For example, the guides have good information on how to prevent insulation/infiltration leaks in the floor/wall interfaces. There are many very useful detailed diagrams in these guides as well.

The Design Process

First, a rough set of specifications should be worked out, prior to a specific floor plan is drawn. These specifications should be cross-checked with some sort of calculation method, such as the solar load ratio method, which is a simplified method based on known correlations between solar gain, thermal load, and solar savings, or with a simulation tool, for example, with the Energy-10 software or something similar, and adjusted appropriately.
Energy-10, which was developed by J. Douglas Balcomb and others at the National Renewable Energy Laboratory, can be obtained from the Sustainable Buildings Industry Council. The SBIC website is http://www.sbicouncil.org/home/index.html.
These specifications are then given to the architect, who draws a floor plan in accordance with the specifications.
After the floor plan has gelled, a final, and preferably more detailed analysis, should be performed to confirm final design decisions.

References

- Balcomb J. D., 1986, Conservation and Solar Guidelines, Passive Solar Journal, 3(3), 221-248.
- Carmody, Selkowitz, and Heschong, 1996, Residential Windows, A Guide to New Technologies and Energy Performance, Norton, ISBN 0-393-73004-2 (paperback).