Equinox House Project

Topic 2 Equinox Angles

Ty Newell – January 27, 2010

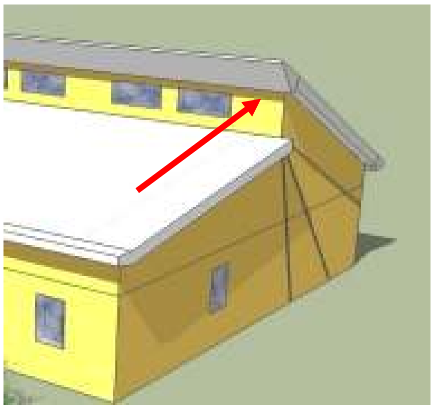
So why name our home the Equinox House? Over the past hundred years, engineering development of building conditioning systems and building lighting systems have resulted in architectural designs that are often oblivious to the seasonal rhythms of nature and the path of the sun throughout the day and year. Unfortunately, this lack of knowledge and indifference to the architectural design's impact on building energy has resulted in the building sector being the largest energy sink of our nation (40%). And this is especially upsetting given that building energy could be a small fraction of its current value. Until building design fees incorporate an energy performance factor, the incentive to reach high performance levels in buildings will not occur.

Our house is named "Equinox" because of the importance of the vernal equinox (~March 21) and autumnal equinox (~September 22) to the comfort conditioning and daylighting of the house. The equinox days are the time of year when we have 12 hours of daylight and 12 hours of "night". For central Illinois, and many other regions in central US latitudes with cold winters and hot summers, the equinox is the time of year when windows should be switched "on" or "off" in terms of allowing "direct" solar radiation from the sun to enter windows. "Direct" solar radiation, also commonly referred to as "beam" solar radiation is the radiation that comes directly from the sun's view on clear sky days. On a clear day, approximately 85% of solar radiation is beam radiation. The other two solar radiation components are "diffuse" or "sky" radiation that is from scattered sunlight in the sky, and ground reflected radiation. On a clear day, diffuse radiation makes up most of the remainder of the radiation (approximately 10 to 15%), and the ground reflected radiation, depending on the ground cover's reflectance and the surface orientation (a horizontal surface can't "see" the ground), is the remainder.

Vegetation can effectively screen a house and provide a nice wind and privacy shield, however, the ability to always have vegetation that appropriately provides shading when desired is difficult. Observe the relationship between buildings and surrounding trees in your community. Are the windows allowing sunlight in during the winter? Is direct sunlight being excluded from the windows during the summer? Even with tall trees in close proximity, it is difficult to ensure shading when needed. On a summer day, an unshaded window can be equivalent to having a 1000 watt heater in a room. Window technology has significantly improved insulation value, solar heat gain and visible light transmission, however one must still carefully assess windows in order achieve the best energy and economic performances.

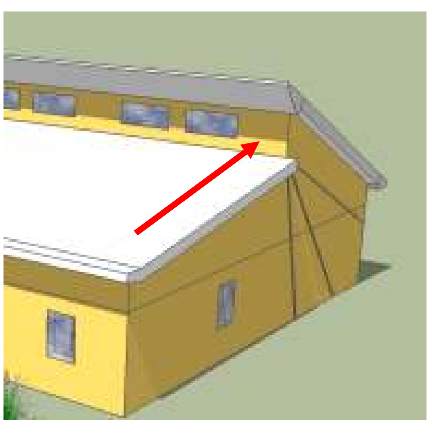
Designing a building such that it inherently shades itself when desired makes sense. It provides an architect with a challenge. The required design tools for determining the energy impact of windows and window shading are readily available. Remember, any building design project you are involved in impacts several future generations. Take the time to make good decisions. Make sure at least as much time is spent on building geometry and orientation as on picking granite for a countertop.

So, let's see how Equinox House is oriented relative to the sun and how we let the sun in when we want, and how we exclude it when it negatively impacts the house energy. The figure at the top of this note shows the Equinox House near noon on the equinox (either spring or fall). The figure below shows an enlarged view of the house. The red arrow is pointing at the edge of the overhang's shading of the clerestory windows. This shade edge stays relatively constant throughout the day (think of the earth's orbital plane as being a slice through the house for any given day).



Clerestory shading on March 21 (and September 22)

The figure below shows the Equinox House 3 weeks later (April 14). Throughout the day, the overhang above the clerestory windows completely shades the windows. The length and orientation of the upper edge of the overhang determines how many days are required before shade covers the entire window. In our case, in order to avoid overheating the house with solar radiation as we enter the spring, we designed our overhang to switch from fully open to fully shaded within a couple weeks. A bit further north with a bit more cold weather and less solar radiation would be best served with an overhang that doesn't begin covering the window until April or May, and maybe takes longer than a couple weeks for shading. The balance for shading also needs to take into account the type of windows, the number of windows, and the window impact on the overall building load.



Clerestory shading on April 14(and September 1)

Notice in the picture above that the bedroom windows on the south side of Equinox are not shaded by an overhang at this time of year. We have some tricks up our sleeve to take care of this and will discuss that later. Also, notice that the white roof of Equinox enhances the solar radiation passing through the clerestory windows when the sun is low in the winter by reflecting radiation off the white metal roof panels below the clerestory windows, and the underside of the overhang above the clerestories. We expect the radiation to be enhanced by 10 to 20% during this time of year, and will measure it to determine the amount. One of the best papers on diffuse solar reflectors was written by Fred ("Rudy") Rudloff in 1978, a graduate school friend of mine from the University of Utah (the article appeared in Solar Energy, the International Solar Energy Society journal). While the house performance doesn't depend on this reflection factor, any freebies are welcome!

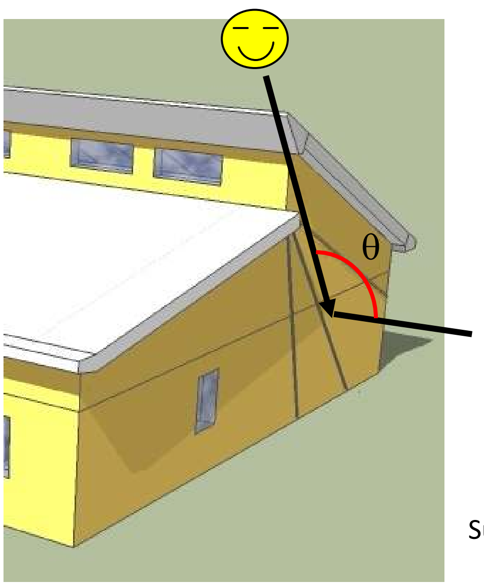
One of the disservices engineers (me) have caused in our efforts to "improve" things has been the development of heating/cooling systems and lighting systems that can handle any kind of condition imposed on a building. This has allowed architects to become indifferent to the position of the sun, the number of windows, and the overall rhythms of nature throughout the day and year. If you examine buildings constructed before 1900, you will not find any rooms that do not have modest daylighting windows in them. Take a look at buildings from the latter half of the 20th century, and you will find many with internal rooms with no windows and others filled with windows. The glass monstrosities that have been glorified and repeated ad nausea exist because my engineering colleagues have allowed architects to design in opposition to nature's energy impact on the structure and the building's internal activities. Pull the plug on electricity in one of these buildings, and the ill comfort and poor lighting of these structures will be immediately apparent.

The two pictures below show what has happened too much in building design. Both pictures are from Madison Wisconsin, one of my favorite places and a place revered by those of us who have been in the solar energy arena for some time. The first picture shows a tensegrity sculpture by Buckminster Fuller in a glass atrium that is a wonderful example of energy inefficient building design (and it's an engineering building on the UW campus, too!). The second picture is some random building with a significant south façade. As Frank Lloyd Wright often commented, any window that needs drapes or shades is a window that is not needed. Madison is the home of some of the earliest, most enduring solar energy research conducted anywhere. The late University of Wisconsin Professor Farrington Daniels book, Direct Use of the Sun's Energy written in 1964, is still one of the best solar primers you will find. The prolific University of Wisconsin Professorial quorumvirate of the late Jack Duffie, Bill Beckman, John Mitchell, and Sandy Klein formed a critical research mass that established the modern basis for solar energy analyses in use today. And so, if bad architectural design can happen in Madison Wisconsin, it happens everywhere.

Bucky tensegrity sculpture at University of Wisconsin in over windowed atrium. The sculpture is wonderful, the atrium is not.

South side of an overglassed building. Based on the shades drawn, 15 percent of the windows used would have been sufficient, resulting in less cost, less energy, and more comfortable occupants.

We'll leave poor architecture and engineering practice alone and end on a positive note. One of the fun features we have designed into Equinox is a sundial incorporated into the east and west sides of the house. A more serious purpose of the sundial is to bring awareness of the sun's relation to the building throughout the day and year. We will install siding on the house later in the spring as the weather improves. Three "rays" will be added to the siding that trace the sun's shadow from the south roof edge along the side of the building. Morning hours will produce a shadow on the east façade and afternoon hours will produce a shadow image on the west façade. One can determine where shadows will fall on a surface by knowing the position of the sun relative to the orientation of a surface. The figure below shows an arrow (ray) from the sun that passes by the south roof panel edge (the low sloped roof) and projects the corner edge's shadow on the east wall. The shadow shown in the figure below is 11:30am on March 21 and September 22. The surface orientation is defined by the black line sticking out from the surface, and the angle between the sunray and the surface define the sun-to-surface relation (called the "incidence angle").

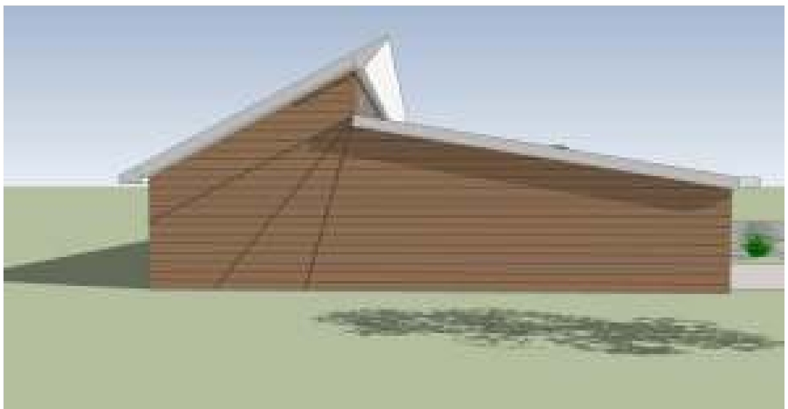


Sunray producing shadow from roof edge on building surface.

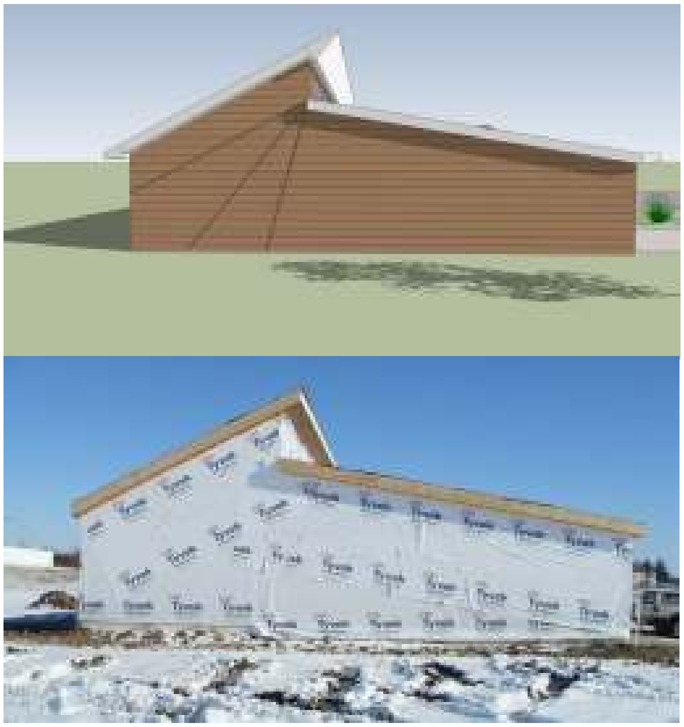
Fortunately, thanks to the magic of Google Sketchup, we can more easily visualize the shadow movement process on the building. As much as I liked sliderules and endless pages of mindnumbing computations when we'd do this in the old days to determine the solar incidence angle, these new analysis tools speed up the process and let you explore many variations and options.

We have three sundial lines that will be installed on the east and west walls. The highest sundial line (lowest angle) represents a line that roof edge shadows will follow on the winter solstice (December 21). The middle sundial line is the equinox line. Roof edge shadows will follow the equinox line on March 21 and September 22. The lowest line with the steepest angle is the summer solstice line (June 21). Roof edge shadows will follow this line in mid-summer. The longest shadow along any line occurs near noon. The shadow length shortens the further the sun position is away from noon.

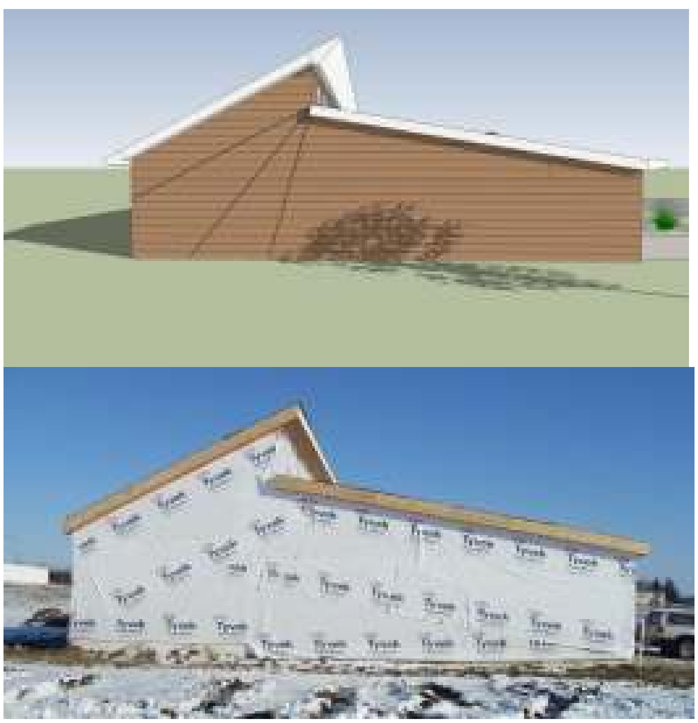
We can check how we did in the design process by taking a look at some recent pictures and comparing them to Google Sketchup renderings for the same year and time of day. A three picture sequence from January 3 just after "solar noon" is shown below. The sun's "noontime" is different from your local noontime because the standard longitude that time is based on is generally different than the longitude of your location, and whether or not daylight savings is enacted. The easiest method for finding solar noon is to check your local newspaper (if it still exists) and finding the local time for sunrise and sunset. Solar noon is the time that is exactly between sunrise and sunset. From the pictures below, the sundial feature works as planned! Notice that the winter solstice ray is parallel to the 6/12 roof pitch of the north roof.



January 3 shadows at 1pm on the west building façade. The upper ray on the siding is the solstice ray representing December 21 shadow paths. January 3 is pretty close to December 21.



January 3 shadows at 1:30pm showing the progression of the shadow edge along the same line as the previous picture.



January 3 shadow at 2:30pm on the west façade of Equinox. The shadow continues following the line, shortening as the sun moves to the west in the latter part of the afternoon.

How about the inside of the house? Where the sunlight travels within the structure is important in order to keep the inside comfortable and free from glare. This is where clerestories and “monitors” can be nice solutions for daylighting a space and providing winter heat. The pictures below show recent photos of the clerestory light on January 9, a sunny, bitter cold (-6F) day. The inside temperature of Equinox, without house doors or garage doors (osb panels screwed over the doorways and house wrap across the garage with a door hole cut in) was 25 to 30F during this time….not bad! The sunspots on the walls from the clerestories have a temperature of 45 to 50F (measured with an infrared thermometer). Each of the sunlit spots are equivalent to a 100 to 200 watt heater for a total of about 800 to 1600 watts, a significant amount of the Equinox House heat requirements on a cold day.

The sunspots move along the upper wall regions throughout the day. In the morning when the sun is in the east, the sunspots are on the west wall. The sunspots travel east along the north wall through the day, and then up the east wall in the afternoon, until finally disappearing at sunset. The first photo taken at 9am shows two of the window sunspots on the west wall with the other four sunspots moving east on the north wall. By 9:20am, one of the west wall sunspots turned the corner and is on the north wall, with only one sunspot left on the west wall moving north. Around 11am, as shown in the third figure, all sunspots are on the north wall traveling east. The movement of the sunspot areas through the day within the large open living area spreads the solar heat within the building. When we discuss thermal characteristics of the house in a future discussion, one of the important characteristics of “storing” heat in the house is surface area. A concentrated “thermal mass”, such as a stone fireplace, often has insufficient surface area for efficiently moving heat into and out of the concentrated mass. It turns out that drywall is one of the most important thermal masses of a well insulated structure.

Ok, so this stuff is quite nerdy, as am I, but let’s not forget the importance of knowing these relations and how our building’s performance is affected by what the sun is doing any time of day and any day of the year. None of these things should be guessed, neglected or ignored when designing an occupied space. Find a nerd to look into this for you!

9:00am clerestory window light

9:20am clerestory window light

11:10am clerestory window light