Passive Solar Heating Development Assessment

Course No: R02-012

Credit: 2 PDH

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PASSIVE SOLAR HEATING DEVELOPMENT ASSESSMENT

This course covers the assessment of potential passive solar heating developments, including a technology history and a detailed description of the computation methods.

Passive Solar Heating History

Passive solar heating (PSH) is the heating of buildings with the solar additions available through windows. The annual heating requirement can be significantly decreased by selecting high-performance windows (low heat loss and high solar transmission) and by orienting the bulk of the window area to face towards the equator (south-facing in the Northern Hemisphere). Researches have shown that houses designed using passive solar techniques can require less than half the heating power of the same houses using windows with random orientation. Passive solar designs can also give a better use of natural daylight for lighting needs; not to mention a pleasant living environment and the adequate selection of shading devices can result in decreased cooling loads.

Generally, the most cost-effective implementation of passive solar designs occurs in new developments since the engineer has the freedom to adapt window orientation and add shading devices at very little extra cost. In a new development the engineer can take advantage of the lower peak heating load to reduce the size of the heating (and possibly cooling) equipment and distribution schemes. Passive solar heating is also cost-effective in retrofits when there are plans to either fix or upgrade the building envelope.

The replacement of made windows with high-performance windows can significantly reduce annual heating requirements.

Passive solar heating is best applied to buildings where the heating requirement is high relative to the cooling requirement. Low-rise residential buildings in moderate to cold climates are the best application. Passive solar heating is more difficult to apply to office and other commercial or industrial buildings where there are high internal heat additions especially during the day. However, even in these commercial or industrial applications passive solar design techniques have been implemented successfully.

Description of Passive Solar Heating Schemes

The primary elements in passive solar heating schemes are windows. Glass has the benefit of adequately transmitting solar radiation, thereby allowing power from the sun to enter the building and warm the interior spaces. Glass is, however, opaque to thermal (or long-wave) radiation, thus heat is not as easily transmitted back outdoors. This phenomenon, known as the "greenhouse effect" is particularly useful for supplying heating power in the winter. Clearly, the bigger the windows, the more sunshine that will enter the building. Unfortunately, windows are not as thermally insulating as the building walls. A passive solar design will optimize window surface area, orientation and thermal characteristics to increase the power input from the sun and minimise heat losses to the outside, while ensuring occupant comfort. Figure 1 shows the floor plan for a house designed with passive solar techniques.

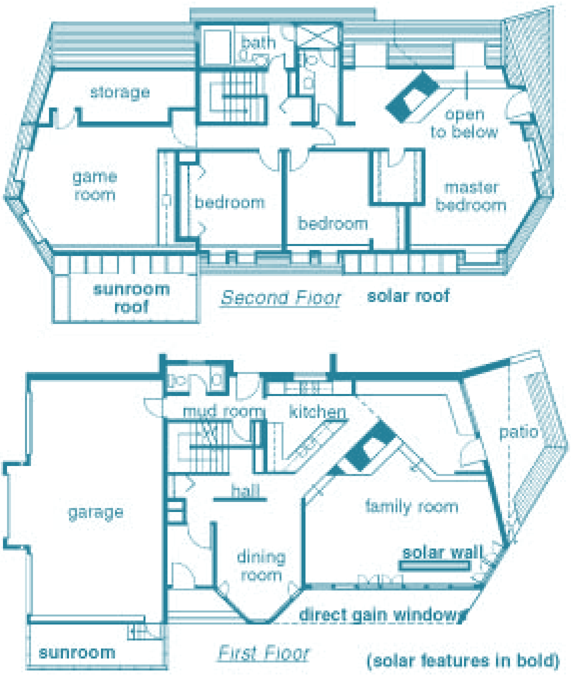

Figure 1. Floor plans for a passive solar house

Sixty percent of the window area is on the south-facing façade. This light mass building has a south-facing window area equal to seven percent of the house floor area. If a bigger window area was applied, extra thermal mass would be required. The windows are triple-glazed with 2 low-e coatings, argon gas fills, and insulating edge spacer in an insulated fibreglass frame. The casement and fixed windows have U-values of 1.11 and 1.05 W/(m^2-°C) and solar heat addition coefficients (SHGC) of 0.38 and 0.45 respectively.

Because the sun shines for only part of the day, its heating power is not always available. A good passive solar design will include some sort of heat storage method. For buildings with modest window area (less than 10% window area to above-grade floor area), traditional North American lightweight development of wood or steel frame walls with gypsum board offers sufficient thermal mass to store solar additions and prevent overheating on cold sunny days. Heavy materials such as stone or concrete can be applied to store heat inside the building during the day releasing it slowly overnight. The thermal mass of the building development is important for passive solar heating schemes with a big window area.

The basic principle of operation of a passive solar design, as compared with a made building design, is depicted in Figure 2.

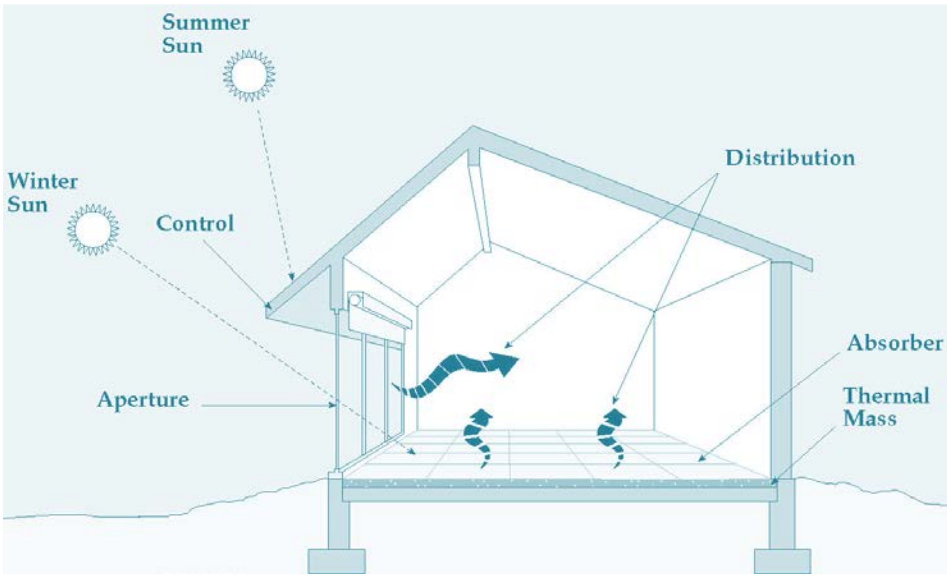

Figure 2. Techniques of operation of passive solar heating

Passive solar heating schemes do have some disadvantages, particularly during the cooling season. The extra heat given by the sun can add to air-conditioning loads or make a building uncomfortably warm in the summer. However, this problem can be alleviated by the use of shading elements. Shading a window from direct sunshine is a good way to reduce the solar additions. There are many ways to shade a window: trees in the surrounding yard, awnings or overhangs overhead, or even drapes or blinds. Good passive solar designs will incorporate shading elements to help ensure occupant comfort and to reduce the summer cooling loads that are generally enhanced by the use of more windows. Another way to help reduce overheating is to minimize the window area on the west side of the building. This passive solar design concept is applied because the building will generally be warmer at the end of the day (e.g. daytime temperatures are normally higher than night-time temperatures, the building has been in the sun all day, etc.) and therefore will likely need less solar power for heating in the afternoon.

In conclusion, passive solar heating calls for the adequate orientation of buildings, adequate location and surface area for windows (most easily implemented in the case of new development), as well as the correct use of power efficient windows, shading and thermal mass to reduce both heating and cooling power requirements. A minimal extra investment in passive solar design techniques (e.g. power efficient windows) can greatly improve the performance of the building envelope with positive financial and environmental benefits.

Passive Solar Heating Modelling

A passive solar heating development model can be applied to evaluate the power production (or savings) and financial performance associated with power efficient window use. The model is intended for low-rise residential applications, even though it can be applied for small commercial buildings, and it applies anywhere in the world where there is a significant heating load. Basically, the model can be applied to check how efficient window use can affect building power use in four ways:

- Enhanced solar heat additions to the building through bigger and better-oriented windows;

- Decreased heat loss through more insulating windows;

- Enhanced or decreased solar additions through the use of adequate glazing; and

- Decreased cooling power requirement due to improved shading.

A passive solar heating scheme can incorporate high-performance windows, modified window areas and orientations, and shading elements.

The computation of solar additions to a building, and the amount of heat lost by conduction is relatively complex. It is dependent upon the solar radiation and outdoor temperature, as well as the thermal characteristics of the window. The most accurate assessment is to compute this heat transfer on an hourly basis based on detailed features of the building. However, hourly data is rarely available for performing a detailed assessment.

The computations provided do not predict the building total heating or cooling power consumption, but rather check the difference in heating and cooling power consumption between the proposed passive solar building and the building without the passive solar design features (referred to as the "base case"). In retrofit situations, the base case building would be the existing building before any passive solar alterations. In a new development, the base case would be a building constructed according to standard practices in that region.

The basic premise of the given computations is as follows: The base case configuration consists of a building with standard windows (e.g. in North America, double-glazed with a wood or vinyl frame) with varying window area in each of the cardinal directions. The proposed case allows for redistribution of the window area in order to collect more incoming solar radiation and allow for an improvement in window characteristics so as to increase solar heat additions and/or reduce conductive heat losses. The comparison is performed in terms of the benefit of a decreased heating requirement and, in cases where a cooling scheme is incorporated, the potential penalty of enhanced cooling requirement.

Simplifying assumptions include calculating heat loss and addition based on monthly mean solar radiation levels and outdoor temperature, as opposed to hour-by-hour data. The utilization (or usefulness) of the solar heat additions in reducing heating requirements is based on a method developed by Barakat and Sander. It is understood that some margin of error will be introduced by simplifying these computations. The net heating and cooling requirements are defined on a monthly basis and summed for the year. The passive solar savings are the difference between the results for the base case and the proposed case buildings. For each month, the net power balance is performed between internal and solar heat additions and conduction losses through the building envelope. The difference between the additions and losses is the net power saved by the passive solar design; a positive variance indicates that the design has contributed to a reduction in the building's power requirement. The model refers to this as alternative power provided even though it may simply represent a reduction in made power use due to more efficient design. A schematic diagram of the power model is displayed in Figure 3.

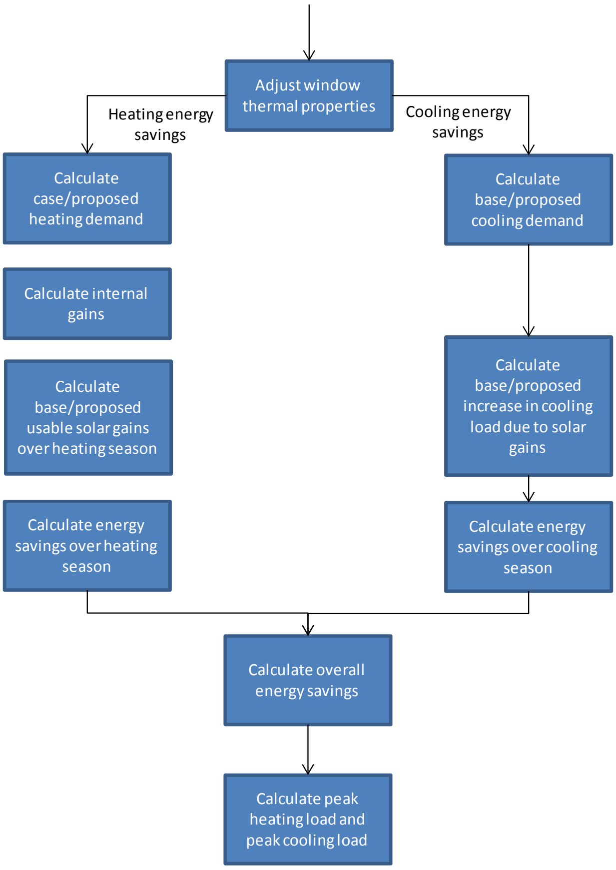

Figure 3. Passive solar heating power computation model

The sections below define how window thermal characteristics are adapted to account for actual window size. Also, computation of heating and cooling power savings is detailed. Finally, the process that sums these contributions to calculate the yearly alternative power provided is given.

The traditional definition of “passive solar heating” usually encompasses both the collection of solar power, for example through windows, and its storage, for example in concrete floors or walls. The given computations deal exclusively with the “window” aspect of passive solar heating. For the majority of applications, this is without consequence. Other limitations of the computations include the fact that:

- The model should only be applied for low-rise residential and small commercial buildings (under 600 m² of floor area) in heating-dominated climates.

- Window distribution is limited to four orientations, with a 90° difference in azimuth (the building can be rotated to face any azimuth angle);

- Shading effects are defined using mean shading factors that are intended to be representative of seasonal mean values. Because shading factors are time-dependent parameters that vary with sun position and time of day, the shading impact should only be viewed as a rough approximation.

These limitations, however, are acceptable at the conceptual design stage to ensure ease-of-use in preparing pre-feasibility researches, especially given the fact that the detailed hourly data for a building is not usually available anyhow.

Adjustment of Window Thermal Characteristics

The first step in the computation process, is to adapt window thermal characteristics for the actual window sizes (not the tested or rated window size) using a method recommended by Baker and Henry (1997).

Dimensions of samples applied to rate windows, with respect to their U-values and solar heat addition coefficients (SHGC), are given in Table 1 for some window types. The SHGC is a dimensionless quantity that is the fraction of the solar power incident on the window that ends up as heat inside the building. In the model it is assumed that all windows of the same orientation have the same SHGC. If there is more than one type of window applied in the building, the individual window SHGC values can be averaged in accordance with their respective window areas.

Window Type	Width (mm)	Height (mm)
Fixed	1,220	1,220
Casement	600	1,220
Sliding	1,550	920
Patio Door	1,830	2,085

Table 1. Standard dimensions of rated windows

To calculate the U-value and SHGC for a window other than the rated size, the following parameters can be applied:

U_t	= Total window U-value from rating process	[W/(m2-°C)]
U_{cg}	= Centre of glass U-value from rating process	[W/(m2-°C)]
$SHGC_t$	= Total window solar heat addition coefficient from rating process	[-]
$SHGC_{cg}$	= Centre of glass solar heat addition coefficient from rating process	[-]
W	= Width of rated product from rating process	[m]
H	= Height of rated product from rating process	[m]

The computation assumes that frame dimensions are fixed, frame solar heat addition coefficient is zero, and edge-of-glass U-value can be approximated from the centre-of-glass and total window U-values. For a rectangular window, the fraction frame, defined as the fraction of total-window area covered by the frame, is given by the simple geometrical relationship:

$$F_{fr} = \frac{(WH)-\left(W-2\overline{H_{fr}}\right)(H-2\overline{H_{fr}})}{(WH)} \quad (1)$$

where $\overline{H_{fr}}$ is the mean frame height. Assuming that the frame does not contribute to the solar addition, the fraction frame is also equal to:

$$F_{fr} = 1 - \frac{SHGC_t}{SHGC_{cg}} \quad (2)$$

Solving (1) for the mean frame height $\overline{H_{fr}}$ gives:

$$\overline{H_{fr}} = \frac{(W+H)-\sqrt{(W+H)^2-4F_{fr}(WH)}}{4} \quad (3)$$

The estimated frame/edge U-value U_{fr}^* is checked by solving:

$$U_t = \frac{U_{cg}A_g+U_{fr}^*A_{fr}}{A_t} \quad (4)$$

where, $A_{t,}$ A_g and A_{fr} are the total, glass and frame areas, respectively, defined from the window width W and height H and from the mean frame height $\overline{H_{fr}}$ through:

$$A_t = (WH) \quad (5)$$

$$A_g = \left(W - 2\,\overline{H_{fr}}\right)\left(H - 2\,\overline{H_{fr}}\right) \quad (6)$$

$$A_{fr} = A_t - A_g \quad (7)$$

Solving Equation (4) leads to:

$$U_{fr}^* = \frac{U_tA_t-U_{cg}A_g}{A_{fr}} \quad (8)$$

Size-specific U-value and solar heat addition coefficient can then be checked from:

$$U_t^* = \frac{U_{cg}A_g^*+U_{fr}^*A_{fr}^*}{A_t^*} \quad (9)$$

$$SHGC_t^* = \frac{SHGC_{cg}A_g^*}{A_t^*} \quad (10)$$

Where U_t^* is the approximate size-specific U-value, $SHGC_t^*$ is the approximate size-specific solar heat addition coefficient, and size-specific areas A_t^*, A_g^* and A_{fr}^* are defined from the actual window dimensions through Equations (5) to (7).

Computations are performed for horizontal-sliding windows and vertical-sliding windows, using different formulas to define the window geometry. Windows can be facing four orientations, with a 90° difference in azimuth (the building can be rotated to face any azimuth angle). For each orientation, values from Equations (9) and (10) are summed to get the global U-value and solar heat addition coefficient for all windows at that orientation:

$$U_n = \frac{\sum_{j=1}^{k} U_{t,j}^{*} A_j}{\sum_{j=1}^{k} A_j} \quad (11)$$

$$SHGC_n = \frac{\sum_{j=1}^{k} SHGC_{t,j}^{*} A_j}{\sum_{j=1}^{k} A_j} \quad (12)$$

where U_n and $SHGC_n$ are the global U-value and solar heat addition coefficient for all windows at orientation n, $U_{t,j}^{*}$ and $SHGC_{t,j}^{*}$ are the total-window U-value and solar heat addition coefficient for the j^{th} window at orientation n, A_j is the area of the j^{th} window at orientation n, and k is the number of windows at orientation n.

Heating Power Savings

Two terms are evaluated each month to check the net heating requirement: heating requirement (gross) and usable solar heat additions. A third term, internal additions, even though part of each monthly evaluation, is assumed constant throughout the year. As noted earlier, computation checks the difference in power consumption between the proposed passive solar building and the same building but without the passive solar features (i.e. the "base case"). The monthly heating requirement and usable solar additions will be different between the base case and proposed buildings because of differences in window characteristics and orientation. The internal heat additions are the same for the two buildings. The following sections define the determination of these three terms.

Monthly heating requirement

The building monthly heating requirement is assumed to vary linearly with outdoor temperature and is based on typical house heat loss coefficients (UA value in W/°C) and indoor heating set point temperature ($T_{set,heat}$ = 21°C). The heating requirement for the base case building for month i, $HL_{base,i}$, showed in Wh, is:

$$HL_{base,i} = UA_{base}\left(T_{set,heat} - T_{avg,i}\right)N_{h,i} \qquad (13)$$

Where $T_{avg,i}$ is the mean outdoor temperature for month i, $N_{h,i}$ is the number of hours in the month, and UA_{base} is the overall heat loss coefficient for the base case building.

The UA value for the base case house is the product of the insulation level and the floor area:

$$UA_{base} = U^{*}A_{floor} \qquad (14)$$

where U^{*} is the insulation level coefficient, and A_{floor} is the total floor area of the building. The value of U^{*} is checked from Table 2, according to a qualitative description of the level of insulation entered by the user.

Insulation Level	$\boldsymbol{U_{wall}}$ $(\boldsymbol{W/m^2-℃})$	$\boldsymbol{U^{*}}$ $(\boldsymbol{W/m^2-℃})$
Low	0.46	3.0
Medium	0.30	2.0
High	0.22	1.0

Table 2. Insulation characteristics of base case building

The proposed building has a slightly different heat loss coefficient because of variations in the size and U-value of the windows. The building heat loss coefficient for the proposed case, is simply:

$$UA_{prop} = UA_{base} - \left[\sum_{n=1}^{4}(U_n - U_{wall})(A_n)\right]_{base} + \left[\sum_{n=1}^{4}(U_n - U_{wall})(A_n)\right]_{prop} \qquad (15)$$

Where U_{wall} is the assumed wall U-value based on insulation level (see Table 2), U_n is the global U-value for all windows at orientation n (see Equation (11)), and A_n is the total window area for orientation n.

Finally, the monthly heating requirement for the proposed case, $HL_{prop,i}$, is evaluated with an equation similar to Equation (13):

$$HL_{prop,i} = UA_{prop}(T_{set,heat} - T_{avg,i})N_{h,i} \qquad (16)$$

where the overall heat loss coefficient UA_{prop} is given by Equation (15).

Monthly internal heat addition

The monthly internal heat addition is the same for both buildings. The daily internal heat addition IG_{daily} is assumed constant throughout the year and is entered by the user. The internal heat addition IG_i for month i is therefore:

$$IG_i = IG_{daily}\, N_{h,i}/24 \qquad (17)$$

where $N_{h,i}$ is the number of hours in the month.

Monthly usable solar additions over the heating season

Solar radiation transmitted into the building through the windows helps offset the heating requirement of the building. However, only some of the solar additions are useful in reducing the heating requirement. This section defines the computation of solar additions and the estimation of the utilization factor determining what part of the solar addition is usable.

Solar additions

The increase in solar heat additions obtained in the proposed case configuration is the sum of two terms: first, the associated increase in solar additions due to higher transmission of short-wave radiation through the glazing, and second, the re-distribution of window area that varies the total amount of solar power captured by the windows due to their orientations. The solar additions for the i^{th} month for the base case $S_{base,i}$, and for the proposed case $S_{prop,i}$, are checked as follows:

$$S_{base,i} = \sum_{n=1}^{4}\left[S_{inc,n,i}\left(1 - D_{base,n,i}\right)SHGC_{base,n}A_{base,n}\right]\, 0.93\, N_{h,i} \qquad (18)$$

$$S_{prop,i} = \sum_{n=1}^{4}\left[S_{inc,n,i}\left(1 - D_{prop,n,i}\right)SHGC_{prop,n}A_{prop,n}\right]\, 0.93\, N_{h,i} \qquad (19)$$

Where $S_{inc,n,i}$ is the total daily solar radiation incident on a vertical surface of orientation n for month i, $D_{n,i}$ is the seasonal shading factor for windows at orientation n for month i, $SHGC_n$ is the global solar heat addition coefficient for all windows of orientation n (see Equation 12), A_n is the global window area for orientation n and is the number of hours in month i. 0.93 is an off-angle incidence correction factor.

The incident solar radiation, $S_{inc,n,i}$, is defined using the methods defined by Duffie and Beckman. The window shading factor ($D_{n,i}$) is selected between two values (both user-defined) according to the season (summer or winter). The seasons are considered six-month periods corresponding to the sun's movement. Regardless of hemisphere, the summer is considered to be the months where the sun is highest in the sky and winter matches to the months where the sun is lowest.

Utilization factor for solar additions during the heating season

The utilization factor, f_i, is defined according to methods originally developed by Barakat and Sander (1982). The factor, which varies by month, is checked from the following equation:

$$f_i = \frac{a+(b\ GLR_i)}{1+(c\ GLR_i)+(d\ GLR_i^2)} \qquad (20)$$

The coefficients (a, b, c and d) are a function of the mass level of building and the acceptable indoor air temperature swing. Values for a 5.5°C temperature swing are applied in the software program (this is likely the maximum swing that could be tolerated in a passive solar house). The variation with mass level is given in Table 3. The mass level is user-defined.

Mass Level	a	b	c	d
Low	1.156	-0.3479	1.117	-0.4476
Medium	1.000	4.8380	4.533	3.6320
High	1.000	0.2792	0.245	0.4230

Table 3. Coefficients applied in utilisation function

The addition load ratio (GLR) is checked as follows:

$$GLR_i = \frac{S_i}{HL_i - IG_i} \qquad (21)$$

Where S_i is the monthly solar addition (Equations 18 and 19), HL_i is the monthly heating load (Equations 13 and 16), and IG_i is the monthly internal addition (Equation 17).

The resulting utilization factor indicates the proportion of the transmitted solar additions that are utilized to offset the heating load. Because the solar additions are likely different between the base case and the proposed case, distinct utilization factors must be computed for each case.

Annual heating power savings

Heating power savings are defined for each month as the difference between the power required to heat the building in the base case and in the proposed case:

$$\Delta q_{heat,i} = \left(HL_{base,i} - IG_i - f_{base,i}S_{base,i}\right)^+ - \left(HL_{prop,i} - IG_i - f_{prop,i}S_{prop,i}\right)^+ \tag{22}$$

The + exponent means that if either value within the parenthesis is negative, the value within the parenthesis becomes zero, because if internal and solar additions are greater than the requirement then there is no need for heating. The various amounts appearing in Equation (22) were deducted in Eormulas (13) and (16) to (20).

The power savings over the heating season, Δq_{heat}, are the sum of the monthly power savings:

$$\Delta q_{heat} = \sum_{i=1}^{12} \left[\left(HL_{base,i} - IG_i - f_{base,i}S_{base,i}\right)^+ - \left(HL_{prop,i} - IG_i - f_{prop,i}S_{prop,i}\right)^+\right] \tag{23}$$

Cooling Power Savings

One of the trade-offs associated with enhanced solar additions is the extra heat that may contribute to cooling power requirement in the summer months. To check annual power savings, the detrimental effects of enhanced solar heat addition must be assessed. For heating-dominated climates, the conductive heat addition through windows in the summer is very small relative to the solar additions and can be ignored Therefore the extra cooling requirement is checked only from the enhanced solar addition.

Even though the utilization function was developed for heating, it can be extended to get a modified utilisation factor, $(1 - f_i')$, that redelivers the monthly proportion of non-usable, or undesirable solar additions received during the cooling season. If the heating and cooling thermostat settings were set at the same temperature, the building would always be in either heating or cooling mode (with no fluctuation in building air temperature). In this scenario, solar additions would either be useful in reducing the heating requirement or contribute to overheating and a cooling requirement. Thus, the contribution to the cooling requirement would be one minus the utilization factor.

However, the heating and cooling thermostat settings are not same. There is a dead band, i.e. a range of temperatures where neither cooling nor heating is required. The modified utilization factor therefore has to be defined with the cooling, rather than heating, set point temperature.

The concept of heating and cooling utilization factors is depicted by example in Figure 4. The lower curve redelivers the utilization factor for heating, for a climate in the Northern Hemisphere. During the winter months the heating utilization approaches 100%, meaning that almost all solar additions are useful towards reducing the heating power requirement. During the summer, this value tapers down to 0% as the need for heating is eliminated.

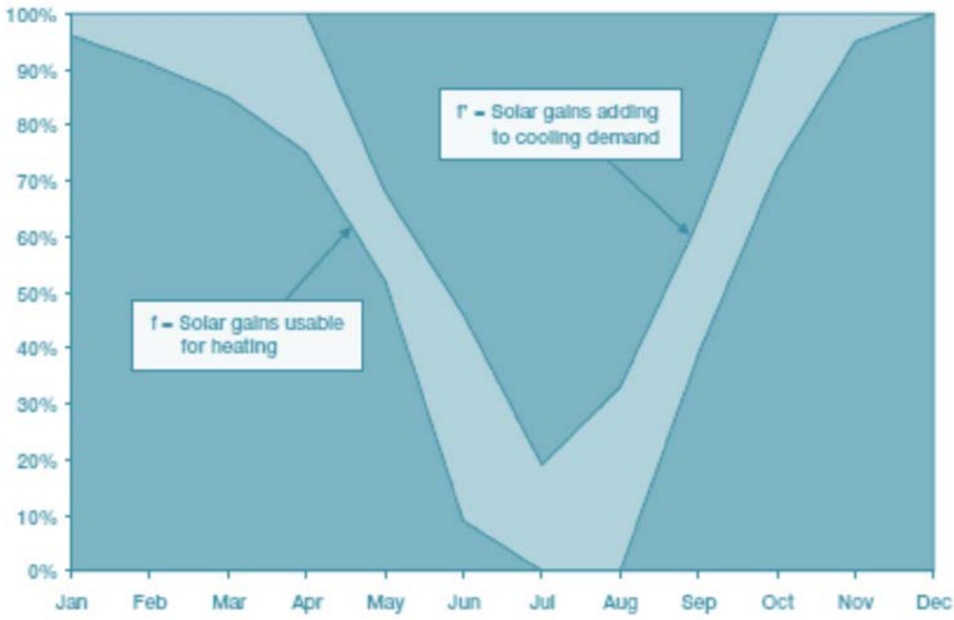

Figure 4. Example of heating and cooling utilization factors

During the winter months the utilization factor for cooling, f', is 100% meaning that the contribution of solar additions to the cooling requirement, $(1 - f_i')$, is 0%. As the cooling utilization factor drops in the summer, its conjugate increases, approaching 100%. Thus in the summer, almost all solar additions are detrimental to the cooling requirement.

The space between the two curves redelivers the dead band. The model ignores the percentage of solar additions that neither reduce the heating requirement nor increase the cooling requirement, as they do not contribute to power savings.

The process followed to calculate the cooling power savings is therefore similar to previous sections, and the power savings over the cooling seasons, Δq_{cool}, are indicated through an equation similar to Equation (23), but with no heating requirement term and with f_i replaced by $(1 - f_i')$:

$$\Delta q_{cool} = \sum_{i=1}^{12}\left[\left(1 - f'_{base,i}\right)S_{base,i} - (1 - f'_{prop,i})S_{prop,i}\right] \quad (24)$$

The modified utilization factor, f_i', is defined through Equation (20). However, the addition load ratio GLR appearing in that equation has to use the heating requirement defined using the cooling set point temperature $T_{set,cool}$ rather than the heating set point temperature $T_{set,heat}$. Equations (13) and (16) are therefore replaced with:

$$HL_{base,i} = UA_{base}(T_{set,cool} - T_{avg,i})N_{h,i} \quad (25)$$

$$HL_{prop,i} = UA_{prop}(T_{set,cool} - T_{avg,i})N_{h,i} \quad (26)$$

In the equivalent models, the cooling set point temperature is set to $T_{set,cool} = 25°C$. As before, because of the differences between cases, separate modified utilization factors are needed for both the proposed case and the base case.

Annual Power Savings

Annual power savings, referred to in the model as alternative power provided, Δq_{del}, are obtained by summing the heating and cooling power savings (Equations 23 & 24):

$$\Delta q_{del} = \Delta q_{heat} + \Delta q_{cool} \quad (27)$$

Finally, the model also calculates the peak heating or cooling load (power) reductions, which indicate to the user opportunities to reduce the capacity of the made heating scheme or that of the air-conditioning scheme. Peak heating load reduction ΔP_{heat} is defined using the following equation:

$$\Delta P_{heat} = (UA_{base} - UA_{prop})(T_{set,heat} - T_{des,heat}) \quad (28)$$

Where UA_{base} and UA_{prop} were defined through Equations (14) and (15), $T_{set,heat}$ is the heating set point temperature (21°C), $T_{des,heat}$ is the heating design temperature. The computation of the peak cooling load reduction ΔP_{cool} is only slightly more complicated:

$$\Delta P_{cool} = \left(UA_{base} - UA_{prop}\right)\left(T_{des,cool} - T_{set,cool}\right) + S_{max} \quad (29)$$

Where $T_{des,cool}$ is the design cooling temperature, $T_{set,cool}$ is the cooling set point temperature (25°C), and S_{max} is the maximum solar addition. This latter value is defined assuming that the peak cooling load occurs on a sunny summer day (normal irradiance equal to 1,100 W/m2); solar angles are defined to approximate the values on north, south, east and west facing windows.

Checklist for Good Design

1. Building orientation: A number of innovative techniques can be applied for getting good solar access on less-than-ideal sites. No matter what the house's design, and no matter what the site, some alternatives for orientation will be more power-efficient than others, and even a very simple review of the site will probably help you choose the best option available.

2. Upgraded levels of insulation: It is possible, of course, to achieve very high power-efficiency with a "super-insulated" design. But in many cases, one advantage of passive solar design is that power-efficiency can be achieved with more modest increases in insulation. On the other hand, if very high power performance is a priority;

for example, in areas where the cost of fuel is high, the most cost-effective way to achieve it is generally through a combination of high levels of insulation and passive solar features.

3. Decreased air infiltration: Air tightness is not only critical to power performance, but it also makes the house more comfortable. Indoor air quality is an important issue, and too complex for a complete discussion here, but in general, the sun tempered and passive solar houses built according to the guidelines provide an alternative approach to achieving improved power efficiency without requiring air quality controls, such as air to air heat exchangers, which would be needed if the house were made extremely airtight.

4. Adequate window sizing and location: Even if the total amount of glazing is not changed, rearranging the location alone can usually lead to significant power savings at little or no added cost. Some power-conserving designs minimize window area on all sides of the house, although it's a fact of human nature that people like windows, and windows can be power producers if located correctly.

5. Selection of glazing: Low-emissivity (low-e) glazing types went from revolutionary to commonplace in a very short time, and they can be highly power-efficient choices. But the range of glazing possibilities is broader than that, and the choice will have a significant impact on power performance. Using different types of glazing for windows with different orientations is worth considering for maximum power performance, for example, using heat-rejecting glazing on west windows, high R-value glazing for north and east windows, and clear double-glazing on solar glazing.

6. Adequate shading of windows: If windows are not adequately shaded in thesummer, either with shading devices or by high-performance glazing with a low shading coefficient, the air conditioner will have to work overtime and the power savings of the winter may be cancelled out. Even more important, unwanted solar addition is uncomfortable.

7. Interior design for easy air distribution: If the rooms in the house are planned carefully, the flow of heat in the winter will make the passive solar features more

effective, and the air movement will also enhance ventilation and comfort during the summer. Usually this means the kind of open floor plan which is highly marketable in most areas. Planning the rooms with attention to use patterns and power needs can save power in other ways too, for instance, using less-lived-in areas (like storage rooms) as buffers on the north side.

8. Addition of thermal mass: Adding effective thermal mass, for example, tiled or paved concrete slab, masonry walls, brick fireplaces, tile floors, etc, can greatly improve the comfort in the house, holding heat better in winter and keeping rooms cooler in summer. In a passive solar scheme, of course, adequately sized and properly located thermal mass is essential.

9. Selection and sizing of mechanical schemes, and selection of power-efficient appliances: High-performance heating, cooling and hot water schemes are extremely power-efficient, and almost always a good investment. Mechanical equipment should have at least a 0.80 Annual Fuel Utilization Efficiency (AFUE). Well-insulated passive solar homes will have much lower power loads than made homes, and should be sized accordingly. Oversized schemes will cost more and reduce the house's performance.

Summary

The provided mathematical model calculates variances in heating requirement and solar additions that result from the adoption of power efficient window technologies. Variances in heating requirement between the base case and the new proposed design are defined by evaluating the variation in the heat loss coefficient related to the proposed variances in the size and U-value of the windows. Variances in solar addition are evaluated by calculating solar additions in both the base and the proposed design, and estimating what part of the solar addition is usable for heating needs. The same methodology is applied to calculate the associated penalty in the cooling requirement during the summer months.

Despite of the simplifications introduced, the predictions of the passive solar heating development formulas prove adequate at the pre-feasibility stage.

References:

Clean Power Development Assessment RETScreen® Engineering & Cases Textbook, Third Edition, © Minister of Natural Resources Canada 2001-2005, September 2005