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INCREASE ENERGY EFFICIENCY AND COMFORT IN HOMES BY INCORPORATING PASSIVE SOLAR DESIGN FEATURES

BY

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Abstract. Sunlight admitted into a building impacts on the building energy consumption in different ways in different seasons. In summer, excessive solar heat gain results in greater energy consumption due to the increased cooling load requirement. In winter, sunlight reaching the south-facing façade can provide passive solar heating. In all seasons of the year the sun improves daylight quality. Well-designed shading devices can significantly reduce the building peak cooling load and corresponding energy consumption and enhance daylight utilization in buildings. Studies of the impact of shading on annual energy use have demonstrated that shading devices reduce the cooling demand in buildings. Shading has been always recommended for solar control and reduction of heat gain in buildings. There are both interior and exterior shade options which can be used to protect windows not otherwise shaded from the sun. In general it is best to block the sun before it reaches the window. The variety of shading strategies shown in this paper is effective at accomplishing that goal.

Key words: passive solar shading; solar control in buildings; shading of the building; passive solar design features; shading of glass.

1. Introduction

Passive design is the key to sustainable building, it responds to local climate and site conditions to maximize building users' comfort and health while minimizing energy use.

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The key elements of passive design are: building location and orientation on the site, building layout, window design, insulation, thermal mass, shading and ventilation. Each of these elements works with the others to achieve comfortable temperatures and good indoor air quality.

The first step is to achieve the right amount of solar access, enough to provide warmth during cooler months but prevent overheating in summer. This is done through a combination of location and orientation, room layout, window design and shading.

Shading of house and outdoor spaces reduces summer temperatures, improves comfort and saves energy. Effective shading (which can include eaves, window awnings, shutters, pergolas and plantings) can block up to 90% of this heat. However, poorly designed fixed shading can block winter sun. By calculating sun angles and considering climate and house orientation, shading can be used to maximize thermal comfort.

2. Orientation for Passive Heating and Cooling

Selecting a site is the first and perhaps most important step in the passive design process. If a site is not suitable for passive design, some elements of the passive design ethos may not work in favour of efficiency and comfort.

For maximum solar gain (on northern hemisphere), a building will be located, oriented and designed to maximize window area facing south, or within 20 degrees of South (Fig. 1), a shallow East-West floor plan. However, this will depend on the site's shape, orientation and topography. Orientation for solar gain will also depend on other factors such as proximity to neighbouring buildings and trees that shade the site.

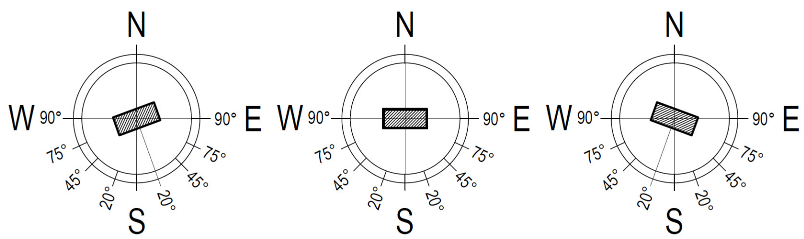

Fig. 1 – Ideal site orientation.

Orientation, location and layout should be considered from the beginning of the design process, ideally, from the time the site is being selected. Once a building has been completed, it is impractical and expensive to reorient later. If optimal orientation can be achieved, it will reduce some of the heating requirement, reduce energy costs and reduce greenhouse gas emissions.

3. Shading of Building

Shading is a simple method to block the sun before it can get into the building. The primary source of heat buildup is sunlight absorbed by the building through the roof, walls, and windows. Secondary sources are heat-generating appliances in the building and air leakage. Shading minimizes the incident solar radiation and cools the building effectively and hence dramatically affects building energy performance. Shading can reduce the peak-cooling load in buildings, thus reducing the size of the air conditioning equipment that will run fewer hours and consume less energy. Energy savings can range anywhere from 10%…40% (Maleki, 2011).

Shading provides for the interception of direct solar radiation before it strikes building openings and heat absorbing materials. Interception techniques range from trees and roof overhangs to lightweight ventilated shading panels attached to walls and roofs (Kamal, 2012). Exterior shading devices are the most effective for creating tempered connections and transitions for indoor/outdoor spaces.

3.1. The Position of the Sun in the Sky (Northern Hemisphere)

The position of the Sun in the sky relative to an observer on Earth is defined by its altitude angle, α (solar elevation angle) and its azimuth angle, Ψ (Fig. 2).

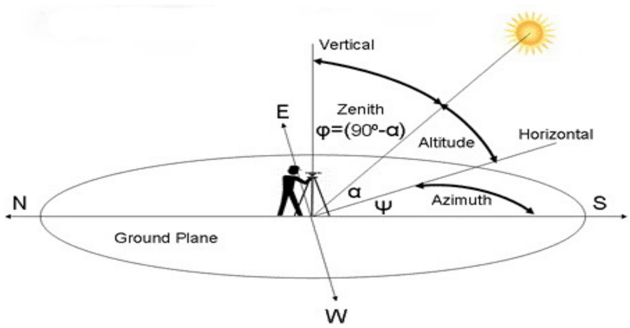

Fig. 2 – Azimuth and altitude for northern latitudes.

In the temperate latitudes of the northern hemisphere, the sun tracks an arc across the horizon as follows:

a) Winter: the sun rises south of due east and sets south of due west. Azimuth angles of ±70° are shown for sunrise and sunset (Fig. 3). The azimuth angle changes on a daily basis.

b) Summer: the sun rises North of due East, crosses to the south of the East-West line during the day as it rises, then crosses back to the North side of the East-West line as it sets and then sets North of due West. Azimuth angles of ±110° are shown for sunrise and sunset (Fig. 4). The azimuth angle changes on a daily basis.

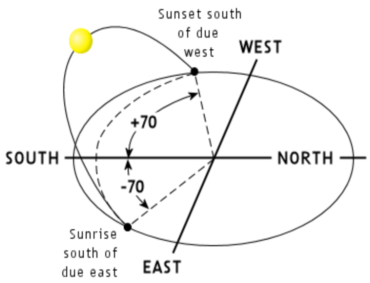

Fig. 3 – The sun tracks in the temperate latitudes of the northern hemisphere, in winter.

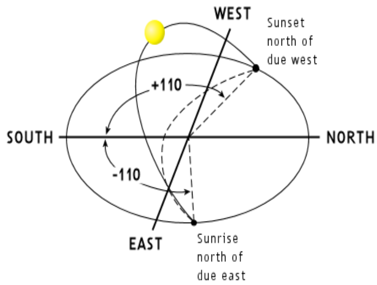

Fig. 4 – The sun tracks in the temperate latitudes of the northern hemisphere, in summer.

The sun reaches its highest point in the sky when it is due south. This is solar noon. In the temperate region of the northern hemisphere, the sun position will always be South of the East-West line. For this reason, the baseline position for measuring the movement of the sun from the East to the West is established by an observer looking due South. The angle that the observer needs to turn to look directly at the sun is the azimuth. Before solar noon (in the morning), the observer needs to turn left. This is defined to be the negative direction of the azimuth. After solar noon (in the afternoon), the observer needs to turn right. This is defined to be the positive direction of azimuth.

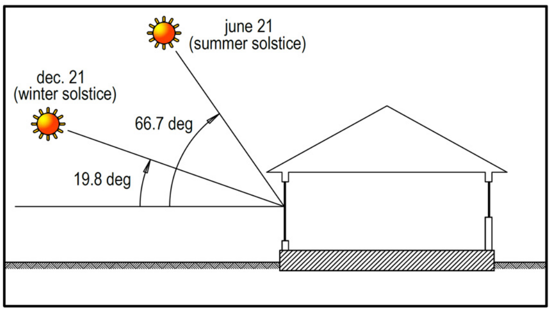

Fig. 5 – Solar altitude over a year (*e.g*. Cluj-Napoca, Roumania).

In mid-latitude countries North of the equator (*e.g*. those of Europe), the sun’s daily trip (as it appears to us) is an arc across the southern sky (of course, it is really the Earth that does the moving). The sun’s greatest height above the horizon occurs at noon, and how high the sun then gets depends on the season of the year; it is the highest in mid-summer, the lowest in mid-winter (Fig. 5).

3.2. Shading by Trees and Vegetation

Proper landscaping can be one of the important factors for energy conservation in buildings. Vegetation and trees in particular, very effectively shade and reduce heat gain. Trees can be used with advantage to shade roof, walls and windows. Shading and evapotranspiration from trees can reduce surrounding air temperatures as much as 5°C (Kamal, 2012). Different types of plants (trees, shrubs, vines) can be selected on the basis of their growth habit (tall, low, dense, light permeable) to provide the desired degree of shading for various window orientations and situations (Kamal, 2012).

Shading with tree reduces ambient temperature near outer wall by 2°C to 2.5°C. On an average a depression of six degree centigrade in room temperature has been observed when solar shading techniques are adopted. The analysis suggested that solar shading is quite useful to development of passive cooling system to maintain indoor room air temperature lower than the conventional building without shade (Kumar *et al*., 2001).

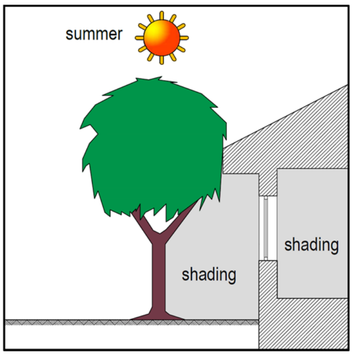

Fig. 6 – Shading by trees in summer.

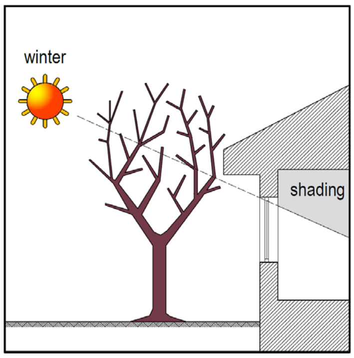

Fig. 7 – Shading by trees in winter.

The following points should be considered (Kamal, 2012):

a) Deciduous trees and shrubs provide summer shade (Fig. 6) yet allow winter access (Fig. 7). The best locations for deciduous trees are on the South and Southwest side of the building. When these trees drop their leaves in the winter, sunlight can reach inside to heat the interiors (Fig. 7).

b) Trees with heavy foliage are very effective in obstructing the sun's rays and casting a dense shadow (Fig. 6). High branching canopy trees can be used to shade the walls, roof and windows.

c) On the West and South sides, evergreen trees afford the best protection from the setting summer sun and cold winter winds.

d) Vertical shading is best for West and East walls and windows in summer, to protect from sun at low angles, *e.g*. screening by trees, dense shrubs, deciduous vines supported on a frame, shrubs used in combination with trees.

e) Shading and insulation for walls can be provided by plants that adhere to the wall (*e.g*. English ivy), or by plants supported by the wall (*e.g*. jasmine).

f) Horizontal shading is best for south-facing windows, *e.g*. deciduous vines (which lose foliage in the winter) such as ornamental grape or wisteria can be grown over a pergola for summer shading.

3.3. Fixed Shading

Fixed shading devices (eaves, pergolas and louvres) can regulate solar access on southern elevations throughout the year, without requiring any user effort. Summer sun from the South is at a high angle and is easily excluded by fixed horizontal devices over openings. Winter sun from the South is at a lower angle and will penetrate beneath correctly designed fixed horizontal devices (Fig. 8). Correctly designed eaves are generally the simplest and least expensive shading method for southern elevations (Fig. 8), and are all that is required on most single storey houses (Babota *et al*., 2013).

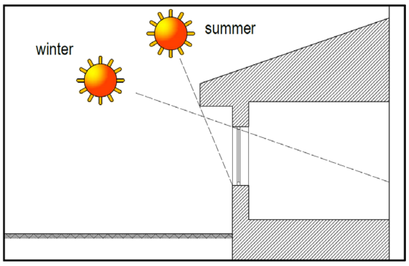

Fig. 8 – Correct eave design.

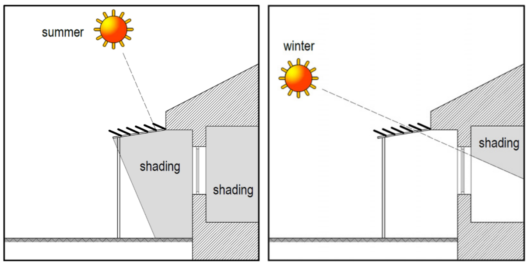

Fig. 9 – Setting louvres to noon mid winter sun angle.

Awnings and pergolas need to extend beyond the width of the South facing opening by the same distance as their outward projection (Fig. 9).

Fixed horizontal louvres set to the noon midwinter sun angle and spaced correctly allow winter heating and summer shading in locations with cooler winters (Fig. 9) (Babota *et al*., 2013). The louvres should be as thin as possible to avoid blocking out the winter sun.

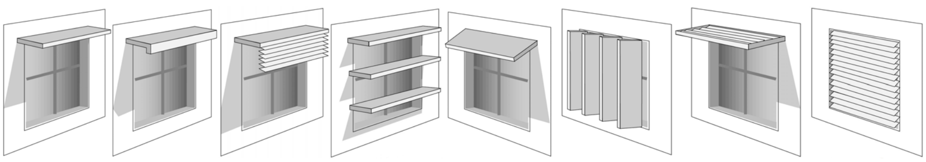

Fig. 10 – Different types of shading devices.

Fixed shading devices (Fig. 10), using correctly sized overhangs or porches, or design the building to be “self-shading” should be installed. Fixed shading devices, which are designed into a building, will shade windows throughout the solar cycle. Permanent sun shades may be built into the building form and they are most effective on the south-facing windows. Awnings that can be extended or removed can also be considered for shading the windows. The depth and position of fixed shading devices must be carefully engineered to allow the sun to penetrate only during predetermined times of the year. In the winter, overhangs allow the low winter sun to enter south-facing windows. In the summer, the overhangs block the higher sun (Babota *et al.*, 2013).

3.4. Adjustable Shading

Adjustable shading allows the user to choose the desired level of shade. Adjustable shading devices can include awning blinds, conventional or roller shutters, adjustable angled slats and removable shade-cloth over pergolas. This is particularly useful in spring and autumn when heating and cooling needs are variable.

4. Software Tools

Shading devices should be integrated to a building's façade at an early design stage. This can be achieved using traditional design tools like solar path diagrams (Figs. 11 and 12), shading masks and special computer programs (*e.g.* Parasol v6.6) that automatically generate the optimum shading device geometry as a function of a set of input parameters (Dubois, 2000).

4.1. Traditional Tools

Although there exist numerous design methods based on solar path diagrams, the Olgyays' (1957) and Mazria's (1979) methods are probably the most popular ones (Dubois, 2000).

In both design methods the building's overheating period is plotted onto the solar path diagram and a shading mask that avoids direct sun during the overheating period is defined. The main difference between the two methods is the kind of solar projection used.

The Olgyays used a projection of the sun onto a horizontal plane parallel to the ground (Fig. 11). Mazria used a projection onto a vertical cylinder (with the long axis perpendicular to the ground). By "unfolding" the cylinder, a two-dimensional diagram is obtained, where the abscissa and ordinate represent the solar azimuths and altitudes and where the curves radiating away from the South represent the solar time (Fig. 12). This projection is advantageous for studies of façade elements like windows and shading devices since the sun's projection is viewed parallel to the building façade (Dubois, 2000).

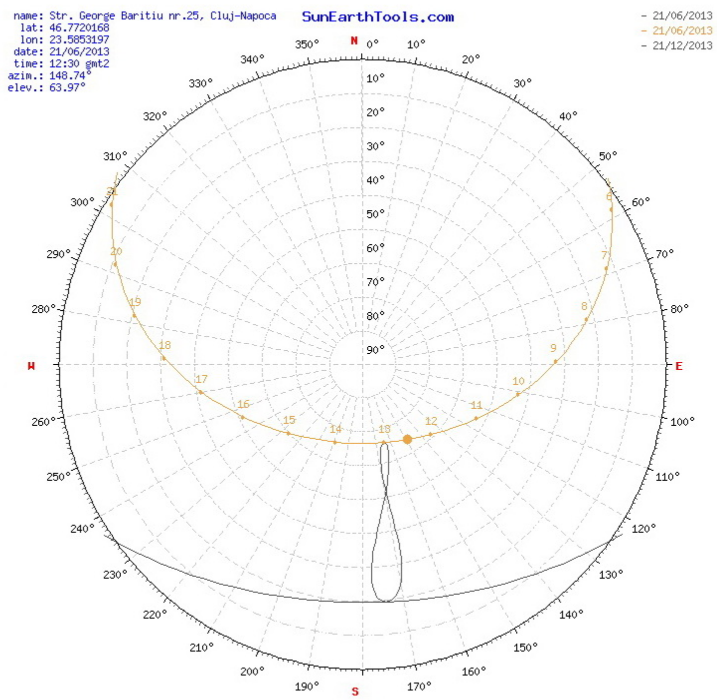

Fig. 11 – Solar path diagram used by the Olgyays.

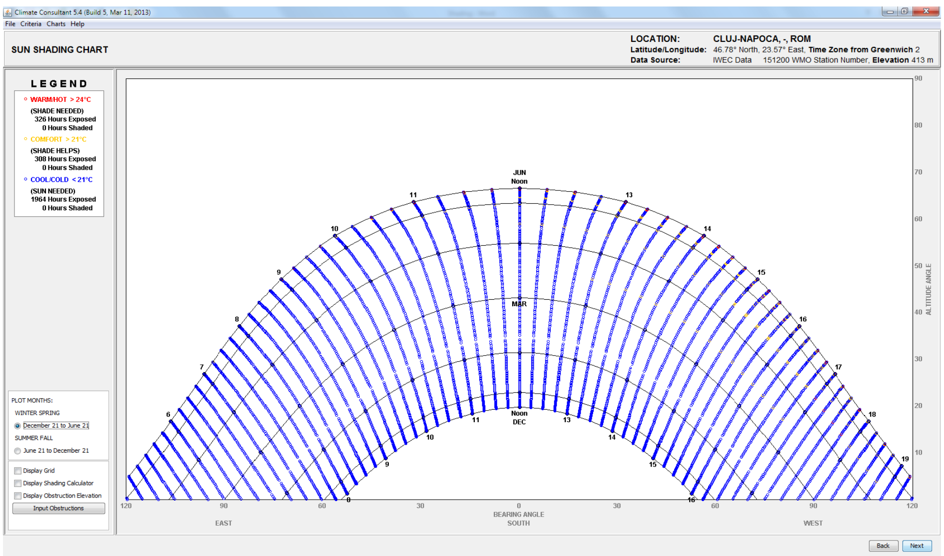

Fig. 12 – Solar path diagram used by Mazria (1979).

4.2. Computer Tools

ParaSol v6.6 is a user-friendly energy simulation tool (Fig. 13) for comparison of energy demand, and peak loads for heating/cooling for different shading devices and glazing.

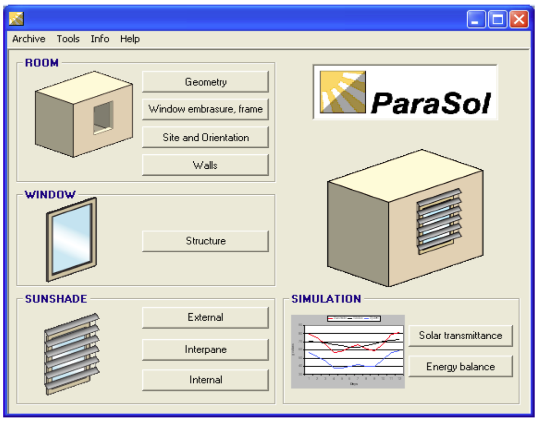

Fig. 13 – Interface of Parasol v6.6.

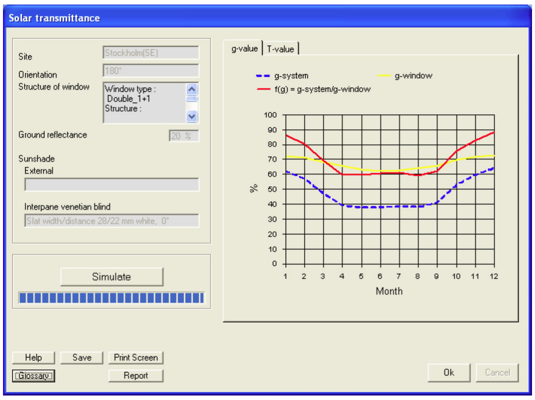

Fig. 14 – Example of simulation of solar transmission.

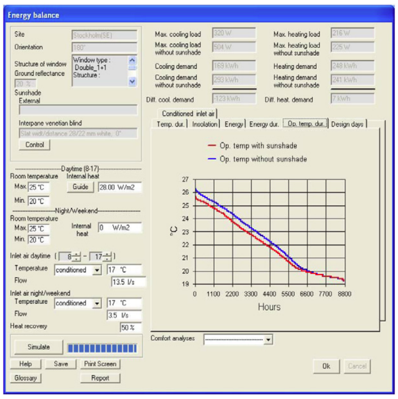

Fig. 15 – Example of simulation of energy balance.

Solar transmission and energy balance are two different kinds of simulation that can be performed with this function. By simulating solar transmission (Fig. 14), the efficiency of the individual sunshade in combination with the window package can be studied, and by simulating the energy balance (Fig. 15), it is possible to study what effects a selected combination of sunshade and window package has on the indoor climate in the room. In both cases it is necessary for the appropriate input data to have been entered in the functions Rooms, Windows and Sunshades.

The simulation of solar transmission calculates the monthly mean values of the indices of effectiveness, *g* and *T*, (total and primary solar energy transmission) for the active combination of sunshade and window package, and the individual window package. The effectiveness of the active sunshade is the quotient *g*-system/*g*-window. The results are presented in different diagrams, but can also be saved to a file for import to other programs.

Examples of performance indices are solar radiation, maximum demand for heating and cooling, monthly and annual heating and cooling demand, and load duration curve for air temperature and operative temperature in the room.

5. Conclusions

The use of solar energy is an important part of energy efficient strategies. Solar radiation entering through transparent building components, such as windows and glazed areas, provides an important contribution to heating, but can also give rise to excessive temperatures or large cooling demands. Solar shading affects energy use in a building by reducing solar gains and by modifying thermal losses through windows. Shading devices also influence daylighting levels in a room and the view to the exterior.

Shading is thus closely connected with energy use in buildings for heating, cooling and lighting and with the occupants' visual and thermal comfort. Both energy use and comfort are crucial issues.

With the software tool ParaSol v6.6, it is possible to estimate the effective *g*-value of shading devices for various orientations in combination with an arbitrary glazing system. Further, effects on heating and cooling (both peak loads and annual energy demands) and operative temperatures of the room can also be simulated.

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* * * http://en.wikipedia.org/wiki/Sun_path
* * * http://www.timeanddate.com
* * * ParaSol v6.6 - software tool

CREŞTEREA EFICIENŢEI ENERGETICE ŞI DE CONFORT ÎN CASE PRIN ÎNCORPORAREA ELEMENTELOR DE DESIGN SOLAR PASIV

(Rezumat)

Este recunoscut impactul pe care-l are lumina soarelui asupra construcţiilor prin consumul energetic al clădirii diferit în funcţie de anotimpuri. În timpul verii, acumularea de căldură solară excesivă determină un consum de energie mai mare, datorită cererii crescute pentru răcire. În timpul iernii, lumina soarelui ajunge la faţada orientată spre Sud şi poate oferi încălzire solară pasivă. În toate anotimpurile anului, soarele îmbunătăţeşte calitatea luminii din timpul zilei. Dispozitivele de umbrire bine concepute pot reduce în mod semnificativ vârful sarcinii de răcire a clădirii şi consumul de energie corespunzător precum şi să mărească utilizarea luminii naturale în clădiri. Studii de impact ale umbririi asupra utilizării anuale de energie au demonstrat că dispozitivele de umbrire reduc necesarul de răcire a clădirilor. Umbrirea a fost întotdeauna recomandată ca o modalitate de control solar şi de reducere a acumularii de căldură în clădiri. Există două opţiuni de umbrire – interioară şi exterioară – care pot fi folosite pentru a proteja ferestrele care nu sunt altfel umbrite de soare. În general, cel mai bine este de a bloca razele de soare înainte de a ajunge la fereastra. Diversele strategii de umbrire prezentate în această lucrare sunt eficiente la realizarea acestui obiectiv.