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Solar Heat Gain Through Glass Walls

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Please note

If the radiant energy from the sun that is constantly falling on the earth's surface had to be bought at ½¢ per kilowatt hour the daily bill would be the staggering sum of $10,000 billion. On a more comprehensible scale, the maximum intensity of solar radiation falling on a square foot of horizontal surface in the temperate latitudes is of the order of 100 watts; for vertical surfaces it is about 75 watts. There is, therefore, a large amount of energy falling on the outer surfaces of every building at certain times of the year - energy that can cause serious performance problems if it has not been fully taken into account by the designer. It is the purpose of this Digest to show the magnitude of the solar heat gain associated with glass areas in the different facades of a building, and to discuss the several ways that it can be reduced.

Intensity of Sunshine

The intensity of the sun's rays that penetrate to the bottom of the atmosphere depends on the clarity of the atmosphere and on the length of their path through it (i.e. the angular elevation of the sun above the horizon). The energy that is incident on a unit area of a particular surface depends upon the intensity of the sun's rays and the angle at which they strike the surface. The maximum intensity for a horizontal surface occurs at noon at the time of the summer solstice for all latitudes outside of the tropics. For example, the maximum insolation on one square foot of horizontal surface is 93 watts at Ottawa (latitude 45°N) and 88 watts at Winnipeg (latitude 50°N). At the winter solstice the corresponding figures for noon on a clear day are 39 watts and 29 watts respectively. (Multiply watts by 3.4 to obtain Btu/hr.)

The radiation that falls on vertical surfaces is, however, often of more importance in building design (because of windows) than the radiation on a horizontal surface. The orientation of a wall is an additional variable. A wall facing south at Ottawa receives a daily maximum of 45 Watts/ft² at noon on June 22nd or thereabouts; but at the equinox the daily maximum has increased to 65 watts/ft²; and the yearly maximum may be as high as 100 watts/ft² in winter if there is snow on the ground to reflect some sunshine onto the wall. East and west facing walls, on the other hand, receive their maximum irradiation in the morning and afternoon, respectively, when the sun's rays are more nearly perpendicular to the wall surface. The annual maximum for east and west facing surfaces at Ottawa is about 75 watts/ft². It occurs at midsummer approximately 4 hours before and after noon respectively (as indicated by a sun-dial). The magnitude of the daily maximum changes very little between midsummer and the equinox, so that the value of 75 Watts/ft² is representative of the daily maximum insolation on east and west facades during the period from April to October.

Transparent Walls

When solar radiation falls on glass and other partially transparent material some of the incident energy is reflected, some is absorbed by the material, and the rest is transmitted to the inside of the building. For ordinary windows the absorption is quite a small fraction and transmission much the largest part. It is not always appreciated, however, that the reflection from the surface of glass varies considerably with the angle of incidence, i.e. the angle between the light rays and a line perpendicular to the surface. Figure 1 shows the variation of the reflection, absorption and transmission of solar radiation by a single sheet of ordinary glass. The noon values of the incident angles for a south wall at Ottawa are shown on Figure 1. They indicate that transmission will have a daily maximum value of 70 per cent of the incident radiation at midsummer and that this will increase to 85 per cent at the equinox and to a maximum of 87 per cent at noon in midwinter.

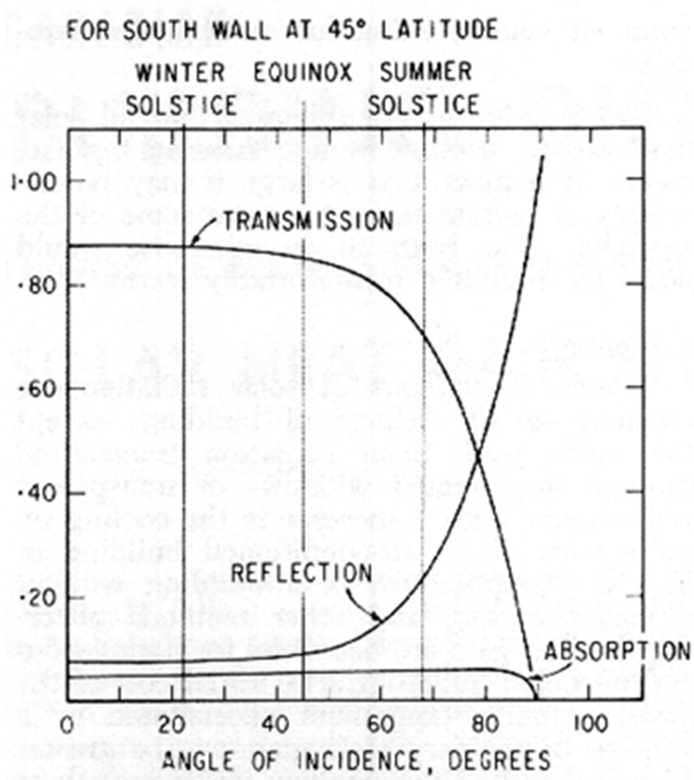

Figure 1. Absorption, reflection and transmission for single sheet of ordinary glass.

It is easy to appreciate why a building designer should take great care to minimize solar heat gain when one considers the cost of the air-conditioning plant needed to remove it. It has been stated that the insolation on east and west facing walls can be 75 Watts/ft² at the daily maximum during the whole period from April to October. The incident angle for these surfaces at the time of peak insolation is less than 40 degrees so that transmission is about 87 per cent for a single sheet of glass. One hundred square feet of ordinary glass in a west facade would, therefore, transmit 6.5 kilowatts to the interior of the building. All this energy must eventually be removed by the ventilating and air-conditioning equipment.

Fortunately all of the transmitted solar radiation does not immediately act to increase the cooling load; some is stored in the floor and internal walls, which absorb the radiation and are warmed by it. The maximum cooling load has been found* to be about 60 per cent of the maximum instantaneous heat gain for a modern multi-storey office building with 80 per cent of the exterior wall made of glass. Thus the maximum cooling load associated with the solar transmission through 100 ft² of ordinary single glazing in a west wall can be taken as 60 per cent of 6.5 kilowatts, i.e. about 4 kilowatts or just over 1 ton of refrigeration.

The cost of an air-conditioning system depends on the type of building and the type of system used, but it usually exceeds $1,000 per ton. This represents about $300 per ton for the central cooling plant with the other $700 for the distribution system. The increase in the cost of a building that can be attributed to the solar heat gain through a window depends, therefore, on whether or not the added heat gain increases the peak cooling load for the building. If it does, the full $1,000 per ton should be charged to the window; other wise, a figure approaching the $700 per ton cost of the distribution system would be more appropriate. If the added light provided will result in a decrease in the use of artificial illumination, however, some credit may be allowed. Thus the initial cost of air-conditioning equipment required to remove solar heat admitted through an east or west facing window may add about $7/ft² of window to the cost of the building. There is in addition an annual operating cost for this equipment. The heat gain from heat conduction through an equal area of insulated opaque wall is less than 5 per cent of the transmission through the glass, so essentially all of the $7/ft² should be added to the cost of the glass to give an equivalent first cost of a window.

The corresponding figures for a window area in a south facing wall are:

- at the summer solstice, a transmission of 70 per cent of the incident beam of 45 watts/ft², which. gives an instantaneous heat gain of 31 watts/ft² at noon;
- at the autumn equinox, a transmission of 85 per cent of the incident beam of 65 watts/ft² for an instantaneous heat gain of 55 watts/ft².

These figures show some of the advantages of orienting a building so that the windows are facing south rather than east or west; the maximum heat gain due to solar radiation transmitted through the glass is less and the maximum occurs at the end of the cooling season so that it does not coincide with the maximum cooling load due to ventilation. North windows, of course, have very small solar heat gains.

Control of Solar Heat Gain through Windows

The real cost of removing the heat that enters a building through the windows is so great that it is economic to spend considerable sums of money to reduce solar heat gain. The most obvious method is to use some form of shade to intercept the radiation before it even reaches the window. This can be done much more easily for south facing windows than for those facing east or west, since for the south facade the angle of incidence is large in summer and projections from the wall consequently cast long shadows.

Solar heat gain through a south facing window can be significantly reduced also by tilting the glass as shown in Figure 2. The energy falling on the window in this configuration is the same as would occur if the window were vertical and had a 1.4-foot projecting shade along the lintel. The tilted glass reflects 45 per cent of the radiation when the incident angle is 78 degrees, compared with 23 per cent when the glass is vertical. This difference in reflectivity decreases as the season progresses toward the winter solstice, and in winter the tilted and vertical windows transmit essentially the same amount of solar energy.

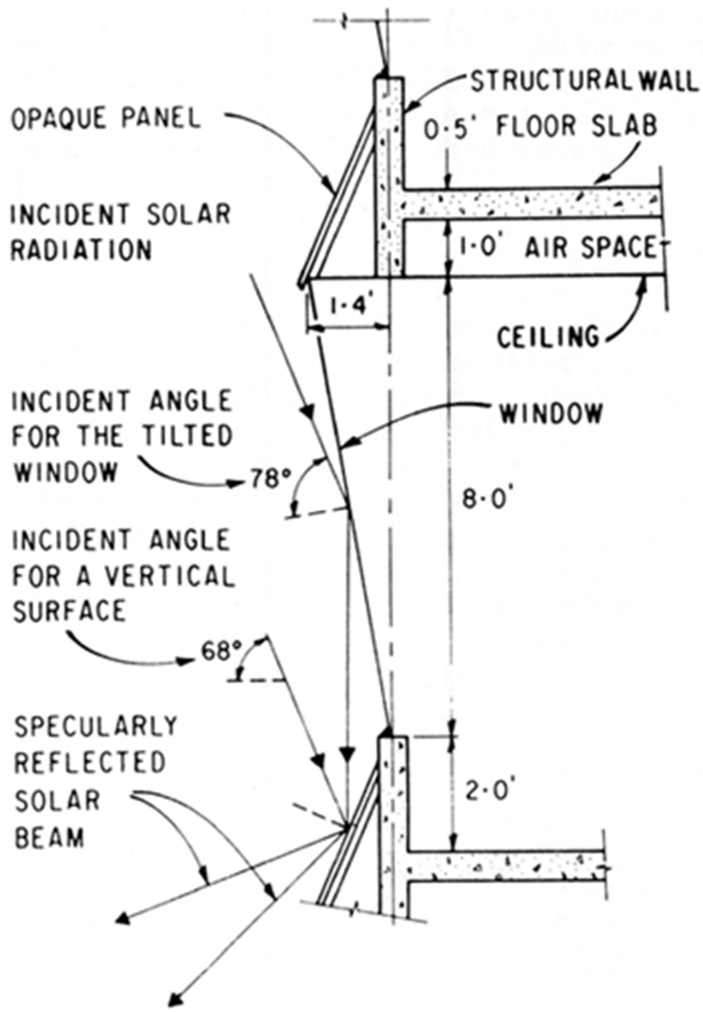

Figure 2. Schematic arrangement of a tilted window in a south facade.

Reflectivity of glass can be increased by coating the surface with either a very thin metallic film or a film of dielectric material that has a high index of refraction. Sealed double glazing units are now available with a reflective coating on the inside surface of the outer pane. Their reflectivity depends on the angle of incidence just as for uncoated glass, but the value at all angles of incidence is higher than for ordinary glass.

Blinds provide another method of solar control. A light coloured blind reflects some of the solar radiation and absorbs the rest. This causes the blind to heat until it is losing heat at the same rate as it receives it from the sun. If the blind is in the room, most of the energy it absorbs is added to the room's cooling load. If it is between the panes of a double window, however, some of the absorbed energy is transferred to the outside air and the room's cooling load is reduced accordingly. It is desirable therefore, to use light coloured blinds and, if possible, to place them between the panes, of a double window.

Heat absorbing glass is also widely used to reduce solar heat gain. Glasses are available that absorb over 70 per cent of the incident radiation so that transmission to the inside of a building is about 20 per cent when the angle of incidence is small and even less when it is large. Absorbing glass is not as good as these figures indicate, however, because the energy that is absorbed by the glass is dissipated to the surroundings on both sides of the window. The proportion of absorbed energy that is transferred to the inside depends on the relative magnitudes of the heat transfer coefficients at the inside and outside surfaces. If cool air is introduced into the room through a grill along the window sill more than half the absorbed energy is transferred to the room side. Thus, the use of heat absorbing glass may cause a higher maximum cooling load than occurs with ordinary glass because part of the absorbed energy is transferred to the room air very soon after it bas been absorbed by the glass. Energy transmitted through ordinary glass is absorbed by the floor, walls and furnishings and released much later. The heat storage capacity of these objects tends to spread the cooling load over a considerable period of time so that the peak value is reduced.

The effectiveness of heat absorbing glass may be increased by using it as the outer pane of a double glazed window so that absorbed energy can be more readily dissipated to the outside air than to the room air. An even greater fraction of the absorbed energy can be rejected to the outside atmosphere if there is a free circulation of outside air through the space between the panes of the double window. The outer sheet of heat absorbing glass is then just a semi-transparent outside shading device.

Heat absorbing glass can sometimes be used to advantage for south windows if shading or tilting are unacceptable for architectural reasons. It has its best application, however, for east and west facing windows where effective outside shading becomes expensive and the simple expedient of tilting has no appreciable effect.

Large areas of glass in the outer walls of a building can cause undesirable glare in the space near the windows. Any method of reducing solar heat gain will also alleviate glare since approximately half of the total radiant energy from the sun is in the wavelength region of visible light.

Heat Gain through Glass during Fall and Winter

The foregoing discussion has been concerned with solar heat gain during the summer. It is also important to consider heat transfer through windows during the other seasons. Any building that has 50 per cent or more of its outside walls made of glass will have sufficient solar heat gain during some hours of the day in spring and fall to require cooling, even though the outside air temperature is well below the desired room temperature. During the dark hours of these same days there will be a substantial heating load because of the high heat loss outward through the glass. The need for cooling during what is normally considered the heating season means that the air-conditioning distribution system must allow for the simultaneous distribution of a heating and a cooling medium; and the building must be carefully zoned so that each area can have the heating or cooling that it requires. As this increase in the complexity of an air-conditioning system is mainly a consequence of the use of transparent walls its cost should be charged against the glass walls.

Glass areas have higher values of over-all heat conductance (U value) than do insulated opaque walls; and large areas of glass in the outer envelope of a building cause higher rates of heat loss during the long winter nights. A larger capacity heating plant is needed, therefore, for a building with extensive areas of glass than for one with walls containing conventional insulation. The net loss of energy through a wall is the difference between the loss by conduction to the outside air and the gain by transmission of solar radiation. This net loss during the winter months depends on the average outside air temperature, or the number of degree-days during the winter, as well as on the amount of radiation that falls on the glass. A double glazing of ordinary glass in a south wall at Ottawa, for example, has a slightly lower net heat loss for a whole winter than has a similarly exposed insulated wall. This small gain is probably offset in most cases by the air leakage through the cracks around a window. There is, therefore, practically no difference in Ottawa in the annual energy requirements for heating when a part of an insulated south wall is replaced by double glazing of ordinary glass. There is a higher net loss for other types of windows or for any windows in other exposures, the maximum, of course, being for north facing windows.

This simple analysis assumes that all solar heat can be used to reduce heating requirements. If a glass area is large it may be necessary at certain times to waste some of the available solar heat; to do otherwise would make the building uncomfortably warm.

Summary

Significant amounts of solar radiation are incident on all surfaces of buildings except the north wall. Solar radiation transmitted through unprotected windows or transparent walls causes a great increase in the cooling requirements of an air-conditioned building or high air temperatures in a building without cooling. Shading and other methods of reducing solar gain are beneficial for both cooled and uncooled buildings. The initial cost of the air-conditioning equipment necessitated by a window of ordinary plate glass can be greater than the cost of the window itself; and there is, in addition, an annual cost of operating the system to pump out the heat that the glass lets in. Both these costs should be included as part of the price that has to be paid when a building designer decides to use large areas of transparent materials in the envelope of a building.

Solar heat gain can be substantially reduced by orienting a building so that there is a minimum of glass in the east and west facades. Windows facing north have very little solar radiation incident on them; this is an advantage in summer, but results in increased energy requirements during the heating season. Solar heat gain through south facing windows can be controlled during the summer by outside shades or by tilting; if they are double glazed such windows do not increase the energy requirements for heating in the southern parts of Canada.

Where windows are deemed necessary in east or west facades the heat gain can be reduced by using double glazing, with the outside pane of heat absorbing glass; the effectiveness of such windows is increased by allowing a free circulation of outside air through the space between the panes. If sealed double glazing units are used a reflective coating on the inside of the outer pane is more effective than a pane of heat absorbing glass with the same light transmission. Finally, blinds can be used to reduce solar heating.

They are more effective when located between the panes of a double window than on the room side of the window.

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* Stephenson, D. G. and G. P. Mitalas. An analog evaluation of methods for controlling solar heat gain through windows. Journal, American Society of Heating, Refrigerating and Air Conditioning, Engineers, Vol. 4, No. 2, February 1962, p. 41-46.