Estimation of Sunlight Entering a Room by Reflection through a North Window for the month of December in Delhi

Krishan Kant Sharma*
Manu Sharma*
N.D. Kaushik*

ABSTRACT

Hourly values of sunlight reflected by a mirror into a room through a north facing window are estimated by simulation. The room is located at the top floor of a building, the plane mirror is placed at a small distance from the window and it can be rotated about its horizontal as well as vertical axes. The values of the angle of incidence of the beam radiation with respect to the mirror have been computed for different positions of sun during the month of December in Delhi. The corresponding values of visible light intensity incident on the mirror have been estimated and hence the values of reflected luminous flux that will be available at the window at different hours during the month have been computed. The radiation filtering characteristics of the mirror and the window glass have been taken into account. The floor areas directly illuminated by the reflected sunlight have been computed and found to be adjustable to a right order of magnitude.

Keywords : Reflected sunlight, North Window, Day-lighting.

1. INTRODUCTION :

Solar radiation provides natural light for our vision. Our brain feels visual comfort and satisfaction in the daylight. The human eye has evolved through billions of years in the light of the sun. Its efficiency to receive sensory-information and transmit it to the brain is the maximum with sunlight. It can easily adjust itself to the variations in the intensity and frequency of the solar-flux which may range from a few lux inside an unlit room to as much as 100,000 lux in bright sunshine.

The temperature at the surface of the sun is around 6000 K and it radiates it radiates energy which corresponds to wavelengths of 0.25 μm to 8 μm. 48% of solar radiation is in the visible range of 0.38-0.78 μm. The peak spectral sensitivity of human eye for photopic (day) vision is at 0.56 μm which lies almost in the middle of the solar spectrum. Moreover, the efficacy of sun light in terms of lumen/watt is very high (100-200 lumen/watt) as compared to the efficacies of incandescent lamps 0-20 lumen/watt or fluorescent lamps 30 80 lumen/watt. Thus for a given visual task, the solar radiation energy used in a room will be much smaller than the energy used by other light sources.

The lighting-load is a major component of industrial energy consumption. In educational buildings and offices about 60% energy is consumed for lighting. The energy consumed by the man made light sources is converted into heat, raising the room temperature and thereby cooling loads in summers. The daylight when properly utilized would impose much smaller cooling loads.

The full spectrum of sunlight is composed of many different waves of electromagnetic energy, both visible and invisible to our eyes. These waves of energy play an important role in human function and evolution. Scientists have found that exposure to sunlight regulates some of the basic biological functions of the body [1]. The basic reason for this is that many hormones and enzymes are very light sensitive. Exposure to sunlight consequently influences a host of physiological and psychological functions. Among these, fertility and mood are two of the most profoundly affected.

Sunlight is also an important source of vitamin D which is required for healthy bones, muscles and for the immune system. The principal function of this vitamin is to promote calcium absorption in the gut and calcium transfer across cell membranes. This contributes to strong bones and a contented nervous system.

Scientists believe that sunlight possibly reduces the risk of several types of cancer including cancers of colon, ovary and bladder.

An illness called SAD (Seasonal Affective Disorder), which is defined as having a number of symptoms including depression, lack of motivation, change of appetite with particular food cravings, memory impairment, headaches, anxiety and irritability is caused by an insufficient exposure to sunlight.

It also appears evident that the pristine, full spectrum sunlight is a logical solution to the modern-day common dilemma posed by SBS (Sick building Syndrome)

However, the main problem in using solar energy for indoor lighting is that it goes on changing direction and intensity with time. We can not have any day lighting before the sunrise or after the sunset and moreover, the availability is restricted by atmospheric conditions, shadows of adjacent buildings and trees and orientation of windows.

In the northern hemisphere, a south facing window receives solar radiation for most part of the day. The east/west facing windows get it in the forenoon/afternoon while the north window gets little time for the direct solar beams.

The problem of window orientation can be tackled by providing a suitable reflector opposite to the window. The reflected ray will go on changing its directions as the angle of incidence of the sun rays relative to mirror changes. However, the mirror can itself be rotated around the vertical axis such that the reflected ray also remains in that plane.

In this case study, the solar azimuth angle changes at the rate of about 13.5° per hour and hence the mirror will have to be rotated at 6.75° per hour about its vertical axis (a 1° change in the angle of mirror leads to 2° change in the reflected ray).

2. THE SYSTEM SCHEMATICS:

A typical room of a building located in Delhi has been considered. The size of the room is 4m × 4m × 3m height and it has a window (size 2.5 × 1.5 m) in the north facing wall. The bottom edge of the window is at a height of 1m from the floor of the room. The plane mirror which will reflect solar radiation through this window is placed as shown in figure 1. It is also assumed that there is a mechanism to rotate the mirror around a vertical axis and a horizontal axis. The mirror is 1m× 1m in area and its centre is located at a horizontal distance of 0.5 m from window surface and the base of the mirror is 1m higher than the top of the window. The reflecting surface of the mirror is assumed to have reflectivity of 0.9 and it is covered with a glass which transmits 80% of radiation passing through it. It is assumed that the window consists of tinted glass which transmits 40% of the reflected beam light entering it. It also transmits 45 % diffuse radiation into the room.

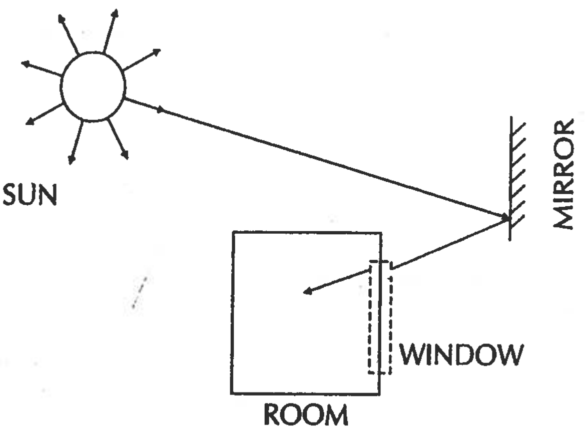

Fig. 1. The system schematics. A plane mirror reflects sun light into the roam through its north window

3. POSITIONING OF THE MIRROR

The position of sun relative to a given location on the surface of earth may be expressed in terms of the following angles:

1. ω (Hour angle), the angular displacement of the sun east west of the local meridian due to rotation of earth around its axis at the rate of 15° per hour
2. Φ (Latitude), the angular location north or south of equator
3. β (Slope of the surface which receives solar radiation-in this case the mirror)
4. δ (Declination), the location of the local meridian with respect to the equator
5. θ (Angle of incidence), the angle between the sun ray and the normal to the receiving surface
6. γ (Surface azimuth), the angle between horizontal projection of normal to the surface and the south direction
7. γ_s (Solar azimuth), the angle between the horizontal projection of the sun ray and the south direction.

The relations among these angles are well defined in literature as in [2], eg

$$\delta = 23.45 \sin (360 (284 + n)/365) \quad (1)$$

where n is the number of day of the year starting with the 1st of January

The solar altitude angle is given by

$$\sin\alpha = \cos\omega\ \cos\Phi\cos\delta + \sin\omega\sin\delta \qquad (2)$$

The solar azimuth angle is given by

$$\sin\gamma = (\sin\omega\sin\delta)/\cos\alpha \qquad (3)$$

And the incidence angle is given by

$$\cos\theta = \sin\alpha\cos\beta + \cos\alpha\sin\beta\cos(\gamma_s-\gamma) \qquad (4)$$

In order to receive the maximum energy from the incident sun-rays, the mirror should be positioned such that the angle of incidence is kept as small as possible. In the present study it is assumed that the mirror can be rotated about a vertical axis and its normal remains in the vertical plane containing the incident sun ray. Hence $\gamma s = \gamma$ and equation (4)reduces to

$$\mathrm{Cos}\,\theta = \sin\alpha\cos\beta + \cos\alpha\sin\beta \qquad (5)$$

From equation (1), the declination on the 1st day of December (n=334) is -22.11° and from equation (2) we get solar altitude angle of 39.29° at noon ($\omega = 0$) for that day. Now if the slope of the mirror is β, the reflected ray will make an angle of $\alpha+2\sigma$ (where σ = 90-β) with the horizontal as shown in the Fig.2. Hence mirror has to be adjusted so that

$$0^\circ < \alpha+2\sigma < 90^\circ \qquad (6)$$

$$0^\circ\sigma < 25^\circ \text{for Dec. 1} \qquad (7)$$

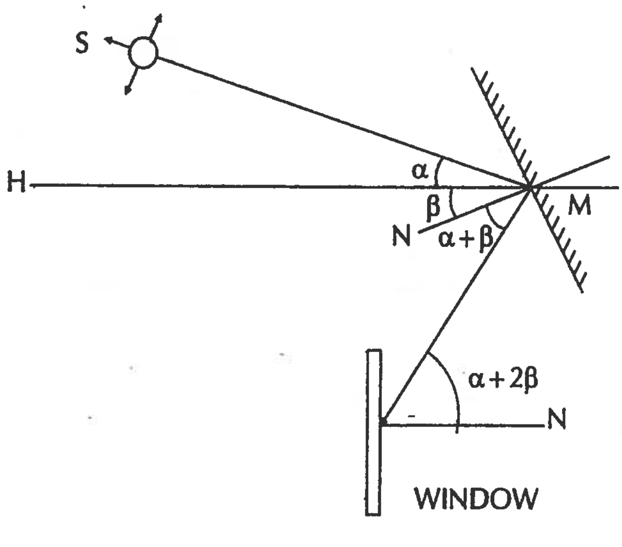

Fig. 2 The angle of incidence of solar radiation on the mirror and the angle of incidence of the reflected beam radiation on the window.

Figure (3) represents the positions of sun at different hours of weekly representative days viz. 1,15 and 29 December in Delhi. The solar azimuth angles are represented along x-axis while the solar altitude angles are along the y-axis. It is seen that the solar altitude does not exceed 40° in the month of December in Delhi. So the slope of the mirror in the present case study may be kept fixed at say 70°. This will result in reflected sun light making an angle r with the horizontal, such that

$$40^\circ < r < 80^\circ \qquad (8)$$

Following [2], the intensity of beam solar radiation incident on the mirror is

$$I_t = 1233\exp(-0.142\ \mathrm{cosec}\ a)\cos 0 \qquad (9)$$

The hourly values of solar energy received by the mirror for the weekly representative days are plotted in Fig. 4.

4. AVAILABILITY OF THE REFLECTED LUMINOUS FLUX:

Olseth and Skartvett [3] have developed the following model for calculating luminous efficacies (lumen/W) for diffuse (L_D) and beam (L_B) radiations, under clear sky conditions, in terms of solar altitude angle:

$$L_D = 137 + 40\exp(-0.08\alpha(\text{lumen/W}) \qquad (10)$$

$$L_B = 107\{1-\exp[2-(\alpha+2)^{.0475}]\} + 2 + 13\exp(0.064\alpha)] \cos[(n-288)360/365] \qquad (11)$$

Using Equations (9) and (11), the hourly values of luminous flux available at the mirror, due to beam radiation, have been calculated. The diffuse radiation enters the window from all directions and the luminous flux due to it has been calculated using Equation (10). The values of diffuse and beam radiations are also available in weather data compiled by various authors such as [4]. Following [5], the attenuation caused by the glass cover of the reflecting surface as well as the window glass has also been taken into account. Fig. 5 shows the total values of the flux entering the room. Fig. 6 shows the areas of the floor surface which will be covered by the reflected beam sunlight:

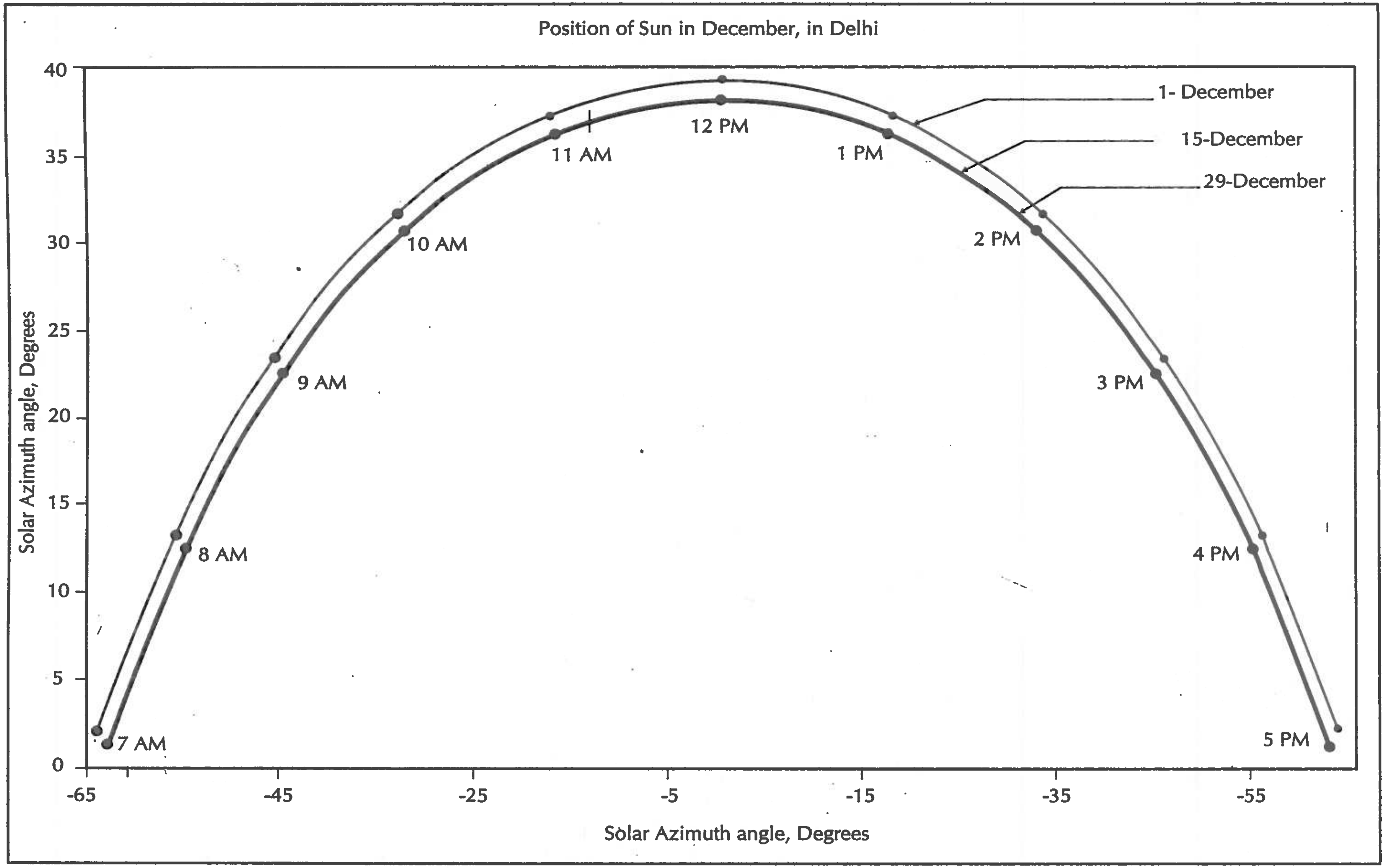

Fig. 3. The positinos of sun at different hours of weekly representative days viz. 1, 15 and 29 December in Delhi

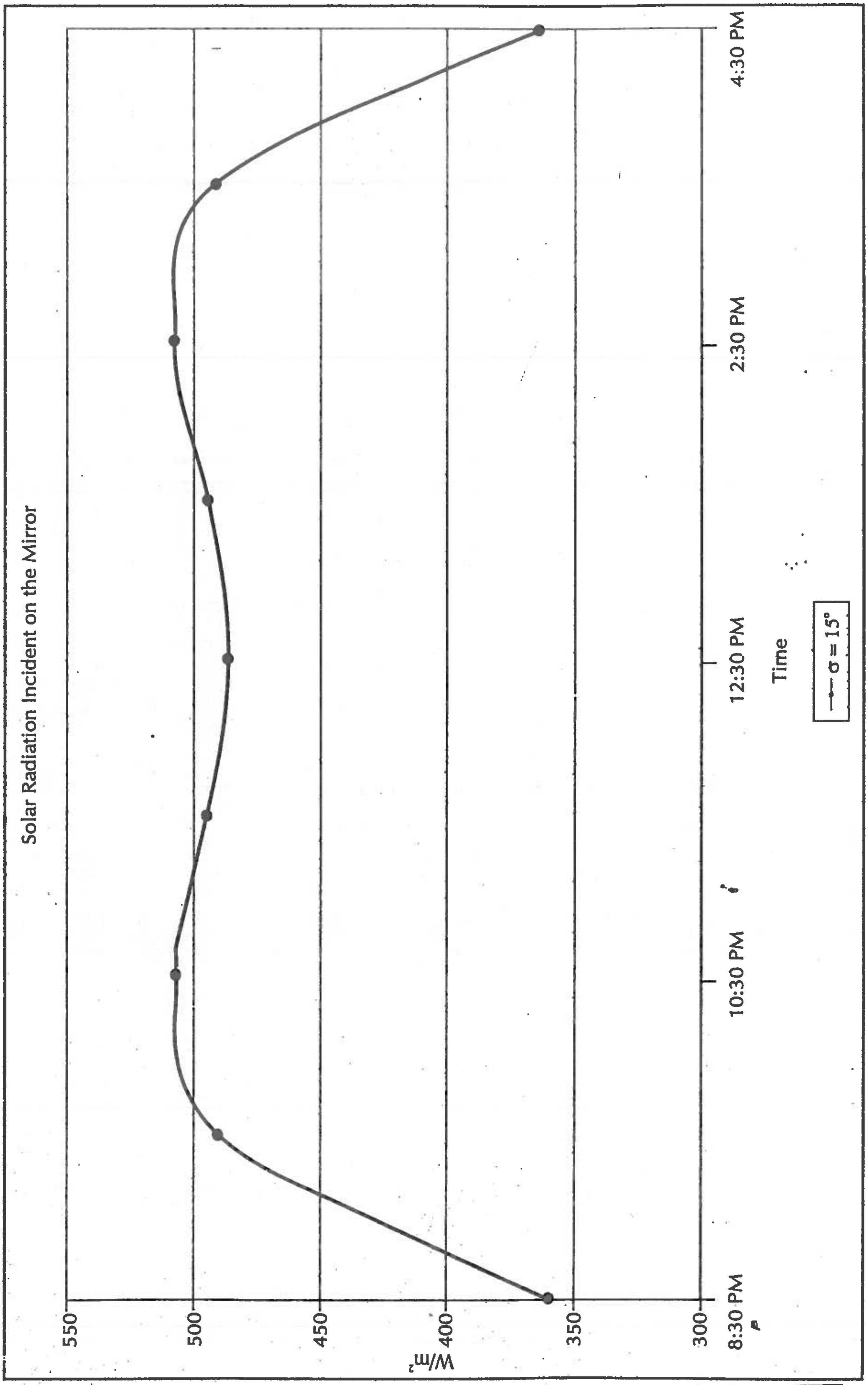
Solar Radiation Incident on the Mirror
550
500
450
400
350
300
W/m²
8:30 PM
10:30 PM
12:30 PM
2:30 PM
4:30 PM
Time
σ = 15°

Fig. 4.

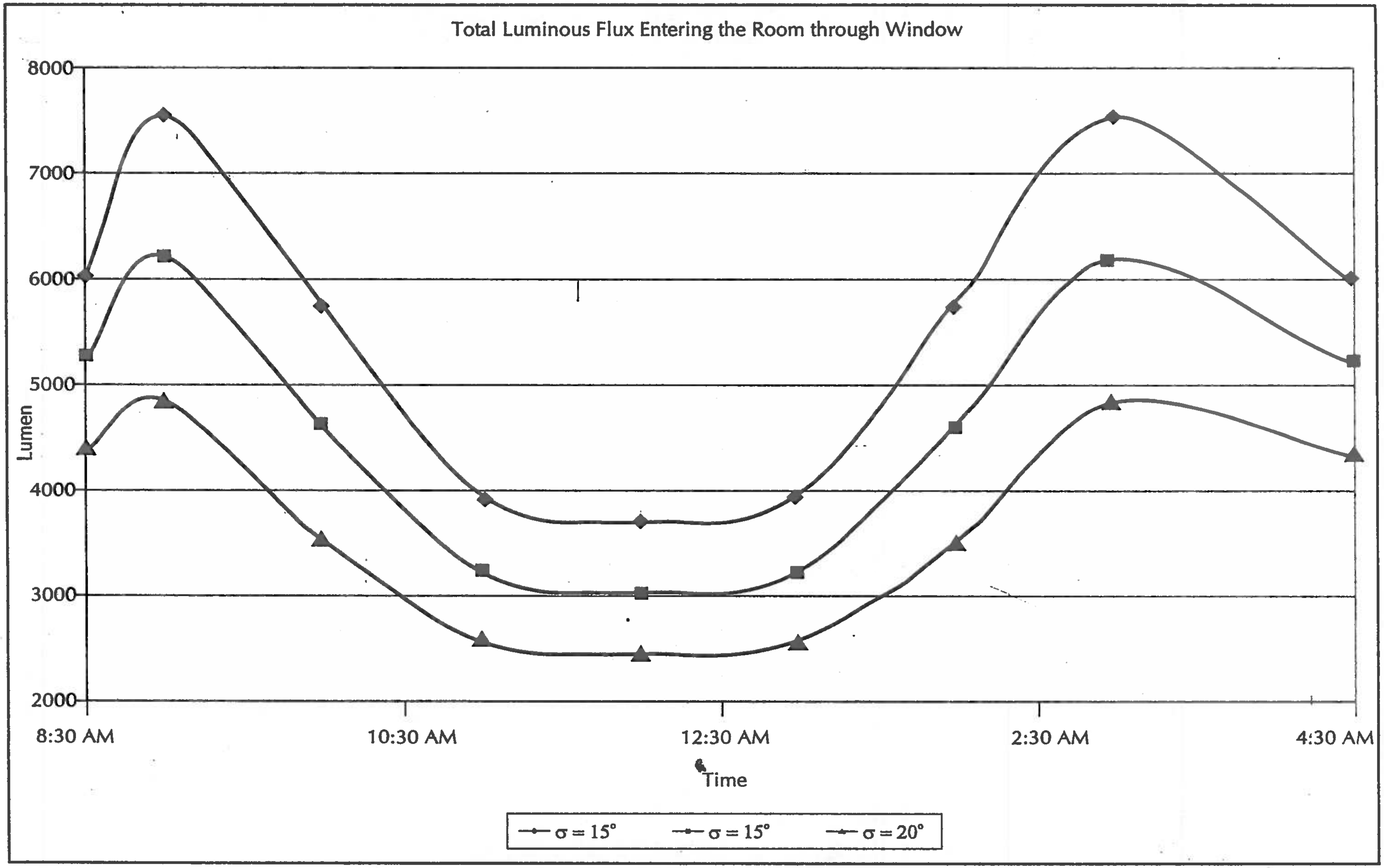

Fig. 5. The total values of the flux entering the room

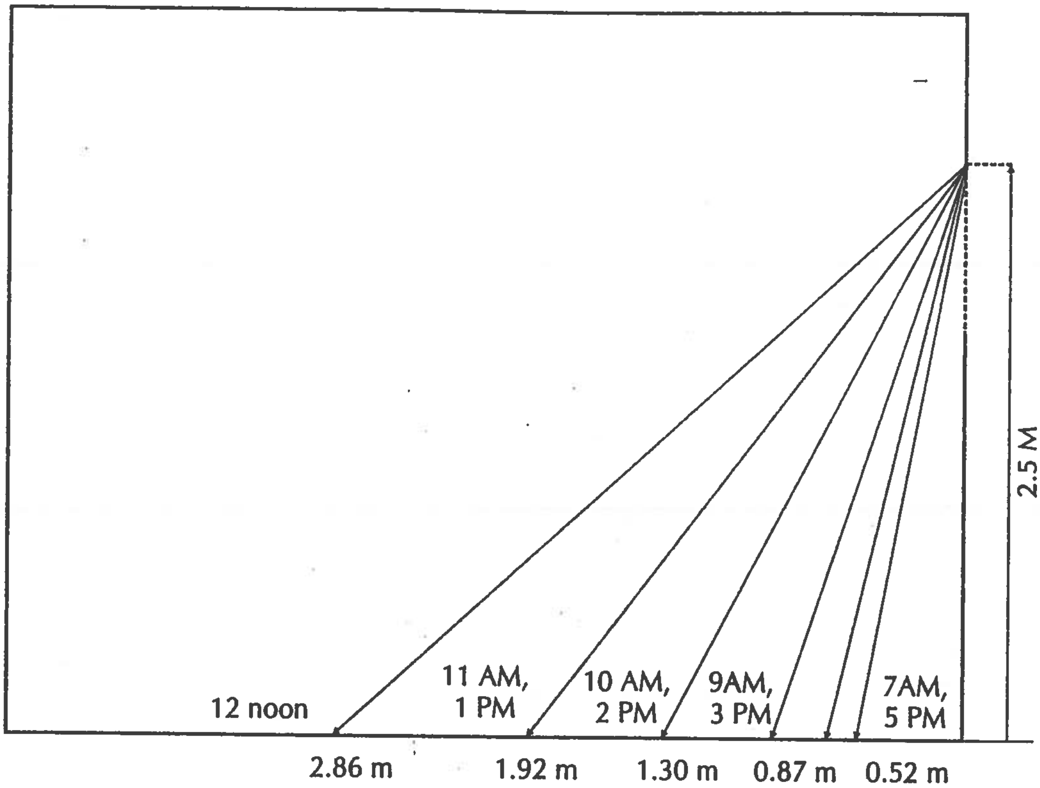

Fig. 6. Length of the room covered by the reflected beam of light through the window

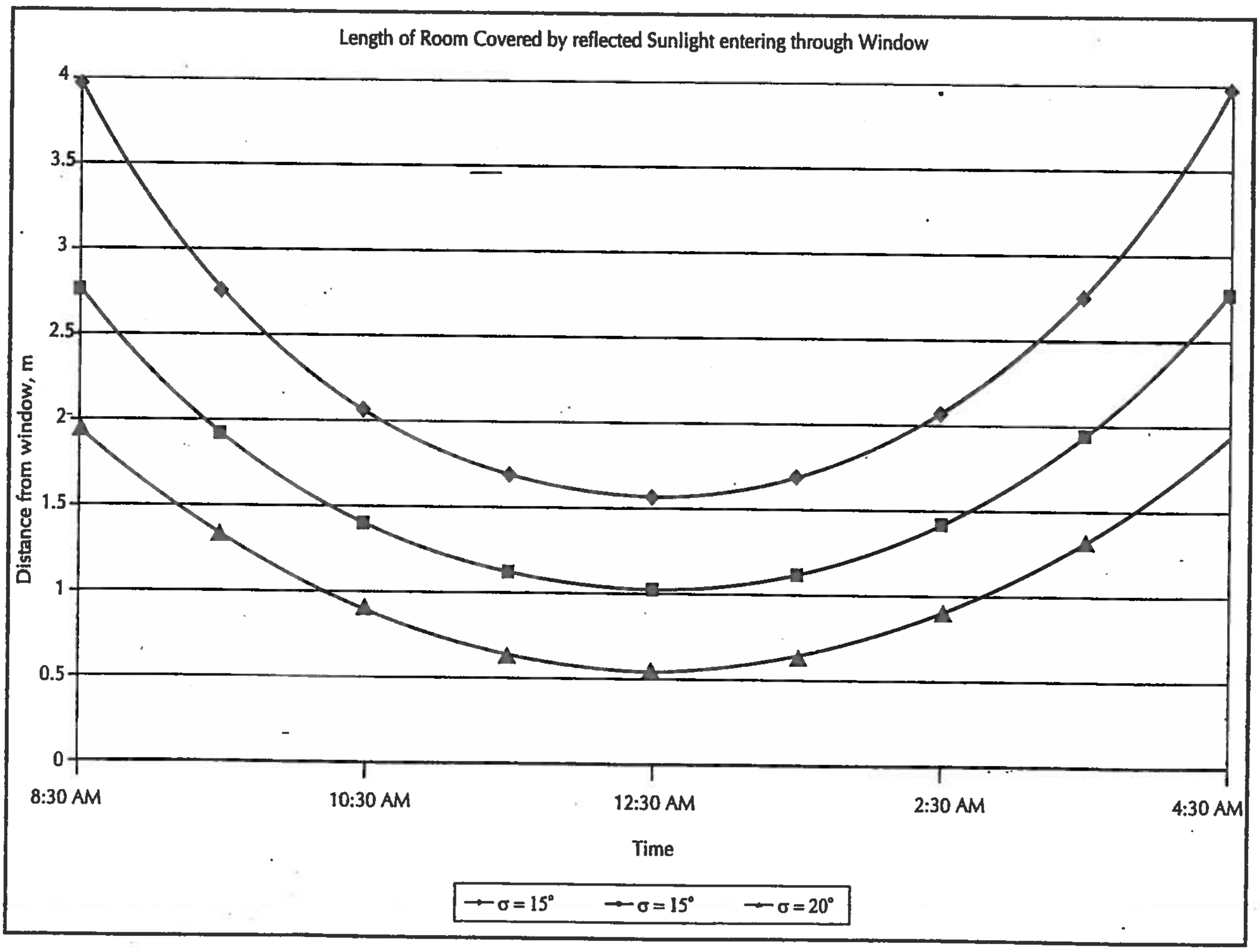

Fig. 7.

5. RESULTS AND DISCUSSION:

The hourly values of solar radiation received by the mirror depend on the time and day of the month as well as the orientation of the mirror. Fig. 4 shows these values for 22nd December in Delhi with the mirror kept at an angle 6 = 15°. It can be seen that the solar energy received by the mirror is at its minimum of about 360 W/m2 at 8:30 AM. It rises almost linearly and reaches about 500 W/m2 at 10:00 AM. From 10:00 AM to 3:00 PM the solar radiation intensity is more or less constant at 500 W/m2 and thereafter it falls rapidly to almost 350 W/m2 at 4:30 PM. However, due to the orientation of the mirror with respect to the window the distribution of luminous flux entering the room at different hours of the day does not follow the trend of solar radiation intensity incident on the mirror. Figure 5, clearly illustrates that the luminous flux is maximum for $\sigma = 10°$ as compared to the cases where $\sigma = 15°$ or $20°$.

The angle of incidence of solar radiation with respect to the mirror also depends on the time and day of the month as well as the slope of the mirror. Since it has been assumed that the mirror is rotated about a vertical axis in such a manner that the reflected rays always directed to the South, the angle of incidence on the mirror is equal to $\alpha + \beta$ and the angle of incidence on the window is $\alpha + 2\beta$. The absorption of energy by the cover glass of the mirror and the window glass depend on these angles and so does the total luminous flux. The length of the room covered by the reflected beam light is equal to $2.5\cot(\alpha + 2\beta)$ and increases with increase in angle β (ie decrease in angle σ). However, when σ is large the reflected beam light entering the room is confined to a small area close to the window and its intensity is high. On the other hand, when σ is small more floor areas is covered but with lesser intensity of light. Fig. 6 shows total luminous flux entering the room through the window for different values of σ and Fig. 7 represents the corresponding values of the length of the room covered by the reflected sunlight.

6. CONCLUSION:

A reflecting mirror placed opposite a north facing window can indeed illuminate a room with day-lighting even during December in Delhi, under clear sky conditions. If a small area close to the window is to be covered, the slope of the mirror should be kept around 70° with the horizontal. However, if a larger area of the room is to be illuminated with the day-lighting, then the slope should be around 80°.

References

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***Bharti Vidyapeeth's College of Engineering**
A-4, Paschim Vihar, New Delhi