

Energy Optimisation in Office Buildings Through Daylighting Design for Climatic Conditions of Central India

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Abstract: This paper is based on the premise that energy optimisation is possible in office buildings through design of daylighting. The motivation for the study was born of the fact that in India, among all building typologies, commercial buildings consume the maximum energy. This energy consumption is mainly for cooling of the building and lighting the interior spaces. Cooling and lighting up spaces generates heat in and around the building, which again increases the cooling load. Out of the total electrical energy required in the building, around 20-40% is used for lighting purposes. Despite availability of daylight during the working hours, artificial lighting is used in offices that have huge internal spaces with large spans. This paper aims at understanding the factors related to daylight penetration into office building in different situations and developing guidelines for achieving maximum daylight penetration in large spaces.

Keywords: Daylight, Office Buildings, Energy Optimisation, Daylighting Design

1. INTRODUCTION

Office building designs have undergone manifold changes because of various technological innovations as well as social and economic transformations. At present, intense international competition is forcing many businesses to examine and rethink their organisational structure. Modern technology is making it possible to use time and energy in offices in new creative ways. Intensive use of modern technology has created issues such as global warming, greenhouse effect and, hence, requires us to think seriously about the importance of saving energy and the necessity of designing energy efficient buildings. Lighting is the major energy consumer in commercial as well as in office buildings.

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Lighting generates heat and increases cooling load of buildings. Various tasks require different intensities and different types of lighting. Sufficient daylight is available during office hours and can be used without any load on electricity for lighting. Daylight is much more comfortable to work with as compared to artificial light. At the same time, sunlight can be very intense and, if not admitted properly in the building, can cause excessive glare, creating problem for users.

Though availability of daylight is useful for reducing energy consumption, simultaneously the designer needs to be very careful the about visual comfort of occupants. Good quality light helps to increase productivity and also saves energy. Studies show that out of the total energy consumption, 20-40% of electricity is used for artificial lighting which can be reduced by appropriate use of daylighting [11].

2. IMPORTANCE OF NATURAL LIGHTING FOR USER PERFORMANCE

Literature review shows that lighting produces a few acids in the human body which then increase impulse control, motivation, calmness and, concentration. Lighting also helps to increase the general well-being of the user. Eye strain, which is considered as a large-scale problem in offices, gets reduced with proper daylighting, resulting in reduction of stress of occupants. Some surveys and studies also reveal that good daylighting induces an increase in productivity in task performance when compared to the same task performed in poorly day-lit conditions. It is also seen that large office spaces designed on the 'open office system' and good lighting conditions also increases interaction between employees.

3. METHODS OF STUDY

Two methods could have been adopted for this study, the first of which is an actual field survey for readings and feedback of users, while the second could be based on techniques of simulation through computer-generated models. Since the case studies are of existing buildings in active use and, correct observations and users' feedback could be obtained, the first method was adopted

3.1 Approaches to the Study

Day-lighting conditions change with change of season, bringing about corresponding changes in daily illumination levels. It was out of the scope of this study to take daily readings throughout the year of illumination level of

the chosen case examples. Readings for daylight were mainly recorded for two seasons, i.e., summer and monsoon. Maximum light and glare can be expected in summer and minimum light and glare can be expected during the rainy season with overcast sky. One particular type of day of each season was then considered for the study. The day selected during summer was a clear, sunny day. The time for taking readings was 12.00 noon – 1.00pm. This allowed the study of an average amount of diffused light (not direct sunlight) that penetrated into the building. The day selected during monsoon was an overcast day with the kind of medium illumination found on most days of the season.

The objective of the study was to address issues related to daylight penetration in office buildings and factors which affect lighting conditions of large areas such as those found in large office buildings. The paper focuses on factors affecting daylight penetration (such as orientation, open spaces around building, vegetation around building, placement of window, layout of interiors, height of partitions, material & colour of internal partitions) and tries to explore guidelines for designing with daylight

3.2 The Study Framework

The Analysis Method used is the parallel or the comparative method. Five office buildings in Nagpur (a city located in the heart of Central India) were selected for the study, out of which three were government office buildings and, the other two were privately-owned Information Technology offices. The buildings were the ‘Block B of the CGO Complex’, the ‘Water Resource Centre’, the ‘Water Resource Training Centre’, ‘Persistant I.T. Park’ and, the ‘Infospectrum I.T. Park’.

4. SURVEY FINDINGS FOR DAYLIGHTING DESIGN IN OFFICE BUILDINGS

Surveys were conducted to calculate the light intensity in the five selected office buildings in Nagpur and intensities were plotted for summer and monsoon. Details of these buildings are given below (Table 1). The Parameters of Comparative study were Orientation, Window Sizes and Placement, Window to Wall Ratio, Illumination Level on each direction and Illumination Level at different floors.

4.1 Case Study 1 - Illumination Level Study – Block - B, CGO Complex

The longer facades of this building face north & south and the window to wall ratio (i.e., the ratio of vertical fenestration area to gross vertical wall [9] is 0.34. The windows are sunken and protected from all sides (Fig. 1a & 1b).

Table 1: Window to Wall Ratio, Daylight and Orientation (Source: Author)

Building	Window to wall ratio	Max. Depth of building for direct light penetration	Orientation
Case Study 1: Block-B, CGO Complex	0.34	20 m	East-West
Case Study 2: Persistent I.T. Park	0.65	30.m	East-West
Case Study 3: Water Resources Training Centre	0.27	7 m	North-South
Case Study 4: Water Resources Centre	0.30	4.5 m	East-West
Case Study 5: Infospectrum I.T. Park	0.10	40 m	East-West

Figure 1a (Right): Section through Window of Block-B, CGO Complex, Nagpur (Source: Author)

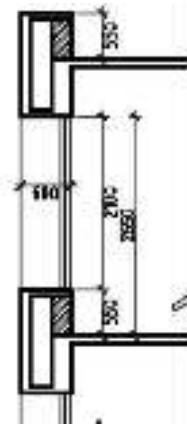
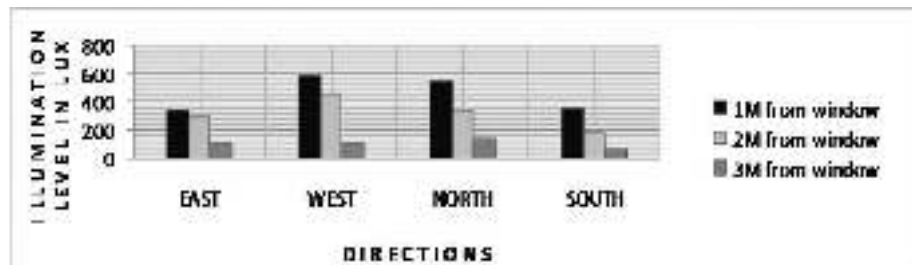


Figure 1b (Far Right): Façade of the Block-B, CGO Complex, Nagpur (Source: Author)



Figure 1c (Below): Chart 1 (Source: Author)



It is observed from the readings shown in Chart 1 (Fig. 1c) that the decrease in illumination level is gradual for every 1m distance from the window. Maximum illumination level is seen at 1m distance from the window. This, however, is as high as 800 lux which creates conditions of glare at the table top. An illumination level of 200 lux – appropriate for table top working – was found at distances of 2.0 – 2.5 m from windows.

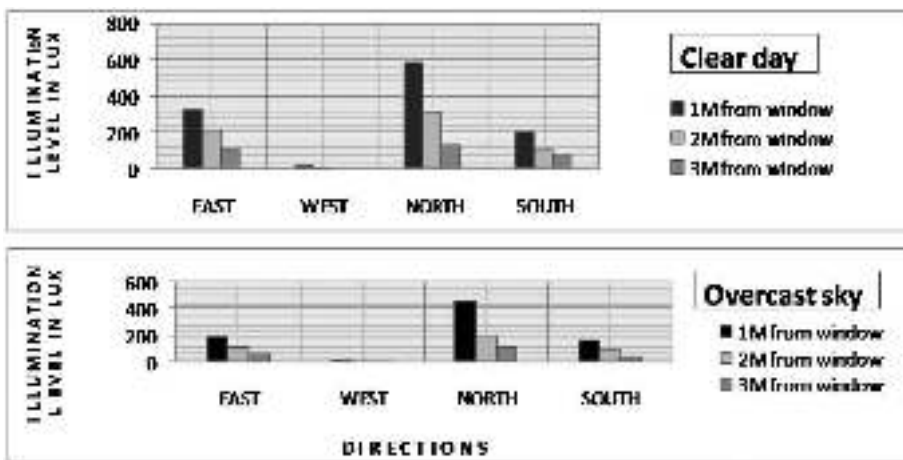
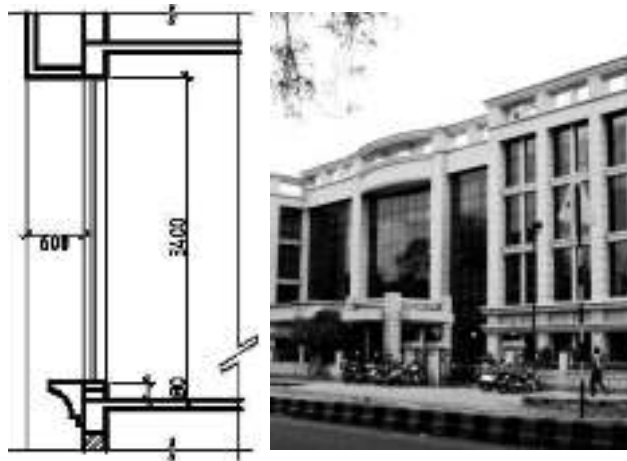
4.2 Case Study 2 – Illumination Level Study – Persistent I. T. Park

The type of window used in this building is also sunken. (Fig. 2a & 2b). The window to wall ratio is 0.65 and the longer facades of the building face North & South. It is observed from the readings given in Chart 2 (Fig. 2c) that decrease in illumination level is gradual for every 1m distance from window. The maximum illumination level at 1m distance from the window is 600 lux, which creates glare on table top. Up to a distance of 2m from window, the illumination level is 200 lux, which is ideal for table top working. Because of the use of tinted glass on windows, the maximum level of illumination -- as compared to the first case study -- is less even if the window size is bigger.

Figure 2a(Right): Section through Window of Persistent I.T. Park, Nagpur (Source: Author)

Figure 2b (Far Right): Façade of the Persistent I.T. Park, Nagpur (Source: Author)

Figure 2c (Below): Chart 2 (Source: Author)



4.3 Case Study 3 – Illumination Level Study – Water Resource Training Centre

The type of window used here is plain with a cantilevered *chajja* above it (Fig. 3a and 3b). The window to wall ratio is 0.27 and the longer facades face East & West. There are no openings on the North & South facades. It is observed from the readings given in Chart 3 (Fig. 3c) that the maximum level of illumination at 1m distance from the window is 1000 lux. It suddenly decreases to 400 lux at 2m and the light penetration is gradual. Though the window to wall ratio is less, the building is well lit and gets sufficient natural light on table tops. As the depth of the building is less that is 7m. high illumination causes problem on table tops located near the windows.

Figure 3a: Section through Window of Water Resource Training Centre, Nagpur (Source: Author)

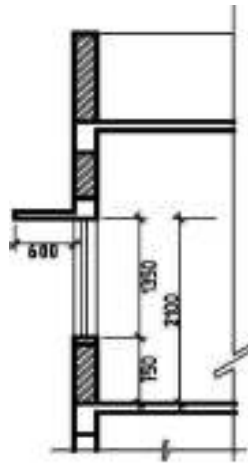
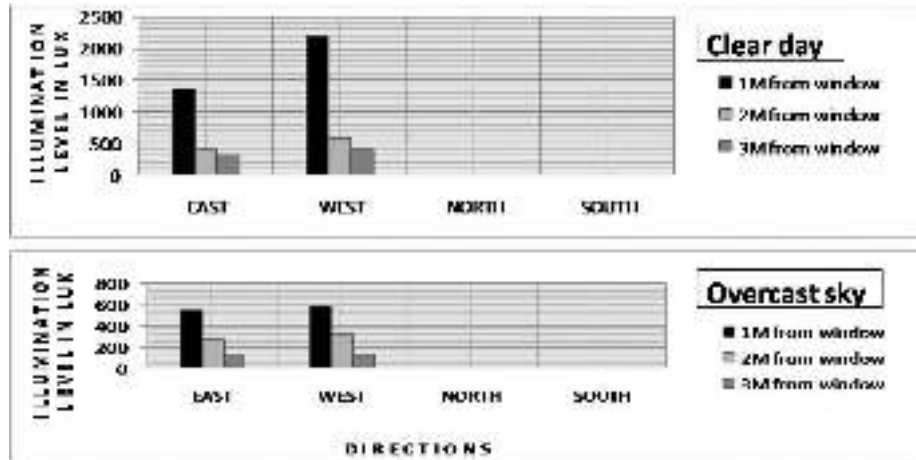


Figure 3b: Façade of the Water Resource Training Centre, Nagpur (Source: Author)



Figure 3c: Chart 3 (Source: Author)



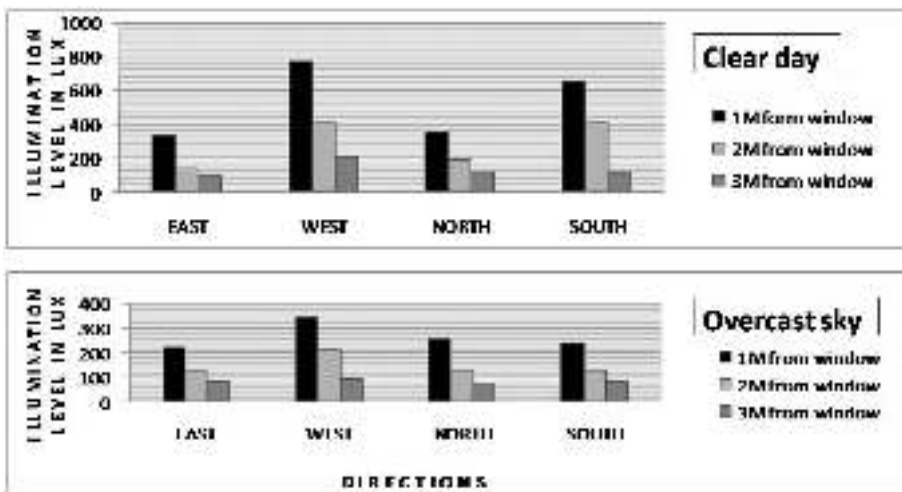
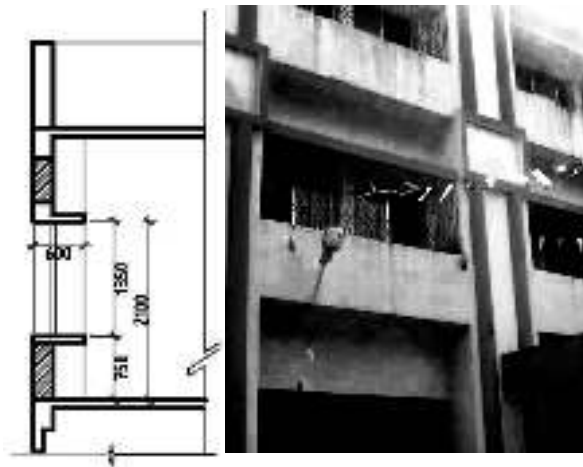
4.4 Case Study 4 – Illumination Level Study – Water Resource Centre

The type of window used here is sunken (Fig 4a & 4b), with a window to wall ratio of 0.30. There are no openings on North & South facades. It is observed from readings shown in Chart 4 (Fig. 4c) that decrease in illumination level is gradual for every 1m distance from window. Sufficient amount of illumination is received up to 2.5 m. In this building interior spaces are partitioned by walls and distance from window to wall is up to 4.0 to 4.5 m. This creates dark patches near partition walls. Maximum illumination level at 1m distance from window is 800 lux which creates glare on table top. Up to 2-2.5m from window, the illumination level is 200 lux, which is as required on table tops for working.

Figure 4a (Right):
Section through Window
of the Water Resource
Centre, Nagpur (Source:
Author)

Figure 4b (Far Right):
Façade of the Water
Resource Centre, Nagpur
(Source: Author)

Figure 4c (Below): Chart
4 (Source: Author)



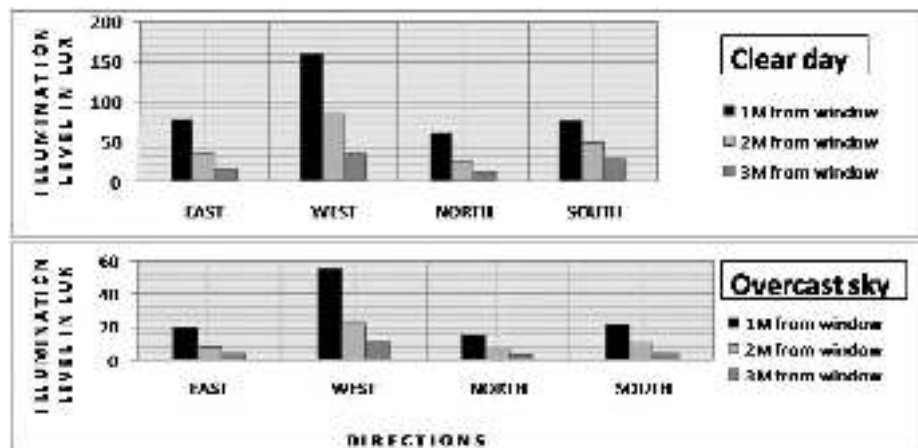
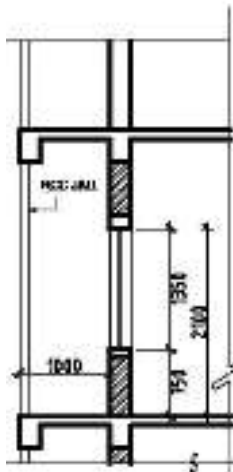
4.5 Case Study 2 – Illumination Level Study – Infospectrum I. T. Park

The type of window used in this building is plain (Fig 5a & 5b) and the window to wall ratio is 0.10. There are very few windows to this building. It is observed from the readings in Chart 5 (Fig. 5c) that decrease in illumination level is gradual for every 1m distance from window. Maximum amount of illumination at 1m distance is 150 lux, which is less than what is required for comfortable regular work. Span of this building is 40 m which leaves several areas completely in dark.

Figure 5a (Right):
Section through Window
of the Infospectrum I. T.
Park, Nagpur (Source:
Author)

**Figure 5b (Far
Right):** Façade of the
Infospectrum I. T. Park,
Nagpur (Source: Author)

Figure 5c (Below):
Chart 5 (Source: Author)



4.6 Summary of Findings and Observations.

- The ideal window to wall ratio on East and West facades is 0.3-0.4 [7]. If the ratio goes above this range, the windows should be designed carefully as the low sun angles for these orientations makes the design of their shading extremely difficult.
- The ideal light intensity at table top is 200 lux. The light intensity in all types of windows studied (Fig. 6) is more than 300 lux up to a distance of 2.00m from windows. This is more than the ideal light intensity of 200 lux and causes disturbing glare on table tops. Light intensity should be controlled to reduce glare in these areas without interrupting daylight penetration beyond 2.0m.
- After the distance of 2m from windows, light intensity suddenly starts decreasing by about 50% for every 1m. This reduction can be worked on to increase the daylight penetration
- In the case of small windows with lesser height (i.e., 1.35m), light (with required intensity of 200 lux) reaches up to a maximum distance of 3.00m and, in case of full height windows light reaches up to a maximum distance of 3.50m
- Windows having protection on top admit more light upto the first one meter as compared to sunken or projected type windows.

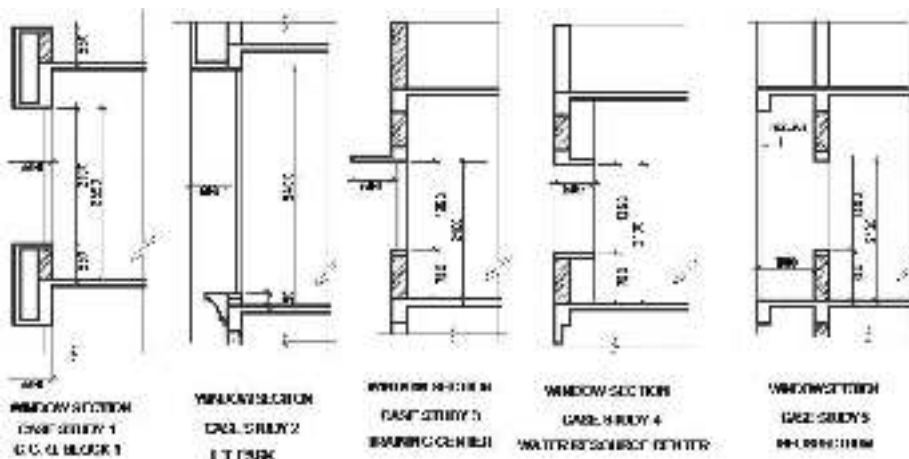


Figure 6: A comparison of window sections of all case studies, showing sill, lintel and window projection / protection (Source: Author)

5. GUIDELINES FOR DAYLIGHTING DESIGN IN OFFICE BUILDINGS

5.1 Consideration for Designing the Guidelines

Office timing considered: 9.00 am to 6.00 pm

5.2 Orientation:

The study shows that the maximum illumination during the summer and monsoon months is on the West and the North sides, whereas in winter, it is on the South and West sides. The preferred shape of the building should be rectangular with the axis making an angle of 0 - 30 degrees with the E-W direction. With this orientation, the maximum level of daylight and thermal comfort will be achieved. In the Central Region of India, the normal office timings are 9.00 am to 6.00 pm. Out of these 9 hours, the sun is on the west side for 6 hours. Planning should be done with this fact and the thermal comfort in mind. Probable locations of service cores are shown in the images, so that the maximum amount of light can be admitted inside the working areas. These conditions are true for a building width up to 8m, with windows on both the longer sides (Fig.7). Wherever the ideal orientation is not feasible, the building may be reoriented according to the site conditions.

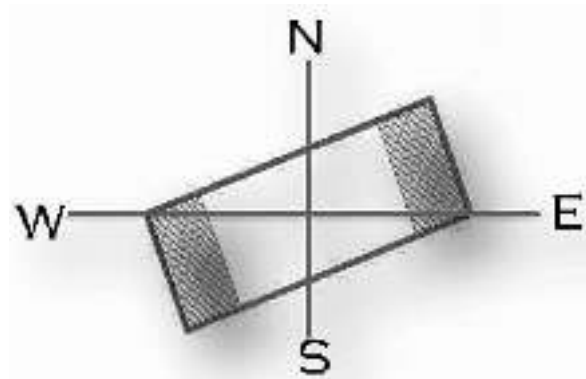


Figure 7 (Left): Preferred shape and orientation of Office Buildings located in Central India (Source: Author)

5.3 Depth of Building for Regular Windows

If working with windows of width 2.0m, height 1.5m and, sill height of 0.6m, and windows located on both sides of the building opposite to each other, and a window to wall ratio between 0.3 – 0.4, the depth of the building

block should not be more than 7.0 m. However, in all cases sufficient care should be taken to reduce glare near windows and provision should be made so that glare and heat gain will be minimised without reducing the intensity of light.

Figure 8 (Centre): The Courtyard Advantage (Source: Author)

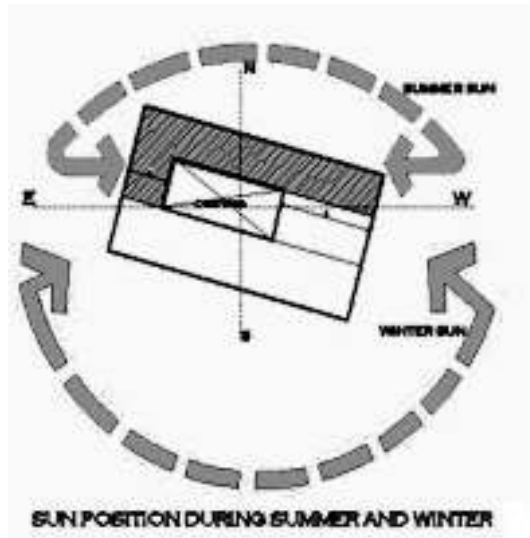
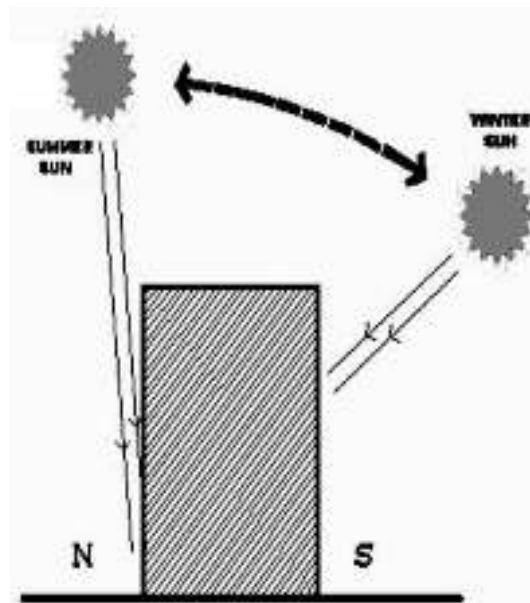


Figure 9 (Right): Summer and Winter Sun Angles (Source: Author)



5.4 Courtyards

Courtyards that help to provide good light and ventilation to a building from two sides, can play a major role in daylighting design. Since the office space is used between 9.00am to 6.00pm, the time period before noon (when sun angles are low) is less and that in the afternoon (with higher sun angles) is more. The advantage of courtyard layout is that reflected diffused light will enhance illumination level through windows on opposite sides of the interior spaces. (Fig. 8 & 9). Also, considering the sun angles and positions, maximum sun light will be achieved during winter and its penetration avoided during summer. Courtyards can also be used for plantation and water bodies, thereby increasing the cooling of interiors. All facades should be designed with light shelves to get maximum of daylight (Fig. 10 & 11).

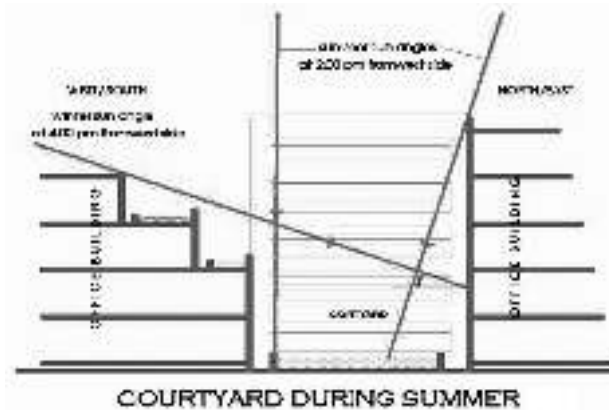


Figure 10: Summer sun penetration in buildings around courtyards
(Source: Author)

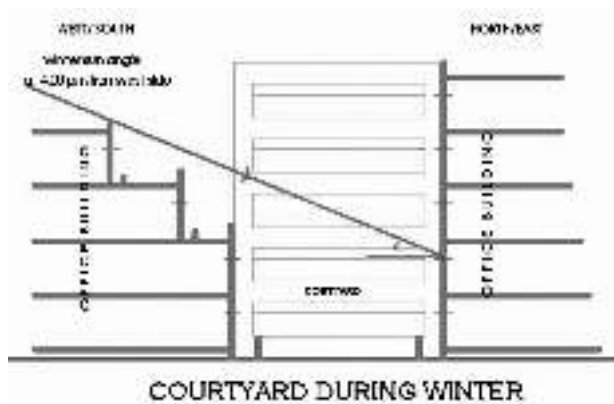


Figure 11: Winter sun penetration in buildings around courtyards
(Source: Author)

5.5 Design of Facades and Fenestrations

The Lawrence Berkley National Laboratory has developed window shelves and light pipes for efficient penetration of daylight inside building. According to the published data by this laboratory windows designed above 2.10 m, i.e., above lintel level, provide diffused natural daylight and prevent glare. Consideration of facade direction and sun angle increases efficiency. Horizontal shelf with louvers above and coating of reflective surfaces allow for reflection and deep penetration of sunlight. Adjustable louvers ensure maximum penetration of light. Maximum distance that can be traveled by light with this arrangement during summer is 6.5m and during winter is 10.0m. The regular window arrangement can be provided at normal height up to 2.1m. This window is horizontally pivoted so it can be used to monitor winter sun penetration. If the window glass is coated with dielectric layer it will reflect maximum light during summer and will not cause glare problem and help to control heat gain.

To reflect more sun light during winter it is also possible provide the shelf without louvers. In that case the shelf itself will be adjustable for various angles of sun during different seasons. If the glass panel is open, louvers will act as ventilators during summer to expel the hot air from office spaces (Fig.12 & 13).

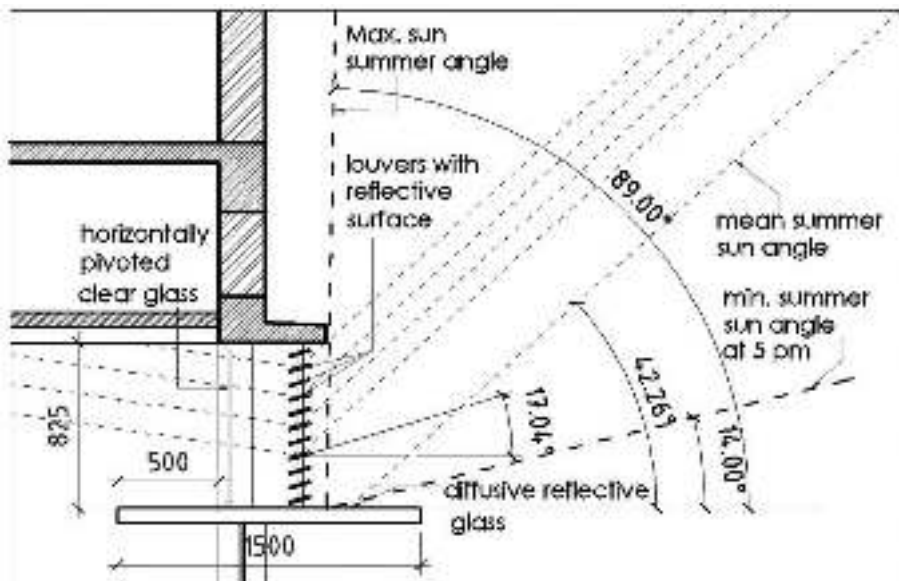


Figure 12: Window Detail showing Light Penetration (Source: Schematic sections developed by author with reference of Lawrence Berkeley Research Laboratory's published data)

and using light shelves with louvers during summer and winter and can help in energy optimisation in artificial lighting. The initial cost and installation cost of light shelves is 60%-75% more than traditional window cost. But this cost can be compensated within 5 - 6 years from installation.

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