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A Pilot Study on the Effect of Daylighting and Orientation in the Office Building: A Case of Kathmandu

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Abstract

Illuminance results in visibility of objects and daylighting is the major source of light for perceiving and carrying out certain function. Office blocks hold the space for people to perform economic task for 7-8 hours daily and humans seek comfort. Lighting the interior is a mindful job, as the space can be over lit or under lit resulting in visual discomfort and high use of energy to maintain human comfort. Quality and quantity of natural light in the indoor is guided by several factors such as climate, latitude, sky condition, site obstructions, orientation, opening design, surface reflectivity, space function etc. The study shows that the best orientation for Kathmandu is 175° N and for the building with window wall ratio greater than 60%, orientation does not play a vital role. Autodesk Ecotect 2011, has been used to simulate the building with the real case scenario in the urban context for the outmost result. The finding adds value during the early design phase and also to prepare guidelines, policies and bylaws relating to wellbeing of occupant for visually and functionally friendly interior.

Keywords: daylighting, visual comfort, orientation, simulation

1. Introduction

Human being spend large quantity of their time indoor, indulging in different activities to keep their life moving. With the development of technology, use of electronic device is high both for business and recreational purpose. The age of 15 to 64 is defined to be working age population (OECD, 2021) and 59.8% of world population was found to be in professional workforce in 2020 (DPE, 2021). The working population of Nepal in 2021 was estimated to be 60.9% (ILO, 2021). Office worker form a considerable amount of population. Daylight is considered an important element for determining the quality of space as it plays a major role in resource conservation as well as in occupant's level of productivity, health and comfort (Hafiz, 2015). People prefer working near windows as it stimulates the mind, reduces stress and increases productivity (Khandelwal,

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n.d.). The amount of sunlight hitting and penetrating the building depends upon the building design and its boundary condition.

Design of buildings with reference to daylight is a process of providing adequate lighting to interior while excluding unwanted light from the room (Singh, 2018). Occupants in day lit and full spectrum office building has reported better health, reduced absenteeism, motivation, increased productivity, financial savings, job satisfaction, and organization attachment (Edwards & Torcellini, 2002). Occupants require proper daylighting to carry out desk work in their working spaces which is influenced by a set of internal and external aspects (Sadat & Nargis, 2021).

Orientation is one of the important variable which greatly affects the daylight autonomy and for each orientation daylight autonomy increases with the increase of window wall ratio and glazing transmittance (Shen & Tzempelikos, 2010). Orientation plays an important role in daylight glare probability (DGP) and daylight factor constantly changes over the orientation and geographical location (Fela, Utami, Mangkuto, & Suroso, 2019). Solar incidence in a space depends upon the latitude of building location and orientation of building fenestration (Munoz, Esquivias, Moreno, Acosta, & Navarro, 2013). Building orientation can avoid or reduce the undesired impact of sunlight such as glare, underlit, overheating. The use of electrical lighting in the interior depends on the amount of daylight that penetrates through building envelope. East and west facing spaces receive maximum glare while the windows facing north offer best orientation for reducing heat gain and glare as it receives no direct sunlight (Stalbosky, 2018).

The architecture of Kathmandu took turn post democratic movement in 1990. The glass box architecture has been highly appreciated by the valley without the consideration of climate, sky condition, weather, geography, environment as well as surrounding context, function of the building and the health of occupant. The lack of land and its high value has resulted in the residential turned office spaces which lack proper daylight design and has high use of artificial lighting or over lighted space with minimum to zero connection to the outdoor environment. The over lighted space causes glare and underlit result in high use of artificial lighting. To solve the over lighted problem, blinds are used which result in loss of connection to nature depriving oneself from its benefits. Either the space be designed or adaptive reuse, architect lose his long-term control over the building. The issue needs an eye as figures displays considerable amount of people spending 7 to 8 hours minimum daily in the interior carrying out desk job.

2. Objective

The objective of the study is:

- To find out the best orientation of office building for satisfactory daylighting

3. Literature review

Daylighting requires an integrated design approach for successful outcome involving decision regarding building form, orientation, climate, building components such as windows and skylights, lighting controls and lighting design criteria (Ander, 2016). Different building orientation will benefit from different daylighting strategies such as light shelves are effective on south-north orientation but ineffective on east-west orientation (Ander, 2016). Northern and southern lighting is easily controlled as northern light is relatively diffuse with little glare and often does not require use of external shading while southern light is abundant and can light deeper into the space with use of light shelve but the glare must be controlled (BOMI International, 2020). To benefit from the sun energy for daylighting, strong sunlight source should be avoided which would become source of glare and discomfort (Singh, 2018).

A study conducted in New York, Chicago, and Los Angeles has found that the daylight autonomy is highest when the façade is facing south and with the increase of window size, UDI ratio shows similar trend for all orientation except south, as south window receives more daylight compared other orientation, so when the window size increases, the average illuminance on the work plane may increase to more than 1000 lux and thus decreases the UDI ratio (Shen & Tzempelikos, 2010). A study conducted in Indonesia concluded that the south facing openings provides minimum useful daylight illuminance (UDI) and south and west oriented openings with 50% window wall ratio is recommended in tropical region (Fela, Utami, Mangkuto, & Suroso, 2019). Daylight Glare Probability (DGP) is lower at south and west orientation compared to north and east for tropical humid areas (Fela, Utami, Mangkuto, & Suroso, 2019). Orientation does not play a relevant role in a space with high window-wall-ratio and bilateral daylighting but the geometric characteristics, built-up surroundings, most influence the daylighting conditions (Munoz, Esquivias, Moreno, Acosta, & Navarro, 2013). Changed orientation result on changed illuminance on work plane (about 15% of work plane is below 100 lux) (Munoz, Esquivias, Moreno, Acosta, & Navarro, 2013). A study in Korea has found that south oriented 3D façade patterns enhance daylighting performance and reduce energy consumption in Korea without any urban context (Eltaweel & SU, 2017). Another study conducted in Komaltar has concluded that 0° orientation has least sunlight penetration while 240° has worst for minimum glare problem and energy saving and those with orientation 30°, 180°, 330°, 60°, 90°, 300°, 150°, 120°, 210°, and 270° are the next one ranking in order. Careful orientation, planning, and calculated shading device are all found to be of utmost importance for energy conscious and environment friendly design (Fadzil & Sia, 2004).

A study in Malaysia shows that the cloudy sky does not effect on different orientation while sunny sky causes critical situation in east and west. Orientation of office space for using desirable daylighting is north and south oriented windows as east and west oriented windows encounter excessive daylight in the morning and evening which require deep shading device resulting in the decrease of interior daylight (Mahdavi, Inangda, & Rao, 2015). Similar window size and its form and shading systems in different orientations is not reasonable because of different response due to sun path (Mahdavi, Inangda, & Rao, 2015). Room orientation has highest impact on UDI followed by depth and height, which are all early stage design decision variables (Han, Shen, & Sun, 2021).

4. Method

The nature of research theme relates to find out the best orientation of office building for daylighting which falls under correlation research as it measures the relationship between two variables, people and daylighting taking visual comfort and orientation as major parameters. This study lies in descriptive research where both the variable cannot be controlled by the researcher and uses correlational strategies to understand the daylighting values which changes with orientation and other parameters. The relationship between availability of daylighting and orientation was examined to find out the strength and direction of relationship.

The prime agenda requires a quantitative analysis for statistical comparison on how orientation affect the daylighting value which is evaluated using Autodesk Ecotect, 2011 for fulfilling the research purpose. The field data were collected using heavy duty meter and simulated with software by creating the virtual model with existing scenario. Various parameters as climate, location, site obstruction, opening details were studied and used for true outcome. The field survey was conducted in the corporate building in Bakhundole named 'The Regency Corporate' focusing in the urban area which represent the highlighted problem of commercial building. Orientation of building is dependent on the climate of locale, latitude, site obstruction and reflection so, the generalization of finding is not possible.

5. Building Description

The Regency Corporate is the commercial building in Bakhundole, lalitpur with office space on lower floors (ground floor to fourth floor) and restaurant with conference hall upper floors. The building is in rectangular shape along the east-west axis with 61′3″ on short side and 104′1″ on long side. The building is 27°40′54″ north oriented with curtain wall on north having site area is 13,500 square feet with plinth area 6000 sq. ft. and built up area 50,000 sq. ft. (approx.). The service areas are located on north and south side of building respectively allowing uncluttered space for offices. The outside walls are 9″ (230mm) thick single leaf brick wall with plaster on both sides. Horizontal sun shading device measuring 2′-0″ from the wall are projected on its south façade above the windows with depth of 1′-9″ which holds the space for plants. The building takes light from all four directions: the north, south, east and west with single 6mm clear glass with standard transmittance value of 75% to 92%.

6. Results and Discussion

6.1 Simulation Setting

The daylight performance of building is carried out on Autodesk Ecotect Analysis 2011 software. After assessing the visual comfort of the building in its existing configuration, an additional series of simulation were performed to identify the best orientation of building for daylighting. The building is simulated under two conditions:

Case I: Base case i.e. 27° north orientation

Case II: Under the changed orientation of the building i.e. best orientation and most plot orientation of Kathmandu (north-south elongated and east-west elongated)

Figure 1: The Regency Corporate, North view

The working hours in the office is set up as 10 am to 6 pm as per the working hours of the office. The total working hours can be calculated as:

Working hours per day = 8 hours (10:00 am to 6:00 pm)

Total Saturdays (holidays) in a year = 4 x 12 = 48 days (holidays for festivals and other office holidays are not considered except Saturday)

Total working days in a year = 365 – 48 = 317 days

Total working hours in a year = 317 x 8 = 2536 hours

All the other parameters were kept same in both the cases except orientation. The simulation results were then compared with each other in terms of visual performance and also verified with the site data.

A. Material consideration:

The properties of glass like visible transmittance, thickness, refractive index etc. are provided by the software itself which were selected as per field data. The type of glass selected is double coated single glazed with aluminum frame.

Table 1: Site details

Site parameters	Description
Latitude	27°40′54″ N
Longitude	85°19′2″ E
Elevation	1310 m
Time zone	+6:00 Dhaka
Local terrain	Urban

Table 2: Surfaces and their reflectance

Surface	Reflectance
Walls, partitions	0.5
Floor	0.2

Table 3: Glazing details

Glass type	Width	Density	Sp. heat	Conductivity	Type	Visible transmittance
Standard	6mm	2300	836.8	1.046	75	0.7

B. Time zone:

The time and date of the year was selected before calculating the amount of daylight penetration in the interior. The simulation was done on the day of March 2, 2022 at 2:00 PM.

C. Analysis grid:

The analysis grid was displayed and adjusted as per the floor area with grid size of 1′ -0″x 1′-0″.

D. Lighting Analysis:

To calculate the natural light level i.e. daylight factor and level, various simulation scenarios were selected.

Table 4: Lighting analysis scenarios selection for simulation

Scenario	Description
Location of light value	Over the analysis grid
Precision of ray-tracing	Very high (8192)
Sky condition	CIE uniform sky
Design sky luminance	8950 lux
Window cleanliness	Average (x0.90)
Mode	Increased accuracy mode

6.2 Site observation

The daylight measurement of the site was taken for three days viz. February 27, March 1 and March 2. The reading was carried out for three times of each day at 11 am, 2 pm and 5 pm on the second floor of the building at the desk height of 2′-8″. Since the floor open floor plan, daylighting level was measured in different points which are near openings, center of space and in the corners. The required illumination in the office space ranges from 100 lux to 2000 lux. Glass curtain wall on north-west, and huge openings in the west, south-west and south has resulted in high illumination (up to 3600 lux at 2:00 pm on February 27) which results glare and unwanted heat. The point I which is at corner appeared to be least illuminated (56 lux at 11:00 am of February 27). The building being oriented 27°N with sun shading devices on the south and its large openings lights the space with more than required illumination.

6.3 Simulation results

Simulation of building gives the light level at different part of the floor. The following simulated results demonstrate the lighting level for 2 pm of March 2 at the second floor considering desk height at 2′-8″ above the floor.

6.3.1 Case I: Base case

The building was simulated using the existing site features such as opening details, surrounding features, materials used in constructions and their properties as well as the orientation of the building. It was found that North, north-west, west and south-west has high lighting level above 1000 lux while the lowest is at point J which is 206 lux. The image below shows the pattern of distribution of daylighting at desk height (2′-8″). The image represents whole floor receiving high illumination level to carry out regular office work resulting in unwanted glare to perform certain task as pc work and other works, as the light level above 750 lux is required only for clerical work and drafting technical drawings.

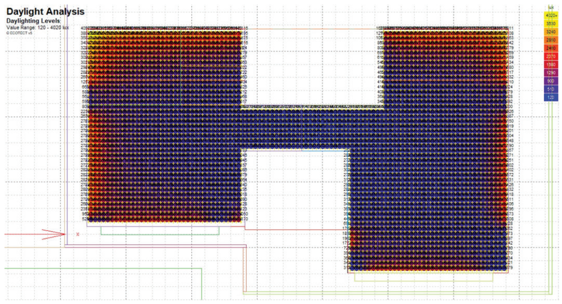

Figure 2: Daylighting pattern as per base case scenario

6.3.2 Case II: Best orientation

The building was simulated changing its original position as the per best orientation calculated by the software which is 175°N for Kathmandu. All the other features as openings details, material used, their properties and surrounding buildings were kept same. No change in the lighting level was found with the changed orientation which may be due to opening on three sides of wall with high window wall ratio which is 60%. Since all the work carried out in the office require different level of lighting level, and lighting level above the required level will cause discomfort glare to the occupants.

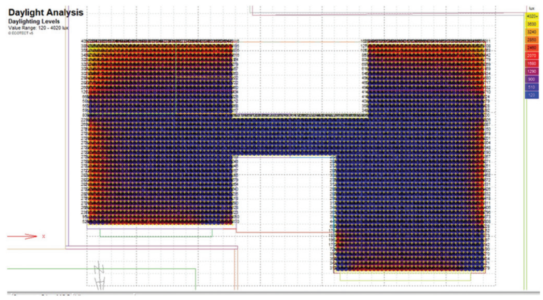

Figure 3: Daylighting pattern with best orientation

6.3.3 Case III: Conventional scenarios relating to plot orientation found in Kathmandu

In this case, the building orientation was changed relating to the most plot orientation found in Kathmandu which are north-south elongated and east-west elongated. So, the building was oriented at 0°, 90° and 180°. All three orientations gave the same reading value as the best orientation and base case, which can be result of building having high window wall ratio as either the windows are floor to floor or have high window wall ratio which is 60%. The wall in the north, north-east, and north west is glass curtain wall while on the other sides openings are with sill height of 2′-0″. And those facing south have sun shading device projected 2′-0″ from the wall surface. If the interior planning of the floor is not done considering the lighting level required to perform certain task, the space will lack visual comfort requiring use internal shading such as blinds to control glare which will disconnect the users with the nature.

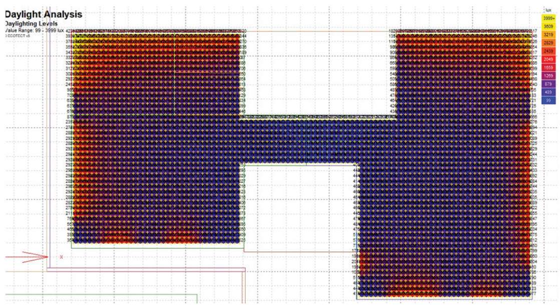

Figure 4: Daylighting pattern at 0° orientation

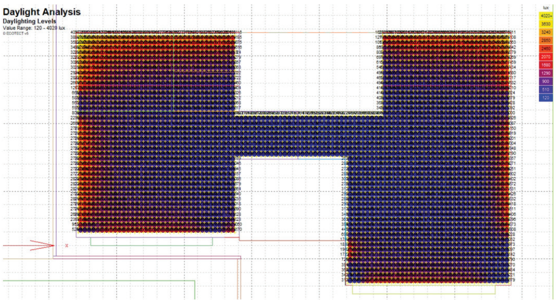

Figure 5: Daylighting pattern at 90° orientation

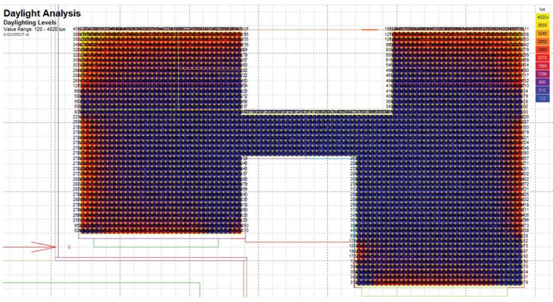

Figure 6: Daylighting pattern at 180° orientation

6.3.4 Comparison of simulation data

All the scenario had same modelling criteria during simulation other than the orientation. The simulated results of five different cases have little to no difference which may be result of openings in the building, their size, proportion and location as the building and high glazing in all of its facades. There is variation in reading in the lighting level of base case and that of best orientation and conventional scenario. These values differ with less numbers though the building was rotated to various orientation as shown in the table below.

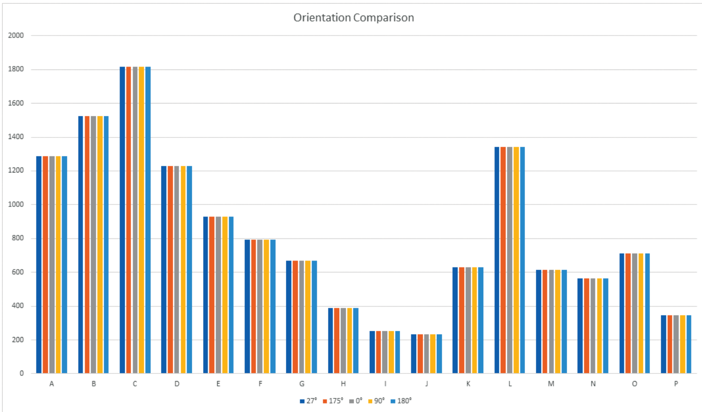

Figure 7: Graph showing comparison of orientation

Table 5: Comparison of daylighting with respect to various orientation

Points	Orientation				
	27°	175°	0°	90°	180°
A	1286	1286	1286	1286	1286
B	1524	1524	1524	1524	1524
C	1816	1816	1816	1816	1816
D	1229	1229	1229	1229	1229
E	929	929	929	929	929
F	793	793	793	793	793
G	667	667	667	667	667
H	389	389	389	389	389
I	254	289	289	289	289
J	234	234	234	234	234
K	631	663	663	663	663
L	1340	1340	1340	1340	1340
M	613	613	613	613	613
N	563	563	563	563	563
O	711	711	711	711	711
P	347	347	347	347	347

6.3.5 Validation of Autodesk Ecotect 2011 data analysis

To verify the result of daylighting of Ecotect simulation, the values were compared with observed data at the site. The average reading of the collected data was taken as light meter gave all three: maximum, minimum and average reading. Both the values are of same day, March 2 and of same time, 2:00 PM. The day and time was selected considering the average time of time and the period after which high glare was encountered as shown by reading where the lighting level increased during considered time. Observed value and simulation values were compared and evaluated as below:

Table 6: Comparison of observed data with simulation data

March - 2, 2:00 PM			
Points	Observed data	Simulation data	Difference
A	765	1286	521
B	1164	1524	360
C	2330	1816	-514
D	2630	1229	-1401
E	3200	929	-2271
F	2950	793	-2157
G	644	667	3
H	313	389	76
I	97	254	157
J	121	234	113
K	396	631	235
L	737	1340	603
M	343	613	270
N	1969	563	-1406
O	1875	711	-1164
P	295	347	52

The table and graph demonstrates the difference between site data and the simulated data, it can be due to several reasons as listed below:The accuracy of heavy duty meter is not exact (+/- (4% + 2 digits) of full scale.

- ✓ The glass used in the opening is two 3mm glass attached with laminated plastic with 20-30 % tint while 6mm standard glass was selected with visible transmittance of 0.7.

Operating condition is suggested to be (0° c – 50°c), < 80% RH.

The surface reflectivity of site and that of one used to model may also vary resulting in difference in calculation. The light meter is very sensitive device and the reading can be affected by with slight change in position and other unintended disturbance. Since the observed and simulated data vary highly, the result cannot be 100% correct and referred for major decisions. To rely fully on the result, further verification of data is required.

7. Conclusion

The literature reveals daylighting have positive impact on health and wellbeing of occupant. It has been stated by several researchers that humans react to their exposed environment as moving their work desk near to windows, drawing blinds when glare is experienced, switching on/off of lights as per lighting level of daylighting and manipulation of blinds. In the daylighting analysis of the building, it was found that changing the orientation of the building with high window wall ratio and bilateral opening has no effect for daylighting which aligns with the finding of Munoz, Esquivias, Moreno, Acosta and Navarro. The best orientation for Kathmandu is 175° N but changing the orientation of building with window wall ratio greater than 60% presents no impact on daylighting level which deduce that daylighting level is also influenced by opening size, opening orientation and its design. This hypothesis can be tested to see if such is true.

Conflict of interest

Not declared by the author(s).

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Appendices

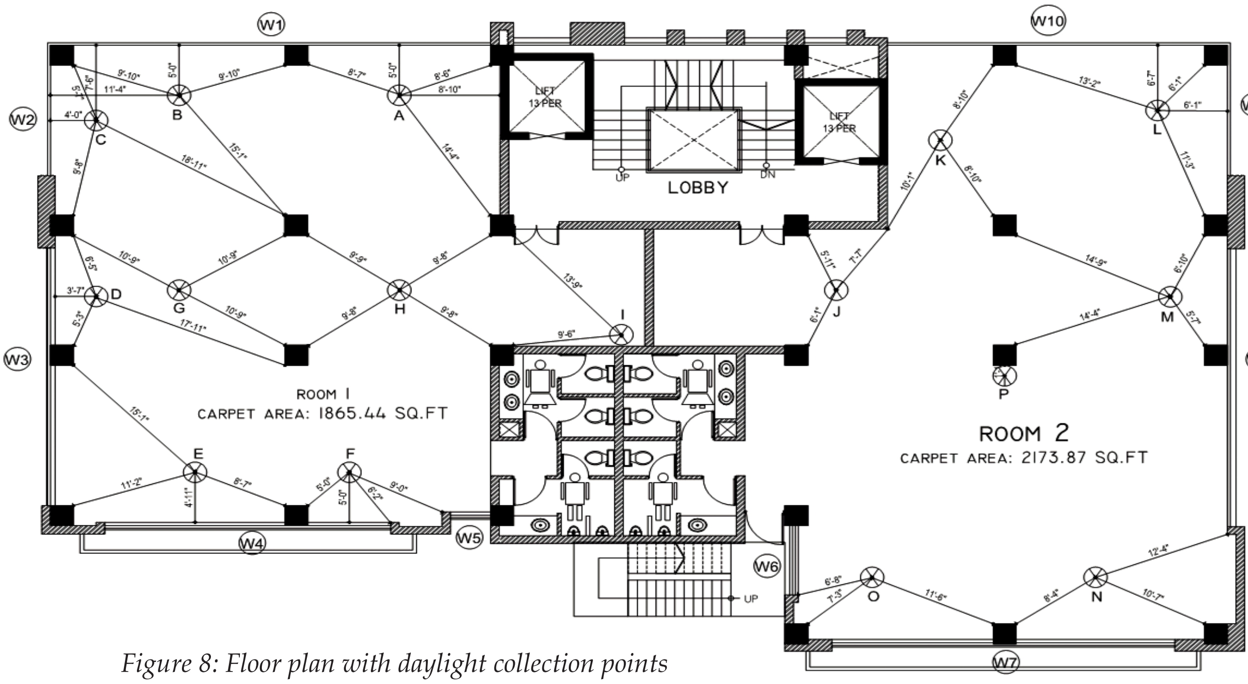

Figure 8: Floor plan with daylight collection points

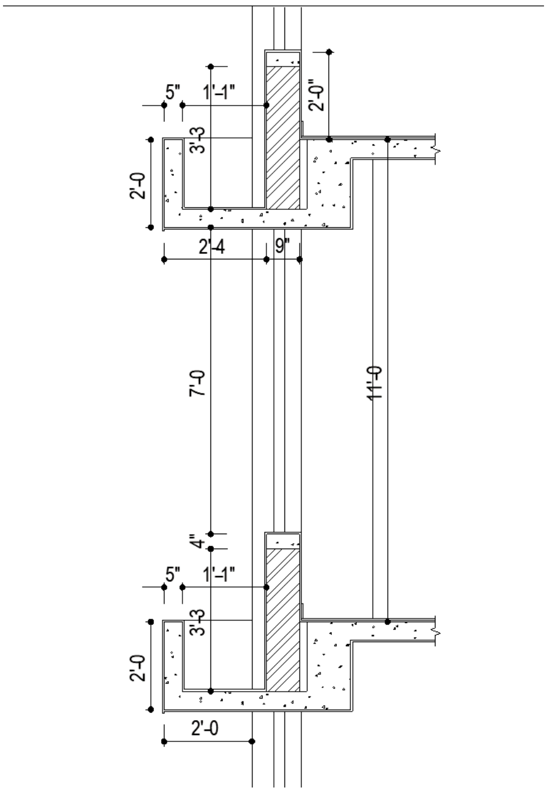

Figure 9: Window section on south with sun shading device

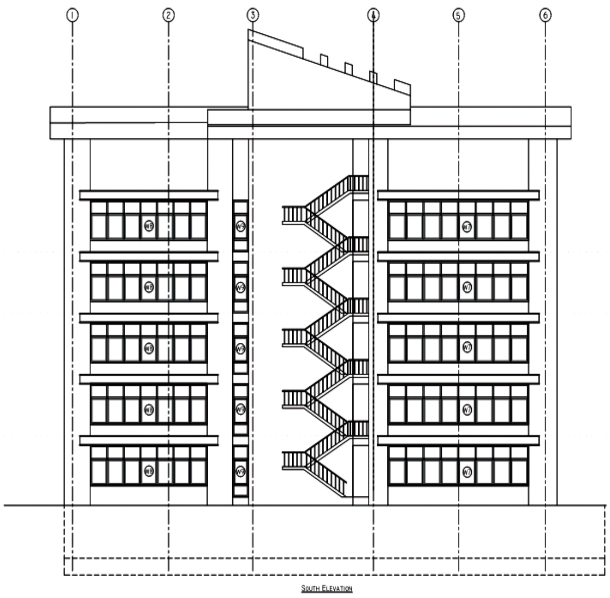

Figure 10: South elevation

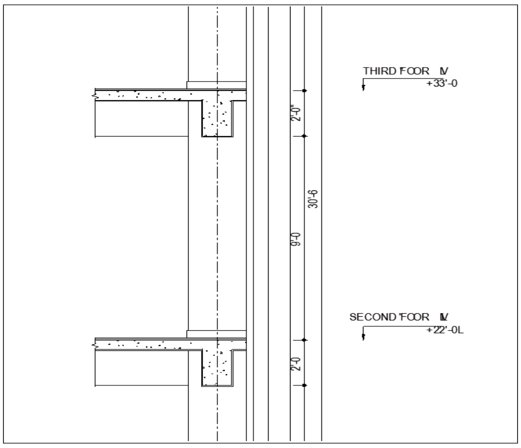

Figure 11: Window section on north with floor to floor glazing

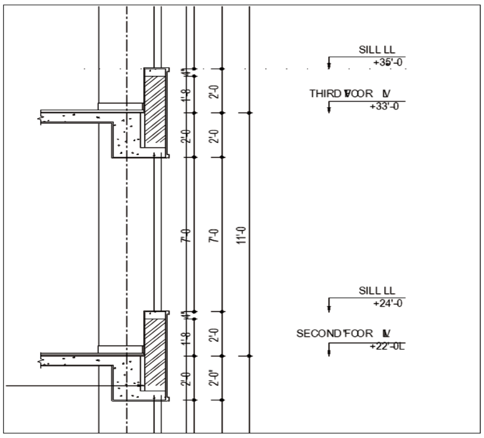

Figure 12: Window section on east and west

Table 7: Field survey data of February 27

February 27									
	11:00 AM			2:00 PM			5:00 PM		
Point	Max	Min	Avg.	Max	Min	Avg.	Max	Min	Avg.
A	1072	1066	1066	1009	959	972	589	577	587
B	1176	1144	1176	1407	1369	1392	3189	3170	3177
C	1145	1124	1148	2580	2460	2500	3760	3740	3755
D	399	364	368	3080	2790	2860	3300	3289	3297
E	2060	1990	2030	3460	2940	2940	2383	2367	2367
F	1790	1595	1595	3600	3040	3460	2132	2112	2124
G	335	342	352	709	698	699	1858	1845	1845
H	229	213	213	286	272	272	297	294	296
I	59	56	56	87	83	85	54	53	54
J	105	96	100	121	119	119	62	59	61
K	911	881	881	284	259	271	154	147	152
L	1817	1734	1795	624	583	607	462	457	457
M	1470	1405	1452	397	380	383	142	133	139
N	1950	1889	1910	2350	2280	2298	2050	2021	2033
O	2340	2160	2160	1801	1685	1705	383	377	379
P	298	266	284	100	94	95	153	144	149

Table 8: Field survey data of March 1

March 1									
Time	11:00 AM			2:00 PM			5:00 PM		
Point	Max	Min	Avg.	Max	Min	Avg.	Max	Min	Avg.
A	1016	838	1049	1206	1148	1163	723	708	716
B	1329	1244	1328	1321	1231	1291	3260	2700	2910
C	1363	1329	1331	3470	3300	3400	4000	3770	3850
D	1219	1152	1235	3430	3190	3400	3770	3080	3580

E	2500	2370	2520	3400	3140	3270	3190	2870	3160
F	2020	1930	1970	2910	2640	2820	2780	2350	2760
G	372	363	375	734	657	677	2140	1950	1970
H	219	207	207	303	295	298	318	251	254
I	79	76	77	97	95	99	60	60	60
J	109	107	112	131	129	131	67	66	66
K	485	453	483	371	349	359	169	158	163
L	1898	1841	1857	960	921	949	470	446	454
M	1207	1163	1204	355	323	350	159	156	158
N	1732	1693	1698	2400	2170	2510	1989	1857	1869
O	1812	1768	1818	1997	1888	1942	485	461	480
P	269	258	260	269	228	267	160	155	155

Table 9: Field survey data of March 2

March 2									
Time	11:00 AM			2:00 PM			5:00 PM		
Point	Max	Min	Avg.	Max	Min	Avg.	Max	Min	Avg.
A	1329	1240	1342	903	765	765	660	615	657
B	1222	1163	1171	1122	1048	1164	4510	4050	4460
C	1442	1421	1445	2230	2150	2330	5770	5410	5410
D	1343	1276	1317	2770	2630	2630	5560	4340	4340
E	2790	2670	2830	3230	3200	3200	1301	1260	1287
F	2110	2010	2030	3010	2850	2950	1208	1166	1169
G	528	514	519	658	644	644	3390	3190	3300
H	302	234	268	321	307	313	397	391	395
I	79	77	79	99	97	97	84	83	83
J	129	123	127	121	116	121	89	85	89
K	536	504	542	405	385	396	149	136	136
L	1950	1920	1970	772	722	737	476	456	456
M	1054	977	1035	351	341	343	207	204	204
N	1335	1269	1285	1929	1822	1969	3230	3030	3120
O	1707	1621	1621	1907	1854	1875	585	578	579
P	249	239	241	306	292	295	212	205	210

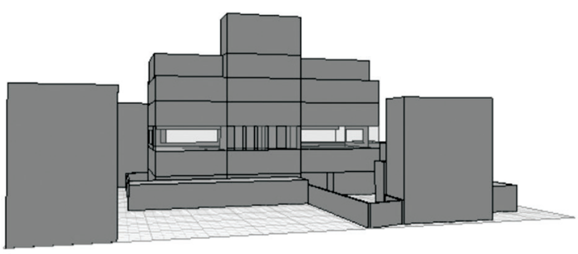

Figure 14: North view

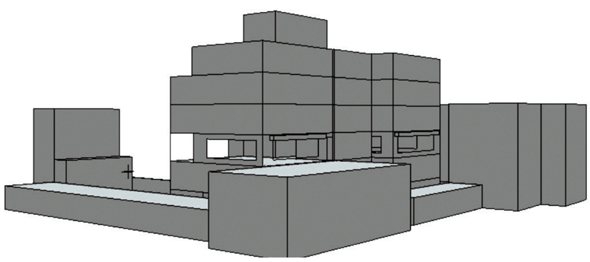

Figure 15: South east view