Enhancing Day-light through Staircase in a Single Unit Residence

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ABSTRACT

For energy conservation and visual comfort in buildings, Daylighting stands as a useful source. In Dhaka city, the indoor spaces of a many residences do not get proper daylight as other buildings surround them from at least 2/3 sides. So, the staircase (if properly designed) can be a good source of natural light during daytime for at least the single-unit residences. The research aims to study the effectiveness of different window conditions and horizontal skylight configurations at the staircase to enhance the daylight condition for the indoor spaces of a single-unit residence. Computer-based software does the Daylight simulation. In the beginning, the model of the case room with a staircase was developed in ECOTECT. The existing lighting condition was analyzed. For generating realistic lighting levels, to validate and crosscheck the ECOTECT results, these models were exported to RADIANCE Synthetic Imaging software. Finally, the performance of different options was evaluated. It is expected that the outcome of this research will help architects and designers to consider the staircase as a lighting device to improve the daylight condition of the indoor spaces of the single-unit residences.

Key Words: Daylighting, Staircase, lighting device, window configurations, skylight configurations, simulation, ECOTECT, RADIANCE

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INTRODUCTION

Daylight is an integral part of sustainable building design. Despite the abundant resource of natural light in the tropics (Ahmed and Joarder, 2007), spaces like- dining space as well as other indoor spaces in most of the buildings in Dhaka experience poor daylight conditions for most of the times. Studies show daylight has a significant impact on individuals' productivity, health, and behavior (Nicklas and Bailey, 1995). In most cases, indoor spaces especially dining spaces (located in a compact urban context of Dhaka) fail to provide adequate daylight during the daytime. Without proper daylight and outdoor views, the use of artificial lighting for prolonged period may harm individuals' body and mind.

Most of the residences in a gridiron pattern planning, do not get proper lighting as 2/3 sides of them are occupied by other buildings. It becomes troublesome to manage daylight into the indoor spaces i.e. dining room as in most of the dining rooms in these planning are located in the middle of the house surrounded by other living spaces. A duplex house can be a solution by positioning the staircase and designing its openings properly so that the staircase may work as a lighting device for the indoor spaces. The examples of daylight simulation presented in this paper would help designers to be more aware of designing staircases as a lighting device in single-unit residences to take the most advantage of daylight- to improve overall visual comfort and save energy for lighting purposes.

Literature Synthesis

Daylight provides a continuous spectrum of light, which enhances visual performance. People will tolerate much lower luminance levels of daylight compared to artificial light, particularly in diminishing daylight conditions at the end of the day (Baker, 2000). Despite the numerous advantages of daylight over artificial lighting, it is not always the preferred lighting solution to professionals because of the difficulties of controlling glare (direct or reflected) and overheating. Moreover, predicting and designing with the intrinsic dynamic nature of daylight is challenging for lighting designers/engineers interested in meeting specific design targets (i.e., lx values). Architects often find it too complicated to consider daylight at an early design stage and are often unable to work strategically with daylight (Dubois, 2001). In composite climates, e.g., Dhaka, designers face overcast conditions, as well as clear blue skies, during each year, and the ways and means of tackling the two circumstances are quite contrasting to each other (Ahmed, 1987). Windows with fixed horizontal overhead are suitable for overcast sky conditions, while vertical and movable devices give satisfactory result for clear skies.

National Standard

National standard According to BNBC (2006), the illumination of work areas within a building should be a minimum of 150 lux. Where work takes place over the whole utilizable area of a room, the general illumination over that area shall be reasonably uniform, and the diversity ratio of minimum to maximum illumination shall not be less than 0.7. The recommended values of illumination required for residential buildings, based on activity, are given in Table 1.

Table 1: The recommended values of illumination required for residential buildings based on activity

	Area/ Activity	**Illuminance (Lux)**
Bedrooms	General	50
	Bed- head, Dressing table	150
Dining Space	Dining table	100
	Reading (Casual)	150

Source: BNBC, 2006

Methodology

Case room selection

The criteria for the selection of the case building were-

- The location of the building should be in the urban context of Dhaka.
- The building should be in a housing having grid- iron pattern planning facing the road having three sides blocked by the other plots.
- The building will be a duplex

• The building should be designed by a qualified professional(s).
• There should be a designated space for dining.

Satisfying the above three criteria, the building at Bosila, Mohammadpur, was chosen as the case study built in the year 2016. (Figure 1 & 2)

The front road is 4.6 wide, and the entrance of the building is from the east.

Figure: 1: Interior view of the space selected for test in the case building

Figure 2: View of the building & staircase

The location of the living cum dining room is at the ground floor. It is a rectangular (11.8m x 11.3m) shaped room with the following characteristics (Figure 1 & 3)

Floor Area of the living cum dining room: 24.4 m2
The clear height of the living cum dining room: 2.9 m
Floor Material: 600mm x 600mm Glazed tiles.
West façade: Window; material: Transparent glass with aluminum frame
Height of the window: 1.4m with drop beam
East façade: Door; material: wood. Door Height: 2m
Door Width: 1 m
South façade: Blocked by Staircase, Kitchen, and Bedroom
North: Two windows; material: Transparent glass with an aluminum frame,
Height of the window: 1.4m with drop beam

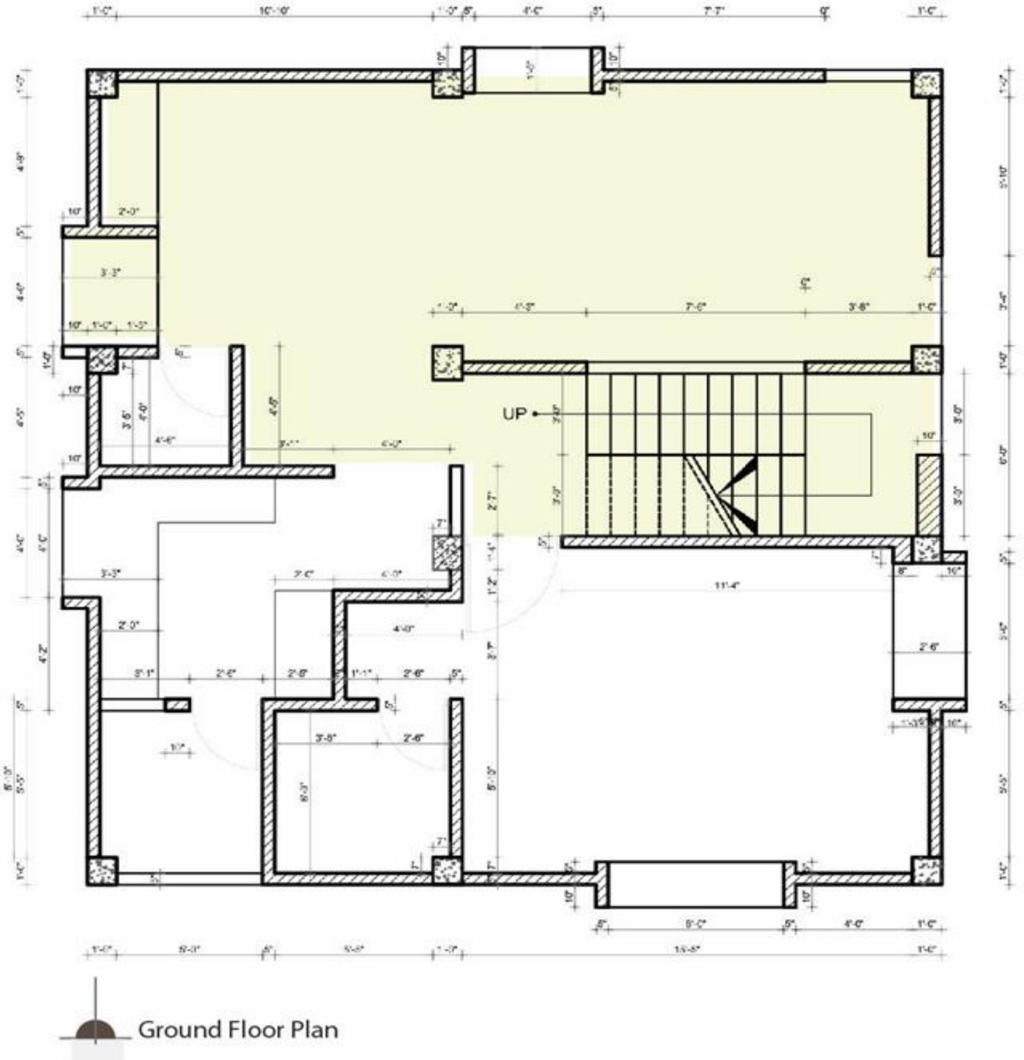


Figure 3: Ground floor plan showing dining cum living room (highlighted)

Climatic parameters

Location: Dhaka, Bangladesh (90.40 E; 23.80 N).
Time: December 21, 2.00 pm
Calculation settings: Full Daylight Analysis
Window (clean)
Sky definition: Sunny
Design sky luminance: 20,000 Lux.

Modeling parameters

The ECOTECT simulation program constructs the initial simulation model. The prevailing situation:

a 914.4mm (3 feet) x 4572mm (12 feet) vertical window on east façade with 2286mm (7′6″) x 914.4mm (3 feet) horizontal skylights on the roof.

Options were taken by doubling the width of these windows and using them separately or both and keeping the dimensions the same but using the skylight or the vertical window individually. Six different options with different shapes of windows and skylights (Figure 4) would be compared with the existing situation (Option 2).

Option 1: 914.4 mm (3 feet)x 4572 mm (12 feet) vertical window on the east façade.

Option 2 (Existing): 914.4mm (3 feet) x 4572mm (12 feet) vertical window on east façade with 2286mm (7′6″) x 914.4mm (3 feet) horizontal skylights on the roof

Option 3: 914.4mm (3 feet)x 4572mm (12 feet) vertical window on east façade, 2286mm (7′6″) x 1828.8mm (6 feet) horizontal skylights on the roof.

Option 4: 1828.8mm (6 feet) x 4572mm (12 feet) vertical window on east façade

Option 5: 182.8mm (6 feet) x 4572mm (12 feet) vertical window on east façade, 2286mm (7′6″)x 914.4mm (3 feet) horizontal skylights on the roof.

Option 6: 1828.8mm (6 feet) x 4572mm (12 feet) vertical window on east façade, 2286mm (7′6″)x 1828.8mm (6 feet) horizontal skylights on the roof .

Option 7: 2286mm (7′6″)x 1828.8mm (6 feet) horizontal skylights on roof.

Selection of test sensor points

The first step of the daylight simulation is to pick the number and location of sensor points. A common approach is to define a grid of illuminance sensors that extends throughout a lighting zone (Donepudi, 2020a). 320 points divide the living cum dining room of the case apartment for the simulation purpose (Seraj. 2018).

a) Test sensor points for simulation of dining cum living

Intersection points in the plan were coded according to letter and number system are shown in Figure 4 and Table 2

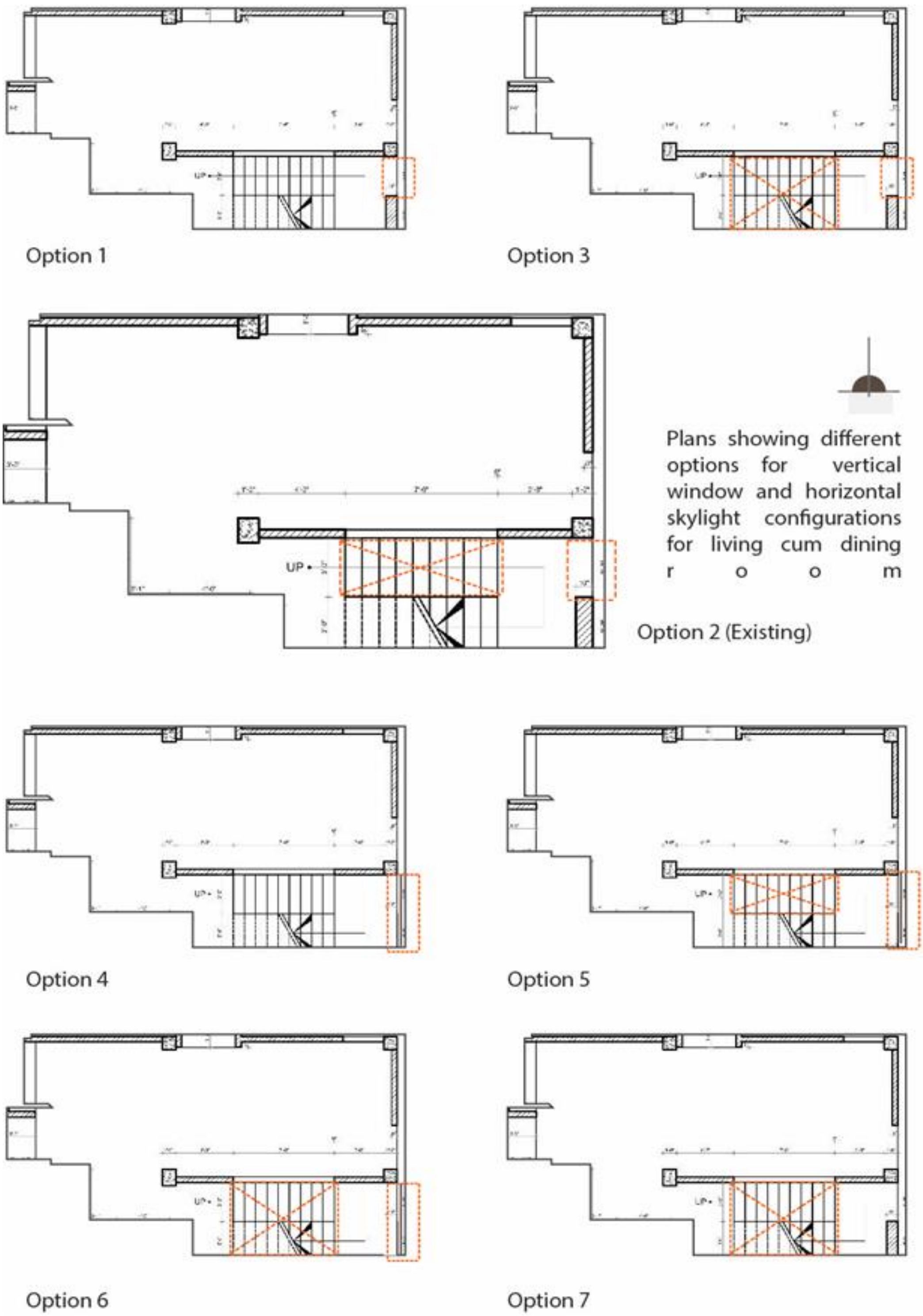


Figure 4: Six different options with different shapes of windows and skylights

Table 2: Test sensor points

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T
1										1 J	1 K	1 L	1 M	1 N	1 O	1P	1 Q	1 R	1 S	1 T
2										2 J	2 K	2 L	2 M	2 N	2 O	2P	2 Q	2 R	2 S	2 T
3										3 J	3 K	3 L	3 M	3 N	3 O	3P	3 Q	3 R	3 S	3 T
4				4 D	4 E	4 F	4 G	4H	4I	4 J	4 K	4 L	4 M	4 N	4 O	4P	4 Q	4 R	4 S	4 T
5				5 D	5 E	5 F	5 G	5H	5I	5 J	5 K	5 L	5 M	5 N	5 O	5P	5 Q	5 R	5 S	5 T
6				6 D	6 E	6 F	6 G	6H	6I	6 J	6 K	6 L	6 M	6 N	6 O	6P	6 Q	6 R	6 S	6 T
7				7 D	7 E	7 F	7 G	7H	7I	7 J	7 K	7 L	7 M	7 N	7 O	7P	7 Q	7 R	7 S	7 T
8	8A	8 B	8 C	8 D	8 E	8 F	8 G	8H	8I	8 J	8 K	8 L	8 M	8 N	8 O	8P	8 Q	8 R	8 S	8 T
9	9A	9 B	9 C	9 D	9 E	9 F	9 G	9H	9I	9 J	9 K	9 L	9 M	9 N	9 O	9P	9 Q	9 R	9 S	9 T
10	10A	10 B	10 C	10 D	10 E	10 F	10 G	10H	10I	10 J	10 K	10 L	10 M	10 N	10 O	10P	10 Q	10 R	10 S	10 T
11	11A	11 B	11 C	11 D	11 E	11 F	11 G	11H	11I	11 J	11 K	11 L	11 M	11 N	11 O	11P	11 Q	11 R	11 S	11 T
12	12A	12 B	12 C	12 D	12 E	12 F	12 G	12H	12I	12 J	12 K	12 L	12 M	12 N	12 O	12P	12 Q	12 R	12 S	12 T
13	13A	13 B	13 C	13 D	13 E	13 F	13 G	13H	13I	13 J	13 K	13 L	13 M	13 N	13 O	13P	13 Q	13 R	13 S	13 T
14	14A	14 B	14 C	14 D	14 E	14 F	14 G	14H	14I	14 J	14 K	14 L	14 M	14 N	14 O	14P	14 Q	14 R	14 S	14 T
15	15A	15 B	15 C	15 D	15 E	15 F	15 G	15H	15I	15 J	15 K	15 L	15 M	15 N	15 O	15P	15 Q	15 R	15 S	15 T
16	16A	16 B	16 C	16 D	16 E	16 F	16 G	16H	16I	16 J	16 K	16 L	16 M	16 N	16 O	16P	16 Q	16 R	16 S	16 T

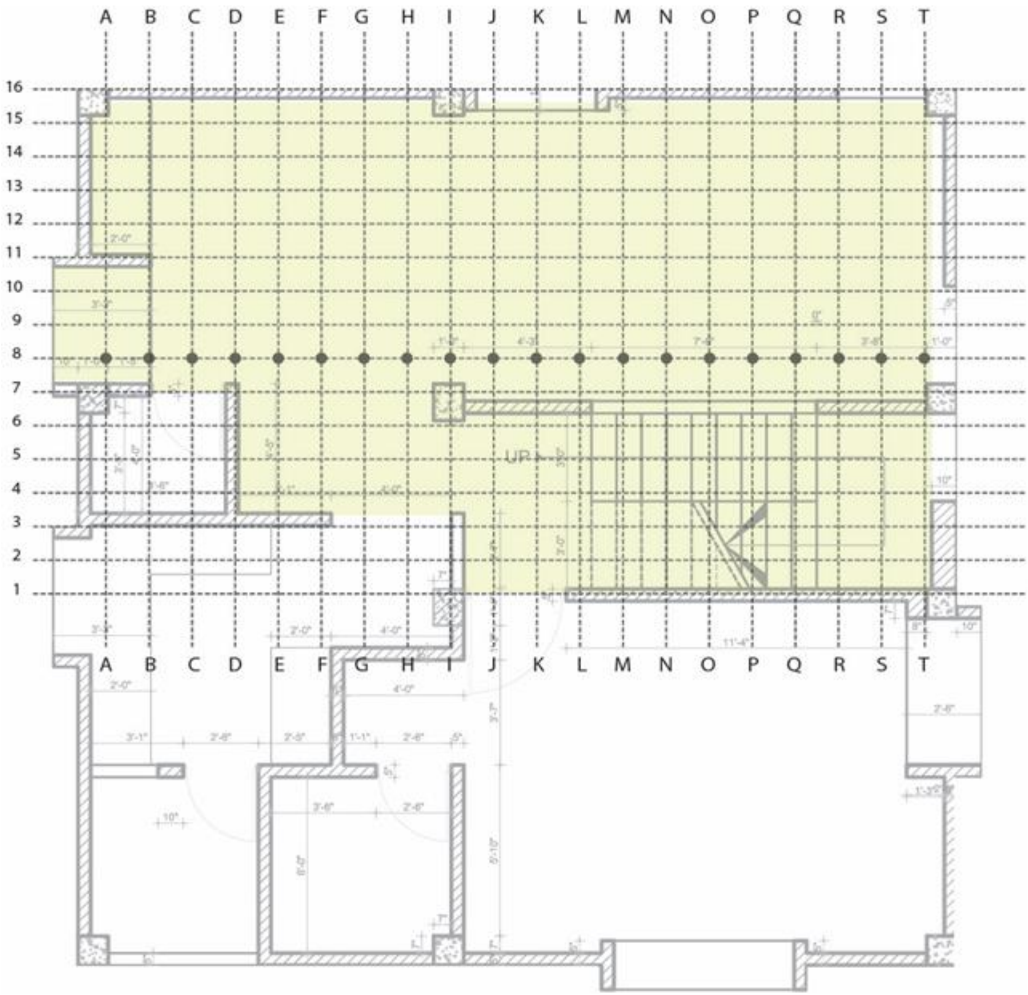


Figure 5: Location of the Test sensor points

Daylight levels in the indoor spaces were simulated by 'ECOTECT' software. Then, the model was exported to RADIANCE (Figure 6). Finally, the impact of different options was evaluated through DAYSIM.

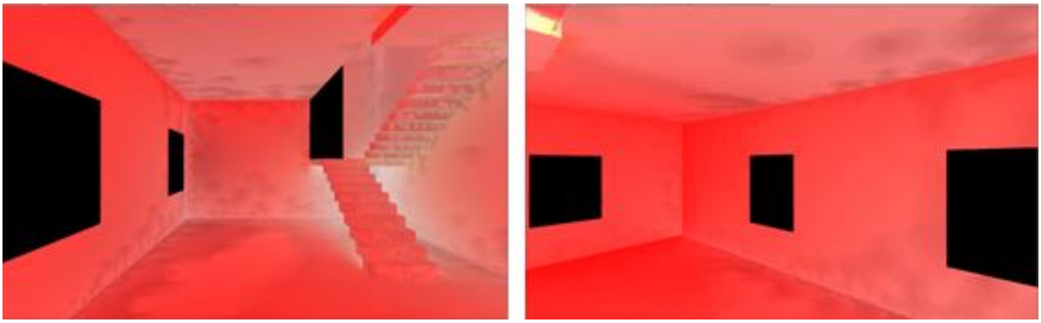


Figure 6: Daylight distribution at the case space for present situation (RADIANCE analysis)

OBSERVATIONS

Table 3: Option 1

O1	DF [%]	DA [%]	DA_{max} [%]	UDI <100 [%]	UDI 100-2000 [%]	UDI >2000 [%]
8A	1.7	51	0	1	98	1
8B	6.2	95	8	0	77	23
8C	6.2	95	13	0	76	24
8D	6.2	95	6	0	78	22
8E	4.3	94	6	0	87	13
8F	3.9	93	6	0	86	14
8G	2.7	87	5	0	90	9
8H	2.6	86	2	0	91	8
8I	2.8	90	1	0	96	4
8J	2.8	90	1	0	96	4
8K	3	91	0	0	100	0
8L	2.9	88	1	0	96	3
8M	2.9	88	0	0	100	0
8N	2.8	86	0	0	100	0
8O	3.2	90	0	0	99	1
8P	3.2	90	0	0	99	1
8Q	2.7	76	0	0	100	0
8R	2.5	72	4	0	93	7
8S	2.2	71	0	0	100	0
8T	1.5	31	0	1	99	0
Avg.	3.31	82.9	2.65	0.1	93.05	6.7

Table 3 shows, sensor points 8B, 8C, 8D provided the highest DF of 6.2% with the highest DA 95%. Sensor point 8A, 8K, 8M, 8N, 8O, 8P, 8Q presented the lowest DA max of 0%, whereas sensor points 8C provided the highest DA max of 13%. The same sensor points 8K, 8M, 8N, 8Q, 8S provided the highest UDI100-2000 [%] value and lowest UDI>2000 [%] value. 8B- 8S provided the lowest UDI<100 [%]. The same process is repeated for the rest of the options, and the following tables show the respective outputs. [Tables (4-9) for Options 2- 8].

Table 4: Option 2 (Existing)

O2	DF [%]	DA [%]	DA max [%]	UDI <100 [%]	UDI 100-2000 [%]	UDI >2000 [%]
8A	1.6	26	0	7	93	0
8B	6.1	85	8	0	76	23
8C	6.3	91	14	0	76	24
8D	4.2	78	6	0	85	15
8E	3.3	73	6	0	91	9
8F	2.7	75	5	0	93	6
8G	2.2	64	5	0	94	6
8H	1.6	53	1	1	95	4
8I	1.1	27	0	4	96	0
8J	1.1	29	4	4	89	6
8K	1.9	65	4	1	92	7
8L	1.9	59	7	1	90	10
8M	2.6	67	7	0	89	11
8N	1.8	45	3	1	95	5
8O	2.2	57	3	0	95	5
8P	2.5	64	7	0	89	10
8Q	2.5	58	7	0	88	11
8R	2.1	47	5	0	93	7
8S	2.1	48	5	0	93	7
8T	1.9	41	5	1	92	7
Avg.	2.58	57.6	5.1	1	90.2	8.65

Table 5: Option

03	DF [%]	DA [%]	DA max [%]	UDI <100 [%]	UDI 100-2000 [%]	UDI >2000 [%]
8A	2	64	0	1	98	1
8B	6.4	93	8	0	75	25
8C	7.2	96	14	0	70	30
8D	5	96	6	0	84	15
8E	4.6	95	6	0	87	12
8F	3.6	92	6	0	90	10
8G	2.9	89	5	0	90	9
8H	3.1	90	2	0	91	8
8I	3.6	93	1	0	90	10
8J	4.7	95	7	0	79	21
8K	5.7	95	6	0	73	27
8L	5.8	96	9	0	67	33
8M	6.3	96	9	0	65	35

8N	5.1	94	4	0	77	23
8O	5.2	94	4	0	76	24
8P	4.5	90	8	0	78	22
8Q	4.5	90	8	0	77	22
8R	4.2	86	10	0	77	22
8S	3.8	84	6	0	86	14
8T	3.3	79	5	0	88	11
Avg.	4.57	90.35	6.2	0.05	80.9	18.7

Table 6: Option 4

O4	**DF** [%]	**DA** [%]	**DA** max [%]	**UDI** <100 [%]	**UDI** 100-2000 [%]	**UDI** >2000 [%]
8A	2.4	72	1	0	94	5
8B	7.1	97	10	0	61	38
8C	7.2	97	15	0	60	40
8D	6	97	7	0	70	30
8E	4.7	97	7	0	82	17
8F	4.5	96	6	0	85	15
8G	4	95	7	0	84	15
8H	3.2	93	4	0	90	10
8I	3.2	93	2	0	94	5
8J	4	96	3	0	85	15
8K	3.8	94	1	0	89	11
8L	3.5	94	1	0	92	7
8M	3.4	92	3	0	95	5
8N	3.3	90	3	0	95	5
8O	2.9	82	0	0	99	0
8P	2.5	74	0	0	100	0
8Q	2.6	76	0	0	100	0
8R	2.2	64	4	0	93	6
8S	2.4	70	0	0	100	0
8T	2	62	0	0	100	0
Avg.	3.74	86.55	3.7	0	88.4	11.2

Table 7: Option 5

O5	**DF** [%]	**DA** [%]	**DA** max [%]	**UDI** <100 [%]	**UDI** 100-2000 [%]	**UDI** >2000 [%]
8A	1.9	61	1	1	95	5
8B	6.7	96	10	0	66	34
8C	6.9	96	15	0	66	34
8D	6.7	96	7	0	69	31
8E	4.7	97	7	0	80	20
8F	4.4	96	6	0	83	17
8G	3.7	94	7	0	88	11

8H	3.6	94	4	0	88	11
8I	3.9	95	3	0	91	9
8J	4.1	95	8	0	81	19
8K	3.7	95	6	0	86	14
8L	4.4	95	9	0	77	22
8M	3.8	92	9	0	84	15
8N	3.7	91	7	0	87	12
8O	3.7	87	3	0	87	13
8P	3.4	84	7	0	83	17
8Q	3.7	87	7	0	81	18
8R	3.6	86	9	0	80	19
8S	2.5	72	5	0	92	7
8T	2.2	63	5	0	92	7
Avg.	4.06	88.6	6.75	0.05	82.8	16.75

Table 8: Option 6

O6	**DF** [%]	**DA** [%]	**DA** max [%]	**UDI** <100 [%]	**UDI** 100-2000 [%]	**UDI** >2000 [%]
8A	1.9	63	1	1	94	5
8B	6.8	96	10	0	66	33
8C	7	97	15	0	62	38
8D	6.1	96	7	0	71	29
8E	4.9	97	7	0	77	22
8F	4.6	96	6	0	81	19
8G	3.7	96	7	0	88	12
8H	3.9	96	4	0	87	13
8I	4.5	96	3	0	80	19
8J	4.9	97	8	0	74	25
8K	5.5	97	7	0	67	33
8L	5.9	97	10	0	63	37
8M	5.1	95	11	0	73	27
8N	5.1	95	8	0	73	26
8O	5.5	95	4	0	71	29
8P	5.4	95	8	0	71	29
8Q	4.6	91	8	0	75	24
8R	4.7	91	10	0	74	26
8S	4.1	87	6	0	84	16
8T	3.3	79	5	0	88	11
Avg.	4.87	92.6	7.25	0.05	75.95	23.65

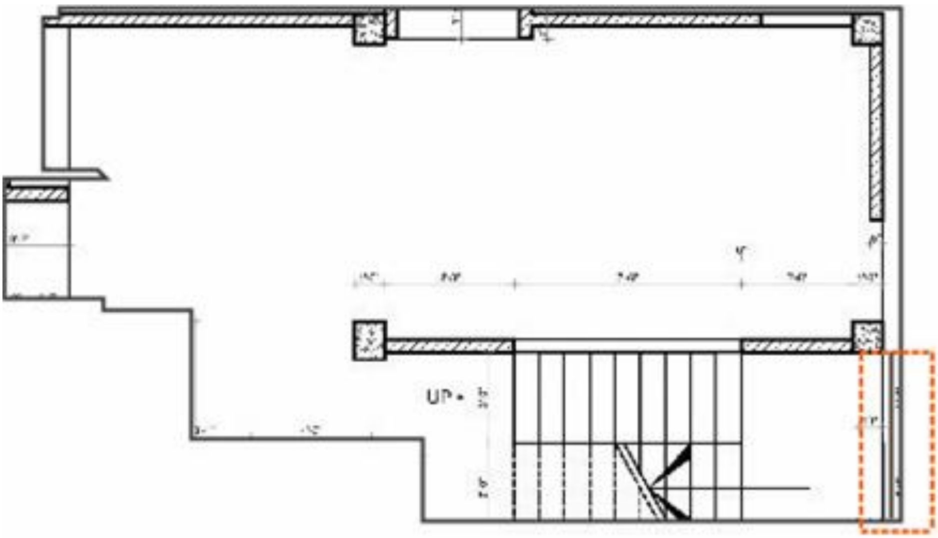
Table 9: Option 7

O7	**DF** [%]	**DA** [%]	**DA** max [%]	**UDI** <100 [%]	**UDI** 100-2000 [%]	**UDI** >2000 [%]
8A	1.9	70	0	3	97	0

8B	6.4	96	14	0	75	25
8C	6.3	97	17	0	75	25
8D	5	96	9	0	81	19
8E	4.3	95	6	0	85	15
8F	2.8	95	6	0	94	6
8G	2.6	94	5	0	94	6
8H	2.6	94	3	0	95	5
8I	3	95	0	0	99	1
8J	3.2	95	7	0	91	9
8K	3.3	94	7	0	91	9
8L	3.5	95	9	0	87	12
8M	3.7	94	10	0	85	14
8N	3.8	95	5	0	91	8
8O	3.8	95	5	0	91	9
8P	3.9	95	10	0	85	15
8Q	3.8	94	10	0	86	14
8R	3.6	94	7	0	87	12
8S	3.6	94	8	0	87	12
8T	3.1	93	7	0	89	10
Avg.	3.71	93.5	7.25	0.15	88.25	11.3

Ratings of results for Different Options

The rating system can be used to find the most feasible window configuration among these seven configurations using the dynamic metrics (Donepudi, 2018). Table 10 presents the rating system. Rating points were considered as 6 point to 1 point, to suggest the configurations from 1st to 6th place (Donepudi, 2020b).



Option 4

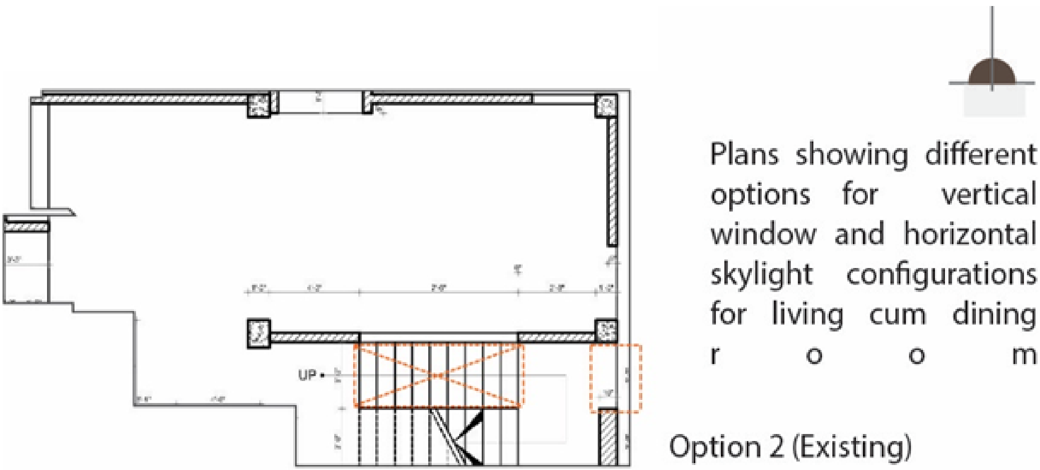
Table 10: Rating points distribution for different dynamic metrics of seven window options

Option	DF [%]	Ra-ting	DA [%]	Rating	DA max [%]	Rating	UDI <100 [%]	Rating	UDI 100-2000 [%]	Rating	UDI >2000 [%]	Rating	Total score	Posi tion
O1	3.3	2	82.9	2	2.65	7	0.1	2	93.05	7	6.7	7	27	2nd
O2	2.5	1	57.6	1	5.1	5	1	1	90.2	6	8.65	6	20	7th
O3	4.5	6	90.3	5	6.2	4	0.05	6	80.9	2	18.7	2	25	3rd
O4	3.7	4	86.5	3	3.7	6	0	7	88.4	5	11.2	5	30	1st
O5	4.0	5	88.6	4	6.75	3	0.05	6	82.8	3	16.7	3	24	5th
O6	4.8	7	92.6	6	7.25	1	0.05	6	75.9	1	23.6	1	22	6th
O7	3.6	3	93.5	7	7.25	1	0.15	6	88.2	4	11.3	4	25	3rd

Considering all dynamic daylight metrics, - 1828.8mm (6 feet) x 4572mm (12 feet) vertical window **(O4)** on the east façade was found superior to the other considerations. It achieved 30 points.

Whereas,

- The **existing (O2)** 914.4mm (3 feet)x 4572mm (12feet) vertical window on the east façade with 2286mm (7′6″) x 914.4mm (3 feet) horizontal skylights on the roof achieved 20 and came out to be the **least desired**.



- (O1) : 914.4mm (3 feet) x 4572mm (12 feet) vertical window on east façade might be the best solution for the existing situation

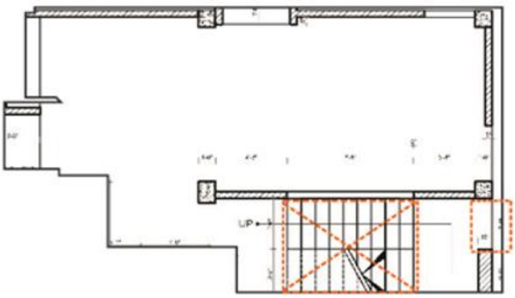
Because,

- **O4** may hamper privacy in spite of having the best rating as it faces the access road.

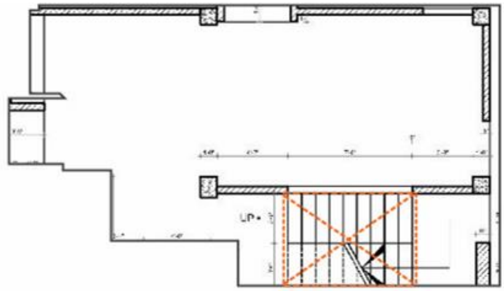
- In the case of **O2** (existing), the horizontal skylight is not providing enough support to enlighten the desired area except for the staircase.

- 2286mm (7′6″) x 1828.8mm (6 feet) horizontal skylights on the roof **(O7)** and 914.4mm (3 feet) x 4572mm (12 feet) vertical window on the east façade &

2286mm (7′6″) x 1828.8mm (6 feet) horizontal skylights on the roof **(O3)** came out to be the 3rd option.



Option 3



Option 7

Suggestions for future research

- Observation for Staircases in different locations is needed.
- There would be consideration for External shading devices.
- More research is required to find out the effective position and configuration of the staircase.
- Consideration for other types of residence along with single-unit residences is required.

CONCLUSION

Different options for vertical windows and horizontal skylights have been compared in this paper to improve daylight condition in the dining room, using computer generated simulation programs. Results indicate that both vertical windows and horizontal skylights in the staircase have the potentials to provide proper daylight distribution in the indoor spaces of the residential buildings. However, future analysis should be done to accept the fact that, the staircase may play an important role to enhance the daylight condition of the indoor spaces of a building.

REFERENCES

Ahmed, Z. N. (1987). The effects of Climate on the design and Location of windows for Buildings in Bangladesh, MPhil thesis (unpublished), Sheffield City Polytechnic.

Ahmed, Z. N. and Joarder, M.A.R. (2007). An Observation on Daylight Inclusion in the Lighting of Offices in Dhaka. Protibesh, 11(1): pp. 51-61.

Baker, N. (2000) We are all outdoor animals, Architecture City Environment, Proc. of PLEA 2000, (eds.) Koen Steemers and Simos Yannas, James & James, London 553- 55.

BNBC. (2006). Electrical & electric engineering services for buildings. Chapter 01. Bangladesh National Building Code (BNBC). Dhaka.

Donepudi, P. K. (2018). Application of Artificial Intelligence in Automation Industry. Asian Journal of Applied Science and Engineering, 7(1), 7-20.

Donepudi, P. K. (2020a). Crowdsourced Software Testing: A Timely Opportunity. *Engineering International*, *8*(1), 25-30. https://doi.org/10.18034/ei.v8i1.491

Donepudi, P. K. (2020b). Leveraging Cloud Computing and High Performance Computing (HPC) Advances for Next Generation Projects and Technologies. *American Journal of Trade and Policy*, *7*(3), 73-78. https://doi.org/10.18034/ajtp.v7i3.499

Dubois, M. C. (2001). Impact of Shading Devices on Daylight Quality in Offices: Simulations with Radiance, Report TABK—01/3062, Lund University, Dept. of Construction and Arch., Sweden.

Nicklas, M. and Bailey, G. (1995). Analysis of the performance of students in daylit schools in Proceedings of the National Passive Solar Conference, 1996, pp. 132-137.

Seraj (2018) Configuration Of Windows And Partition Walls Of Residential Apartments To Improve Daylight Condition In Dining Spaces

DECLARATION

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