Retrofitting for Daylight Enhancement of Institutional Buildings

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Abstract

Retrofitting offers prospects for enhancement of daylight in built spaces. However, the quantum of its effect is a function of the architectural features of the space and the possibilities of its modification. The study sought to ascertain the extent to which some architectural modifications and strategies could improve daylight in the corridors on the upper floor of some new buildings in Modibbo Adama University of Technology, Yola. The simulated experimental design deployed lux meter to evaluate lighting levels at selected points on the floor of the existing corridors, and outside the building. Each of the corridors measured about 29.5m long, 2.0m wide and 3.0m high. Light levels were also observed on the corresponding points in and outside of the space in an architectural model of upper part of the building constructed at scale 1:25. Different roofs with monitor light of various sizes over the corridor were mounted on the model; reflective surfaces were introduced on the corridor walls and ceiling. Daylight levels were observed in each case with and without the reflective surfaces under four different lighting conditions. Data generated were analysed using descriptive statistics including percentage, mean and range. Daylight factors were estimated for different cases of the space, and used as a measure of daylight performance. Results showed over 2500% improvement of daylight factor in the corridor, from 0.61% in the existing situation to 16.3% in the proposed monitor roof opening about 12% of corridor floor area, and reflective wall surfaces. The study recommends employing retrofitting concepts on the existing buildings to enhance daylight factor in the corridors.

Keywords: Corridors, Daylight Factor, Retrofitting, Institutional Buildings

INTRODUCTION

Building retrofitting is the act of modifying an existing building in order to improve its energy efficiency through reduced system running and maintenance cost, and to enhance occupant's level of satisfaction as well as measurable return of investment (Martine, 2016; Rabani, Madessa & Nord, 2017). According to Zhenjun *et al*. (2012), retrofitting should be considered as one of the main approaches to achieving sustainability in the built environment at relatively low cost and high uptake rates. This is largely because existing buildings consume about 40% of final energy used in most countries (Janda, 2009). Artificial lighting is identified as one of the major sources of energy consumption corresponding to 15-60% of the final energy use in the buildings (Spyropoulos & Balaras, 2011; Jason and Thomas, 2007). The world's stock of old buildings far outnumbers the new ones (Thaleia and Ulrich, 2011); thus retrofitting the old buildings will help significantly reduce electricity demand for illumination in a room by more than 50% (Jamaludin *et al*, 2015; Lechner, 2009). Thus, day-lighting design becomes a significant part of building retrofitting especially when building component that have influence on its day lighting performance are replaced (Christoffersen *et al*, 2000).

The problem of building retrofit optimization include the determination, implementation and application of the most cost effective technologies to achieve enhanced energy performance while maintaining satisfactory service levels and acceptable indoor thermal comfort, under a given set of operating constraints (Ma, Cooper, Daly & Ledo, 2012). Finding the optimum retrofit strategy, according to Rabani *et al.* (2017), is a complex procedure that needs to be critically investigated. Ray (2004) highlighted three main types of architectural retrofit strategies: (i) stabilization strategy consisting of a set of incremental interventions that do not fundamentally modify either the substance or the appearance of the building; (ii) the substitution strategy which consisting of a complete change of certain elements transforming simultaneously the substance and appearance of the building; (iii) the double-skin facade strategy which consists of partially stabilizing the existing facade and adding a new glass skin, resulting in a complete metamorphosis of the building's appearance but maintaining a significant part of its original substance.

The conscious use of natural light in non-residential buildings such as educational and institutional buildings has become an important strategy to improve energy efficiency by minimizing lighting, heating, and cooling loads. Thus the use of various architectural day-lighting strategies right from conceptual design stage of a building helps considerably in the improvement of the quality of indoor space such as lightning. According to Vincenzo, Gianpiero and Luigi (2017), day-lighting is a process that makes use of daylight to achieve some expected lighting effects in buildings, such as lighting up a task area, highlighting some objects while obscuring others, or even totally avoiding its contribution under particular circumstances. Jamaludin *et al.* (2015) on the other hand, defined day-lighting as a technique that brings natural daylight into a building, through openings so that the day's natural light provides effective internal lighting. Conceptually day lighting can be distributed to interior space through openings from sides, top, or the combination of the two, and interior finishes and furnishings of adequate surface reflectance.

Michael (2008) noted that top lighting strategies in institutional buildings include skylight (horizontal glazing placed embedded in flat or sloped roofs) and roof monitors (vertical or sloped glazing raised on elevated roof planes). Choice of strategy is driven by the building type, height, aspect ratio, massing, dominant climatic conditions, site obstruction and adjacent buildings (Christoffersen, Aschehoug, Edmonds and Jakobiak, 2000). It has also been pointed out that the innovative day-lighting systems work by redirecting incoming sunlight and/or skylight to areas where it is required, and, at the same time controlling glare. These systems are particularly appropriate where an interior space is too deep for conventional windows to provide adequately uniform lighting or where there are external obstructions (Christoffersen *et al.*,2000). Jamaludin *et al.* (2015) wrote that the effectiveness of day-lighting depends on several factors, including the building architectural features (shape, window area, glazing type), the building locations the surrounding climate. Thus, daylight retrofit could be accomplished through the modification of these architectural features which might be inhibited or enhanced by the buildings structural systems (Sedor, Griffin and Konis, 2012).

Buildings as old as a century retrofitted in the last two decades are reported to be 57 to 61% more energy efficient with Energy Star ratings ranging from 92 to 98 (The New Building Institute & Preservation Green Laboratory, NBI &PGL, 2011). Other benefits of day lighting in buildings have also been investigated and reported. For instance, Kesten and Tereci (2015) studied the effect of daylight availability on visual comfort and cost of lighting electricity in educational spaces and found that students and lecturers were more alert, and ready to work under appropriate daylight visual comfort conditions. Dilay and Aysegül (2015), Martine (2016), and Jamaludin *et al.* (2015) also indicated that a higher day lighting quality can increase health, self-assessed performance, and lead to a higher job satisfaction and productivity in work environment. However, these studies are largely after the facts, being the outcomes of real life and existing building retrofits, and without any premonition of what such outcomes would probably be ahead of the real retrofitting strategies.

Various methods have been deployed to predict the potentials of building retrofit strategies. Among these are energy simulation models such as physical models, gray box and black models, multi-objective mathematical models, and building information models (Hestnes & Kofoel, 2002; Thaleia & Ulrich, 2011; Ma *et al*, 2012). With these models, operations such as energy auditing, building performance assessment, economic analysis, risk assessment and measurement, and verification of energy savings can be performed on proposed building retrofit strategies. The physical model simulation seems the most practical, faster and common method but the least applied or reported in building retrofit studies, probably due to the tedious process of making the models manually as it was written that Computer programs still remain less pliable than physical models early in the design phase and many times it is more intuitive and quicker for the designer to construct a physical study model to test the results of sun lighting effects on the built form than using a computer model (Yancey, 2010).

Modibbo Adama University of Technology Yola (MAUTECH) is replicated with existing building stock which may be suitable for retrofitting. Preliminary survey reveals poor lighting of varying degrees in most of the buildings, which may be ameliorated through architectural retrofits. Considered most critical is the corridor of the upper floor of the newly constructed buildings which is the subject of this study.

METHOD

The particular building under study is the one accommodating the Departments of Surveying/Geoinformatics and Building in Modibbo Adama University of Technology (MAUTech), Yola - Nigeria. The building has classrooms arranged around a courtyard located at the ground floor while the first floor houses offices which were arranged along a corridor facing one another as shown in figure one below.

Plate 1: An aerial view of selected building to the right with same replica to the left.

Physical measurement of parameters around the study area was conducted in which components parts that have an effect on the study were taken in to cognisance. They are floor, ceiling, walls and window in which their area was considered. This data was used to generate the architectural drawings and physical model scaled in the ratio of 1:25, using embossed paper of different colours as wall finishing, while glass and aluminium foils were used as reflective surfaces for the purpose of simulation following Nicholas (2011), that simulation involves devising a representation in a small and simplified form (model) of a system, which can be manipulated to gauge effects. This provides an artificial environment in that it does work with original materials at the same scale but calibrated with scale so as to represent the real sense so as to have reliable results. In addition, several variables constituting different roofs with monitor light of various sizes over the corridor were mounted on the model (Figures 5 and 6). Simulated experimental design was used in which a lux meter was deployed to evaluate lighting levels at eleven (11) selected points on the floor of the existing corridors, and outside the building. Each of the corridors measured about 29.5m long, 2.0m wide and 3.0m high. Light levels were also observed on the corresponding points in and outside of the space in an architectural model of upper part of the building, reflective surfaces were introduced on the corridor walls and ceiling. Daylight levels were observed in each case with and without the reflective surfaces under four different lighting conditions. Various architectural strategies were applied in which the resultant changes in lighting were noted thereby inference could be drawn in the process. Data generated were analysed with descriptive methods that include percentage, mean and range. Daylight factors were estimated for different cases of the space, and used as a measure of daylight performance. Figure (6) show sections and elevations of retrofitted upper floor showing five different sizes of roof monitors used for the simulation.

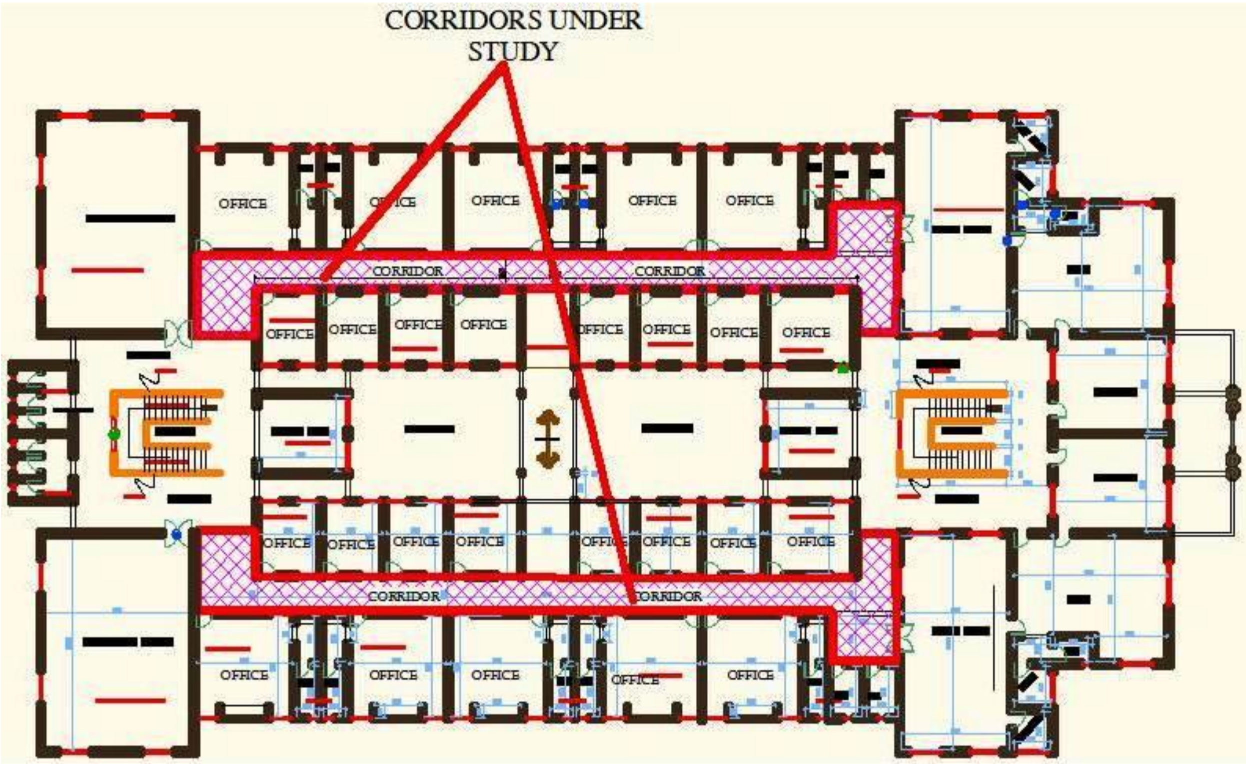


Figure 1: First floor plan of Surveying/Geoinformatics & Building Departments showing corridors under
study

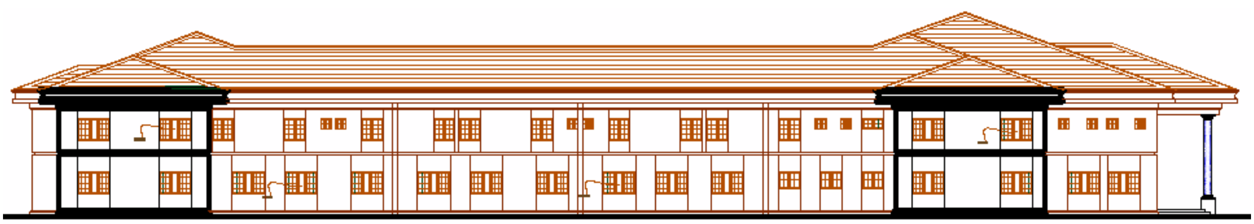


Figure 2: Typical side elevation of Surveying/Geoinformatics & Building Departments, showing windows proportions

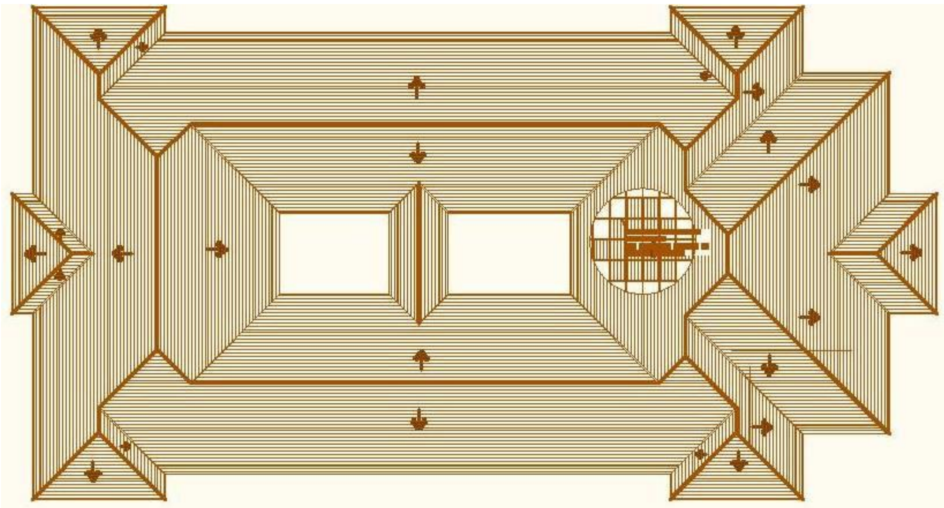


Figure 3: Roof plan of the Surveying/Geoinformatics & Building Departments

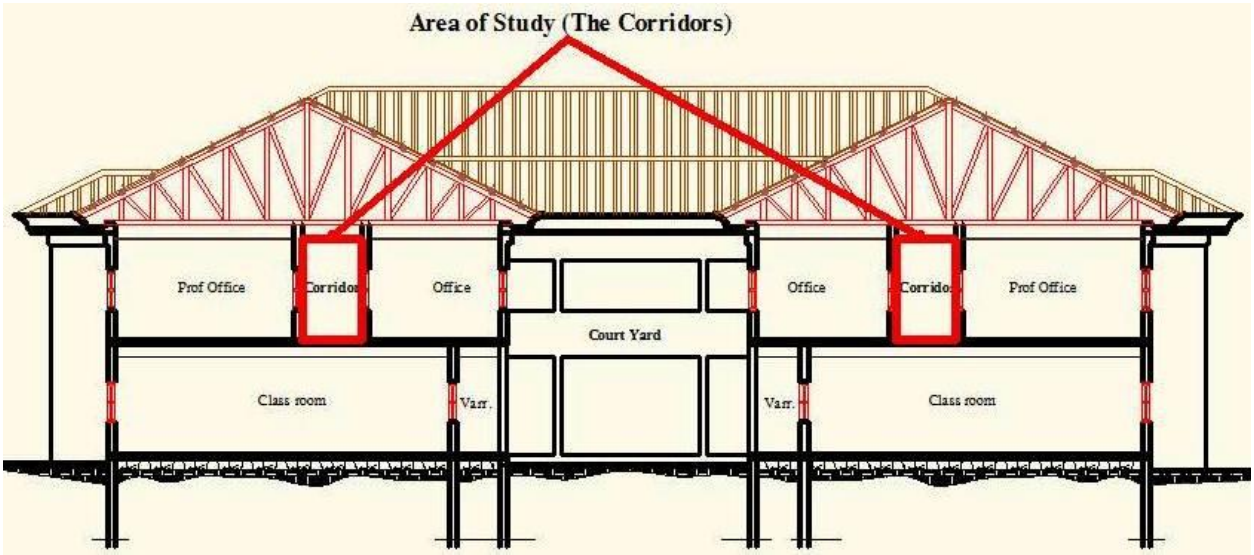
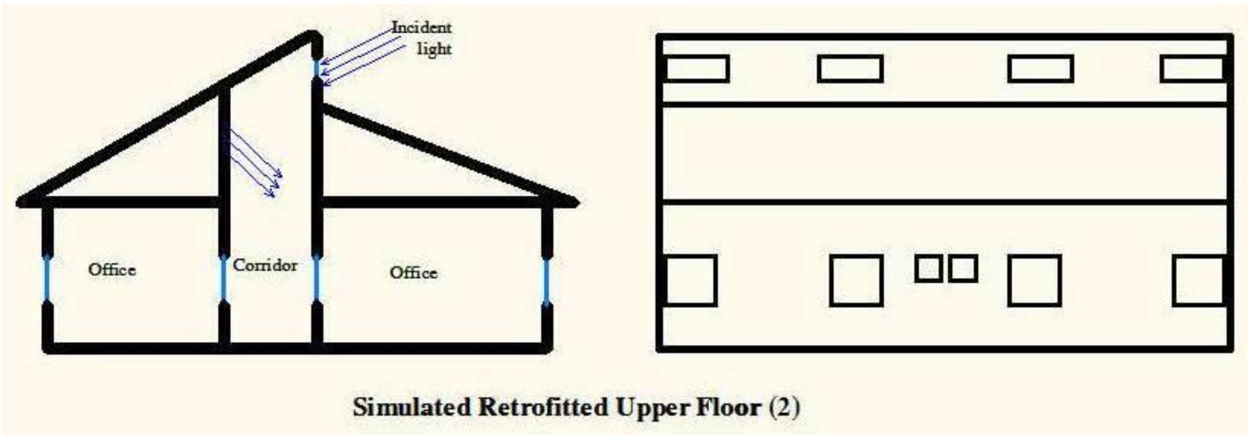
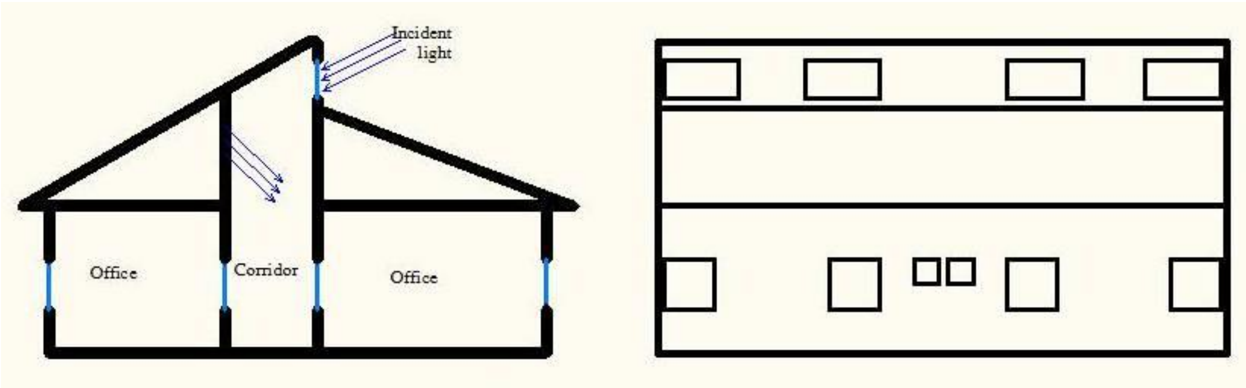
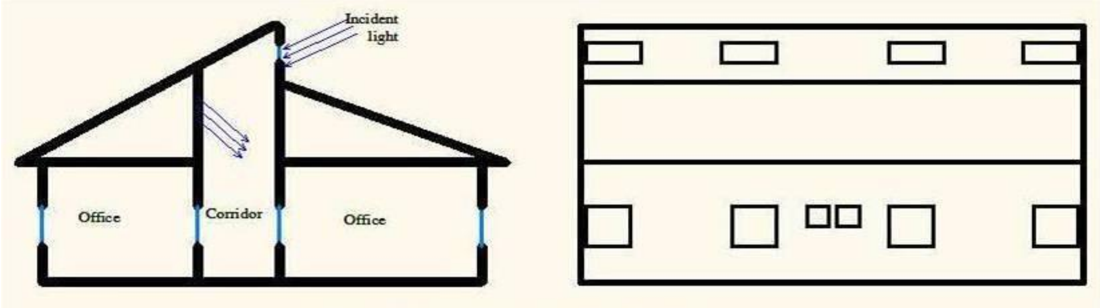


Figure 4: The building Section showing the corridors.

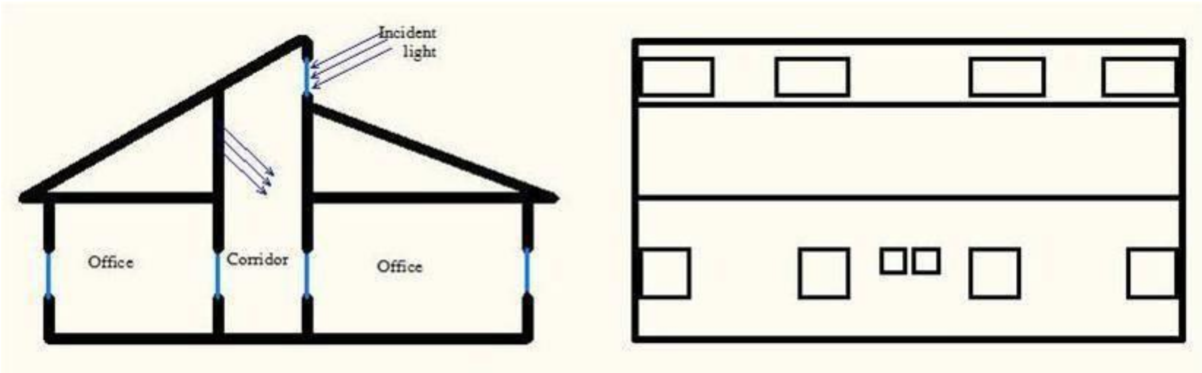




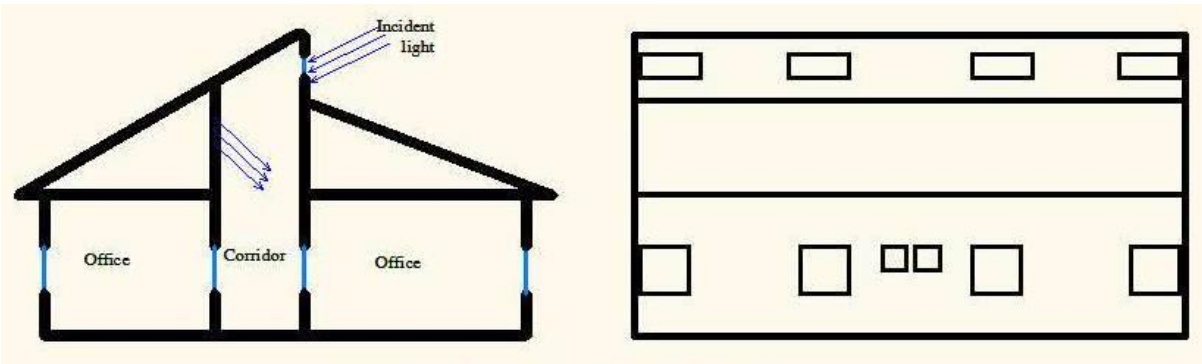
Simulated Retrofitted Upper Floor (1)



Section and Elevation of retrofitted roof monitor II



Section and Elevation of retrofitted roof monitor II



Simulated Retrofitted Upper Floor (2)

Figure 6: Section and Elevation of simulated Roof Monitor II

RESULTS AND DISCUSSION

Results

The illumination levels at eleven selected points on the floor of the lobby in the simulated (model of) section of the existing building under four daylight conditions (Table 1). The illumination levels at the selected points on the floor when roof monitors retrofit only were introduced over the lobby of the simulated section of the building were indicated in Tables 2 and 3. When reflective materials were mounted on the lobby walls of the roof monitor retrofitted lobby, the illumination levels observed at the selected points of the floor are shown in Tables 4 and 5. Figure 7 is a graphical representation of the effects of roof monitors and reflective wall materials on the daylight factor of the lobby floor.

Table 1: Simulated existing lobby illumination levels (lux) *Space daylight-condition*

	One open-side				*Two open-side*				*Three open-side*				*Four open-side*			
	a		b		a		b		a		b		a		b	
Point 1	002	009	001	027	005	012	001	024	016	047	012	165	011	019	002	043
Point 2	003	012	002	030	005	021	002	027	014	090	013	250	009	038	004	051
Point 3	003	014	004	035	006	028	006	036	019	136	029	260	011	072	005	068
Point 4	004	027	002	033	011	033	005	036	039	165	025	317	015	014	005	065
Point 5	003	027	001	031	010	034	003	035	028	148	013	318	012	063	003	068
Point 6	007	029	007	029	011	035	005	034	038	175	029	250	015	091	005	071
Point 7	003	025	003	024	009	030	005	029	041	175	028	395	011	064	006	062
Point 8	005	027	002	042	009	031	003	007	036	190	009	105	012	079	001	035
Point 9	004	024	002	018	006	028	004	019	024	152	018	223	010	047	006	041
Point 10	005	020	003	012	007	033	003	014	039	173	026	120	012	058	004	025
Point 11	004	015	002	007	007	026	002	011	055	148	028	074	013	040	003	019
Indoor mean															10.8 lux	
Outdoor mean															1778.4 lux	
Mean Daylight factor															0.61%	

Table 2: Roof monitor and reflective wall retrofit simulated lobby illumination levels

Position	*One open-side*		*Two open-side*		*Three open-side*		*Four open-side*	
	a	**b**	**a**	**b**	**a**	**b**	**a**	**b**
Point 1	315	091	038	068	072	201	033	096
Point 2	289	124	072	093	177	225	062	190
Point 3	314	144	077	115	134	281	109	145
Point 4	100	125	112	123	203	284	130	142
Point 5	120	154	125	126	222	281	141	170
Point 6	139	151	134	124	206	239	190	182
Point 7	115	117	122	194	295	218	142	111
Point 8	121	009	135	018	218	019	163	011
Point 9	093	183	107	086	230	180	104	089
Point 10	084	065	102	060	183	084	129	056
Point 11	079	038	065	042	150	063	090	036
Indoor Mean							135.1 lux	
Outdoor Mean							1932.3 lux	
Mean Daylight Factor							7.0%	

Table 3: Roof monitor retrofit simulated lobby illumination levels

Position	*One open-side*		*Two open-side*		*Three open-side*		*Four open-side*	
	A	B	A	B	A	B	A	B
Point 1	060	403	028	081	072	269	035	085
Point 2	125	333	046	085	177	275	045	136
Point 3	203	378	066	138	205	309	089	165
Point 4	522	333	098	099	265	286	090	116
Point 5	225	429	077	111	223	281	078	156
Point 6	234	396	095	106	316	273	123	134
Point 7	227	472	074	105	219	204	072	086
Point 8	304	025	069	012	257	047	098	005
Point 9	296	125	057	060	148	143	061	017
Point 10	447	026	054	040	183	072	067	015
Point 11	189	049	045	027	125	041	054	011
Indoor Mean							153.4 lux	
Outdoor Mean							1923.7 lux	
Mean Daylight Factor							8.0%	

Table 4: Average Level (lux) of each point on the basis in the model when reflective device applied

Position	*One open-side*		*Two open-side*		*Three open-side*		*Four open-side*		mean
	lux	df	lux	df	lux	df	lux	df	
Point 1	406	21.28	106	5.56	237	14.31	129	6.76	228.5
Point 2	413	21.65	165	8.65	342	17.92	252	13.21	293
Point 3	458	24.00	192	10.06	415	21.75	252	13.21	329.25
Point 4	225	11.79	235	12.32	487	25.52	272	14.26	304.75
Point 5	274	14.36	251	13.16	503	26.36	311	16.30	334.75
Point 6	281	14.73	258	13.52	445	23.32	372	19.50	339
Point 7	232	12.16	316	15.96	513	26.88	253	13.26	328.5
Point 8	130	6.81	153	7.73	237	12.42	174	9.12	173.5
Point 9	276	14.47	193	10.12	410	21.49	193	10.12	268
Point 10	149	7.81	162	8.49	267	13.99	185	9.70	19.75
Point 11	111	5.82	107	5.61	213	11.16	126	6.60	140.75
Indoor Mean								266.3 lux	
Outdoor Mean								266.3 lux	
Mean Daylight Factor								13.8%	

Illumination levels ranged from 001 to 035 lux under each of the first and second daylight condition; and from 012 to 395 lux and 03 to 079 lux respectively in the existing simulated lobby under the third and fourth daylight conditions as indicated in Table 1. The indoor mean illumination level was 10.8 the mean outdoor illumination was 1778.4 lux with a resultant daylight factor of 0.61%.

In the simulated roof monitor only retrofit lobby was considered. Illumination levels under the four conditions of daylight ranged from 009 to 315 lux, 018 to 194 lux, 019 to 295 lux and 011 to 190 lux from the first to the fourth in that order. The indoor mean illumination in the lobby of the retrofit under the four daylight conditions was 135.1 lux, while the outdoor mean illumination was 1932.3 lux with 7.0% resultant daylight factor (Table 2 and Figure 7). When the size of the roof monitor was increased, the indoor mean illumination level also increased to 153.4 lux with a resultant daylight factor of 8.0%.

When a reflective material was applied on the walls of the initial roof monitor retrofit, illumination levels under the four daylight conditions ranged separately from 111 to 458 lux, 106 to 316 lux, 213 to 513 lux and 126 to 372 lux. The indoor mean illumination level was

266.3 lux with the outdoor mean illumination level at 1929.7 lux and a resultant daylight factor of 13.8% (Table 4 and Figure 7). Indoor mean illumination level increased to 312.6 lux with a resultant daylight factor of 16.3% in the lobby with the reflective material and larger roof monitor opening (Table 5 and Figure 7).

Table 5: Average Level (lux) of each point on the basis when fenestration sizes increases

	One open-side		*Two open-side*		*Three open-side*		*Four open-side*		mean
	lux	df	lux	df	lux	df	lux	df	
Point 1	463	24.33	109	5.73	341	17.92	120	6.31	258.25
Point 2	458	24.33	131	6.88	452	23.75	181	9.51	305.5
Point 3	581	30.53	204	10.72	514	27.01	254	13.35	388.25
Point 4	855	44.93	197	10.35	551	28.95	260	13.66	452.25
Point 5	654	34.37	188	9.88	504	26.48	234	12.30	395
Point 6	630	33.11	201	10.56	589	30.95	257	13.50	419.25
Point 7	699	36.73	179	9.41	423	22.23	158	8.30	364.75
Point 8	329	17.29	81	4.26	504	26.48	103	5.41	204.05
Point 9	421	22.12	117	6.15	291	15.29	78	4.10	226.75
Point 10	473	24.86	94	4.94	255	13.40	82	4.31	226
Point 11	238	12.56	72	3.78	166	8.72	65	3.42	135.25
Indoor Mean								312.6 lux	
Outdoor Mean								1917.8 lux	
Mean Daylight Factor								16.3%	

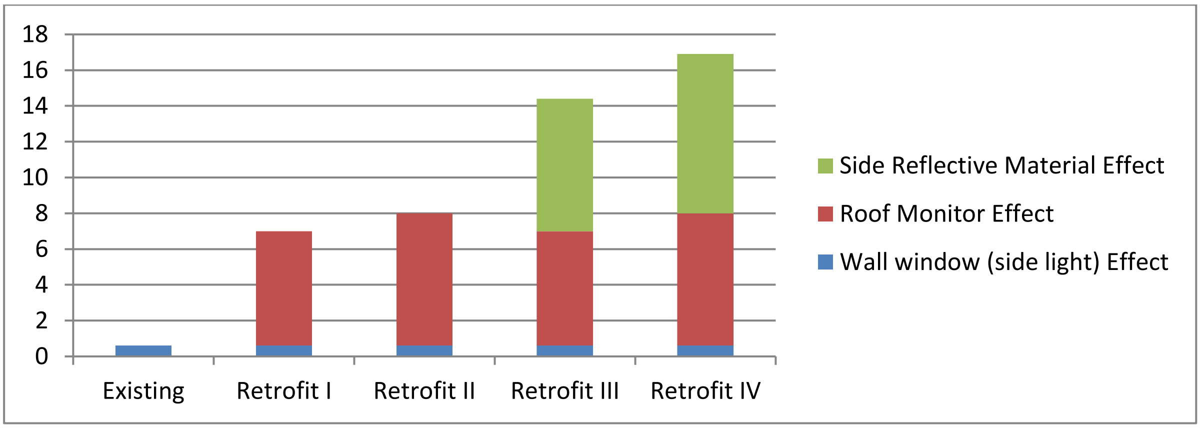


Figure 7: Effect of the retrofits on lobby daylight factor

DISCUSSION

There seem to be a significant difference among the indoor mean illumination levels in the simulated existing and retrofit proposals of the lobby. This difference suggests that daylight could appreciably be enhanced in otherwise 'dark' lobbies through some architectural retrofits, which in this study included introduction of roof monitor and reflective wall finish in the lobby. Previous works with which to compare the quantum of increase in daylight due to retrofit in this study could not be established since the known works (NBI & PGL, 2011; Jamaludeen *et al*, 2015; Martine, 2016; Rabani *et al*, 2017) were on energy efficiency and cost implications, and not on daylight quantity differentials of retrofit. An implication from these known works is that the enhanced daylight from the retrofit may translate into a more energy efficient and cost saving building. It could also be implied from Kesten & Terea (2015) and Dilay & Aysegul (2015) that the enhanced daylight would conduce to enhanced visual comfort, health, performance, job satisfaction and productivity of lecturers, students and other users of the building after retrofit.

While the introduction of roof monitor and the mounting of reflective wall finish in turn produced momentous effect on the lobby illumination level, the effect of changes in roof monitor opening size only seemed relatively low. The extent of modifications of these architectural features have, however, been influenced by the buildings structural systems, thus in line with the submission by Sedor *et al.* (2012).

CONCLUSION

In this study, the potentials of some architectural retrofitting strategies to enhance daylight in a poorly lit lobby was investigated through a simulated experimental design. The effect of roof monitor of different opening sizes and reflective wall finish on the illumination level of a lobby was investigated. Significant positive change in indoor mean illumination levels and daylight factors were observed due to the roof monitor and reflective wall finish retrofits of the study lobby. These daylight strategies hold a high potential for sustainable interior lighting, rather than resorting to electric lighting. It was hence found expedient to recommend that roof monitors and wall finishes of high reflectance be strongly considered to enhance daylight of indoor spaces totally bounded by internal walls.

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