

**Evaluation of LEED Interior Design Environment
to Improve the Indoor Environmental Quality
Through Enhancing Lighting Parameters
of UAE Campus Buildings**

تقييم بيئة التصميم الداخلي لبرنامج الريادة في الطاقة والتصميم الداخلي
لتحسين جودة البيئة الداخلية من خلال تعزيز معايير الإضاءة
لمبنى الحرم الجامعي في الإمارات العربية المتحدة

by

HANAN A. HASHAYKEH

**A thesis submitted in partial fulfilment
of the requirements for the degree of
DOCTOR OF PHILOSOPHY IN SUSTAINABLE BUILT
ENVIRONMENT**

at

The British University in Dubai

November 2023



**Evaluation of LEED Interior Design Environment
to Improve the Indoor Environmental Quality
Through Enhancing Lighting Parameters
of UAE Campus Buildings**

تقييم بيئة التصميم الداخلي لبرنامج الريادة في الطاقة والتصميم الداخلي
لتحسين جودة البيئة الداخلية من خلال تعزيز معايير الإضاءة
لمبنى الحرم الجامعي في الإمارات العربية المتحدة

by
HANAN A. HASHAYKEH

A thesis submitted to the Faculty of Engineering and IT
in partial fulfilment of the requirements for the degree of
DOCTOR OF PHILOSOPHY IN SUSTAINABLE BUILT ENVIRONMENT
at
The British University in Dubai
November 2023

Thesis Supervisor
Professor Hanan Taleb

Approved for award:

Name
Designation

Name
Designation

Name
Designation

Name
Designation

Date: _____

DECLARATION

I warrant that the content of this research is the direct result of my own work and that any use made in it of published or unpublished copyright material falls within the limits permitted by international copyright conventions.

I understand that a copy of my research will be deposited in the University Library for permanent retention.

I hereby agree that the contents of this dissertation for which I am author and copyright holder may be copied and distributed by The British University in Dubai for the purposes of research, private study or education and that The British University in Dubai may recover from purchasers the costs incurred in such copying and distribution, where appropriate.

I understand that The British University in Dubai may make a digital copy available in the institutional repository.

I understand that I may apply to the University to retain the right to withhold or to restrict access to my thesis for a period which shall not normally exceed four calendar years from the congregation at which the degree is conferred, the length of the period to be specified in the application, together with the precise reasons for making that application.

A handwritten signature in black ink, appearing to read 'Hanan', written over a horizontal line.

Signature of the student

COPYRIGHT AND INFORMATION TO USERS

The author whose copyright is declared on the title page of the work has granted to the British University in Dubai the right to lend his/her research work to users of its library and as an open source and to make partial or single copies for educational and research use.

The author has also granted permission to the University to keep or make a digital copy for similar use and for the purpose of preservation of the work digitally.

Multiple copying of this work for scholarly purposes may be granted by either the author, the Registrar or the Dean only.

Copying for financial gain shall only be allowed with the author's express permission.

Any use of this work in whole or in part shall respect the moral rights of the author to be acknowledged and to reflect in good faith and without detriment the meaning of the content, and the original authorship.

ABSTRACT

This study investigates the integration of interior artificial lighting, daylight, and quality views, all of which fall under Indoor Environmental Quality (IEQ), a key LEED (ID+C) credit in interior design environments. The research focuses on a campus building in the UAE, specifically the British University in Dubai. Effective design of these variables can enhance visual comfort and improve the building's indoor environment, including lighting quality and user performance. The methodology combines online surveys, field measurements, and computer simulations using DIALux EVO 11. It also considers human factors among students and staff through a mixed-method approach to validate findings and correlate data. The study aims to connect objective and subjective assessments of environmental factors in both daylight and artificial lighting, including lux value, uniformity ratio, glare, and daylight factor, according to EN 12464-1 (2021) standards. Field measurements validate outcomes from the base model in the software. The research offers practical insights into enhancing IEQ in campus buildings through various lighting strategies and scenarios. It analyzes different spaces based on LEED classifications, such as auditoriums, classrooms, libraries, and administration areas. The key findings emphasize the need to balance lighting parameters and conditions to achieve optimal results. The results show improved lighting conditions, enhanced lux values, glare reduction, and balanced light distribution across various spaces, benefiting user experience and performance. For instance, in the corridor areas, the lux value met the target value, ensuring the desired lighting quality. In other locations, such as the auditorium and classroom FF-111, lux values significantly exceeded the target levels, with values reaching 527lx and 602lx, respectively, greatly enhancing overall lighting conditions. The study's actionable insights cater to designers, architects, and stakeholders involved in campus building projects in the UAE. By

integrating sustainable standards, this research promotes environmentally sustainable indoor environments that prioritize occupant well-being and enhance the quality of educational spaces.

Keywords: artificial lighting, daylight, lighting quality, indoor environment

الملخص

تناول هذه الدراسة التحقيق في تكامل الإضاءة الاصطناعية الداخلية والنهارية وجودة الرؤية، والتي تدخل جميعها ضمن مجال الجودة البيئية داخل المباني. يركز البحث على مباني الحرم الجامعي في الإمارات العربية المتحدة، وتحديدًا الجامعة البريطانية في دبي. إن التصميم الفعال لهذه المتغيرات يمكن أن يعزز الراحة البصرية ويحسن البيئة الداخلية للمبنى، بما في ذلك جودة الإضاءة وأداء المستخدمين. تجمع منهجية البحث بين الاستطلاعات الإلكترونية، القياسات الميدانية، وأنظمة المحاكاة عبر الحاسوب. تشمل الدراسة أيضًا العوامل البشرية بين الطلاب والموظفين من خلال نهج مختلط للتحقق من النتائج وربط البيانات. تهدف الدراسة إلى التقييم المنهجي الفعلي و الاعتباري للعوامل البيئية فيما يتعلق بالإضاءة النهارية والاصطناعية، بما في ذلك قيمة اللوكس، ونسبة التوحيد، والوهج، وعامل الإضاءة النهارية، وفقًا للمعايير المستخدمة لتصاميم الإضاءة الداخلية. تقوم القياسات الميدانية بالتحقق من النتائج بالمقارنة مع النموذج الأساسي في برنامج المحاكاة. يقدم البحث رؤى عملية حول تحسين الإضاءة في مباني الحرم الجامعي من خلال استراتيجيات وسيناريوهات مختلفة. كما يحل مختلف الفضاءات بناءً على التصنيفات المعمارية الداخلية، مثل القاعات الكبيرة والفصول الدراسية والمكتبات ومناطق الإدارة. تشدد النتائج الرئيسية على ضرورة توازن معاملات الإضاءة و شدتها لتحقيق النتائج المثلى. تظهر النتائج تحسناً في ظروف الإضاءة، وزيادة قيم اللوكس، وتقليل الوهج، وتوزيع متوازن للضوء عبر مختلف الفضاءات، مما يعود بالفائدة على تجربة المستخدم وأدائه. على سبيل المثال، في منطقة الممرات، تم مطابقة قيمة اللوكس للقيمة المستهدفة، مما يضمن الإضاءة المطلوبة. بينما في مواقع أخرى، مثل القاعة الكبيرة والفصل، تجاوزت قيم اللوكس بشكل كبير المستويات المستهدفة، حيث بلغت القيم 527 و 602 لكس على التوالي، مما حسن ظروف الإضاءة بشكل كبير. تقدم الدراسة رؤى قابلة للتنفيذ للمصممين والمهندسين المعماريين وأصحاب المصلحة المشاركين في مشاريع أبنية الحرم الجامعي في الإمارات العربية المتحدة. من خلال دمج المعايير المستدامة، تسهم هذه الدراسة في تطوير بيئات داخلية مستدامة بيئياً تولي اهتماماً برفاهية المستخدمين وتعزز الجودة العامة للأماكن التعليمية

كلمات البحث: الإضاءة الاصطناعية، ضوء النهار، جودة الإضاءة، البيئة الداخلية

DEDICATION

A Mother's Love: Defying the Odds with Tricho-Hepato-Enteric Syndrome (THES)

Once upon a time in 2018, I was a mother to a charming boy and the devoted wife of a supportive husband. Life was filled with dreams, and one of them was pursuing the highest degree in a field I was passionate about.

Little did I know that our story was about to take a remarkable turn, in the sweet month of May in 2019, I received a precious gift from the heavens – a daughter named Ayla. From that moment on, my life became a tapestry of extraordinary events, for Ayla arrived in this world with a challenge that few could fathom: a rare condition known as Tricho-Hepato-Enteric Syndrome (THES). It was a condition so rare that fewer than 100 cases were known to exist worldwide.

Ayla's presence in our lives marked the beginning of an incredible journey. THES brought with it a myriad of complexities, testing the very limits of my strength and love. This condition cast its shadow over Ayla's liver, her delicate digestive system, and even her hair. It left her vulnerable to infections and malnutrition, demanding our unwavering attention and care.

For an entire year, Ayla never left the hospital. Our home became a web of wires, pumps, syringes and a lot of medical supplies, and here my roles multiplied exponentially. I was not just a mother; I had transformed into a dedicated nurse, a vigilant caregiver, and above all, Ayla's unwavering support system. The hospital became our second home, and I immersed myself in a world of medical terminology and treatment options. But I wasn't about to let THES define our story.

I made a momentous decision, one that would take me far from everything and everyone I loved. I left Dubai and embarked on a journey to Michigan, seeking better treatment and the possibility

of a life-saving liver transplant for Ayla. It was a daunting road, but I held onto the belief that miracles could happen every day and that the word "impossible" was merely a roadblock, not the end of the journey.

I am still running for her, I still have faith..... BismiAllah.

ACKNOWLEDGEMENTS

Completing my Ph.D. journey has been an incredible and transformative experience, and I owe a debt of gratitude to the many individuals who have supported me along the way.

First and foremost, I would like to express my deepest appreciation to my first advisor, Prof. Hanan Taleb and Prof. Bassam Abu-Hijleh as a second advisor of my research. Your guidance, expertise, and unwavering belief in my research were instrumental in shaping this dissertation. Your mentorship went beyond academic boundaries, and I am profoundly grateful for your patience and dedication. I am indebted to the vice chancellor of Dr. Abdullah Alshamsi, faculty and staff of my university in sustainable built environments department, who created an enriching academic environment where I could flourish intellectually. To my fellow Ph.D. students and colleagues at British University in Dubai, thank you for your camaraderie, encouragement, and countless discussions that expanded my horizons. Our shared experiences made this academic journey all the more memorable. My heartfelt thanks go to my family and my friends for their unwavering support, love, and understanding. Your encouragement during challenging times provided me with the strength to persevere.

To my beloved husband Alaa, my son Adam, and my miracle daughter Ayla, and to my lovely family, your belief in me sustained my determination, and I cherish the moments we shared throughout this endeavor.

In conclusion, this journey has been a collective effort, and I am immensely thankful to everyone who played a part, whether big or small, in helping me reach this significant milestone in my academic career.

TABLE OF CONTENTS

Chapter 1 : Introduction.....	1
1.1 LEED as Leading Sustainability Assessments	1
1.2 LEED Interior Design and Construction Status -Globally	2
1.3 Sustainable Interior Design Status in UAE	8
1.4 LEED Sustainable Indoor Environmental Quality in Campus Buildings	12
1.5 Sustainable Indoor Environment Quality Status in Campuses Building in UAE	14
1.6 Motivation and Scope of the Research.....	16
1.7 Aims and Objectives	20
1.8 Significance of the Study	24
1.9 Research Focus and Limitations	26
1.10 Thesis Contents and Structure.....	30
Chapter 2 : Literature Review	33
2.1 Overview	33
2.2 Indoor Environment Quality as Per LEED (ID+C)	34
2.3 Interior Lighting	39
2.3.1 Importance of Light	39
2.3.2 Source of Lighting (Natural light and Artificial light)	42
2.3.3 Basic Lighting Parameters and Terminologies.....	45
2.4 Significance of Lighting in Educational Buildings	58
2.5 Lighting Strategies and Performance in Educational Buildings.....	61

2.6	Impact of Lighting on Occupants' Satisfaction and Working Environment in Educational Buildings	67
2.6.1	Artificial Light and Well Being.....	67
2.6.2	Day Light and Quality View	70
2.7	Lighting Innovation Approach in Buildings.....	72
2.8	DIALux EVO Theory	77
2.9	Climatic Condition in Dubai.....	79
2.10	State of Art.....	82
2.11	Research Questions and Hypothesis	87
2.12	Summary of Chapter 2: Literature Review	87
Chapter 3 : Methodology		90
3.1	Introduction	90
3.2	Field Measurements.....	93
3.3	Survey Method	99
3.4	Computer Simulation:.....	105
3.5	A Summary of Research Approaches:.....	112
3.6	Research Case Study	119
3.6.1	Overview of the Study Environment-Existing Conditions:.....	125
3.7	Methodological Framework	160
Chapter 4 : Analysis and Results		165
4.1	Introduction	165
4.2	Lighting Assessment in the University Spaces.....	166

4.3	Field Measurements.....	167
4.3.1	Artificial Lighting Parameters Analysis.....	170
4.4	Survey.....	215
4.4.1	Summary of Survey Findings.....	242
4.5	Computer Simulation.....	244
4.6	Base Case Model	245
4.6.1	Scenario 1: Existing luminaries' types and arrangements -At night	247
4.6.2	Scenario 2: Existing luminaries' types and arrangements- During the day (11:00AM) 260	
4.7	Strategies to Enhance Daylight and Artificial Light on the Campus	268
4.7.1	Strategy 1: Daylight Enhancement.....	268
4.7.2	Strategy 2- Artificial Light	280
4.8	Strategy 3: Combine Daylight with Artificial Light.....	309
4.8.1	Scenario 1: Combine artificial light and daylight while all curtains closed-Daytime (At 11:00AM)	310
4.8.2	Scenario 2: Combine artificial light with daylight when curtains half way open and dimming artificial fixtures (At 11:00AM)	317
4.9	Analysis Chapter Summary	324
Chapter 5 : Result and Discussion.....		326
5.1	Introduction	326
5.2	Discussion of Computer Simulation Results.....	329
5.3	Summary of Contributions Findings	371
Chapter 6 : Conclusion		376

6.1 Summary	376
6.2 Main Findings	378
6.3 Linking the Findings with Literature Review	383
6.4 Study Importance	396
6.5 Recommendations for Further Research Work	398
References	402

LIST OF TABLES

Table 1: Highlights of LEED v4.1 ID+C, (<i>Source: USGBC, 2018</i>)	5
Table 2: Study Structure, (<i>Source: Author, 2023</i>)	22
Table 3: Sustainable Design Guidelines for Education Buildings, (<i>Source: DiLaura et al. 2011</i>)	59
Table 4: Summarized latest researchers case studies, (<i>Source: Author, 2022</i>)	83
Table 5: Summary of methodologies to enhance the indoor environmental quality in terms of lighting and user's wellbeing, (<i>source: Author, 2023</i>)	113
Table 6: Plan layout of the auditorium space, (<i>Source: Author, 2023</i>)	130
Table 7: Plan layout and space specifications of auditorium space, (<i>Source: Author, 2023</i>) ...	131
Table 8: Plan layout of the classroom FF-111 space, (<i>Source: Author, 2023</i>)	134
Table 9: Plan layout & space specifications of the classroom FF-111, (<i>Source: Author, 2023</i>)	135
Table 10: Plan layout of the library space, (<i>Source: Author, 2023</i>)	138
Table 11: Plan layout and space specifications of the library, (<i>Source: Author, 2023</i>)	139
Table 12: Plan layout of the administration area, (<i>Source: Author, 2023</i>)	141
Table 13: Plan layout and space specifications of the administration area, (<i>Source:</i> <i>Author, 2023</i>)	142
Table 14: Plan layout of the group study room, (<i>Source: Author, 2023</i>)	145
Table 15: Plan layout and space specifications of the group study room, (<i>Source: Author, 2023</i>)	146
Table 16: Plan layout of the students lounge, (<i>Source: Author, 2023</i>)	149
Table 17: Plan layout of the students lounge, (<i>Source: Author, 2023</i>)	150
Table 18: Plan layout and photos of the board room, (<i>Source: Author, 2023</i>)	152
Table 19: Plan layout and specifications of the board room, (<i>Source: Author, 2023</i>)	153

Table 20: Plan layout and photos of individual offices, (<i>Source: Author,2023</i>)	156
Table 21: Plan layout and specifications of individual offices, (<i>Source: Author,2023</i>)	157
Table 22: Plan layout and photos of general circulation areas (Corridors), (<i>Source: Author,2023</i>)	159
Table 23: Plan layout and specifications of general circulation areas, (<i>Source: Author,2023</i>)	160
Table 24: Lighting reference as per EN124641 standards, (<i>Source: IES, 2000</i>)	169
Table 25: Illuminance[lux]values for auditorium, and presentation area, (<i>Source: Author,2022</i>)	174
Table 26: Illuminance[lux] for classroom FF-111, (<i>Source: Author,2022</i>)	178
Table 27: Illuminance[lux] for the library, (<i>Source: Author,2022</i>)	184
Table 28: Illuminance[lux] values for the administration area, (<i>Source: Author,2022</i>)	187
Table 29: Illuminance[lux], and luminance values for the group study room, (<i>Source: Author,2022</i>)	191
Table 30: Illuminance[lux]values for the students lounge, (<i>Source: Author,2022</i>)	194
Table 31: Illuminance[lux] values for the board room, (<i>Source: Author,2022</i>)	197
Table 32: Illuminance[lux]values for the corridor, (<i>Source: Author,2022</i>)	200
Table 33: Illuminance[lux] values for the registration and chief office, (<i>Source: Author,2022</i>)	203
Table 34: Horizontal illuminance Lux value measurements in different BUiD indoor spaces along with uniformity ratios, (<i>Source: Author,2022</i>)	203
Table 35: Color temperature reference value. (<i>Source: DiLaura et al. 2011</i>)	206
Table 36: Color temperature through various spaces (Kelvin), (<i>Source: Author,2022</i>)	208
Table 37: The color spectrum measurements in BUiD campus building spaces, (<i>Source: Author,2022</i>)	209

Table 38: The General CRI values (Ra) for BUiD campus building spaces, (<i>Source: Author,2022</i>)	213
Table 39: Summary report of different zones in the campus, base case model, scenario1:at night, (<i>Source: Author,2023</i>)	259
Table 40: Summary report of different zones in the campus- base case model, scenario2, During the day, (<i>Source: Author,2023</i>).....	267
Table 41: Summary report of different zones in the campus- Strategy 1, scenario 1: All curtains fully opened, (<i>Source: Author,2023</i>).....	274
Table 42: Summary report of different zones in the campus- Strategy 1, Scenario 2, All curtains halfway down, (<i>Source: Author, 2023</i>)	280
Table 43: Summary report of different zones in the campus- strategy 2, scenario 1: Adding more lighting fixtures from the existing type, (<i>Source: Author, 2023</i>).....	293
Table 44: Summary report of different zones in the campus- strategy 2, scenario 2: switching and rearranging the current fixtures to the new type- At night, (<i>Source: Autor,2023</i>).....	308
Table 45: Summary report of different zones in the campus- strategy 3,scenario 1:combine artificial light and daylight while all curtains closed, (<i>Source: Author 2023</i>)	317
Table 46: Summary table of different zones in the campus, strategy 3-scenario 2: Combine artificial light with daylight when curtains half way open and dimming artificial fixtures, (<i>Source: Author ,2023</i>).....	323

LIST OF FIGURES

Figure 1:Minimum illuminance on work plane (horizontal) for drawing and minimum illuminance on conference rooms.	7
Figure 2:Glare specifications on different countries worldwide.	8
Figure 3:Sustainable pillars.	9
Figure 4: Project breakdown of LEED certified projects in UAE.	11
Figure 5: Energy consumption in US buildings in terms of different activities	18
Figure 6: LEED- IEQ occupant well-being and productivity structure.	37
Figure 7: Lighting quality: the integration of individual well-being, economics & architecture	38
Figure 8: Variables affecting humans.	41
Figure 9: Artificial light production.	43
Figure 10: Basic parameters used in lighting.	48
Figure 11: Colour rendering index and colour temperature scale.	52
Figure 12: Source of glare.	55
Figure 13: Light Reflectance Value (LRV).....	56
Figure 14: Daylight Factor (DF)	57
Figure 15: Lighting percentage of the total energy consumptions by sectors.....	59
Figure 16: Illuminating the effects of dynamic lighting on student learning.....	70
Figure 17: Core Sun Light System (CSLS).....	74
Figure 18: Light tube technology	75
Figure 19:Al Bahar Tower in AD	76
Figure 20:Siemens Headquarters (HQ) in AD	77
Figure 21: Average of high and low temperature in Dubai.....	80

Figure 22: Sunshine hours distribution in Dubai	81
Figure 23: Sekonic- C7000- lighting machine	95
Figure 24: Integrative design process of efficient lighting system in campus	98
Figure 25: Model simulation framework	109
Figure 26: BUiD location map and external views of the campus.....	120
Figure 27: Plan layout of the old block- 1st Floor - Block 11 BUiD	123
Figure 28: Plan layout of the old block- 2nd Floor - Block 11 BUiD.....	124
Figure 29: Plan layout of the new block 1st Floor - Block 10 BUiD.....	125
Figure 30: Spaces categories as per LEED ID+C guidelines- Shared regularly multi occupant spaces	127
Figure 31: Spaces categories as per LEED ID+C guidelines- non- regularly occupied spaces and individual occupants' spaces	127
Figure 32: Chart of the methodological framework of the study	162
Figure 33: Auditorium furniture layout plan drawing, illuminance value	174
Figure 34: Classroom FF 111 furniture layout plan drawing, illuminance values.....	178
Figure 35: Library furniture layout plan drawing, illuminance values	183
Figure 36: Adminstration area furniture layout plan, illuminance values.....	187
Figure 37: Group study room furniture layout plan, illuminance values	190
Figure 38: Students lounge area furniture layout plan-illuminance values.....	194
Figure 39: Board room furniture layout plan- illuminance values.....	197
Figure 40: Corridors plan layout- illuminance values.....	200
Figure 41: Registration and chief office furniture layout plan-illuminance values	203
Figure 42: BUiD population distribution of students and the staff	217
Figure 43: Age distribution of BUiD students and staff	218
Figure 44: Gender distribution among students and staff at BUiD.....	219

Figure 45: BUiD students' level of education.....	220
Figure 46: BUiD staff job categories compromised between academic and non-academic staff	221
Figure 47: Hours spent in the class room/ office per week at BUiD	222
Figure 48: Lighting conditions: How do you feel about the working areas.....	223
Figure 49: Environmental conditions: Its effect on the user's satisfaction	225
Figure 50: Satisfaction levels with artificial lighting in working areas	226
Figure 51: Accessibility of outside views in different spaces	227
Figure 52: Quality of daylight in different spaces satisfaction levels	229
Figure 53: Glare on computer screens and how this effect the students' performance	230
Figure 54: Glare produced from the electrical lighting fixtures.....	231
Figure 55: Glare produced from presence of daylight	232
Figure 56: Glare and its effect on the student's abilities to see the presented materials	233
Figure 57: Summary chart of glare experience in different situation	234
Figure 58: Satisfaction level of all users in the library	235
Figure 59: Satisfaction level of all users in the students lounge	236
Figure 60: Satisfaction level of students in the group study room.....	237
Figure 61: Satisfaction level in the board room	238
Figure 62: Satisfaction level of all users in the auditorium.....	239
Figure 63: Daylight satisfaction level	241
Figure 64: Artificial lighting satisfaction level	242
Figure 65: Campus building 3D model by DIALux EVO 11	246
Figure 66: Auditorium light lux level and uniformity ratio	248
Figure 67: Classroom FF 111- light lux and uniformity ratio.....	249

Figure 67: Library- light lux and uniformity ratio	250
Figure 68: Administration area- light lux and uniformity ratio	251
Figure 69: Group study room - light lux and uniformity ratio	252
Figure 70: Student lounge room - light lux and uniformity ratio.....	253
Figure 71: Board room - light lux and uniformity ratio	254
Figure 72: Corridor - light lux and uniformity ratio.....	256
Figure 73: REG Office - light lux and uniformity ratio	257
Figure 74: Artificial lighting fixtures used in the base case model.....	258
Figure 75: Classroom FF 111- light lux and uniformity ratio.....	262
Figure 76: Library - light lux and uniformity ratio	263
Figure 77: Student lounge - light lux and uniformity ratio	265
Figure 78: Registration office - light lux and uniformity ratio	266
Figure 79: Classroom FF 111- daylight factor and lux value	270
Figure 80: Library - daylight factor and lux value	271
Figure 81: Student lounge- daylight factor and lux value	272
Figure 82: Registration office- daylight factor and lux value	273
Figure 83: Classroom FF 111- daylight factor and lux value	276
Figure 84: Library - daylight factor and lux value	277
Figure 85: Student lounge- daylight factor and lux value	278
Figure 86: Registration office- daylight factor and lux value	279
Figure 87: Auditorium- lux value and uniformity ratio	283
Figure 88: Class room FF 111- lux value and uniformity ratio	284
Figure 89: Library- lux value and uniformity ratio	285
Figure 90: Administration area- lux value and uniformity ratio	287

Figure 91: Study room- lux value and uniformity ratio	288
Figure 92: Student lounge- lux value and uniformity ratio	289
Figure 93: Board room- lux value and uniformity ratio.....	290
Figure 94: Corridors- lux value and uniformity ratio.....	291
Figure 95: Registration office- lux value and uniformity ratio	292
Figure 96: Luminaire list-DIALux EVO 11.....	296
Figure 97: Auditorium- lux value and uniformity ratio	297
Figure 98: Classroom FF-111- lux value and uniformity ratio	298
Figure 99: Library- lux value and uniformity ratio	300
Figure 100: Administration area- lux value and uniformity ratio	301
Figure 101: Group study room- lux value and uniformity ratio.....	302
Figure 102: Students lounge- lux value and uniformity ratio	303
Figure 103: Board room- lux value and uniformity ratio.....	304
Figure 104: Corridors- lux value and uniformity ratio.....	306
Figure 105: Registration office- lux value and uniformity ratio	307
Figure 106: Classroom FF 111 - day light and lux value.....	312
Figure 107: Library - day light and lux value	313
Figure 108: Students lounge - day light and lux value.....	314
Figure 109: Registration office - day light and lux value	315
Figure 110: Classroom 111- day light and lux value	319
Figure 111: Library - day light and lux value	320
Figure 112: Students lounge - day light and lux value.....	321
Figure 113: Registration office - day light and lux value	322
Figure 114: Auditorium chart- Night time scenarios	330

Figure 115: Auditorium graphical colored maps-Night scenarios	332
Figure 116: Class room FF-111 chart -Night time scenarios	333
Figure 117: Classroom FF-111 graphical colored maps-Night scenarios	335
Figure 118: Class room FF 111 chart at day time scenarios	336
Figure 119: Classroom FF-111 graphical colored maps-Day time scenarios	339
Figure 120: Library chart- Night time scenarios	340
Figure 121: Library graphical colored maps-Night time scenarios.....	342
Figure 122: Library chart -Day time scenarios	343
Figure 123: Library graphical colored maps-Day time scenarios	346
Figure 124: Administration area chart -Night time scenarios	347
Figure 125: Administration area graphical colored maps-Night time scenarios.....	349
Figure 126: Group study room chart -Night scenarios.....	351
Figure 127: Group study room graphical colored maps-Night time scenarios	353
Figure 128: Students lounge chart -Night time scenarios	355
Figure 129: Students lounge graphical colored maps-Night time scenarios	356
Figure 130: Student lounge chart -Day time scenarios	357
Figure 131: Students lounge graphical colored maps-Day time scenarios	359
Figure 132: Board room chart at night time scenarios	360
Figure 133: Board room graphical colored maps-Night time scenarios	361
Figure 134: Corridors (General circulation zone) chart -Night time scenarios.....	362
Figure 135: Corridors graphical colored maps-Night time scenarios	364
Figure 136: Registration office chart -Night time scenarios	366
Figure 137: Registration office graphical colored maps-Night time scenarios.....	367
Figure 138: Registration office chart -Day time scenarios	368

Figure 139: Registration office graphical colored maps-Day time scenarios 371

LIST OF ABBREVIATIONS

Abbreviations	Definitions
USGBC	U.S. Green Building Council
LEED	Leadership in Energy and Environmental Design
ESID	Environmentally Sustainable Interior Design
UN	United Nations
COP	Conference of Parties
UNFCCC	UN Climate Change Conference
BREEAM	British Research Establishment Environmental Assessment Method
IEQ	Indoor Environmental Quality
HBS	Harvard Business School
SHJU	Sharjah of University
BUiD	British University in Dubai
UAEU	UAE University
BMS	Building Management System
HVAC	Heating, Ventilation, and Air Conditioning
IES	Information Exchange System
HCL	Human Centric Lighting
VCP	Visual Comfort Probability
LENI	Lighting Energy Numeric Indicator
EPBD	European Energy Performance of Buildings Directive
LEDs	Light Emitting Diodes

CFLs	Compact Fluorescent Lamps
SI	International System of Units
cd	Candela
lm	Lumens
Φ	Luminous flux
I	Luminous intensity
E	Illuminance
L	Luminance
lx	Lux
W	Watt
(lm/w)	Lumens per Watt
UO	Uniformity
CRI	Colour Rendering Index
CT	Colour Temperature
K	Kelvin
UGR	Unified Glare Rating
LRV	Light Reflection Value
IMV	Illuminance Maintenance Value
DF	Daylight Factor
SDA	Spatial Daylight Autonomy
UGR	Unified Glare Rating
ft ²	Square Foot

CR	Colour Render
US	United State
ADS	Anidolic Lighting System
CSLS	Core Sun Light System
FL	Fluorescent Lamp
JUST	Jordan University of Science and Technology
OLED	Organic Light-Emitting Diode
HQ	Head Quarters
CAA	Commission for Academic Accreditation
UAE	United Arab Emirates
UK	United Kingdom
LQAM	Lighting Quality Assessment Method
Sqm	Square meter

Chapter 1 : Introduction

Climate change is undeniably one of the most significant global challenges today. It refers to long-term shifts in weather patterns and Earth's temperature. It primarily results from the emission of Greenhouse Gases (GHGs), with carbon dioxide emissions being the most prevalent. These emissions stem from various human activities, including industrial practices, fossil fuel combustion, and deforestation, all of which release GHGs into the atmosphere.

Buildings account for 39% of the global greenhouse gas emissions (Kantola, 2020). Hence, incorporating sustainability practices outlined in the LEED rating system into new buildings and projects helps conserve resources, reduce greenhouse gas emissions, carbon emissions, waste, and energy consumption, as well as conserve water. Furthermore, these practices contribute to creating healthier and more resilient communities. LEED standards offer a comprehensive framework that promotes sustainable development, playing a crucial role in mitigating the impacts of climate change on the built environment (USGBC, 2018).

1.1 LEED as Leading Sustainability Assessments

The term LEED (Leadership in Energy and Environmental Design) was introduced in 1993 by the U.S. Green Building Council (USGBC). Initially, the LEED rating system was designed to assess the performance of green buildings, ensuring they operate sustainably. Xuan (2012) noted that LEED encompasses planning, design, architecture, and development of buildings while considering environmental factors, in alignment with industry standards. Over the past 18 years, various versions of LEED have been introduced to progressively advance the global sustainable building industry, resulting in over 93,000 certified and registered projects (Xuan

,2012). Additionally, the LEED system fosters environmental integration by promoting the adoption of best design practices. Since 1994, LEED has extensively covered several areas within its best practices. LEED comprises five rating systems: LEED Neighbourhood Development (ND), LEED Building Design and Construction (BD+C), LEED Homes (HOMES), LEED Interior Design and Construction (ID+C), and LEED Building Operations and Maintenance (O+M).

According to Qutab et al. (2016), the LEED green building rating system evaluates and grants credits based on five main categories. With numerous performance criteria and categories, LEED has gained recognition as an essential tool for sustainability assessment since its inception. LEED is a market-driven system used to assess the sustainability of construction projects, with approximately 26,000 construction projects in the U.S. region alone (Qutab et al., 2016). According to USGBC (2018), LEED Version 3 (v3) was introduced in 2009 to address social, environmental, and economic impacts of projects, the system has evolved and adapted to incorporate various performance criteria, allowing for the design of different types of structures and buildings with sustainability as a primary objective.

1.2 LEED Interior Design and Construction Status -Globally

The emergence of LEED (Leadership in Energy and Environmental Design) system helped in highlighting the opportunity for construction sector to highlight and promote the development of green buildings. According to the USGBC statistics, in 2022, the number of LEED certified projects worldwide exceeded 100,000, and the United States led as the largest global market for LEED, with over 511 million square feet certified to the standard (USGBC, 2023). Focusing on

the LEED system of interior design and construction offers the world the opportunity to enhance buildings' performance through sustainable rating system and increase environmental sustainability. Currently, there is a relatively low rate of LEED certified buildings in the U.S. region, with approximately 80 % of business offices or buildings lacking sustainability certificates. Hence, implementing the LEED practices can help these building in improving the environment performance and the environment sustainability as the dimensions of new or existing building construction or renovation; thereby contributing to the increased opportunities for safe environment (Penny, 2014).

The construction and design sectors typically operate independently, resulting in fragmented solutions to their respective challenges. These solutions can sometimes lead to unintended, often negative, outcomes. It is suggested that by integrating various construction and design practices, significant synergies can be achieved, enhancing project performance and yielding benefits for human health, the environment, and the economy (Gurgun & Arditi, 2018).

Moreover, Gurgun and Arditi (2018) proposed certification levels related to the LEED system, taking the above considerations into account. The suggested certification levels within the LEED system include LEED Platinum, LEED Gold, LEED Silver, and LEED Certified. These categories in LEED interior design are determined based on the construction credits earned by the building. Furthermore, aligning the project location with the LEED system streamlines the process of identifying credit opportunities and optimal site selection. This approach not only ensures sustainable construction practices but also enhances the overall site selection process for building projects. Within the New Interior Design and Construction Credits of LEED version 3 (2009), a wide range of criteria is focused on the use of sustainable

construction materials (Kaplow, 2013). Additionally, there is a significant emphasis on the sourcing and procurement process, which increases transparency in the supply chain and the procurement of raw materials.

The integration of construction parameters and commercial interior design within the LEED framework places a heightened emphasis on control requirements, particularly focusing on the management of sustainable construction's controllability system. Additionally, LEED construction project criteria prioritize effective management of acoustic performance to address lighting concerns. Kaplow (2013) outlined various categories of LEED version 3, including location and transportation, water efficiency, energy and atmosphere, materials and resources, design and innovations, indoor environmental quality, and regional priority.

Each aspect of the LEED system is directed toward distinct objectives. For instance, the atmosphere and energy categories concentrate on establishing efficient energy systems, utilizing alternative and renewable energy sources, and supporting ozone layer protection protocols. The materials and resources aspect emphasize the use of materials that reduce waste and environmental impact while minimizing material requirements. Conversely, the indoor environmental quality aspect aims to enhance air quality, manage or eliminate indoor pollutants, ensure system controllability and thermal comfort, and establish a connection between occupants and the outdoor environment. It also simplifies the attainment of credits for acoustic and daylight performance, promoting views, daylight, and interior light performance during the design process. These aspects also enhance flexibility for designers, allowing them to effectively address considerations like sound transmission between spaces and excessive sunlight.

The design and innovation process aspect centers on recognizing fundamental performance achieved in LEED (ID+C) credits and identifying sustainable building features not covered by the existing LEED (ID+C) credits (Penny, 2014). According to the US Green Building Council, each category in LEED ID+C consists of different scorecard points. For instance, energy and atmosphere comprise 37 score points, location and transportation score 18 points, materials and resources 13 points, water efficiency 12 points, interior quality views, light, and daylight 6 points, innovation and design process 5 points, and interactive process 1 point. Furthermore, indoor environmental quality (IEQ) accounts for a total of 17 points. Table 1 shows the breakdown of IEQ points under different categories.

Table 1: Highlights of LEED v4.1 ID+C, (Source: USGBC, 2018)

Indoor Environmental Quality Credit Points		17
Prerequisite	Min Indoor Air Quality Performance	1
Prerequisite	Environment Tobacco Smoke Control	1
Credit	Indoor Air Quality	3
Credit	Low-Emitting Materials	3
Credit	Construction Indoor Air Quality Management Plan	1
Credit	Indoor Air Quality Assessment	2
Credit	Thermal Comfort	1

Credit	Interior Lighting	2
Credit	Daylight	3

Furthermore, in accordance with LEED (ID+C), the interior lighting and daylight together account for 5 points, underscoring the critical role played by both natural and artificial lighting on a global scale. This highlights the significance of lighting details within interior lighting systems, aiming to provide an overview of the consistency and variations in lighting standards, codes, and specifications worldwide. These aspects encompass considerations related to glare, colour rendering, colour temperature, and minimum illuminance levels on the work plane across different interior spaces (IES, 2000).

LEED categorizes occupation settings based on various criteria, such as occupied vs. unoccupied spaces, regularly vs. non-regularly occupied spaces, and individual occupants vs. shared multi-occupant spaces. Notably, several recommended standards are outlined in world maps. For instance, Figure 1 represents a comparison of various countries worldwide, focusing on specifications for visual performance in offices, specifically the minimum illuminance levels on the work plane in areas like drawing rooms and conference spaces. For example, in the USA, the minimum illuminance on the work plane varies from 100 to 1000 lux, depending on factors such as contrasts and task size. In China, the minimum illuminance on the work plane falls within the range of 300 to 500 lux, while in Europe, it is consistently set at 500 lux. In Russia, the minimum illuminance on the work plane is established at 300 lux.

The Unified Glare Rating (UGR) anticipates the discomfort-inducing glare resulting from an electric lighting system, using a psychometric scale. UGR helps estimate the extent of discomforting glare generated by a specific lighting setup for a given set of conditions. UGR is used by lighting designers to manage the potential for occupants of a building to encounter glare originating from artificial lighting. Figure 2 provides a comparison of specifications for visual performance in office spaces in terms of the unified glare rating (UGR). For instance, in countries like China, Japan, India, Malaysia, Europe, and South Africa, the UGR requirement is set at <19, while in Russia, the UGR for computer workstations is stipulated to be <15.

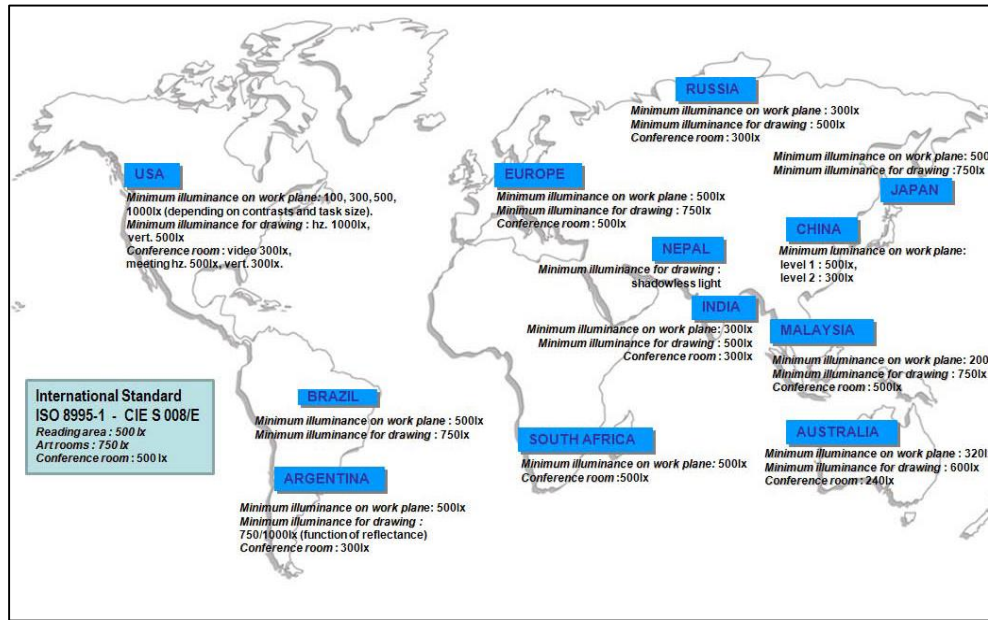


Figure 1: Minimum illuminance on work plane (horizontal) for drawing and minimum illuminance on conference rooms.

(Source: ISO 8995-1, 2002)

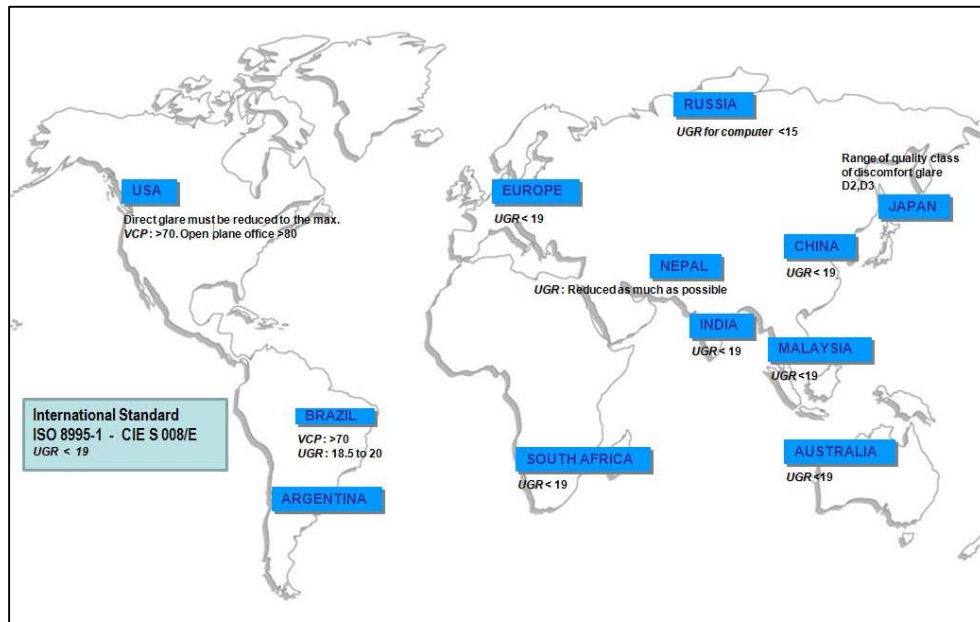


Figure 2: Glare specifications on different countries worldwide.

(Source: ISO 8995-1, 2002)

1.3 Sustainable Interior Design Status in UAE

Recently, designers and architects have embraced a social responsibility for sustainable interior design due to the increasing awareness of the ethical obligations of professional interior designers in promoting societal and public health benefits. As a result, interior designers have shifted their focus towards adopting sustainable practices, incorporating sustainable materials, construction techniques, and building systems to address environmental concerns. However, at earlier stages, traditional interior design primarily concentrated on enhancing the aesthetics of indoor spaces without sufficient consideration for occupants' health, pollution reduction, and emissions. However, Hayles (2015) pointed out that the criteria for Environmentally Sustainable Interior Design (ESID) have gained significant attention, emphasizing sustainability as

designers and architects recognize its importance in the building and construction environment. The core principle of ESID for sustainable design is to promote both physical well-being and a safe indoor experience, enhancing psychological comfort. Sustainable interiors contribute to improved human health by mitigating the adverse effects of indoor environments through the incorporation of various quality measures that assess the impact of indoor spaces on physical and psychological comfort. Additionally, sustainability underscores the importance of design effectiveness in reducing adverse environmental consequences (Mazarella, 2016), as illustrated in Figure 3 below.



Figure 3:Sustainable pillars.

(Source: Sow, 2016)

Since signing onto the United Nations (UN) Sustainable Development Goals framework in 2015, the United Arab Emirates (UAE) has made significant progress in the realm of sustainable development (Sow, 2016). Sustainability has become a prominent theme in the UAE's construction industry over the past few years, signalling a clear direction for the nation's future.

From numerous sustainable developments observed in Dubai to making sustainability a cornerstone of the Expo 2020 plans, the country has been making notable strides towards achieving sustainability. Furthermore, the UAE is set to host the 28th Conference of Parties (COP 28) for the UN Climate Change Conference (UNFCCC) at Expo Dubai in 2023, bringing together global efforts to address one of the most pressing challenges of our time (Embassy of UAE Washington DC, 2023). Considering the nation's conscientious efforts to secure a sustainable future, this research delves into the subject, with a specific focus on the highly innovative sustainable developments in the region, aiming to understand how they contribute to reducing carbon emissions.

In 2017, more than 550 projects in the UAE implemented LEED system practices, with Dubai ranking among the top 10 cities with the majority of LEED-certified buildings, as highlighted by Summertown (2019). Additionally, Dubai made history by becoming the first city to achieve this prestigious certification while embracing LEED practices in 2019. The UAE's interior design sector also places a significant emphasis on LEED certification. Figure 4 provides a visual representation of the distribution of LEED-certified buildings and LEED-registered projects in the UAE (Summertown, 2019).

Certain projects in the UAE, like Al Zahia City Centre, have focused on designing a mall as both a shopping center and a regional entertainment hub. By adhering to LEED practices, the project achieved a significant 15.52% reduction in energy consumption, leading to substantial sustainable benefits. Another noteworthy case, centered on LEED ID+C, is the Smart Office D3, which witnessed remarkable improvements in energy conservation and enhanced environmental quality through the implementation of the LEED system (CCC, 2019).

The Dubai Chamber's Head Quarters stands as another example of a UAE-based building committed to sustainable interior design. The project achieved a remarkable 91% reduction in energy consumption and implemented efficient ratings. With LEED design, the Dubai Chamber's headquarters earned recognition as a green building over 15 years after its construction (USGBC, 2021). Notably, energy consumption decreased by 47% between 1998 and 2008, prompting the Dubai Chamber to pursue the upgrade of its head office in accordance with green building standards, facilitated by the use of LEED practices. This approach not only underscored the significance of green building standards but also encouraged environmental sustainability. Furthermore, the implementation of sustainable design has yielded numerous benefits, including approximately \$49,729 in operational savings annually, along with financial savings, the realization of a green and sustainable building, and the expansion of knowledge in this domain.

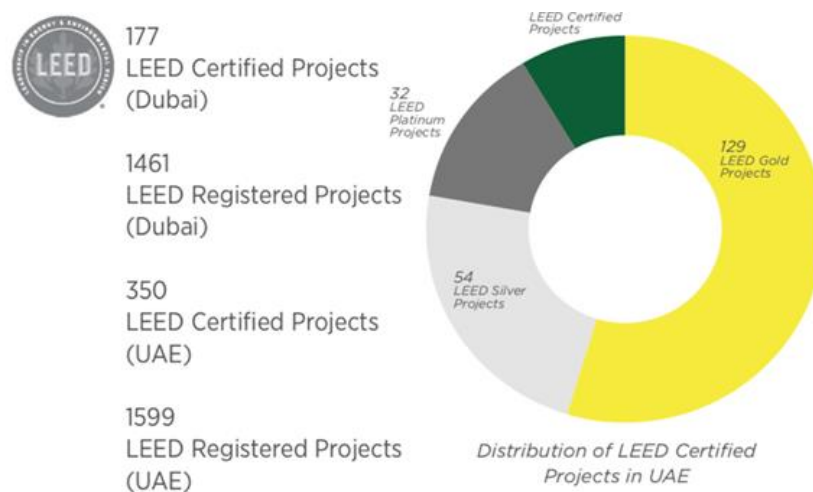


Figure 4: Project breakdown of LEED certified projects in UAE.

(Source: Summertown, 2019)

Al Bahr Towers, another exemplary sustainable project, features a protective skin comprised of 2,000 umbrella-like glass elements that automatically adjust to varying sunlight intensity. These elements draw inspiration from the traditional “Mashrabiya”, wooden lattice screens used as windows in the 14th century. The building is dynamically controlled, with these adjustable shades effectively reducing heat gains by up to 50% (Cilento, 2012). These eco-friendly shades were among the first architectural features in the Gulf region to receive a silver rating in LEED.

Emirates GBC (2019) noted that several rating systems in the international market have targeted the UAE region. Notable systems include Leadership in Energy and Environmental Design (LEED), Al Sa'fat Green Building Rating System, Ras Al Khaimah Green Building Regulations (Barjeel), British Research Establishment Environmental Assessment Method (BREEAM), and the Pearl Rating System. Introduced by the Dubai Municipality, the Al Sa'fat system focuses on adhering to Dubai's green building specifications and regulations. In 2009, Abu Dhabi introduced the Estidama system as an organic sustainability initiative in the Middle East. Additionally, the Pearl Rating System was implemented to ensure that buildings are constructed in a sustainable manner, with new buildings required to align with sustainability principles during the Development Review Process in Abu Dhabi (2019).

1.4 LEED Sustainable Indoor Environmental Quality in Campus

Buildings

Efforts are made for enhancing indoor environmental quality for improved work performance and health outcomes. (Choi et al., 2014) highlighted five aspects to rate green building: resources and material, IEQ, water efficiency, atmosphere and energy consumption, and sustainable

location. IEQ is a combination of traditional approaches (like thermal control and ventilation) and innovative design strategies, including advanced lighting metrics (daylight credits), monitoring and source controlling for user-identified pollutants (enhanced Indoor Air Quality credit), low emitting and carbon footprint materials credit, and lighting quality credit. Indoor Environmental Quality (IEQ) is referred to indoor conditions focusing on occupants' health and in an educational building, it mainly emphasizes on students' outcomes and classroom conditions in context of their course satisfaction, occupants' satisfaction, and their perception about its impact on learning. IEQ has a significant impact on performance in learning, home or work environments. Moreover, it is also observed that poor indoor conditions tend to have a negative impact on students' performance in educational buildings (Choi et al., 2014). Particularly, since students spend a lot of time in classrooms as compared to other interior environments of the institution for academic purpose. Therefore, IEQ of classrooms have a direct impact on students' learning and satisfaction.

Concerns about environmental performance have grown in the university sector, driven by the demands of both parents and students for improved indoor environments. Since 2010, higher education institutions have collectively achieved a total of 571 credits, with around 256 universities boasting 446 LEED certified buildings. Furthermore, there has been a recent surge in sustainability initiatives, compelling numerous universities to pursue U.S. Green Building Council LEED certification for their new campuses. This shift aims to enhance occupants' performance, productivity, and health by adopting various Indoor Environmental Quality (IEQ) parameters (Mihai and Iordache, 2016). For instance, the Harvard Business School (HBS) campus underwent a renovation and redesign to create a healthy and sustainable learning

environment, with a particular emphasis on the comfort and satisfaction of students and staff, while also achieving energy savings.

Kime and Alibaba (2018) noted the importance of daylighting in educational environments, recognizing it as a valuable resource for achieving energy efficiency and improving the visual comfort of building occupants. In educational spaces, whether it be classrooms or libraries, providing occupants with good lighting is essential for their comfort and productivity. The integration of natural daylight into library buildings, in particular, offers the potential to enhance the quality of the environment, reduce energy consumption, and contribute to thermal comfort for users. However, this integration comes with architectural challenges, especially when considering the impact of direct sunlight on the indoor environment.

1.5 Sustainable Indoor Environment Quality Status in Campuses

Building in UAE

LEED has a whole set of categories focused on indoor environment. IEQ category, which includes credits and prerequisites for construction and design of new and existing buildings, rewards decisions of project teams regarding thermal comfort, ventilation, indoor air quality, quality viewing, daylight and indoor lighting. Sustainable buildings with higher IEQ offer comfort and wellbeing to occupants, decrease absenteeism, reduce designers' liability for building, increase building's value, and enhance productivity. LEED system has been implemented in UAE universities for enhancing productivity, performance, and wellbeing of academic staff and students and for improving IEQ.

One of the prominent universities influenced by climate and policy considerations is the United Arab Emirates University (UAEU), located in Al-Ain city, Abu Dhabi. This region is characterized by a very dry climate. The university comprises two campuses: Engineering College, which is the older campus, and a new building housing other colleges. Presently, the United Arab Emirates University does not fully adhere to the LEED indoor environment specifications, which has a significant impact on the efficiency and comfort of its users.

The selection of this university as an example is aimed at illustrating the importance of implementing LEED Indoor Environmental Quality (IEQ) requirements and how the omission of essential indoor criteria affects user performance. This specific campus is highlighted due to several key factors, including the age of its buildings, which exceed 10 years, a substantial student population of approximately 9,000, and its location, as indicated in the Ministry of Infrastructure Developments report (2019).

Several crucial parameters were identified for evaluating the building in alignment with LEED IEQ standards at UAEU. These include Indoor Air Quality in terms of particulate matter (PM). While PM-2.5 (aerodynamic diameter smaller than 2.5 μm) levels are within the normal range, PM-10 (aerodynamic diameter smaller than 10 μm) slightly exceeds the normal limits by 5%. Daylight factor is at 6%, offering an average of 210 lux. In terms of acoustics, there is no sound quality balance, and noise stemming from HVAC systems is observed. Thermal comfort is maintained at an average indoor temperature of 23°C, largely due to the Building Management System (BMS). Ventilation levels fall below 750 cubic feet per minute (CFM). The methodology employed in this campus assessment is divided into two methods: data collection

and analysis, and IES simulation, which evaluates the campus's performance throughout the year based on IEQ requirements.

The methodology which has been followed is divided to two types, first the data collection and analysis. Second IES simulation which shown the performance of the building during the year based on indoor environmental quality requireOne more example is Sharjah University (SHJU) is situated in Sharjah city with a moderate climate. There are three building within the campus; however, this study will focus on the main building of the campus containing Islamic Affairs College and Engineering College. The LEED-based IEQ requirements are partially implemented in the building currently. Higher intensity of daylight provides a comfortable environment for users, along with increased energy consumption. The reason for selecting this campus include it is locations, a large number of students (5000), and the age of the building (15 years old). Main parameters for evaluating LEED IEQ in Sharjah University are as follows: Indoor Air Quality- the PM10 and PM2.5 are within the normal level, Daylight Factor (DF),14% glass to floor area with average of 400 lux, for acoustic- sound quality highly balanced, no noise of HVAC systems, on the otherhand the thermal comfort the average indoor temperature is 24 c° as of sky light, and regarding the ventilation is lower than 850 CFM.

1.6 Motivation and Scope of the Research

Dubai has established an "Academic City" that houses numerous international institutions, demonstrating it is commitment to higher education. The country has created a favourable environment for advanced learning and is continuously striving to enhance it further. Due to the

large-scale and diverse student and academic population, there is a genuine need to investigate the indoor environmental quality on campus buildings and develop a sustainable framework specifically for indoor spaces. One crucial outcome of this research will be the integration of building codes in educational buildings throughout the UAE. The study emphasizes the enhancement of Indoor Environmental Quality (IEQ), specifically addressing daylight, interior lighting, and quality viewing through the implementation of LEED Interior Design and Construction guidelines and EN 12464-1 (2021) standard, which primarily prescribes lighting requirements for indoor workplaces. The study centers on strategies for optimizing daylight and artificial lighting in campus buildings, with the primary objective of improving occupants' comfort, well-being, and productivity.

Additionally, engineers predominantly prioritize applying sustainability measures to the building envelope or exterior, rather than focusing on implementing sustainability factors within the buildings' interior. Most analysis and research have been conducted on retail spaces and business offices, rather than campus buildings. The UAE has recently embarked on the Green Economy for Sustainable Development initiative, which addresses various issues such as green building practices, minimizing carbon emissions, efficient construction management, refurbishment projects, sustainable water supply, balanced urban growth, recycling, ethical sourcing of building materials, and adapting to climate change impacts. However, there has been limited emphasis on interior lighting and improving indoor environmental quality and addressing occupant health-related concerns in interior design. The focus has primarily been on reducing carbon footprint and energy consumption. This lack of priority for human well-being and comfort in sustainability efforts has led to a credibility gap among the public, architects,

designers, and policymakers. Considering that individuals spend approximately 90% of their time indoors, poor indoor environmental quality can significantly impact the academic potential of students and the overall working environment for staff, particularly in a campus setting. It is crucial for each area and room in a campus building to have appropriate lighting that aligns with its function and meets recommended levels. Buildings constitute significant energy consumption, as illustrated in Figure 5, which presents an energy distribution chart for US buildings. It is noteworthy that space heating and lighting collectively account for more than 50% of the annual energy consumption in buildings.

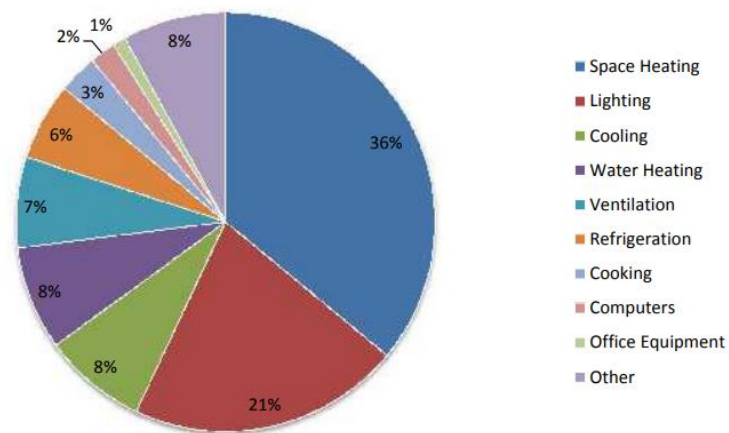


Figure 5: Energy consumption in US buildings in terms of different activities

(Source: USGBC 2021)

While buildings provide physical shelter, their interiors are equally important for daily comfort. Lighting accounts for a significant portion of energy consumption in residential, commercial, and public sectors. The World Health Organization (WHO) recognizes that wellness encompasses social, physical, and mental well-being, which can be influenced by

lighting. Light plays a crucial role in regulating physiological processes and behaviors, including circadian rhythms. Maintaining proper light exposure is essential for circadian entrainment and sleep patterns, as excessive light at night can negatively impact sleep and other aspects such as mood and attention (Ticleanu et al., 2021). Moreover, Halonen and Tetri (2010) conducted a study that highlights the energy consumption of lighting in different building categories. Results showed that in the residential sector, for instance, lighting accounts for 17% of the energy used. In commercial buildings, lighting ranges between 12% and 57% of the total energy used by the structure, with 22% being the average. In the public sector, lighting accounts for 23% of the total energy used.

Research on campus indoor environments and their impact on the health, well-being, and productivity of the academic community is limited. There is a need for studies addressing the local context, climate responsiveness, and cultural considerations. The development of campus interior guidelines specifically focused on sustainability is lacking, which hampers the establishment of effective policies by management. In the UAE, especially within the educational sector, lighting consumes a substantial amount of energy each month. Therefore, there is a pressing need for additional research and the development of comprehensive campus interior lighting guidelines in the UAE. These guidelines will provide invaluable support to institutes of higher learning, assisting them in realizing their long-term goals and sustainable aspirations. Despite the significant expansion of campuses in Dubai, discussions and awareness regarding indoor environmental quality are lacking. The limited availability of research and publications on this topic indicates that it is still in its early stages. However, this presents an

opportunity to advance and mature the understanding of indoor environmental quality, especially interior lighting in campus settings.

1.7 Aims and Objectives

The current study focuses primarily on the campus-built environment, with specific emphasis on indoor characteristics. This sector has immense potential to drive innovation, intellectual growth, and climate resilience, making it a vital area for transformation. As educational institutions are expected to be hubs of innovation and intellectual capacity, their future climate action plans are likely to reflect these aspirations. Over the years, significant progress has been made in improving lighting quality and addressing issues related to poor or excessive lighting, which started by the introduction of “lighting codes” by the Illuminating Engineering Society (IES) back in 1924. Well-designed lighting spaces can have a profound impact on productivity and user satisfaction. Many lighting designers advocate for the use of sustainable lighting fixtures and smart-controlled lighting, aligning with building codes and standards that prioritize energy-saving measures (McKellar and Sparke, 2004).

This study will focus on innovative strategies to improve lighting within campus buildings, emphasizing both daylight and artificial light in work environments. A specific case study will be analyzed and simulated to investigate various strategies and scenarios, with the goal of achieving an optimal lighting design to enhance user performance and productivity. The study seeks to enhance the comfort and well-being of campus occupants by exploring the implementation and improvement of established international green building rating systems,

including LEED Interior Design and Construction, and by referencing the relevant IES standards, as outlined in the objectives below and summarized in

Table 2. The objectives of the proposed research are:

- 1- Assess the status of campus buildings worldwide and in the region to identify challenges and perform gap analyses in relation to indoor lighting parameters in educational building based on LEED ID+C and EN 12464-1 (2021) lighting standards.
- 2- Identifying sustainable strategies and practices that significantly improve environmental quality in terms of lighting either natural or artificial lighting within campus interiors.
- 3- Investigation into both natural and artificial lighting parameters and their direct correlation with user satisfaction levels.
- 4- Evaluate the lighting conditions in existing campus buildings in Dubai, which are occupied both during the day and at night.
- 5- Highlighting the benefits of implementing interior lighting strategies as per LEED ID+C requirements, and EN12464-1 lighting standards to increase efficiency, enhance productivity, reduce energy consumption, and positive environmental impact, especially in campus buildings.

Table 2: Study Structure, (Source: Author, 2023)

Research Question	Aim	Objective	Input Data	Methodology	Result
What is the status of campus building worldwide and in the region in terms of indoor natural lighting and artificial lighting status?	Reviewing various case studies Understanding challenges in indoor environments Focus on lighting-related challenges	Investigating lighting enhancement applications Exploring strategies for improving indoor lighting Assessing impacts on user performance	Spaces specifications and task. Natural lighting and artificial lighting variables.	Literature review Field study	Analyzing space classifications Evaluating lighting scenarios Assessing user experiences
	Exploring lighting standards requirements	Categorizing spaces based on activities Defining lighting	Identifying lighting parameter standards	Field measurements	Examining target values for each space Researching strategies to

	Investigating strategies for enhancing indoor lighting standards in educational campus spaces	benchmarks for different space categories	Establishing target values for each parameter		enhance the spaces
What are the recommended guidelines, strategies, and scenarios to enhance the interior lighting parameters both day light and artificial light?	Identifying sustainable strategies for enhanced productivity and well-being Suggesting applications to improve indoor lighting based on standards	Emphasizing the benefits of tested enhancement strategies Drawing from literature, user feedback, and computer simulation data	Lighting parameters Satisfaction levels in different spaces Innovative artificial lighting types and arrangements Enhancement of daylight	Computer simulation Survey	User satisfaction levels Awareness of lighting's impact on user performance Proposed strategies for improving indoor lighting quality

1.8 Significance of the Study

The United Arab Emirates (UAE) is currently witnessing extensive construction practices that result in high embodied energy consumption. Consequently, the UAE government is actively addressing issues of green conservation and preservation, particularly in relation to buildings' exteriors and interior spaces. Additionally, there is growing concern regarding poor indoor environmental quality, including air and lighting, which can lead to significant pressure, stress, health problems, and reduced productivity levels. With humans spending approximately 80-85 percent of their time indoors, it is crucial to assess and improve the existing conditions in indoor environments. Enhancing the quality of the indoor environment can yield several positive outcomes, including increased occupant satisfaction, improved productivity and performance, enhanced marketing, and liabilities, increased operational efforts, and lower maintenance costs in the campus building. This study focusses on achieving high-performance IEQ through optimal lighting, and the use of green materials with recommended LRV as per the standards and improve the spaces specifications in terms of natural and artificial lighting. It also emphasizes the significance of suitable IEQ, particularly in educational institutions like universities, as it directly affects students' learning processes, concentration, and long-term health. Furthermore, implementing IEQ measures covered by LEED Interior Design and Construction standards can promote occupant comfort, well-being, and productivity by improving day light and artificial lighting covered by EN12464-1 standard in UAE campus buildings.

Dubai, being a center of innovation and sustainability, takes pride in its progress in various fields, including skyscrapers and space missions. Conducting genuine research on campus

sustainability would further strengthen Dubai's position as a sustainability lead in the region. Such research would be the first of its kind in the area. Given the rapidly evolving higher education landscape in the UAE, encompassing a diverse array of students and academic institutions, there is a pressing necessity to delve into campus indoor environmental quality (IEQ) and devise an appropriate sustainability framework. One of the key outcomes of this study will be to pave the way for future research endeavors, which can focus on proposing guidelines for optimizing daylight and artificial lighting in UAE campus buildings. Additionally, it aims to establish new benchmark standards and lighting strategies tailored specifically for campus environments, while also fostering greater awareness of sustainable interior design practices within the campus community. Campus buildings, as institutions of higher learning, play a pivotal role in sustainable development. Understanding their potential, addressing limitations, identifying regional barriers, and building a knowledge base for informed decision-making among key stakeholders are crucial. This study aims to bridge these gaps and contribute to the development of a sustainability framework for campus indoors especially in day light and artificial light parameters, aligning with the UAE's efforts to foster a smart ecosystem for creativity and accelerate the country's progress.

The findings of this study are expected to have significant implications for investors, researchers, shareholders, manufacturers, policymakers, and government entities. By promoting a commitment to professional optimum, the study seeks to inspire campus, organizations, and researchers to prioritize enhancing students' visual comfort through indoor lighting enhancements. The results will also be valuable to future researchers in the field, as well as government entities seeking to implement policies for student success. Moreover, the study will

shed light on the importance of adequate lighting environments in campus buildings, which can positively influence students' academic performance. By providing insights and resources, this thesis will assist in effectively implementing policies and programs that contribute to safe and healthy campus environments.

Furthermore, this study focuses on determining the optimum indoor characteristics for sustainable campus buildings, taking into account health, wellness, and cognitive abilities, particularly in the context of Dubai, based on relevant standards. By analysing the global scene, the study will provide a comparative perspective and assess works carried out in other regions. The expected outcomes include practical knowledge on improving lighting quality, indoor lighting strategies, and awareness campaigns. The findings will empower stakeholders, including policy makers, regulators, planners, engineers, and more, to apply the study outcomes to their environments, considering similar profiles. Ultimately, this study will contribute to sustainable development in the campus building sector and support the UAE's goals for a greener future.

1.9 Research Focus and Limitations

This work aims to investigate innovative approaches for enhancing lighting conditions in campus buildings, considering their diverse functions, occupancies, and users. These users encompass various age groups, academic and non-academic staff, as well as students ranging from undergraduate to postgraduate levels. The case studies selected for this thesis will examine the different aspects of lighting in various space categories, recognizing its significance in influencing occupants' well-being, health, and productivity while also addressing energy

consumption. However, it is crucial to acknowledge that the uncontrolled intensity of daylight can result in challenges such as energy consumptions and issues with glare (Bonda and Sosnowchik, 2014). Achieving optimal daylighting quality and quantity in buildings relies on factors such as the building's orientation, window dimensions, and their strategic placement. These strategies can be implemented during the early stages of building design. However, in the case of existing buildings where the building façade cannot be altered, alternative solutions need to be implemented internally. The provision of views for building occupants is crucial, especially in specific building functions such as schools, universities, and various other facilities. For example, in cases where natural views are not readily available on the site, other solutions such as interior landscaping can be incorporated to enhance the visual experience. These solutions will be discussed in detail in the proposed strategies and scenarios section.

Nevertheless, it is widely recognized that campus buildings often do not receive the necessary attention they require due to various factors and barriers. Extensive research has shown that overcoming these barriers necessitates thoughtful strategies, which may vary based on different geographical locations and cultural contexts. According to Ticleanu (2021), the current focus in lighting practices primarily revolves around visual aspects. This implies that lighting solutions aim to enhance visibility and clarity in various settings. However, it is important to note that certain sectors, such as classrooms, libraries, auditorium also consider aesthetic requirements to improve the overall appearance of the environment, individuals, and objects within it. This perspective aligns with the common assumption that the main function of light is to support visual perception and satisfaction by providing appropriate lighting conditions for safe, accurate, efficient, and comfortable performance of human tasks.

It is also crucial to acknowledge that light can have physiological effects on humans that extend beyond its visual or perceptual aspects, as highlighted by Boyce (2014). These non-visual effects of light on human physiology demonstrate the multifaceted nature of lighting and its potential impact on overall well-being and performance. According to Sulaiman et al. (2013), lighting plays a crucial role in shaping the overall campus experience. When lighting is not well-designed, it can negatively impact the atmosphere of a space, as well as the well-being and productivity of its users. In educational buildings, electrical lighting must be tailored to the specific purpose and function of each space, considering factors such as the intended use of the space and the time of day it will be utilized. Additionally, it is important to consider the category of the spaces based on LEED criteria, as mentioned previously, and to determine the appropriate balance between daylight and electrical lighting to create a pleasant and comfortable environment.

In the context of lighting design, the primary focus should be on satisfying the users' requirements and ensuring their overall satisfaction, rather than merely aligning with the interior design aesthetics. This user-centric approach to lighting design acknowledges that different spaces have distinct functions and tasks, and lighting should be tailored accordingly to support these activities and meet the users' needs based on the standards. Therefore, a well-designed lighting scheme in educational buildings should prioritize user satisfaction and strive to create an optimal lighting environment that enhances the overall campus experience, promotes well-being, and supports productivity, while taking into consideration the occupants' demographics and task characteristics (Alhamad and Saraiji, 2022). The physical environment of campus buildings plays a significant role in the learning process, encompassing factors such as day light

and interior lighting (Michael and Heracleous, 2017). A well-maintained and welcoming facility promotes a sense of safety and excitement among academic, non-academic staff and students, reducing absenteeism and enhancing the overall learning experience. By providing a clean and conducive environment, the campus can better facilitate the learning process and create a positive atmosphere for students and focus to ensure that the suggested lighting enhancements align with sustainability goals and energy efficiency of the building. This includes evaluating the use of energy-efficient lighting technologies and sustainable design principles to decrease the environmental impact.

While this study aimed to cover its objectives comprehensively, it faced certain unavoidable limitations. Firstly, due to resource constraints, the study focused on a selected campus in Dubai, specific to the UAE's cultural context and climatic conditions and may not be directly appropriate to the other regions with dissimilar environmental and cultural factors, which may limit the generalizability of the research findings. Additionally, the sample size of staff interviewed was limited comparing to the total population in the campus. Moreover, It is important to acknowledge that not every environmental and physical factor influencing student learning could be identified. And users within campus buildings may have different needs and preferences when it comes to interior lighting. The research may not take full scale of individual differences users need. The lack of accessible offline and online data was a significant drawback, making it challenging to determine the full extent of the effects.

Additionally, restrictions to enter the campus building due to the COVID-19 pandemic have impacted the ability to collect data or conduct on-site observations. Another limitation is the absence of student input, as students are not physically attending on-campus buildings, which

presents challenges in data collection related to their behaviors, interactions, and activities within the campus spaces. Also, the limited interactions between day light and artificial lighting conditions and other variables that effect well-being and productivity of the users as specific tasks being performed or individual health factors. However, despite these limitations, the study sheds light on the critical role of the physical environment in educational settings and provides valuable insights into the interconnected factors influencing student learning. Future research should aim to address these limitations and further explore the broader scope of enhancing learning environments for optimal educational outcomes.

1.10 Thesis Contents and Structure

This work is consisting of six chapters and organized as per the following:

1. Chapter One - Introduction:

The introductory section of the study provides an overview of the research, articulates the problem statement, clearly stating the issue or gap in knowledge that the study aims to presents, the study's aims and objectives, research questions, highlights the significance of the study, defining the boundaries and extent of the research in terms of its focus and coverage, and establishes the assumptions.

2. Chapter Two - Literature Review:

This chapter aims to offer valuable understanding of the current state of campus facilities, as supported by researchers' findings. Specifically, it focuses on the indoor environmental quality, with a particular emphasis on lighting conditions within these facilities. The

objective of this chapter is to establish the correlation between these factors and their effects on academic performance and the overall well-being of the working environment, while establishing the research gap filled by this study.

3. Chapter Three - Methodology:

This chapter provides a detailed description of the methodology and the procedure followed in this work, the instruments used for data collection in the field measurement, observations made during the study, and the overall design of the research. Moreover, the study will explore the case studied scenarios and the simulation process used to generate the results. The preferred investigation methods, including the subjective study and parametric study, are clearly outlined and explained in this chapter.

4. Chapter Four – Analysis and Results:

This chapter provides detailed descriptions and explanations of the research results, which aim to address the research questions of the study. The results specifically examine the differences between fluorescent lighting, and LED lighting products in different interior spaces and how they impact the productivity and users' comfort in various working environments. These effects are compared with the combined effects of sufficient daylight. Furthermore, the chapter explores the impact of interior finishing materials with different light reflectance factors on the obtained results. The results primarily focus on performance indicators as evidence of campus effectiveness.

5. Chapter Five – Results and Discussion:

This chapter serves as the core of the research, encompassing the presentation of research findings, data analysis, interpretation of results, comparison with prior research, exploration of alternative explanations, connections to the theoretical framework, and consideration of practical implications. It provides meaningful insights and contributes to the field's body of knowledge by analyzing data within the context of existing literature.

6. Chapter Six – Conclusion and Recommendations:

This chapter will provide an overview of the meaningful aspects of the research results and findings. The chapter will also incorporate insightful comments on these aspects, and thoroughly examine the applicability of the strategies in diverse regions. Furthermore, based on the findings presented in the earlier chapter, additional suggestions and recommendations will be proposed. Overall, this comprehensive overview sets the foundation for the study, providing a clear roadmap of its objectives, motivations, limitations, assumptions, ultimately guiding the research process and framing the subsequent analysis and findings.

Chapter 2 : Literature Review

2.1 Overview

Numerous studies have emphasized the impact of IEQ on people's overall performance and well-being, irrespective of the particular setting in which they are situated, whether it is the workplace, home, or classroom. The quality of the indoor environment, including factors such as air quality, lighting, ventilation, temperature, and acoustics, has been shown to significantly influence cognitive functions, concentration, mood, and overall satisfaction.

On the other hand, a considerable amount of literature has been investigated in this section on campus building IEQ with a focus on interior lighting design parameters and user satisfaction. In the context of a university campus building, lighting characteristics were specifically explored as an essential aspect of IEQ. Lighting not only affects visual comfort but also plays a significant role in creating an atmosphere conducive to learning and productivity. Adequate lighting levels, appropriate colour temperatures, and the balance between natural and artificial light sources have been identified as crucial factors in enhancing students' focus, alertness, and overall well-being.

Understanding the interplay between users' satisfaction, well-being, and IEQ can inform architects, designers, and facility managers in optimizing the learning environment within university buildings. Data from several sources have identified that by prioritizing IEQ considerations and incorporating user feedback, educational institutions can create spaces that support students' academic achievements, foster their well-being, and contribute to a sustainable and healthy learning environment.

2.2 Indoor Environment Quality as Per LEED (ID+C)

LEED (Leadership in Energy and Environmental Design) credits within the Interior Design and Construction (ID+C) category hold significant relevance to indoor environmental quality (IEQ), particularly in educational interior design contexts.

1- Focus on IEQ enhancement, the ID+C category of LEED emphasizes several credits specifically aimed at improving IEQ. These credits address various aspects such as lighting quality, thermal comfort, indoor air quality, acoustics, and access to daylight. Each of these factors directly influences the well-being, comfort, and productivity of occupants within educational spaces.

2- Occupant health and performance, the IEQ significantly impacts students' and educators' health, well-being, and performance. Adequate lighting, optimal thermal conditions, good air quality, and acoustic comfort foster a conducive learning environment. LEED (ID+C) credits offer a framework that encourages designs prioritizing these factors, contributing to healthier and more productive educational spaces.

3- Sustainability and environmental responsibility LEED promote sustainable practices, and the ID+C category aligns these principles with interior design and construction. By emphasizing credits for IEQ, LEED encourages designs that not only prioritize occupant comfort but also reduce environmental impact through energy efficiency and resource conservation.

4- Tailored standards for educational spaces by LEED (ID+C) recognize the unique requirements of educational settings. It offers guidelines specific to these spaces, ensuring that

lighting, ventilation, acoustics, and other factors align with the needs of students, teachers, and administrative staff. (USGBC,2021).

In educational interior design, where creating conducive and healthy learning environments is paramount, LEED (ID+C) credits serve as a comprehensive guideline to achieve these goals. Adherence to these credits ensures that educational spaces prioritize IEQ, supporting the physical, mental, and academic well-being of occupants while fostering sustainability and environmental responsibility. The study focus on lighting quality and interior lighting within the British University in Dubai aligns closely with the core principles of LEED (ID+C) credits related to indoor environmental quality (IEQ) enhancement. By concentrating on these aspects, addresses crucial elements highlighted by LEED for fostering healthier and more sustainable educational interior environments. It also showcases a practical application of the principles outlined by LEED (ID+C) credits, emphasizing the importance of adequate lighting, optimal illumination levels, glare reduction, color temperature, and lighting design considerations tailored to educational spaces.

Many studies have demonstrated the far-reaching impacts of IEQ on occupants' performance, health, and well-being. Several researchers explored how users of buildings perceive the interior and indoor environments and what factors contribute to their comfort and mental well-being. Therefore, making efforts to enhance the work environment is highlighted as one of the most effective ways to enhance productivity and overall performance. On the other hand, Companies try to enhance IEQ for providing better health and working conditions, as well as to enhance the performance of learning environments. In the case of educational buildings, researchers believe that poor indoor and classroom environment tends to decrease the overall performance of

students. Choi et al. (2014) conducted a study that focused on examining the relationship between the indoor environmental quality of various university classrooms and its impact on students' academic performance, their perceptions of learning, and course satisfaction. The study noticed that as students spend the majority of their time in classrooms for their learning activities, the quality of these classroom environments directly shapes their learning outcomes, satisfaction, and overall productivity. In order to test a conceptual model hypothesis, data gathered from University of Minnesota in USA students (N = 631) were examined using a path analysis. According to the research, the IEQ of the classrooms including their thermal, indoor air quality, acoustic, lighting, furniture, aesthetics, technology, and view conditions was linked to better student outcomes.

As highlighted by many researchers, the green building rating system in the context of interior design and construction includes five aspects of sustainability which are: resources and materials, water efficiency, sustainable locations, energy and atmosphere, and indoor environmental quality. Hence, the majority of the IEQ revolves around indoor air quality, acoustics, thermal comfort, day light and quality viewing and interior lighting. In order to examine the viewing, interior lighting, and daylight, these studies emphasize on main IEQ strategies and techniques for enhancing users' productivity and well-being on university campuses (USGBC,2021). Figure 6 illustrates the structure of IEQ - LEED (ID+C) in the context of users' productivity and well-being grading system. Furthermore, it consists of a list of LEED credits representing generic concerns related to IEQ covered in the LEED rating system. Nonetheless, according to USGBC (2021), there might be some variations in rating systems with respect to these credits.

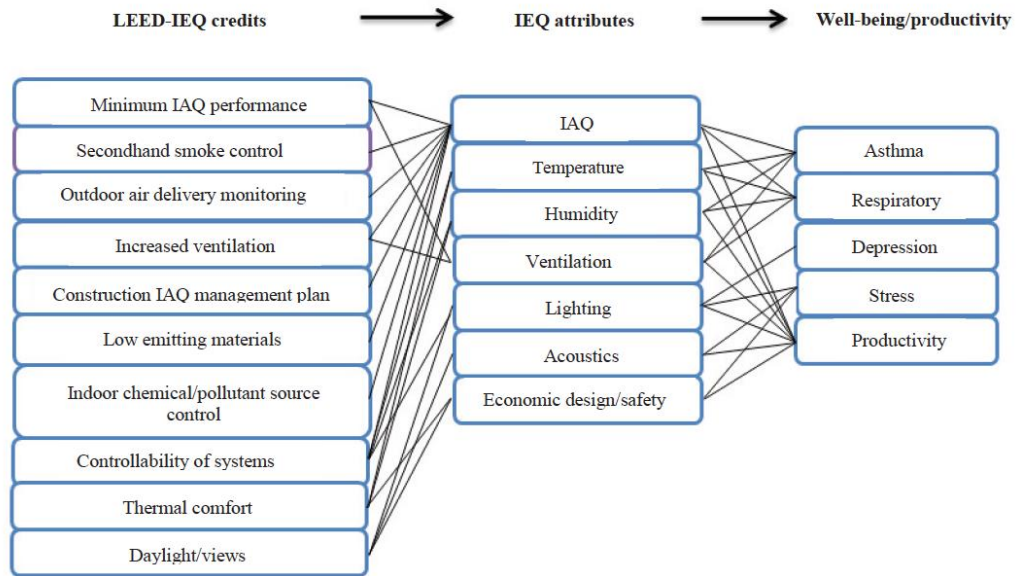


Figure 6: LEED- IEQ occupant well-being and productivity structure.

(Source: USGBC,2021)

In a certain learning environment, there are a number of factors that influence the academic performance of students, where aesthetic and physical factors play a vital role in increasing the effectiveness of academic environments. It is believed that well-designed indoor environments can directly affect students by making them more motivated, positive, and enthusiastic. Furthermore, indoor lighting of spaces and classrooms can affect the quality of the learning and teaching process as well. Hence, architects and designers must understand the relationship between the environment and the lighting for improving the interior designs within classrooms to positively affect the academic performance of students.

According to Choi et al. (2014), indoor lighting has a notable impact on students' performance, particularly in the learning environment, and can be categorized into two types:

artificial and natural lighting. The researchers emphasized that both artificial and natural lighting offer substantial advantages and should be utilized based on the activities taking place in classrooms. Consequently, insufficient lighting in educational settings tends to hinder students' learning abilities, leading to persistent eye strain, increased stress levels, and reduced absorption of knowledge. Samani and Samani (2012) identified three major factors that affect the quality of indoor lighting, these include: architecture, the well-being of individuals, and economic factors. These factors are further divided into subcategories as demonstrated by Figure 7. Based on this, they believe that by seeing through individuals' perspectives of well-being, the lighting might influence activity, alertness, visibility, well-being, health, moods, and comfort of people in the classroom.

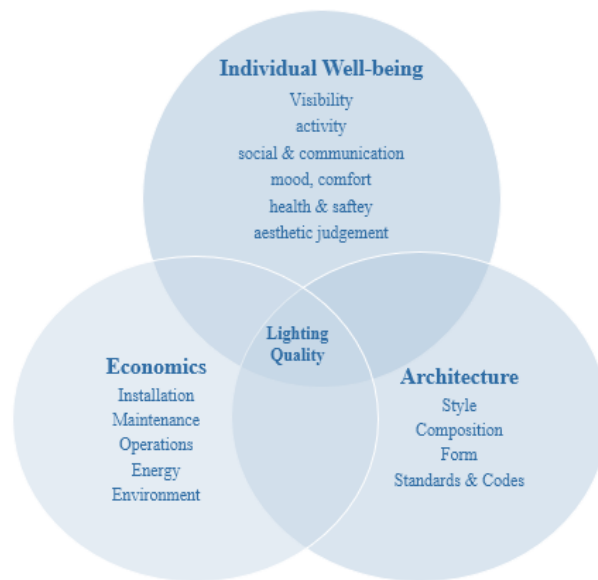


Figure 7: Lighting quality: the integration of individual well-being, economics & architecture

(Source: Samani and Samani, 2012)

2.3 Interior Lighting

2.3.1 Importance of Light

Light, within the electromagnetic spectrum, serves as an essential stimulus for visual perception, rendering objects perceptible to the human eye. This electromagnetic phenomenon comprises a wavelength range that falls between approximately 380 nanometers (nm) to 780 (nm) and is commonly denoted as visible light, representing the spectrum of light that the human eye is sensitive to. In diurnal settings, our visual perception is predominantly mediated by specialized retinal cells known as cones. These cone cells exhibit sensitivity to varying wavelengths within the visible light spectrum, enabling the human visual system to discriminate and perceive a wide spectrum of colours. Consequently, they facilitate the discernment of the diverse and vivid colors present in our environment during daylight hours.

In the nocturnal context, a distinct class of retinal cells, referred to as rods, assumes a more prominent role in visual function. Rod cells exhibit heightened sensitivity to diminished light levels, yet they lack the capacity to discriminate among different wavelengths as efficiently as cones. Consequently, under low-light conditions, the human visual system experiences limitations in color perception. Instead, the night vision is characterized by the perception of a monochromatic world, wherein various shades of gray predominate, owing to the absence of the colour differentiation capabilities inherent to cone cells.

Furthermore, Human Centric Lighting (HCL) represents the positive impact of lighting and light on the performance, well-being, and health of people. Lighting plays an important part in the way architecture is understood and experienced by people. Whether structures, buildings, or

any architecture is lit artificially or naturally, lighting is the main medium through which people are able to view and appreciate the buildings and their surroundings' aesthetic. In addition to that, light helps in seeing the world by distinguishing through colours, details, movement, and brightness of monuments, buildings, infrastructure, and people. As highlighted by DiLaura, et al. (2011), light significantly affects emotional, aesthetic, and visual aspects, along with psychological and physiological impacts on mood, perception, well-being, productivity, performance, visual, and comfort.

Addressing environmental factors, economic reliability, and efficiency of energy, lighting has a variety of effects on buildings and their occupants. When considering environmental factors, the application of lighting in academic and campus buildings stands as a significant domain where lighting exerts its influence. Utilizing daylight energy conservation through lighting control, intelligent lighting, and efficient luminaires such as LED technologies are quite effective. Moreover, these benefits can be further expanded by considering ergonomic aspects that focus on enhancing performance through the establishment of standards for fundamental visual requirements, such as illuminance, glare control, and uniformity ratio. Lastly, emotional aspects consist of enhancing concentration, opening the room ambiance through brightened walls and ceilings; feeling healthy and at ease leading to improve performance. According to medical evidence, light improves the cognitive performance of individuals. Furthermore, it suggests that adjusting light according to visual tasks and activities, such as blackboard lighting to meet high visual demands for accommodating distant vision while copying or reading from the blackboard. Figure 8 represents the link between different variables affecting health, perception and mood of humans and the lighting (DiLaura, et al., 2011).

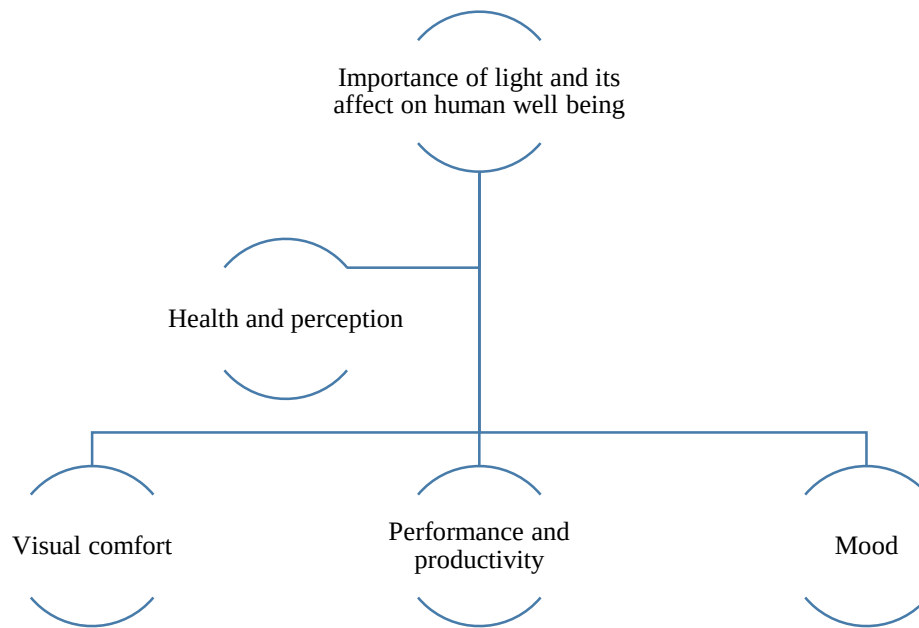


Figure 8: Variables affecting humans.

(Source: DiLaura, et al. 2011)

On the other hand, energy efficiency in buildings is regarded as one of the key elements that significantly affect the built environment, the surrounding area, and the climate. Some of the following factors that play a positive role in reducing energy consumption include:

- Intelligent consideration of hours used for energy consumed
- Sensible control of lighting
- Energy-efficient lamps
- Optimize the use of daylights

- Use of presence detectors
- Constant maintenance/ lighting control
- Use of lighting solutions and luminaries based on need as required for the respective applications (IES, 2000).

2.3.2 Source of Lighting (Natural light and Artificial light)

Light sources can be broadly categorized into two main types: artificial/electric lighting, which has been a commonplace source of illumination for approximately 130 years since its invention, and natural light, which includes daylight or sunlight diffused through reflections and skylights. While natural light offers numerous advantages, the demands of modern-day living necessitate the ubiquitous use of artificial lighting. In contemporary society, our daily activities often extend into the late hours, and a significant portion of our time is spent indoors, be it in educational institutions, workplaces, recreational areas, or dining establishments. Even outdoor spaces are frequently illuminated with artificial lighting, serving both decorative and traffic management purposes. Consequently, there exists a substantial and consistent demand for artificial lighting, with the expectation that it should be readily available in the required quantity and quality, irrespective of location or time. In addition to accessibility, there is a growing emphasis on the eco-friendliness and affordability of artificial lighting solutions, aligning with the evolving needs and sustainability concerns of society.

With extensive innovations, modern-day artificial lights are produced with high quality and efficiency. Nevertheless, lighting in the European region still accounts for up to 14% of total energy consumption and approximately 19% of the total energy consumed across the world

(DiLaura et al., 2011). The industry of artificial lighting has introduced a wide range of lamps since 1879 after the invention of the incandescent lamp by Thomas Edison and is now being manufactured on a large scale. Individual lights and lamps are available in different designs and sizes with varied of outputs or the energy in which light is produced. One of the most important criteria for producing light in modern days includes efficiency, high quality, long service life, and low energy consumption level. Figure 9 illustrates different ways of producing artificial light.

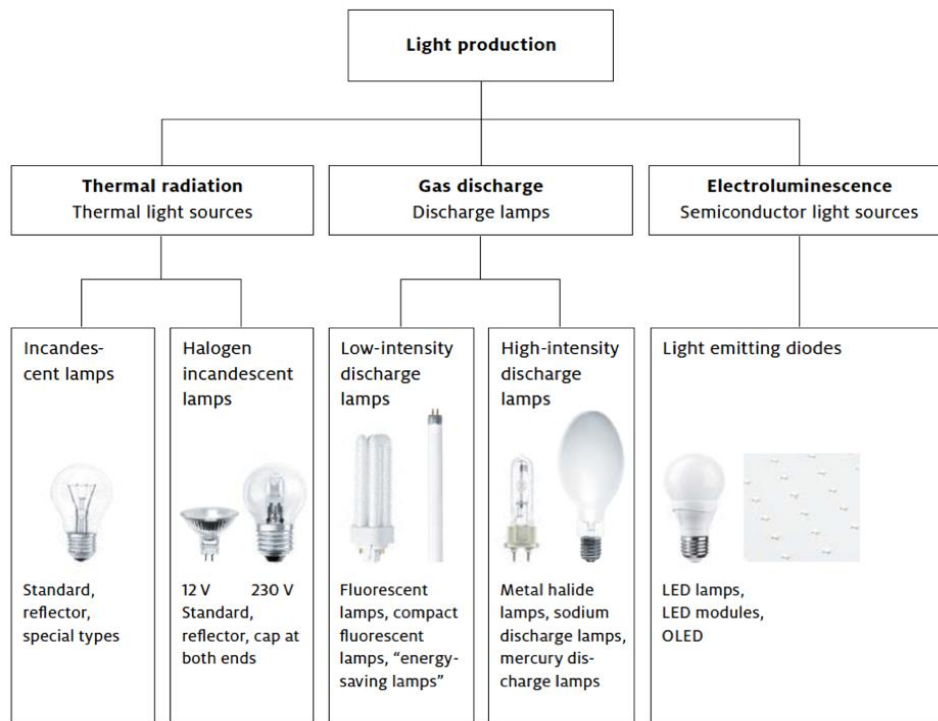


Figure 9: Artificial light production.

(Source: DiLaura, et al. 2011)

Furthermore, light can be cost-effectively produced with the help of three main sources as : semi-conductor light sources, thermal light sources, high and low -intensity discharge lamps. Preliminary work on luminaire types further suggested that there are several types of artificial lights, such as Light emitting diodes (LEDs), halogen incandescent lamps, and fluorescent lamps, and all three have different features and characteristics. The fluorescent lamps have high to very high energy efficiency, long-term service life, efficient wide-area lighting, dimmable, wide standard options, and good to excellent colour rendering. Halogen incandescent lamps include features, such as low or mains voltage, much better energy efficiency and service life than simple incandescent lamps, excellent colour rendering, dimmable, and bright light. They have multiple uses: decorative applications, domestic and retail areas, and hospitality.

In contrast, LEDs are a clear winner not just in the context of the amount of energy it consumes, but also in the way it helps in managing savings. Energy Star Led light can perform well up to 25 years without replacing the lamps, as compared to a service life of 1 year for incandescent light (Energy Star, 2006). Within this capacity, LEDs tend to outperform other artificial lights in several ways, such as low maintenance costs. Furthermore, their clarity and brightness provide better sight and clear view from a farther range of strategic points with a wide range of artificial light levels.

In addition to this, Energy Star (2006) claims that LED's full-matrix display is also highly flexible. Additionally, LED lights expose individuals to high colour temperatures, around 65000K. They indicate a higher colour recognition and visual comfort among people as compared to when they are exposed to fluorescent lamps. Avci and Akbay (2022) highlighted a significant advantage of LED lights, often observing that LED lights produce less mental

exhaustion and fatigue among people than halogen and fluorescent lamps within working environments. Moreover, LED lighting has a high-efficiency production, long-lasting service life, excellent production of coloured lights, good to excellent colour rendering, can be dimmed or switched on/off as needed, and offer a wide range of options. They can be used for decorative and functional purposes in indoor environments, particularly within academic buildings.

In contrast to incandescent lamps, LED (light-emitting diode) lights, exhibit higher luminous efficiency. These technologies involve different mechanisms for converting electrical energy into light, often relying on the excitation of phosphors or the passage of electrons through semiconductors to produce visible light. The advancements in these technologies have allowed for greater energy efficiency and reduced energy wastage (Avci and Akbay, 2022). Meanwhile, understanding the distribution of energy produced by light sources is essential for energy conservation, environmental sustainability, and optimizing lighting design. By considering the

efficiency and spectral output of different lighting technologies, it is possible to select lighting solutions that minimize energy consumption while maximizing the desired visual effects.

2.3.3 Basic Lighting Parameters and Terminologies

The energy that is produced by any form of light is not completely recognized as light energy. For example, only a certain amount of electric energy is transformed into radiant energy by incandescent lamps. The energy produced by light sources encompasses more than just visible light energy. In fact, the transformation of electric energy into radiant energy by various lighting technologies results in a complex distribution of energy forms, with a significant portion being

converted into heat rather than visible light. This phenomenon is particularly evident in incandescent lamps, where the majority of energy is recognized as heat, while only a fraction around 10 percent is perceived as visible light by the human eye.

The conversion of electric energy into light involves physical processes within different lighting technologies. In the case of incandescent lamps, electrical current passes through a filament, typically made of tungsten, which heats up due to its resistance to the flow of electricity. As the filament reaches high temperatures, it emits electromagnetic radiation across a broad spectrum, encompassing both visible and non-visible energy. However, In the case of incandescent lamps, where a significant portion of the energy is emitted as heat, it becomes clear that the luminous efficiency, defined as the ratio of visible light output to electrical input, for such lamps is relatively low.

Furthermore, DiLaura, serving as the lead author of the 10th edition of the Lighting Handbook (DiLaura et al., 2011), provided an extensive explanation of various lighting-related variables and terminology. This included, but is not limited to, luminous intensity, which pertains to the amount of light emitted by a specific light source in a particular direction. Luminous intensity is a metric sensed by the human eye and serves to measure the brightness or concentration of light within a specific direction. This term is frequently employed when describing the brightness of directional light sources like spotlights, flashlights, or automobile headlights. Luminous intensity is a critical parameter for applications that require focused or controlled illumination, offering insights into how bright a light source appears in a given direction.

On the other hand, Luminous Flux is referred to the entire amount of light emitted by a light source in different directions within a second and measured by lumens (lm). It depicts the strength of light as perceived by the human eye while taking in to account the eye's sensitivity to various light wavelengths. The lumen (lm), a derived unit in the International System of Units (SI), is the unit of light flux and it is represented by the Greek letter (Φ). When describing the brightness or light output of light sources like light bulbs, lamps, and LED devices, the term "luminous flux" is commonly used. Regardless of the actual spectral properties of the light, it offers a standardized measurement of the volume of visible light produced by a source.

It's essential to remember that while luminous flux indicates a source's overall production of light, it ignores the distribution of that light. The luminous intensity, which is expressed in candelas (cd), describes how light is distributed in various directions. Both the luminous flux and the luminous intensity (I) of a source must be taken in to account in order to show how bright of source is overall to the viewer (McKellar & Sparke, 2004).

Figure 10 represents the previously mentioned parameters adding to the illuminance or luminous levels, which is referred to as the ratio between the surface and the luminous flux emitted on the surface. Different activities and environments require different illuminance levels to ensure adequate visibility and comfort. Lux (lx) is used for measuring illuminance and is represented by the sign (E). Equation (2.1) is used for defining the illuminance is as follows:

$$E = \frac{\Phi}{A} \quad (2.1)$$

Where E is the illuminance (lux), Φ is the luminous flux (lm), and A is the area (m^2)

According to this equation, the higher the luminous flux emitted by the surface, the higher the luminous levels. Additionally, the luminous levels explain the amount of luminous flux hitting the surface and illuminance is the only major parameter of light recognized by human eyes, also it explains the impression of the brightness of the light source (Shams et al., 2021). The luminance (L) is just the fundamental light parameter that is seen by the eye. It indicates the brightness of a surface besides is basically dependent on its reflectance which is the materials finish and colour, the unit of luminance is cd/m^2 .

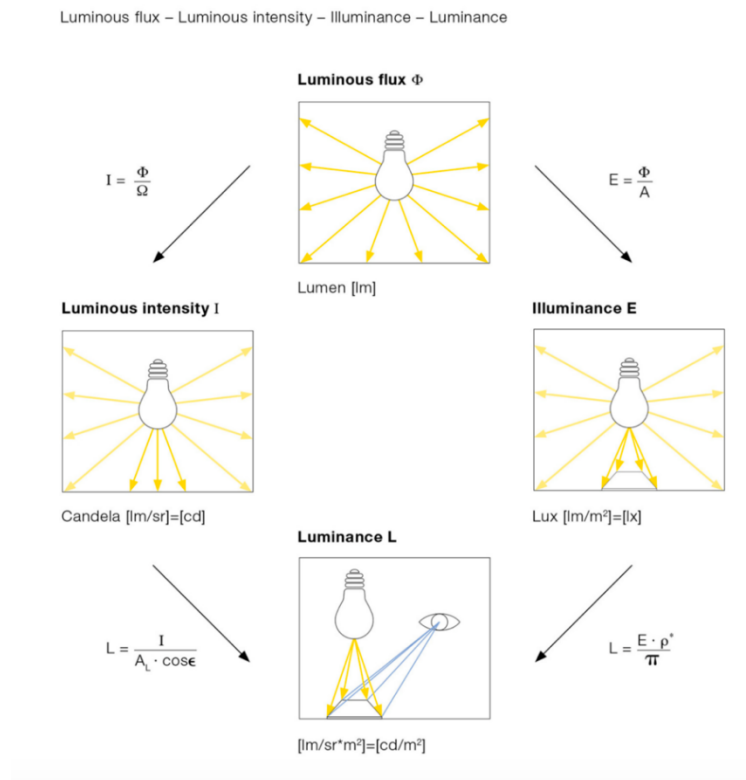


Figure 10: Basic parameters used in lighting.

(Source: DiLaura, et al. 2011)

Furthermore, the term Luminous Efficiency is the ratio of luminous flux of light per energy input, it is measured in lumens per watt (lm/w) based on International System of Units (SI). This means that the smaller the watt and the higher the value of the lumen, the more efficient the light is. Compared to more conventional lighting sources like incandescent and fluorescent lamps, LED (Light-Emitting Diode) lights are renowned for their exceptional energy efficiency. The quantity of light an LED light emits for every unit of electrical power used is known as its luminous effectiveness. It assesses the LED's ability to effectively transform electrical energy into visible light. In contrast to LED lights to incandescent and fluorescent lighting, LED lights offer a much better luminous effectiveness. The development of LED technology has allowed for substantially higher lumen values to be obtained while using relatively less electricity. Incandescent lights, which have recently been the subject of multiple research, have a relatively poor luminous efficacy, typically between 15 and 25 lumens per watt (lm/w). This indicates that they create 15 to 25 lumens of light for every watt of electrical power used. The primary way that incandescent lights create light is by heating a filament, which wastes a lot of energy as heat instead of light (Shams et al., 2021).

Numerous studies have attempted to explain and compare the efficiency of different types of lighting sources like: Compact Fluorescent Lamps (CFLs) and other fluorescent lighting are more energy-efficient than incandescent lighting. They typically range from 50 to 90 lm/W in luminous effectiveness. Fluorescent lamps work by employing an electric discharge to excite phosphors deposited on the inside of a glass tube. Fluorescent lights still lose some energy owing to heat generation even if they are more energy-efficient than incandescent lights. whereas, depending on the exact LED technology and design, LEDs have a substantially higher luminous

efficacy, often ranging from 80 to over 200 lm/W. This indicates that LEDs are highly efficient since they can produce more light output per unit of electrical power input. LEDs' semiconductor-based construction enables greater light production control, reducing energy waste. Meanwhile, LEDs have a higher luminous efficacy than traditional bulbs, which results in energy savings and a longer lifespan. It enables LED lights to provide brightness levels that are similar to or greater than before while using substantially less energy. As a result of its energy economy, LED lighting has been widely used for a variety of applications, such as lighting for homes, businesses, and industries as well as educational buildings (Halonen and Tetri, 2010)

IES (2000) recommends that several lighting quality parameters should be taken into account when designing lighting criteria for a certain application or venue. These features contribute in ensuring that the lighting design complies with particular regulations and standards. Here are some typical attributes of good lighting:

- **Uniformity Ratio (UO):** The uniformity of a specific area's lighting distribution is referred to as uniformity. In order to prevent areas of excessive brightness or blackness, it ensures that there are no noticeable changes in illuminance levels. Having homogeneity is essential for eye comfort and a comfortable viewing experience. The uniformity ratio in campus building, specifically in lighting design context, indicates to the evenness and symmetry distribution of light in interior spaces. Uniformity ratio measures how equally the illuminance of light (light level) is dispersed thru the entire work-plane area of the room or floor area. Uniformity in lighting is important in educational campuses to deliver a visually consistent, and comfortable environment for both students and staff. It helps to

generate a comfortable environment for learning and teaching and hence, reducing distractions and visual discomfort. Based on EN 12464-1 standard, each zone and task in campus buildings require a specific level of uniformity ratio. Standard values for the level of uniformity ratio in classrooms, library, meeting rooms, and multipurpose hall is 0.6, while in corridors and circulation area around 0.4. (DiLaura et al., 2011).

- Colour Rendering Index (CRI): is a measure of how accurately a light source renders colours compared to a reference light source. It is rated on a scale from 0 to 100, with higher values indicating better colour rendering. A CRI of 100 indicates that the colours of an object under artificial light appear the same as they would appear in natural light. However, a CRI of less than 80 is not appropriate to be used at workplaces, as illustrated in Figure 11. A high CRI is important in applications where accurate colour perception is essential, such as retail, art and galleries, and (IES, 2000). The recommended CRI value for educational spaces is 80, which confirms the equity of good colour rendering, appropriate for most lecture halls and classrooms. However, for auditoriums spaces, CRI values of 85 or higher may be recommended. The Colour Rendering Index (CRI) in campus and educational buildings can have indirect impact on student learning environment overall and on user's behaviours. It plays a part in creating a conducive atmosphere and comfortable for learning environment, which, that can influence students' engagement, attitudes, and performance. Quality of light with high Colour Rendering Index can help students' overall well-being. Also, exposure to natural- light can enhance regulate circadian rhythms. Students who are better in mental and physical health might show additional positive behaviours in the classroom (Ford, 2010).

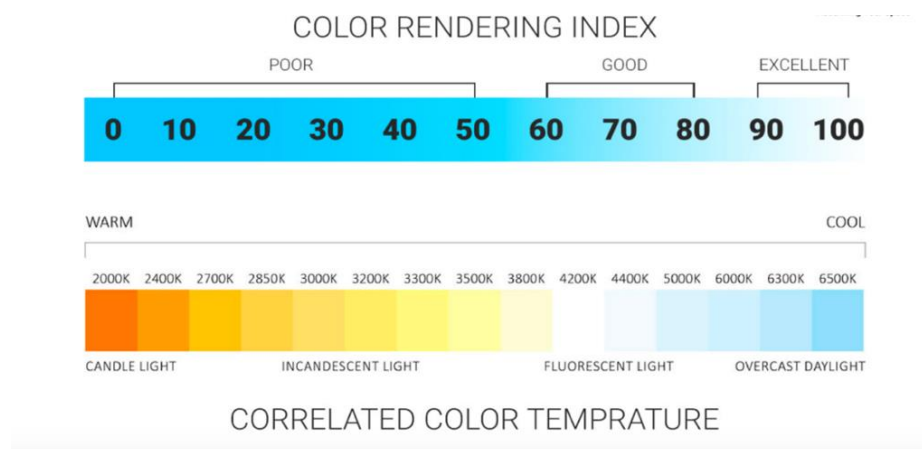


Figure 11: Colour rendering index and colour temperature scale.

(Source: Ledmyplace, 2022)

- Correlated Colour Temperature (CCT): is a measure of the colour appearance of light emitted by a source. It is expressed in Kelvin (K). Lower CCT values (e.g., 2700K) produce warm, yellowish light, while higher values (e.g., 5000K) produce cool, bluish light. CCT selection depends on the desired atmosphere and the purpose of the space. The colour temperature of the natural light is about 5000-6000 K. On average, the LED lights with a CCT of 4200 Kelvin are most appropriate to be used for classrooms. But, it is healthier and better to use the LED lights with a colour temperature of around 5000-6000 K for classrooms with dedicated to various activity and test. The lighting situation and condition is one of the main aspects that affect the health, emotions, and vision of the human beings. Selected lighting could lead to a comfortable visual perception and well-being of the users. The significance of illumination and mainly the effects of colour

temperature standards on human behaviour is being exposed from different perceptions every day. Catalbas and Kobav (2022) underscore the significance of their study by noting that approximately 80% of individuals spend the majority of their daily lives in indoor environments, making the effects of indoor lighting crucial. They emphasize the importance of color temperature, a parameter signifying the color of the light source, in photometric research. The research suggests that the color temperature value within indoor environments has distinct and substantial effects on human behaviour and perception. This is particularly pertinent given that a substantial portion of people's daily routines, including students, is spent indoors. Wang et al. (2017) reviewed the influence of the colour temperatures on visual performance in working area, which displayed that the efficiency and productivity of users was significantly improved when the higher colour temperature were implemented in interior spaces. Furthermore, the LED lights with higher colour temperatures could increase and productivity as well as the well-being of workers in educational buildings.

- Glare: glare occurs when excessively bright light sources or reflections cause discomfort or hinder visibility. It can be categorized as disability glare (reduces visibility) or discomfort glare (causes discomfort without necessarily reducing visibility). Proper light fixture design and placement helps minimize glare and enhance visual comfort. Moreover, it emerges from extremely bright lighting objects or from high brightness contrasts in the visual plane, produced by a reflecting surface or luminous light. Sources of glare include: incorrectly installed or designed artificial lighting, computer screens, windows or glossy magazines. Glare has a significant impact on human sight, resulting

in increased frequency of mistakes, loss of concentration, and fatigue negatively affecting motivation, mood, and performance and increased number of sick leaves/ absenteeism among employees within work settings. The glare emitted from lights that are regularly used in the room can be analysed by using the Unified Glare Rating (UGR) method. Unified Glare Rating system presents its measures in different standards and value. It is additionally advanced to evaluate the glare level created from the artificial lighting systems and cannot be used to measure the daylight circumstances. Lower daylight values indicate less potential for glare, but the higher values suggest a greater risk of glare (Bangali, 2018). The values in UGR method can differ based on reflection factors of walls, floor, and walls, the size of the room, and the viewing and position, direction and distance of the viewer within the room as seen in Figure 12 . According to DiLaura et al. (2011), the method suggests five classes with limited UGR values ranging from 28 (highest), 25, 22, 19, and 16 (lowest glare value). Use of reflective surfaces such as glass, polished metal, and glossy finished on wall, ceiling, flooring and materials of furniture's or mirror helps to increase the glare in interior spaces, also, the open windows, minimal windows covering, natural lights, and artificial light with bright and focused luminaires encourage to increase the glare (Inan, 2013).

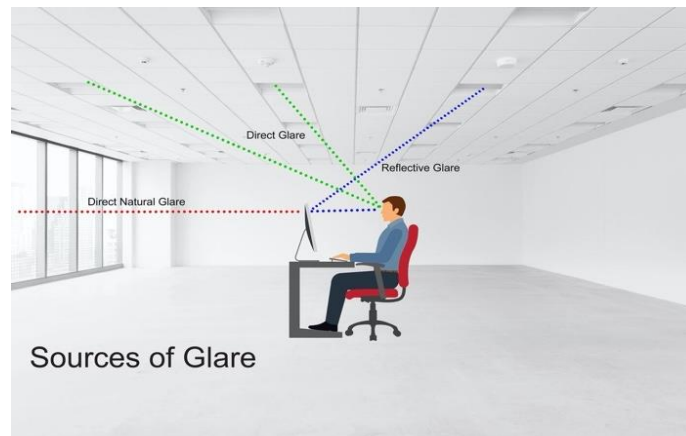


Figure 12: Source of glare.

(Source: Inan ,2013)

- **Light Distribution:** light distribution refers to how light is distributed in a given space. It can be categorized as direct lighting (directly illuminating a surface or object) or indirect lighting (illuminating the surrounding environment). The choice of light distribution depends on the specific requirements of the application and the desired aesthetic effect.
- **Light Reflection Value (LRV):** LRV helps in measuring the quantity of usable and visible light that is absorbed into or reflected from a painted or colourful surface. The reflecting features of the rooms and surface of the object not just determine room's view, but also the light reflected; thereby, also helps in determining brightness of the room. Figure 13 demonstrates the quantity of light reflected by a specific colour. It is measured and tested with the help of a spectrophotometer on scale of 0 to 100.

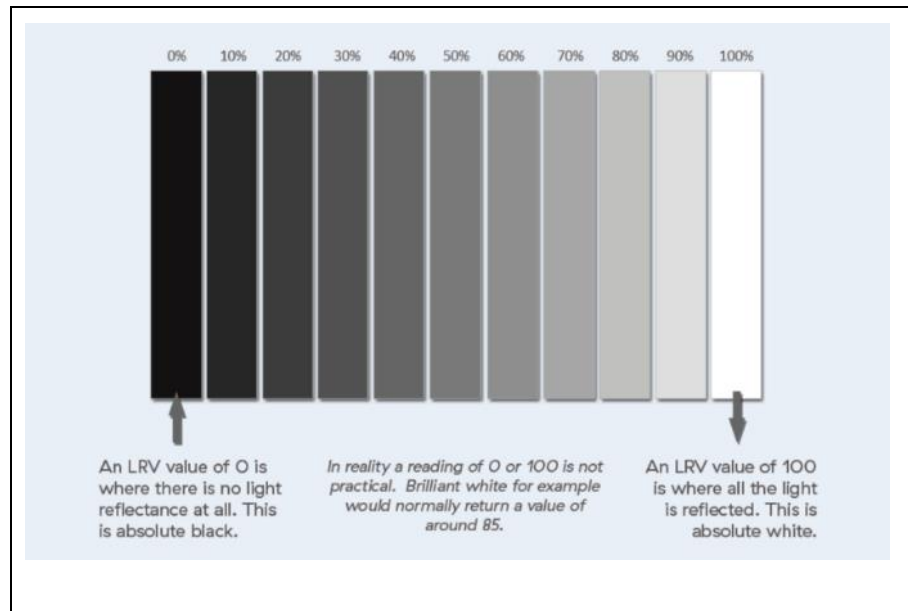


Figure 13: Light Reflectance Value (LRV).

(Source: Integrated door sets,2022)

LRV is significant in relative to the quality of artificial light and daylight in campus buildings, LRV plays a dynamic part in determining the well-being and the visual comfort of building occupants. So, materials used in different interior space with higher Light reflectance value reflect extra light besides contribute to a brighter as well as improve the visually comfortable space. This is mainly significant in zones where natural daylight is limited, while the light-coloured in the materials used can assist to maximize available light in interior spaces. In the spaces that depend on natural daylight, like offices and classrooms, the materials selected with suitable LRV values can helps to improve the daylight utilization. Light-coloured surfaces used in ceilings, walls, and flooring can efficiently reflect and distribute daylight, and decreasing the need of the artificial lights

through the day besides promoting energy efficiency in the buildings. (DiLaura et al., 2011).

- Daylight Factor (DF): It is referred to ratio between the level of light outside the structure to the level of light inside the structure as shown in Figure 14 . Daylight factors can be defined by equation (2.2) as follows:

$$DF = \frac{E_i}{E_e} \times 100\% \quad (2.2)$$

Where DF is the daylight factor, E_i is the illuminance level of lighting inside the structure due to daylight, and E_e is the outdoor illuminance level of daylight outside the structure. The guidelines of DF for educational/classroom is 2-5 % for offices, 7-12 % for precision tasks, and more than 12 % for exceptional light requirements. When the average of DF is 5% or greater, an interior space will appear to be well lighted, while for A DF of less than 2%, the interior space will seem dimly lighted (IES, 2000).

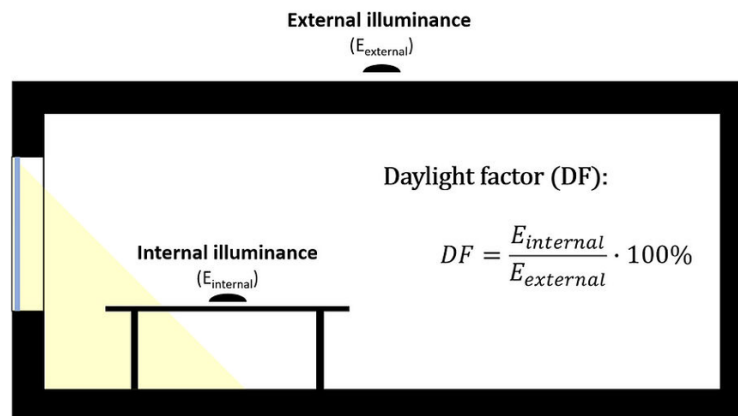


Figure 14: Daylight Factor (DF)

(Source: IEN Consultants. Ltd., 2022)

2.4 Significance of Lighting in Educational Buildings

Many studies (Choi et al., 2014; Halonen and Tetri, 2010; Woo et al., 2021) examined the importance of both natural and artificial lighting in the planning of academic buildings on university campuses. It focused on the impact of daylight and artificial lighting systems on occupant well-being, energy efficiency, and learning outcomes to highlight the many advantages of integrating both types of lighting systems into interior design. Interior designers can create visually beautiful and useful spaces that provide an optimal setting for learning, socializing, and overall satisfaction for users by comprehending the significance of different lighting sources. While, Students, instructors, and staff spend a large percentage of their time in university campus buildings, which are important venues. For these spaces to be of higher overall quality, lighting systems that include both natural and artificial illumination must be strategically integrated.

Fostering an environment conducive to learning through effective lighting controls not only supports educational objectives but also contributes to environmental sustainability. Whether illuminating a room for aesthetic purposes or ensuring road safety, proper lighting enhances the modern features of one's environment or space. The lighting system in universities is traditionally a combination of artificial electric lights and daylight for illuminating spaces, like labs, hallways, auditoriums, offices, classrooms, studios, libraries, etc. Energy Star (2006) indicates that the cost of energy is the highest operating expense for campus buildings and educational institutions. Figure 15 illustrates lighting percentage of the total energy consumptions by sectors.

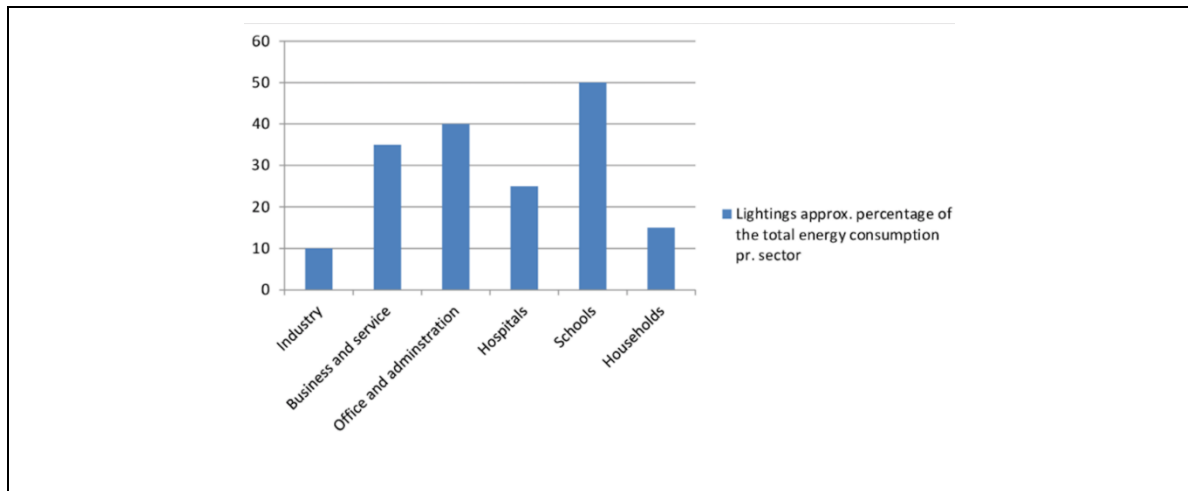


Figure 15: Lighting percentage of the total energy consumptions by sectors.

(Source:Energy Star, 2006)

Table 3 highlights different types of interiors, activities or tasks performed within educational spaces with a defined number of each light parameter: Colour Render (CR), Illuminance standards (Em), Uniformity Ratio (UO), and Unified Glare Rating (UGR).

Table 3: Sustainable Design Guidelines for Education Buildings, (Source:DiLaura et al. 2011)

Type of interior, task or activity	Em -Lux	UGRL	UO	CR
Circulation areas and corridors				
Circulation areas and corridors	100	28	0.4	40
Office				
Conference and meeting rooms	500	19	0.6	80
Reception desks	300	22	0.6	80
Libraries				
Bookshelves	200	19	0.4	80
Reading areas	500	19	0.6	80

Type of interior, task or activity	Em -Lux	UGR _L	U _o	CR
Counters	500	19	0.6	80
Educational buildings				
Lecture hall	500	19	0.6	80
Classrooms for evening classes and adult's education	500	19	0.6	80
Practical rooms and laboratories	500	19	0.6	80
Black, green wallboards and whiteboards	500	19	0.7	80
Computer practice	300	19	0.6	80
Entrance halls	200	22	0.4	80
Stairs	150	25	0.4	80
Student common rooms and assembly halls	200	22	0.4	80
Teachers rooms	300	19	0.6	80
Auditorium	500	19	0.6	80
Podium area	200-300	-	0.7	80

Choi et al. (2014) stated that good lighting, either artificial or natural, has a significant role to play in enhancing health and safety in learning spaces or work places. More detailed work usually requires higher levels of lighting, such as in factories for working on micro products and to create a safer and more comfortable environment for work. On the other hand, educational buildings need illumination between 300 to 750 lux. Nonetheless, the lighting system of classrooms requires 500 lux, which much be spread across the classrooms so that all students receive the same amount of light to maximize their achievement. Furthermore, based on EN

12464-1 (2021) lighting requirements for the auditorium spaces the LUX level required is 500 lux, with uniformity ratio 0.6, and glare rating UGR is 19, but in some occasions, the lighting should be controllable and convenient to accommodate the different various of tasks can be done during this space.

Lighting conditions can influence cognitive performance and student engagement. Lighting design solutions that encourage optimum conditions for different educational settings, such as classrooms, libraries, and study areas, should be taken in to account by interior designers. Interior designers can design aesthetically appealing, energy-efficient, and user-centric places that improve occupant well-being and support fruitful learning outcomes by taking the significance of these lighting sources into account. The holistic integration of natural and artificial lighting should take in to account the particular needs of each location within the campus environment.

2.5 Lighting Strategies and Performance in Educational Buildings

Lighting in commercial buildings of United State (US) consumed around 20.2 percent energy in 2013 (U.S Department of Energy, 2014). Hence, it is critical to develop strategies and plans that can help in minimizing the intensity of lighting energy used to obtain low-energy levels for sustainability. In addition, advanced controls of lighting provide one of the most cost-efficient ways of reducing carbon footprint, operating costs and energy consumption of existing structures and improve user satisfaction by providing controls over lighting conditions. Daylight controls (shades, curtains or blades) and artificial lighting controls are both necessary to regulate lighting conditions in indoor environments. One of the most effective ways to control energy

consumption is to design lighting system in a way that lights automatically turn off with the intensity of daylight coming into the room. This will help in saving a large amount of energy consumed by artificial lights. Also, the role of shading devices in enhancing the comfort level of occupants and the day light improvements for educational buildings. Bogerd et al. (2021) assessed buildings energy and well-being demand, and suggested different lighting and shading control strategies to increase energy savings as well as improve the visual comfort of educational.

According to Woo et al. (2021), the modern type of building designs with completely double-glazed exteriors encompass the highest levels of perceived productivity and overall satisfaction and comfort, while the traditional type of building designs constructed in late 20's, recognized for deep floor plates had the lowest levels of satisfaction and comfort. The heritage type of buildings or structures had lower wall to window ratios; however, it highlighted increased satisfaction among users across all IEQ regions as compared to the conventional buildings including the lighting systems. The research findings highlighted that regular maintenance and renovations of buildings can enhance satisfaction and comfort of occupants within campus buildings. These research findings are useful for property managers and designers seeking strategies to enhance building performance such as educational sites.

Another research conducted by Singh & Arora (2014) identified a new lighting strategy for applying innovative lighting technologies as sustainable lighting like LEDs that help in enhancing work place conditions, and increasing energy savings and productivity. The researchers suggested that the lighting used in sustainable educational buildings were higher than the non-sustainable educational buildings. According to education regulations, classroom

lighting is required to maintain a minimum illuminance level of 500 lux at all times. Moreover, in classrooms within green-rated educational buildings, the observed illuminance levels were notably higher, with recommended levels reaching 570.38 to 760.63 lux. In contrast, classrooms situated in non-sustainable educational buildings fell short of the accepted standards, with illuminance levels values of 195.84 to 269.16 lux.

Garcia-Fernandez and Omar (2022) have introduced a forward-thinking approach to optimize daylight utilization in the Alexandria Library, with a focus on an integrated innovative solar lighting system. To improve energy efficiency and enhance user satisfaction, the library is also planning to replace all four existing artificial light sources (metal halide 150 W, halogen lamps 150 W, fluorescent 21 W, and fluorescent 26 W) in the reading facility with energy-efficient LED lights. According to an electrical analysis, this transition is expected to yield an impressive energy savings of approximately 89 %. Moreover, the integration of an Anidolic Lighting System (ADS) is under consideration to further augment the influx of natural light within the library. This system would be equipped with appropriate controls to maximize the utilization of natural light. The library's architectural features, including the roof design and the sloped interior, make LED lights a fitting solution that can seamlessly blend with the existing indoor spaces and support library activities.

In contrast, research conducted by Castilla et al. (2018) revealed that fluorescent lamps (FL) were rated negatively by students across multiple aspects over a four-year period. Students did not find FL lighting to be stimulating, cutting-edge, cozy, comfortable, or attractive. On the other hand, LEDs received positive ratings from students in various aspects, with students perceiving LED lighting as stimulating, efficient, attractive, and cutting-edge technology.

However, comfort ratings for LEDs were neutral, and they received the lowest ratings in the cozy aspect according to the students' assessments.

Freewan & Al Dalala (2020) conducted a research on classrooms located in the lecture hall buildings at Jordan University of Science and Technology (JUST). The researchers assessed different daylight technologies on indicators, such as energy saving, illuminance levels, and uniformity ratio. Using an advanced simulation tool and the real-time experiments, the researchers studied how different natural light technologies such as lighting shelf, anidolic day light system and window to enhance uniformity distribution and illumination levels. The research findings indicated that daylight technologies can significantly increase the illuminance levels to meet the standards in the regions or spaces with low illuminance levels, and improve the lower rate of discomfort glares and uniformity distribution. Findings also suggested that these technologies reduced energy consumptions in classrooms approximately up to 40 to 50 % of the total lighting consumed. Furthermore, they highlighted that windows, light shelf and anidolic systems in rear areas to the glazed corridors demonstrated better performance and increase the illuminance levels by an average of 100 percent.

Additionally, Makaremi et al. (2017) study focused on analysing the relation between two variables: light reflectance value of indoor surfaces and visual comfort indices under artificial lighting environments. The researchers highlighted the significant and critical role of reflective characteristics of surfaces, particularly walls, in setting the parameters of visual comfort in educational campus buildings. Based on the changing reflectance values at surface from the first part to the last part, the research concluded that the wall reflection factor affects UGR and average illuminance. Although, the impact of floor reflection on the selected guides was

significant. In reality, using materials of light colour and increasing reflection factor of indoor surfaces can be appropriate passive solutions or effective lighting strategy for increasing energy efficiency and enhancing indoor environments. Even though, it is important to meet the limitations of discomfort glare for different visual activities.

In another research, Avci & Akbay (2022) highlighted that visual comfort factor is the most significant factor affecting quality of lighting in indoor environments. The researchers highlighted different technologies that provide illumination in indoor environments, out of which three most important ones are: LED, incandescent and fluorescent lighting. Alternative technologies include Organic Light-Emitting Diode (OLED). Their research findings indicated that visual comfort obtained from OLED lighting was significantly different in terms of colour perception and illuminance level. Furthermore, they used good colour perception, ceiling reflections and illuminance levels as important criteria for assessing the overall comfort of OLED lightings in indoor settings. However, due to practical constraints, the study faced limitations while using OLED lighting in offices and educational environments. Furthermore, there is far too little attention paid to this strategy, thus very limited information is available. Another innovative strategy is to apply occupancy sensors as the control lighting system in educational buildings. According to Energy Star (2006), occupancy sensors not just help in saving energy but also help in reducing maintenance cost. It was further suggested that turning off FLs for 12 hours a day can help in extending expected service life up to 7 years, approximately increasing by 75 percent. Furthermore, it is imperative to ensure that wall switches are readily accessible in classrooms to control occupancy sensors. Additionally,

implementing a strategy that combines dimming and scheduling for light control after specific hours is recommended for hallways, as suggested by Makaremi et al. (2017).

Based on the recent evidences and the strategies highlighted by previous researchers of different spaces, it is concluded that there are different types of artificial lighting which can be used as initial design strategies is an integrated design process based on LEED standards in interior design and construction. In order to enhance occupants' productivity, well-being and comfort by providing a high-quality lighting system, USGBC (2021) suggested the following strategies:

- A. Using light fixtures with less 2500 cd/m^2 luminance ranging between 40 to 90 degrees for all usually occupied spaces. Except, as specified by data of manufacturers, wall wash fixtures used for wall, indirect up lighting fixtures when one cannot view anything into these up lights from space above, and other adjustable fixtures.
- B. Using light sources with 80 or higher CRI for the entire building. Exceptions include: fixtures or lamps particularly designed for providing coloured lighting effect for site lighting.
- C. Use of lamp lights that are LEDs which rated life of 24000 hours in at least 75 % of the total load of connected light.
- D. Use lights that meet the thresholds for area-light reflectance value for surface, i.e. 25 on at least 90 % of the occupied space.

- E. For area with at least 75 % of occupancy, lights can be used that meet the ratio of average work surface illuminance to wall surface lights within 1:10 range, by displaying 60 % area- light reflectance value for walls.
- F. For at least 75 % of the occupied floor space, using illuminance that meets the ratio of average ceiling to work surface illuminance, where the ratio must be within 1:10; by displaying area-weighted reflectance surface of 85 percent for roofs and vaults.

2.6 Impact of Lighting on Occupants' Satisfaction and Working

Environment in Educational Buildings

2.6.1 Artificial Light and Well Being

Student performance and learning in universities is related to indoor environment of classrooms which is normally equipped with different objects, such as air-condition, lamps, soft board, furniture, whiteboard, fan, etc. Furthermore, the efficiency and effectiveness of a learning process might not be measured only by assessing capability and ability of students, since attention and concentration of students is also significantly affected by physical classroom environment primarily associated with indoor lighting system (Choi et al., 2014).

Lighting is considered to be an important aspect in an indoor environment affecting individual's productivity, well-being and satisfaction levels. Samani and Samani (2012) stated that the purpose of lighting designs is to provide suitable colour temperature, lighting and illuminance for meeting the psychological to physical visual needs of users. Some researchers argued that lighting does not have any impact on performance or mood of people. However,

others believe that lighting can have a direct impact on users' mood and performance. Thus, learning spaces must be designed to meet varied needs of learners from kindergarten till university level. Ocirk, et al., (2009) claimed that bright colours and light make people feel uplifted and joyful. The researchers further highlighted that installing lights all around at high levels instead of placing lamps focused on desktops can have positive psychological impact on students' and teachers' performance and on classroom environment. These lights not just make the space look brighter, but also influence people's mood. In another research conducted by Sulaiman et al. (2013), the findings highlighted that majority of the people prefer adapting to bright lighting rather than dim. Among the 370 participants surveyed, 50% expressed a preference for daylight and indicated that they refrain from closing curtains to allow natural light to enter the space.

Another critical factor is the illumination controls in the learning environment. John and Timothy (2005) stated that inadequate light controls lead to a number of issues, along with health issues, such as musculoskeletal injuries to eyestrain, stress, decreased attentiveness, increased body temperatures, subsequently contributing to poor teachers' and students' performance. Jago and Tunner (1999) mentioned that unsuitable levels of illuminations damage the human eye and unfortunately have negative physiological outcomes. In reference to this, Veitch (2010) identified six types of human requirements met by lighting. These include: comfort, mood, judgments, aesthetics, safety and health, task performance, visibility, social behaviour and communication. Furthermore, Samani and Samani (2012) argued that increasing quality of illumination enhances motivation and well-being among people; thereby, enhancing their performance. Thus, solving lighting issues is critical as it can increase satisfaction and

encourage students in educational institutions to learn and perform better. Accordingly, light controls can certainly affect performance and productivity via the following mechanisms:

- A. Interpersonal relationships: people are able to see each other properly, and hence, they can communicate and cooperate in a better way.
- B. Visual comfort: the performance can increase by reducing discomfort glaring as concentration level is enhanced and distraction level is decreased.
- C. Visual performance: with proper light people are able to see their tasks clearly, so they perform better. However, some tasks may not require much light in order to be performed, so in certain cases visual performance may not have significance.

Referring to an innovative study of Mott et al. (2012), the study introduces a specialized lighting system called "School Vision," expressly designed for educational institutions. This system serves as an instructional tool aimed at fostering a positive learning environment and enhancing students' performance by promoting desired behaviors across various activities. These activities encompass tasks such as nurturing creativity during art sessions, fostering heightened focus during tests, and promoting collaboration among students while mitigating restlessness when they become overly excited. The researchers devised four distinct light settings within the classroom environment, considering the interplay between colour temperature and its impact on the mind and body. These settings include "calm," "energy," "normal," and "focus," each tailored to correspond with different classroom activities. Teachers are afforded the flexibility to select any of these settings through a control panel, with the "normal" setting catering to routine classroom activities. In contrast, the "focus" setting is

designed to enhance students' concentration levels during testing. The "energy" setting proves beneficial during daytime hours, particularly in the morning when students may experience a dip in energy. Lastly, the "calm" setting is appropriately suited for group tasks that require communication and cooperation among students. The School Vision system has demonstrated its effectiveness as an energy-efficient learning support tool. Figure 16 showcases the impact of dynamic lighting on students' performance based on Mott et al. (2012) work.

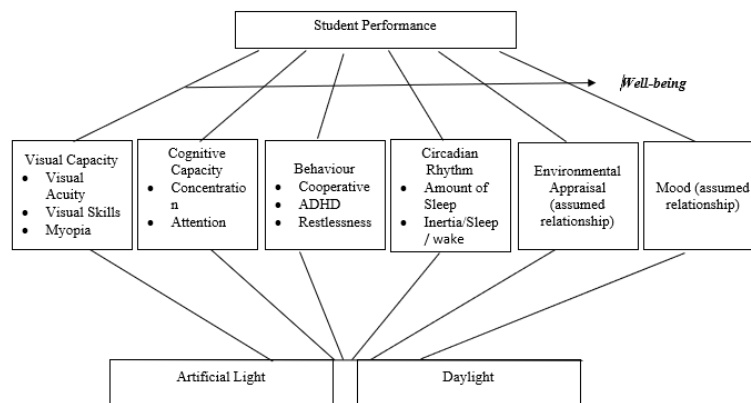


Figure 16: Illuminating the effects of dynamic lighting on student learning

(Source: Mott et al., 2012)

2.6.2 Day Light and Quality View

Natural lighting is referred to as daylight, where light is emitted by sunlight and reflected on the surface before illuminating into a space or area. It is one of the primary factors that should be considered while designing educational building performance and assessing energy efficiency of learning environments. Choi et al. (2014) referred to one of the educational buildings in Malaysia, where all the lights are switched on during the day and only switched off

during break or at the session end time. Nonetheless, daylight is effective source for majority of the buildings, particularly within learning environments, where natural light quality is better as compared to artificial light. Choi et al. (2014) investigated factors that influence the satisfaction, grade, and performance of students within educational facilities. Preliminary research demonstrated that the use of daylighting tends to enhance students' performance in reading tests by 26 % and math tests by 20 %. Furthermore, good view can improve learning among students while poor indoor air quality, direct sunlight, and glare can worsen it. In addition, natural daylight in the classroom helped in reducing absenteeism by an average of 3.5 days/ year as compared to classrooms with less daylight exposure. Similarly, Norazman et al. (2018) found that staff, student and teacher absenteeism in sustainable buildings of Canadian Schools enhanced by 2 to 7.5 %, while performance among students enhanced by 8 to 19 % as compared to conventional school buildings. However, far too little attention has been paid on indoor environment quality within educational setting; this study failed to identify the main parameters that may affect satisfaction of occupants in educational buildings.

A survey study conducted by Miller et al. (2009) demonstrated that enhancing natural light and artificial lighting can reduce absenteeism by 3 days/ year and increase productivity by 4.8 %. Furthermore, the study highlighted that appropriate interior lighting and comfortable colour temperatures directly influence the sense of productivity, health and satisfaction. Another study conducted by Fisk (2000) indicated that green indoor environments can decrease sick building syndrome by 9 to 20 % and decrease the asthmas and allergies by 8 to 25 %, consequently saving in lost productivity and time up to \$10 to \$35 billion. Similarly, El Asmar et al. (2014) identified that improving IEQ in terms of day light and artificial lights contributes

to reduced work hours and perceived absenteeism as a result of depression, stress, asthma and respiratory allergies, and contributes to improved productivity. The study highlighted substantial improvements in productivity.

A site analysis in the British University of Egypt identified that 84 % of the students perceived that artificial lighting is most commonly used at labs; while 73 % students of these preferred natural lighting over artificial. The students also believed that daylight is linked with increased productivity, positive attitudes, reduced eyestrain, reduce fatigue, reduced defects and errors, and has physiological and psychological effects on students (Shams et al., 2021). Before the introduction of artificial lights, natural lighting was the main source of light in schools and other learning environments. Lighting systems started shifting from daylight to artificial lighting, after the appearance of electricity, and classroom began integrating artificial lighting as their primary source of lighting. This led to a decrease in window areas, making classrooms disconnected from the outside environment. Thus, this led to psychological suffocation. According to previous researchers (Fielding, 2006; Pulay, 2010), visual environments influence student's skills to learn and observe visual stimuli, affecting their performance and mental manner. Most importantly, students will be more successful, if they are motivated by interior environment at school. Samani and Samani (2012) highlighted that a well-lit classroom consists of accent on, higher reflectance ratings, glare control system, and balanced brightness.

2.7 Lighting Innovation Approach in Buildings

The construction sector understands the significance of incorporating daylight in the illumination system of buildings for improving lighting quality and energy performance. There

are different renowned techniques that designers and engineers use for increasing the natural light levels in buildings, such as skylights and windows. However, these techniques are not effective in illuminating the core areas of building, and can increase the usage of energy due to low insulation. There are other methods that are used for illumination, but all of them have their respective limitations that prevent their extensive adoption. Some of these include: heliostat system, core sunlight system and sun pipe system.

Core Sun Light System (CSLS), is an alternative technique to illuminate the core of the building. A core sunlight system captures the light at the roof of the building and transfers it to the core, unlike buildings with huge glaze areas, where natural light can only penetrate the perimeter of buildings (Jensen and Jensen, 2016). Some of core sunlight systems include: roof-mounted and facade collectors as shown in Figure 17. One of the currently use design of core sunlight is the CSLS consisting of two important parts: a sunlight collector to track the sun with a mechanical element and concentrate and redirect the light to the actual location; and light guides to distribute the sunlight across the building. However, the only disadvantage is that it only works with sunlight, thus it is not effective in an overcast day.

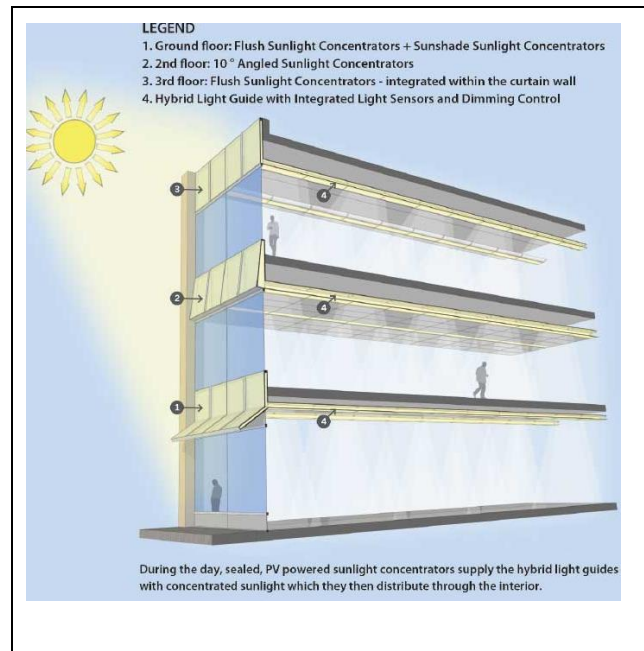


Figure 17: Core Sun Light System (CSLS)

(Source: Jensen & Jensen, 2016)

Another popular method is the Sun light tube system , also known as the Light pipe in Figure 18, which is an innovative technology that allows daylight into the building during daytime and helps in saving 80 % of the energy cost (Khosravi et al., 2014).

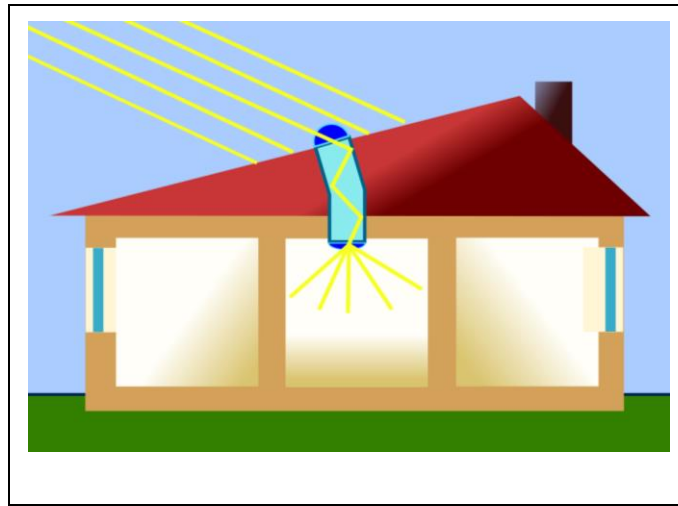


Figure 18: Light tube technology

(Source:Khosravi et al, 2014)

One of the recent buildings using this technology is Al Bahar Towers Responsive Facade / Aedas in Abu Dhabi. As shown in Figure 19:Al Bahar Tower in AD ,screen operators are used as curtain wall that sit on an independent frame, two meters outside the buildings (Cilento, 2012). Each part is coated with fiberglass and directly responds to the sun's movement in order to reduce glare and solar gain. All screens are closed in the evening. It is estimated that this technology reduces solar gain by 50 % or more. Furthermore, it has enabled the designers to be selective with glass finishing. The screen also gives architects an option to use naturally tinted glasses to let the light in for better illuminance. One of the key benefits of this technology is that it requires artificial light usage only when there is a need to light interior spaces. This whole system is automated; thereby, it does not cause any disturbance for the occupants (Cilento, 2012). This technology in the building was provided by Zumtobel company for the purpose of being sustainable and meeting the LEED standards.

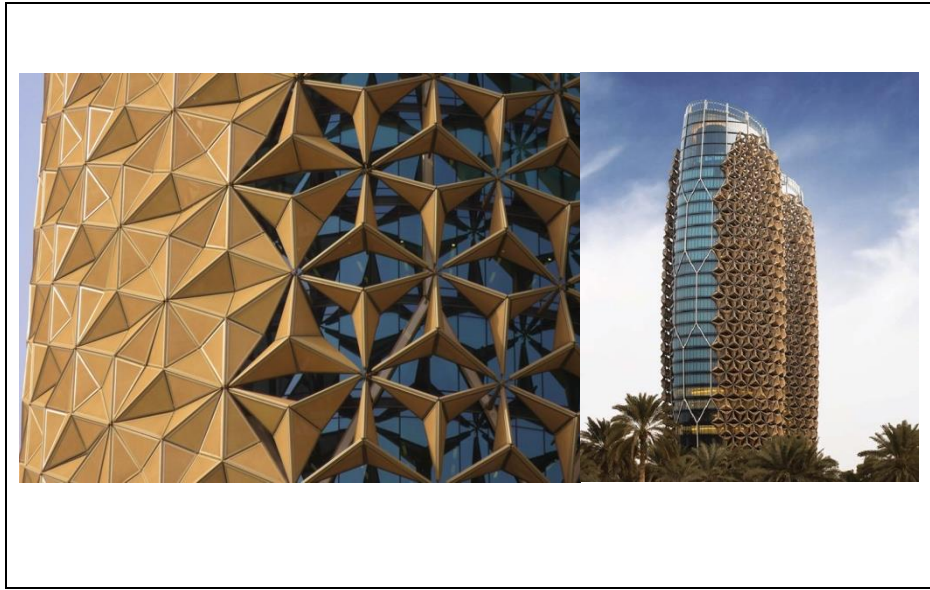


Figure 19:Al Bahar Tower in AD

(Source :Cilento, 2012)

In Figure 20:Siemens Headquarters (HQ) in AD another example is Siemens Headquarters (HQ) in Abu Dhabi (AD). It is the first sustainable building to receive LEED Platinum certification. It is designed in cubic shape and the key feature of this building is high functionality and simplicity. The airtight façade designed in a way to decrease the thermal conductivity in the building; and the exterior facade of the building surrounding with aluminium external shading system in a lightweight used to reduces solar heat gain at the same time as increasing the daylight and quality views from the building, and allowing passive ventilation to be improved for the internal spaces of the building (AECOM, 2018).

Another significant example of an innovation strategy used on the library is the campus building of Alexandria University. Three parallel routes were developed for improving energy

efficiency along with the Anidolic Lighting System (ADS) for increasing the amount of daylight let in the room in a controlled method .The shape of the roof and interior spaces make the lighting collectors a suitable solution that can be incorporated with the present indoor lighting system (Garcia-Fernandez & Omar, 2022).

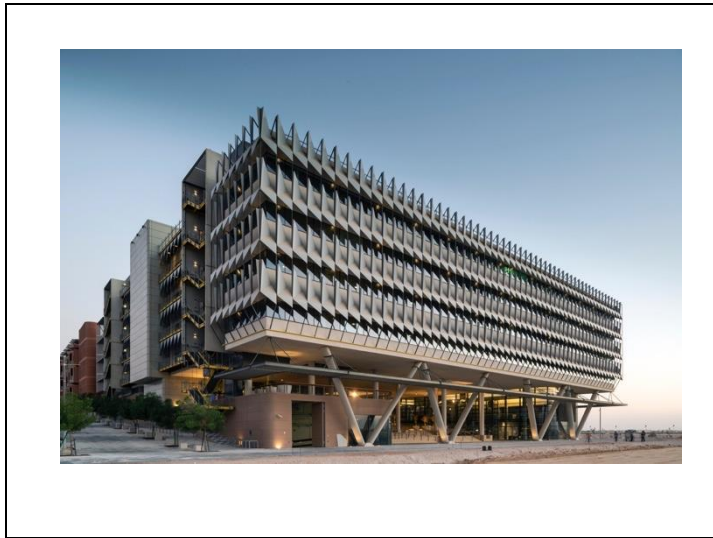


Figure 20:Siemens Headquarters (HQ) in AD

(Source: AECOM, 2018)

2.8 DIALux EVO Theory

DIALux EVO is a specialized lighting design software, commonly used in different majors like interior design filed, architecture, and lighting engineering. The first version of the software was published by the German company DIAL GmbH in 1994. The DIALux software views for "Digital Illumination Interface" and offers a complete and comprehensive with a set of tools collection for interior lighting design to be used internal or external of the buildings, analyzing

as well as visualizing, lighting clarifications and solutions for different functions and applications. Some key features and competences of DIALux software are:

- **Lighting Calculation:** DIALux enables professionals and users to perform accurate lighting calculations, encompassing both daylight and artificial lighting, in accordance with various lighting standards applicable to their specific location. It utilizes a comprehensive database and considers factors such as luminaires, light sources, reflectance, and room geometry to assess and calculate important parameters, including illuminance, luminance, and other relevant metrics.
- **Three Dimensions (3D) Visualization:** DIALux software empowers users to create 3D detailed drawings and models of both indoor and outdoor spaces. This versatile software allows users to import CAD files or employ its integrated modelling tools to generate virtual areas. Moreover, it provides the capability to visualize lighting outcomes in real-time, facilitating the assessment of the impact of lighting design on the overall ambiance of the environment.
- **Light Fixtures Selection:** The software includes an extensive database of illumination fixtures from various manufacturers. Users have the capability to explore, compare, and select luminaires for their projects, considering factors such as energy efficiency, photometric data, and aesthetic considerations.
- **Energy Analysis:** The software incorporates energy data analysis tools that enable users to calculate the efficiency of lighting systems and the overall energy consumption. Users can assess the impact of various control strategies, lighting design scenarios, and energy-saving measures on energy consumption

- **Reporting and Documentation:** DIALux software can generate comprehensive reports with various features, including plan drawings for lighting design, technical standards and specifications, as well as simulation results. These reports and documentation play a crucial role in presenting lighting designs to a diverse audience, including customers, engineers, designers, architects, and other stakeholders. DIALux software provides an extensive database that aids lighting professionals in crafting energy-efficient, visually appealing, and well-suited lighting designs. It supports the entire lighting project design process, from concept development to report generation, enabling users to make informed decisions and achieve their desired lighting outcomes. Moreover, this software has gained widespread acceptance within the lighting industry and has become a standard tool for lighting design and specification (DIALux evo manual, 2023).

2.9 Climatic Condition in Dubai

The most populous of the United Arab Emirates, Dubai, has a subtropical desert climate with fairly moderate to pleasantly warm winters and extremely scorching summers when the combination of heat and humidity makes the heat feel truly oppressive. In fact, the Persian Gulf provides moisture throughout the summer when the wind typically blows directly from the sea. In contrast, the hot season, which runs from May 14 to September 24, lasts 4.3 months and has an average daily high temperature of over 100°F (37.7°C). With an average high of 106°F (41°C). and low of 86°F (30°C)., August is the hottest month of the year in Dubai. From December 3 to March 5, the cool season lasts 3.1 months, with an average daily high temperature below 81°F (27°C). With an average low of 58°F (29°C) and high of 75°F (23°C). January is

the coldest month of the year in Dubai. Figure 21 below demonstrates the average of high and low temperatures in Dubai (Weather Spark, 2013).

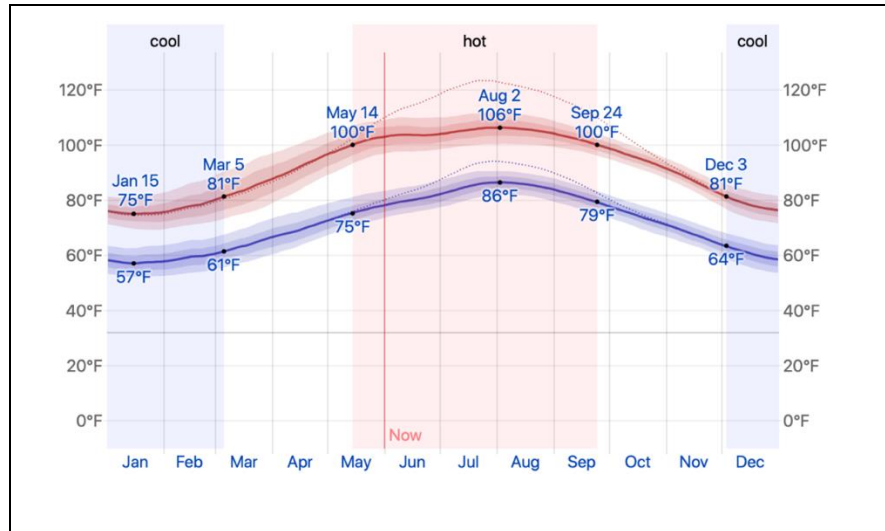


Figure 21: Average of high and low temperature in Dubai

(Source: Data.org,2019)

In contrast, when the winds are from the south, the temperature in winter can drop to about 30 °C (86 °F), while in spring and autumn, it can reach 40 °C (104 °F) as early as April and once again in October. It certainly gets worse in the summer: from June to August, highs of 48/49 °C (118/120 °F) are possible. On the plus side, relative humidity drops when the wind comes from the south and originates in the Arabian Desert. In Dubai, abundant sunshine and clear skies are a common occurrence every day as demonstrated by Figure 22. However, from December to March, certain cloud banks may affect this region, while in the summer, some cloudiness may be delivered by the southern Arabian monsoon, which has very little impact in this area. With a mean of 12.15 hours per day, June is the month with the most sunshine. There

is a total of 376.7 hours of daylight throughout the duration of said calendar period. The average number of sunshine hours per day in Dubai is lowest in January. There are about 8.78 hours of sunshine each day and a total of 272.31 in January. In Dubai, an average of 127.66 hours of sunshine are counted per month and around 3884.56 hours throughout the year.

Knowledge on sun path average hours over the year is important for designer and architects in the early stages of the design process to decide the building orientation, windows opening areas, shading device, integration between the indoor environment and the outdoor, landscaping, as well decide the solar collector area. However, all of these decisions can enhance the built environment in terms of all sustainability pillars.

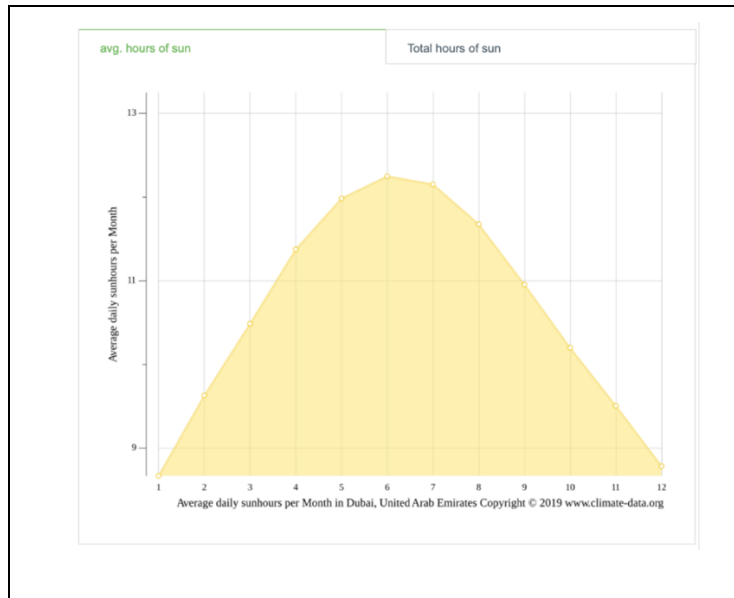


Figure 22: Sunshine hours distribution in Dubai

(Source: Data.org,219)

The average proportion of sky covered by clouds in Dubai varies significantly seasonally throughout the year. September 2 marks the start of Dubai's clearer season, which lasts for 7 months and ends around April 1. In Dubai, October is the clearest month of the year, with 90% of the time experiencing clear, mostly clear, or partly overcast skies. Beginning around April 1st and lasting for 5 months, the cloudier period of the year ends around September 2nd. In Dubai, July is the cloudiest month of the year, with the sky being overcast or mostly cloudy 46% of the time on average (Weather Spark, 2013).

2.10 State of Art

"State-of-the-art," often referred to as "cutting-edge" or "leading-edge," signifies the highest level of common advancement within a particular research domain during a specific period. Table 4 below presents information on 8 distinct scientific articles from Gulf Cooperation Council (GCC) countries, the Middle East, and international regions. These articles delve into crucial aspects of indoor environmental quality within campus buildings, specifically focusing on parameters related to daylight and artificial lighting. They also scrutinize the substantial influence of lighting on occupants' performance and satisfaction. The table provides comprehensive data, including the project name, research title, citation, location, building types, research methodologies applied in each article, parameters investigated, key features and strategies employed, lighting methods and types employed, as well as the research findings. All this information is presented in Table 4, following the conventions of academic style.

Table 4: Summarized latest researchers case studies, (Source: Author, 2022)

Case Study in GCC countries		
Project name	King Abdul Aziz University	University of Sharjah
Research title	The impact of daylighting in classrooms on students' performance	Daylighting in Educational Buildings: Its Effects on Students and How to Maximize Its Performance in the Architectural Engineering Department of the University of Sharjah
Citation	(Dahlan and Eissa, 2015)	(Al junaibi et al., 2018)
Location	Jeddah, KSA	Sharjah, UAE
Building type	Campus educational building	Campus educational building
Parameters	Daylight Artificial lighting Students' performance and productivity. Quality views	Day light Energy consumption Physiological and psychological effect Visual comfort
Key features strategies	Students' performance Levels of classrooms daylight compared with standard requirements	Scenario 1: Base case Scenario 2: Increase the window ratio Scenario 3: Light shelves Scenario 4: Vertical light tubes

Lighting method and type	Day light	Integration between daylight and artificial
Findings	Daylight in educational classrooms has a significant impact on the environment and reduces operational costs. It enhances students' vision, perception, health, comfort, and productivity. North and south-oriented classrooms have illumination levels exceeding 500 lux during the peak of the year. South-oriented classrooms, on average, have over 1,110 lux throughout the year. Skylight affects some classrooms on upper floors, both south and north-oriented.	Daylighting is crucial for students' academic health and performance. Daylighting reduces energy consumption in buildings and enhances visual comfort for students and employees. Among different scenarios, the vertical light tubes were the most efficient, providing 497 Lux with zero (KWH) energy consumption for three classrooms per year. In contrast, the existing case offered 286 Lux with an energy consumption of 262.5 (KWH), large windows provided 357 Lux with 196.9 (KWH), and light shelves resulted in 412 Lux with 131.1 (KWH) energy consumption.
Case Study in Middle East Countries		
Project name	Arab University	Eastern Mediterranean University
Research title	Optimization of daylight utilization in energy saving application on the library in faculty of architecture, design and built environment	Comparative Analysis of Day lighting and Artificial Lighting in Library Building; Analyzing the Energy Usage of the Library.
Citation	(Omar et al., 2018)	(Kime and Alibaba, 2018)
Location	Beirut, Lebanon	Famagusta. North Cyprus, Turkey
Building type	Campus educational building	Campus educational building
Methodology	Literature Review Computer simulation: AutoCAD Ecotect & DIALux EVO software. Survey	Literature Review Computer simulations RELUXDESKTOP software Survey

Parameters	Day light Artificial light Users Behavior	Day light Artificial light
Key features strategies	Light distribution analysis. Enovation way to improvement the daylight illumination system and artificial light throw the followings: Architectural elements including space depth, window size, external obstruction angle.	Day light and artificial lighting integration through: Lighting dimming controls Integration of shading devices to improve the overall energy performance. Enhance the illuminance levels for visually comfortable environments.
Lighting method and type	Combination between daylight and artificial light.	Day light and artificial light.
Findings	Combining daylight with technology like Hollow Cylindrical Prismatic Light Guides (CPLGs) can have multiple benefits. Benefits include enhanced health and well-being, a 33% reduction in daily artificial lighting energy consumption, high workplane efficiency (64.7% to 78.8%), prevention of glare, and maintenance of high colour reproduction. Yearly daylight levels improved for clear sky from 47 lx to 57 lx and for relatively cloudy sky from 17 lx to 21 lx.	Enhance visual and interior lighting in library and educational settings. Reduce energy consumption from artificial lighting. Integrate daylighting with artificial lighting systems. Optimal window area in libraries should be around 4.5% of the total interior surface area. Increasing window height significantly improves daylight factor and illuminance.
Case Study in International Countries		
Project name	Korea University	University of Pisa
Research title	Natural Light Influence on Intellectual Performance- A Case Study on University Students	A method to assess lighting quality in educational rooms using analytic hierarchy process
Citation	(Porras Álvarez , 2020)	(Leccese et al. 2021)
Location	Korea	Pisa, Italy
Building type	Campus educational building	Educational building

Methodology	Literature Review The statistical calculations (Computer simulation) Field experiment	Computer simulation Survey Questionnaire
Parameters	The exam scores Attendance and participation Students' performance Day light	Day light Users' perception
Key features strategies	Number of students per class Differences on the ratio of male and female students. Windows in classes vs. no windows in classes (Day light)	Average illuminance values Illuminance uniformity The luminance ratios Daylight factor
Lighting method and type	Day light	Day light
Findings	Results show a strong negative impact of the lack of natural light on short-term academic ability. Classrooms with windows consistently outperformed basement classrooms in exams. Statistical comparison of exam and attendance scores for students in basement vs. windows classrooms. Students in classrooms with windows scored much better on exams, with score differences ranging from 13.17% to 7.73%. Attendance differences did not significantly improve.	Lighting Quality Assessment Method (LQAM) results highlight the absence of a shading system for solar radiation as the most significant weakness in the educational building. The choice of artificial lighting systems is considered suitable for static visual tasks. In classrooms, insufficient indoor comfort levels can notably impact students' learning capability and performance. LQAM serves as a valuable tool for lighting design engineers, architects, and infrastructure decision-makers to assess lighting quality in existing buildings and guide improvement interventions

2.11 Research Questions and Hypothesis

In order to identify problems and conduct gap analyses in connection to global environmental assessment systems like LEED ID+C, this research was built on the goal of applying green building rating and reviewing the state of campus buildings globally and in the region. To evaluate how worldwide green building grading systems, affect campus buildings' IEQ in terms of lighting factors. Finding sustainable methods and technology that greatly enhance the environmental quality on campuses can help solve the issue. The author intends to contribute to a firm, well-supported baseline response at the end of this study. It has been demonstrated through verified scientific study for the following questions:

- 1- What is the status of campus building worldwide and in the region in terms of indoor natural lighting and artificial lighting?
- 2- What are the recommended guidelines, strategies, and scenarios to enhance the interior lighting parameters both day light and artificial light?

2.12 Summary of Chapter 2: Literature Review

Chapter 2 provided an extensive literature review of lighting in education campus buildings, emphasizing the critical role of ongoing research and development aimed at enhancing the luminous efficiency and overall performance of lighting systems. This, in turn, contributes to the creation of more sustainable and energy-efficient lighting solutions tailored to diverse applications. As shown in Table 4 above, summarized case studies all around the world

conducted by different researchers and academics represent a broad variety of approaches and parameters to optimize and enhance a sustainable interior environment at campus buildings.

Furthermore, as highlighted in the previous case studies, the use of artificial lighting is a necessary component of natural lighting and complements it by providing sufficient illumination throughout the day and in places where natural light is scarce. This study looks at numerous artificial lighting factors, including colour temperature, glare, lighting settings, and fixture choices and arrangements. It highlights the significance of striking a balance between energy efficiency and visual comfort and the contribution of interior designers to the design of artificial lighting. The standards needed and welfare of building occupants should come first when integrating natural and artificial illumination. The importance of user-centric design strategies, including task lighting and zoning, is discussed in order to offer the proper lighting levels for various activities and areas within the campus buildings. Moreover, the effects of lighting on performance, safety, and beauty is also addressed in this work.

Moreover, several researchers emphasized the importance of combination of both natural and artificial lighting in the interior architecture of university campus buildings. Interior designers can design aesthetically appealing, energy-efficient, and user-centric places that improve occupant well-being and support fruitful learning outcomes by taking the significance of these lighting sources into account. The holistic integration of natural and artificial lighting should take in to account the particular needs of each space within the campus environment.

The gap analysis revealed a critical need to extend our research beyond singular, specialized spaces and instead focus on improving and optimizing both natural and artificial lighting across

multiple areas within campus buildings. By aligning our study with LEED ID+C and EN12464-1 lighting standards, to address this gap comprehensively. The approach involves categorizing various spaces based on LEED occupants' settings, considering factors like space layout, size, specifications, lighting types window availability and the Light Reflectance Value (LRV) of interior materials. Moreover, specify evaluate lighting layouts, types, and specific task functions within each space. The goal is to match recommended Lux values, enhancing energy efficiency and uniformity ratios while adhering to standards for color temperature and color rendering. Additionally, extends to improving the LRV based on LEED guidelines and minimizing Unified Glare Ratios (UGR) to enhance overall daylight and artificial light quality. By implementing these enhancements, aimed to elevate user satisfaction levels, creating a more sustainable and healthier campus environment.

Furthermore, one of the significant gaps identified involves the absence of established benchmark standards, regulations, and actionable strategies to enhance both daylight and artificial lighting in campus buildings in UAE. This gap isn't limited to the UAE but extends to a global context. The objective is, to establish benchmark standards and regulations that can serve as a framework for enhancing lighting conditions in educational spaces in UAE, Secondly, developed practical, implementable lighting design strategies, offering adaptable solutions to improve lighting environments in campus buildings irrespective of location. This approach seeks to provide a comprehensive framework that can be tailored and applied in diverse contexts, promoting healthier, more sustainable, and conducive learning environments globally.

Chapter 3 : Methodology

3.1 Introduction

This study employs a methodology that involves the development of various strategies and scenarios aimed at analyzing the impact of indoor environment in terms of lighting conditions on user's performance and wellbeing in campus building. This will be achieved through a mixed mode method to analyze and understand the lighting parameters and indoor conditions, which will serve as the conceptual framework for the study. The available data type and the required instruments were taken into consideration when choosing the research methodology to achieve the aims and address the questions for this study. This chapter will develop a methodological framework based on a scientific basis from other studies that addressed the same field of investigation. This will also make it easier to precisely set study parameters. In the interior environment, case studies have long been used to give a thorough investigation of the various approaches that have been found to analyze indoor environmental quality and improve the integration and efficiency of interior spaces. Each of them has benefits and drawbacks, which will be thoroughly discussed in this chapter.

On the other hand, the chosen approach in this study is based on the literature review which guide the researcher towards the current and most recent knowledge regarding the indoor environmental quality specifically about the lighting conditions and its effect on the user's performance. Starting by the field measurements technique, which were employed to assess and understand the current situation of existing campus building in terms of artificial light and natural light in different educational and working spaces in the campus. Meanwhile, this method

is also considered an effective way to measure and understand the existing situation by taking real measurements of various lighting technical parameters in different zones. This enables the analysis and evaluation of spaces based on these measurements. Moreover, through the field measurements, the author can identify the internal finishes and each space layout which will be used as input data to build the base case model using the DIALux Evo software.

Sustainable interior design aims to create an internal environment that offers the occupants the utmost comfort, complies with safety and health regulations, and achieves economic savings and environmental responsibility. It does this by adhering to the main sustainable design principles and strategies. In order to achieve the social, economic, and environmental goals of the design and improve the overall performance of the building in terms of lighting conditions and interaction with the surrounding environment over the lifecycle of the materials, it has become essential to link the designers and their designs to the core meaning of sustainable interior design. In the physical environment, the function of interior designers is to produce environments that satisfy the requirements of their clients through a process of analytical reasoning, research, and inventive solutions. In addition to considering other factors like the client's health, safety, and wellbeing, the designer should also think sustainably about the environment's influence. Furthermore, as discussed in the previous chapters, lighting is not a singular technology providing a single function. Instead, lighting needs to be tailored to address the diverse requirements of users based on their activities and the surrounding environment. Nowadays, a variety of methods, standards, and characteristics that have an impact on the humanities and our built environment are brought about by the sophistication of the design process in the early stages and integrative way of thinking.

In the second phase, the study will use and analyse through a survey method for the spaces users to investigate their feelings and awareness of lighting conditions of the existing situation of the chosen spaces. directly related to achieve the desired solutions for a sustainable interior design. Boyce (1996) discussed that every task is unique in terms of the balance between visual, cognitive, and motor components. He argues that it is this uniqueness that makes the existence of a formula that quantifies the precise relationship between lighting conditions and task performance for a wide range of tasks impossible.

On the other hand, the goal of educational facilities is to ensure that students learn to their full potential. This goal cannot be achieved exclusively through the curriculum, teaching methods, instructional materials, assessments, or coordination of the institute management; the physical environment that surrounds students in classrooms, libraries and other spaces can also play a significant role. As mentioned in several research, in order to successfully create an effective interior lighting design in campus building, many factors must be carefully considered from the very beginning of the project. These factors include the building's environment, location, functional needs, orientation, the arrangement of the building's openings, shading devices, glazing materials, and lighting technologies. Not only does daylight help people feel more connected to their surroundings, but it also helps them understand the time of day and satisfies their urge to stay in contact with the outside world. The internal biological clock of the human body is regulated by these day-night, light-dark fluctuations, which also balance circadian rhythms and have an immediate impact on alertness, sleep, and cognitive abilities (IES, 2000).

Furthermore, the third method employed in this study involves computer simulation using the DIALux EVO software. This software is specifically designed for the analysis of lighting conditions within interior spaces, taking into account the space layout and other parameters. Through this software, a comprehensive understanding of the existing situation is developed by creating a base case model that closely mirrors the actual model and specifications derived from field measurements. Subsequently, the study explores suggested strategies and scenarios to enhance interior lighting conditions. It's worth noting that the software is supported by global manufacturers, and the lighting fixture products it recommends have been tested and certified as environmentally friendly, making them suitable for use in various zones, each matching the specific task and function of that zone.

3.2 Field Measurements

The analysis of the existing situation at BUiD was conducted through field measurements to evaluate various lighting factors. During the site visit, various variables were measured using a dedicated lighting instrument, the Sekonic C-7000. It's noteworthy that this equipment is readily available at BUiD, making the data collection process more convenient and efficient, especially for BUiD students as it is provided at no cost. Data were gathered using this equipment as shown in Figure 23. The Sekonic C-7000 is a highly regarded instrument used by professionals in various fields where both the quantity and quality of lighting are crucial. Its precision and versatility make it an indispensable device for conducting lighting assessments and field measurements. This device aids users in achieving the best and most optimal lighting conditions. Furthermore, it can be used to analyze and measure various lighting parameters, including:

- Illuminance (Lux): This parameter quantifies the amount of light falling on a surface, providing information about the light intensity in a particular area.
- Luminance (cd/m²): Luminance measures the brightness of a specific light source or object, offering insights into how that light source appears to an observer.
- Colour Rendering Index (CRI): CRI assesses how accurately a light fixture renders colors compared to natural daylight, indicating the fixture's ability to reproduce colors faithfully.
- Colour Temperature (CCT): CCT is used to measure the color appearance of light sources, helping customers and users select lighting with their preferred cool or warm tones.

This analysis and data collection were carried out at the BUiD campus during its normal operating hours, taking into consideration the COVID-19 restrictions in place at that time. These restrictions affected the timing of entry into campus buildings and the ability to conduct measurements, as a significant portion of classes were being held online.

On the other hand, multiple measurements of illuminance (lux) are gathered from various locations within each area, along with measurements of luminance. Using the Sekonic C-7000 device to obtain several measurements serves to validate and confirm the accuracy of the data collected, reducing the margin of error associated with individual field measurements. Additionally, in educational settings such as classrooms, where the nature of activities, tasks, and furniture layouts can change frequently, the ability to adapt to these changing environments

is essential. This allows for the identification of uneven illumination within the space, ensuring that lighting conditions remain suitable for various activities (Gleason et al., 2019).

It's important to note that only a single measurement per area is obtained for other parameters, including colour temperature and colour rendering index, for each zone. These parameters will be discussed in more detail in the following sections.



Figure 23: Sekonic- C7000- lighting machine

(Source: Author,2022)

However, extensive research has been conducted to establish correlations among various subsequent measurements, such as Lux measurements, brightness, light spectrum, colour temperature, and colour rendering index, in relation to recommended values. The IES Lighting Handbook, which serves as a reference for determining lighting power distribution and interior lighting zones, is based on LEED V4 guidelines.

Alcaráz et al. (2018) conducted on-site measurements using a lux meter and investigated data analysis in a classroom space within a higher educational building in Mexico. Their research showed that incorporating natural light in educational environments has a positive impact on

students' performance, encompassing aspects like well-being and comfort. Their study aimed to gather information about both natural and artificial lighting. They employed field measurements to understand the different effects of lighting conditions on users during both daytime and nighttime, as the campus was occupied by graduate and postgraduate students, as well as academic and non-academic staff, during both periods (Králíková et al., 2022).

The study of Králíková et al. (2022) focuses on assessing the lighting in a university classroom that is utilized for both daytime and evening classes. They also reviewed legal requirements for evening programs and adult education. On-site illumination measurements were taken using a Radio Lux 111 lux meter. The study compared the results of these measurements and simulations with each other and with the requirements specified by legislation and standards. Furthermore, their research emphasized the importance of evaluating whether a project aims to create something entirely new or improve an existing structure when deciding between a new project and a reconstruction. It's also crucial to ensure that the lighting system complies with legal and regulatory standards appropriate for the specific type of space and the activities conducted within it. The choice of this approach was justified to conduct a comprehensive analysis of the existing situation in an existing building. This helps in understanding the specifications of each zone, which will be discussed in detail in the following sections, and establishing correlations between these variables and the existing lighting conditions while taking into consideration the tasks and activities within each zone.

In a study by Sokol et al. (2023), researchers aimed to determine consumers' preferences by exploring practical methods for creating "personas for lighting." These personas are designed to

capture users' satisfaction with various lighting settings and predict how they will behave in different lighting situations. The study discusses and compares three distinct approaches:

1. **Lighting measurements and observations:** This method involves taking on-site measurements and observing the lighting conditions in various structures. It is considered a practical way to understand and analyze the existing situation, particularly with respect to the lighting conditions in each zone and whether they are suitable for the required tasks. The data collected from this method includes details about the space layout, availability of natural light, interior materials and finishes, furniture layouts, types and specifications of lighting fixtures, and the arrangement of artificial lighting. These parameters are analyzed and documented to create a base case model in the software, which is used to enhance the lighting conditions and determine suggested strategies and scenarios for testing and analysis.
2. **Interviews:** This method involves direct interactions with users to gather information about their lighting preferences and needs.
3. **Online surveys:** This method relies on surveys distributed to users to collect data about their lighting preferences and behaviors.

The personas created using these methods serve to support user-centric design methodologies, helping depict typical users and their specific needs, viewpoints, and expectations. While all three strategies can be applied in various building types and spaces, the personas generated by each method have their own unique constraints. Figure 24 illustrates the steps involved in this study for assessing the existing lighting system in different spaces using

the field measurement method. This method involves a detailed analysis of lighting conditions, space layout, and various parameters to create a comprehensive understanding of the existing situation and inform improvements in lighting conditions through suggested strategies and scenarios.

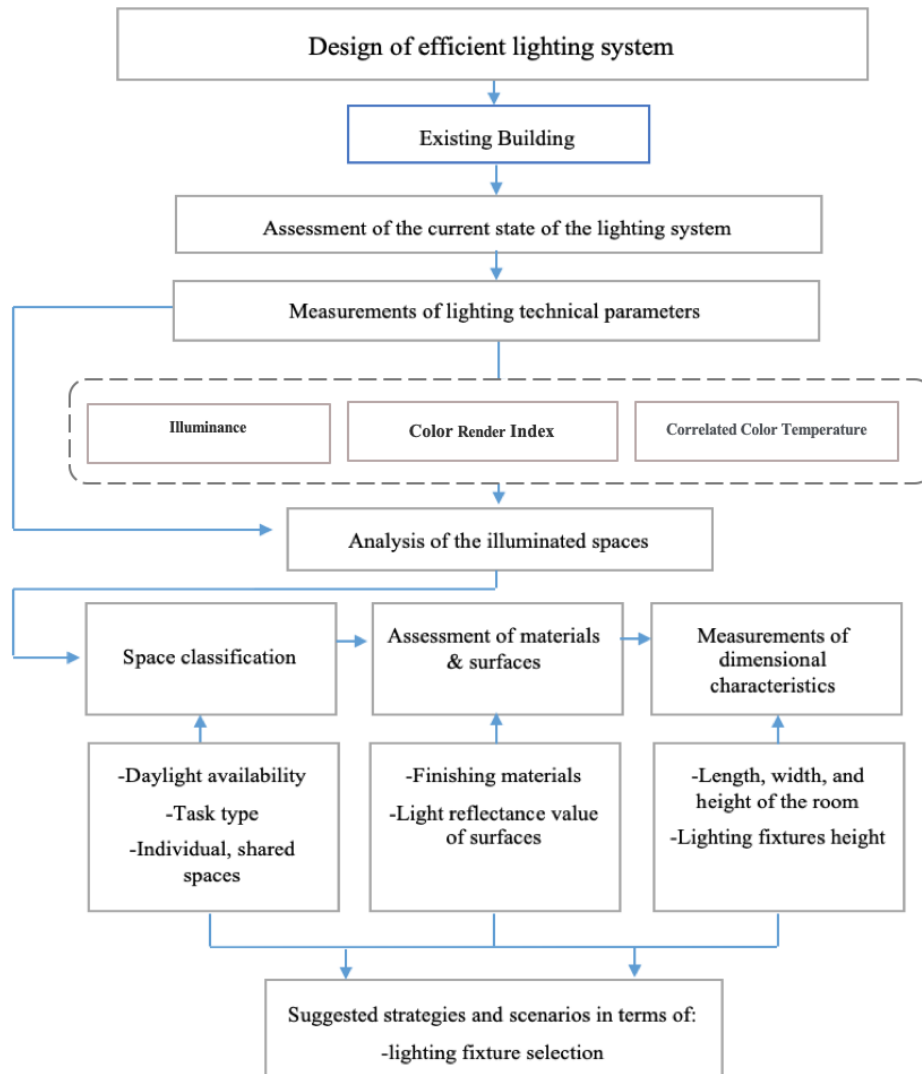


Figure 24:Integrative design process of efficient lighting system in campus

(Source: Author,2023)

3.3 Survey Method

The study utilized an online survey as a supplementary data collection method to assess the satisfaction levels of both students and staff on the campus, with a specific focus on lighting conditions and the indoor environment. It was designed to gain insights into their awareness of sustainable design concepts related to lighting and how these concepts may impact their productivity and performance in various zones within the campus. Additionally, the survey aimed to gather their suggestions and recommendations for enhancing the existing situation from their perspective. This approach helps ensure that the input and viewpoints of the campus community are taken into account when considering improvements in the lighting and indoor environment

In comprehensive studies like this, it's essential to employ a variety of techniques and correlate their outcomes to gain a deeper understanding of the subject. The study in question employed the "lighting personas" approach, which was applied to different building types and locations. This approach was based on interviews with 87 users from five different types of facilities and resulted in the identification of six variables: task, age, gender, visual comfort, mood, and time of day.

The second method categorized people into four groups based on their lighting preferences: those who prefer natural light, artificial light, balanced light, and those with no specific preference. The final method involved conducting an online survey for both students and professionals from seven different nations to gather information about the visual lighting

situation in home workplaces. This data was used to create personas that represent the varied lighting requirements and preferences of the average users.

Despite the complexity of the study and the versatility of these approaches, the personas generated differ due to the specific constraints of each method. The authors conclude by suggesting that future research should focus on creating more precise lighting personas that consider a broader range of variables affecting lighting preferences. They also emphasize the need for further testing in real-world projects to fully comprehend the impact of these personas on lighting research methodologies (Sokol et al., 2023).

The study conducted by Ortiz and Bluysen (2022) aimed to gain a better understanding of the interests and demands of office workers who were compelled to work from home due to the COVID-19 pandemic. The researchers employed a survey technique and grouped respondents based on their self-reported preferences for indoor environmental quality (IEQ) and psychosocial comfort in their most frequently used home workspaces. The questionnaire was administered to employees from ten offices in the Netherlands, resulting in 102 respondents.

Two models of two-step cluster analysis were used to categorize the respondents. The first model focused on variables related to IEQ preferences, while the second model focused on psychosocial comfort preferences. The analysis revealed four clusters related to IEQ preferences and six clusters related to psychosocial comfort preferences. The findings showed that differences in factors such as sound, odors, the presence of windows, localized temperature, and building systems defined the IEQ preference clusters. Additionally, these clusters revealed

differences in how people perceived natural light, overall illumination, control over shades and lighting, and the significance of various factors for enhancing work performance.

In terms of psychological preferences, the clusters varied in aspects like workstation customization, ergonomics, cleanliness, and space size. The psychosocial preference clusters differed significantly in their views regarding the importance of several factors for improved work performance. The study also indicated that both IEQ and psychosocial comfort preferences were influenced by the individuals' circumstances and gender.

However, the study had some limitations, including a low response rate of 29% for the questionnaire and a low completion rate of only 27% for the 80% of respondents who received it. These limitations may have been due to the use of a self-reported questionnaire completed electronically and collected via email. Given these insights, the plan to apply an online questionnaire to understand the visual comfort of campus users, both students and staff, in educational spaces and working environments should consider the potential limitations and challenges associated with using self-reported electronic questionnaires, such as low response and completion rates. Efforts can be made to maximize response rates and the quality of responses to ensure the questionnaire's effectiveness in gathering valuable data about visual comfort and preferences in the campus environment.

The study conducted by Avci and Akbay (2022) to investigate OLED lighting conditions and their impact on visual comfort in an indoor office setting is significant in addressing the crucial component of high-quality lighting, which is visual comfort. While prior research has primarily focused on how OLED lighting affects illuminance levels, there has been limited exploration

into how it influences other aspects of visual comfort. In this study, twelve volunteers from the Faculty of Architecture at Ankara University participated. The researchers assessed the participants' overall visual comfort under OLED lighting settings using an office lighting survey. Unlike previous lighting research, this study exclusively considered the participants' subjective assessments of visual comfort as they went about their typical tasks in an indoor office environment.

It's important to note that Avci and Akbay (2022) study serves as an initial exploration, laying the groundwork for future, more comprehensive investigations. The findings from this study will contribute to a better understanding of the impact of OLED lighting on visual comfort and pave the way for more in-depth research in the future. Unlike previous lighting experiments, this study did not involve evaluation instruments but focused on observing people's daily activities in an indoor office setting while they were exposed to OLED illumination. This approach allowed researchers to concentrate solely on visual comfort, offering valuable insights into how this emerging lighting technology affects the comfort and well-being of individuals in office environments

The study discussed by Alcaráz et al. (2018) highlights the benefits of integrating natural daylight into educational buildings and spaces. These benefits include improvements in student health, performance, and comfort, as well as providing optimal lighting conditions for users' vision and energy savings. However, achieving these advantages requires careful planning during the design phase. The research observed classrooms in campus buildings in two different geographical locations: Prague and Mexico City. Data collection involved using a lux meter for site measurements and the utilization of lighting mockups and DIALux simulation software for

data analysis. Additionally, a survey was conducted among 60 persons including students and staff to gain insights into their individual perceptions of lighting quality in these spaces. The survey questionnaire focused on several aspects of lighting, including darkness, shadows, suitable natural lighting, glare, and light intensity. It was designed to capture real-world scenarios and specifically measured the level of discomfort induced by daylight glare, with respondents using a scale ranging from "intolerable" to "imperceptible" to indicate their level of discomfort. Each survey was designed to be completed in less than 5 minutes.

Hence, this study recognize that lighting has a broader spectrum of effects than previously thought, influencing both physiological systems and providing visual information for interactions with our surroundings. Therefore, the survey's primary purpose was to investigate how lighting conditions affect human circadian function, as well as visual comfort and well-being indoors, considering both visual and non-visual factors.

Therefore, the survey questions were carefully designed to capture all necessary information from users and assess their awareness of the effects of lighting on their satisfaction levels and productivity. The first group of questions aimed to understand the demographic distribution of campus users in this international educational building, including their ages, gender, and highest level of education. The staff were categorized as academic or non-academic staff, considering their different roles, working hours, and usage of various zones throughout the day and night in the normal course of operations. The specific survey questions employed in this study are:

- 1- Where are you from?
- 2- How old are you?

- 3- What is your gender?
- 4- Highest level of education
- 5- Job category
- 6- Hours spent in the classroom/office per week

Whereas, the second group of the questions were designed to investigate the lighting conditions and the user's feelings and moods toward different variables that might affect their productivity and performance. The following questions were included in this group:

A- Lighting conditions: How do you feel about the following?

- 1- My department/office/ class room is a good place to work?
- 2- The environmental conditions in my work area support my personal productivity?
- 3- Are you satisfied with the artificial lighting in working area as a whole?
- 4- Your access to a view of outside from where you sit/ if applicable?
- 5- Overall quality of natural lighting in your work area/ if applicable?

B-How often do you experience glare?

- 6- On your computer screen (classroom, study room, office)?
- 7- From electric lighting fixture?
- 8- From daylight?
- 9- Your ability to see the materials presented in your classroom?

C- How satisfied are you with the following spaces?

- 1- Auditorium?
- 2- Library?
- 3- Students lounge?
- 4- Group study room?
- 5- Meeting room?

The last group of the survey questions were focused on the user's comments and suggestions to improve the spaces lighting conditions which consequently will affect their experience, performance, and productivity. What should be improved to support your effectiveness at your working area? In terms of four variables such as: day light, artificial light, and finishing materials. At the end of the survey, the participants asked to add their comments and suggestions to improve the quality of indoor environment in campus building. The survey of this study helped the author to understand the user's feelings and experience in different spaces of the campus. So, it is considered as an insightful tool to be correlated within the results of the field measurements for various lighting parameters.

3.4 Computer Simulation:

The utilization of DIALux Evo is becoming increasingly popular in academia due to its ability to create virtual studies, which offer significant time and cost savings through simulation. By employing virtual studies, a better understanding of the model to be implemented can be achieved. Through the application of the proposed model to real-life interiors based on such simulations, it becomes possible to examine the impact of light in those interiors.

A study conducted by Pratiwi and Djafar (2021) highlighted the importance of light in interior spaces. Both natural and artificial illumination, or a combination of the two, can satisfy these demands. The goal of this study is to assess the effectiveness of natural lighting, particularly the daylight factor, in the Faculty of Engineering Hall at the State University of Gorontalo and to offer recommendations for enhancing lighting in the space. The hall is frequently utilized for events including seminars, guest lectures, and other student activities. Given the significance of this space, comfort is a crucial consideration. Furthermore, the study approach was carried out through a computer simulation utilizing DIALux Evo 9.0 software by comparing the old model and the optimized engineering design model. According to IES (2000), it's necessary to get a good lighting system; theoretically, five conditions must be met. Specifically, the quantity or intensity of light on a given surface, distribution of light density; limitations to prevent eye glare, lighting direction and shadow formation, and light colour and colour reflection. Knowing the brightness level of a space is essential for achieving visual comfort.

The DIALux Evo 9.0 application was used to simulate and analyze lighting performance. This finding is in line with many other studies done by different researchers on various spaces, investigated that the space properties and specifications such as: the position and size of the windows, the proportions of the room, the arrangement of surfaces (the type of furniture layout) vertically and horizontally in the room, and the reflectivity of the inner surface materials had the greatest and considerable effect on the distribution of lights in space. This study is quantitative and use the simulation methodology. analyzed using statistics, namely descriptive statistical analysis. Tables and graphs are used to present the findings of the simulation.

Králiková et al. (2022), analyzed a university classroom located on the first floor in the Department of Environmental Engineering building located in Košice, Slovakia. The study application section includes simulation and measurement of lighting. The simulation was carried out using the lighting design programs DIALux EVO 10. Therefore, the lighting simulation tools were used to improve the lighting system design concerning its energy efficiency and costs. In order to calculate and optimize lighting systems, this study highlights the advantages of using free computer software. The findings of the study indicate that simulation tools can be useful in assessing and developing the lighting system.

Alcaráz et al. (2018) study consists of three main stages. First, the physical conditions and environment of the classrooms were assessed. Second, measurements of daylighting and artificial lighting were taken, along with a survey on glare. Lastly, computer simulations using DIALux EVO were utilized to analyze the behavior of light within the classrooms. This analysis aimed to determine the potential percentage of energy savings and compare the two classrooms located in different cities. The study investigates the importance of emphasizing and controlling the use of natural light in educational environments. It suggests that installing artificial lighting devices that work in conjunction with natural light can provide an efficient solution to inadequate lighting. However, the implementation of such solutions requires careful planning. Various tools like shading devices (curtains), can assist in achieving the desired lighting conditions. Moreover, it facilitates energy conservation and provides optimal lighting conditions for human vision.

Hence, incorporating natural light requires meticulous planning. The objective of this study is to investigate the lighting conditions in educational settings, with a specific focus on visual

comfort. The simulation was performed using lighting simulation software DIALux Evo 11, where different lighting designs can be compared, enhanced, and defects can be found. The processing of the results in numerical and graphical formats is made simple and clear by the lighting design tools. To gain a deeper understanding of users' subjective experiences, a survey was conducted to establish correlations between their perceptions and the lighting conditions.

Figure 25 illustrates the framework of the computer simulation model, including the input data, tested variables, and space categories as classified by LEED v4. This classification is based on the base case model, which was constructed using data collected during field measurements, along with additional information gathered from the campus database. The suggested strategies and scenarios were developed to build upon each other and ultimately reach the optimal scenarios for each tested space. This approach allows for a comprehensive analysis of lighting conditions and user experiences, helping to identify the most effective strategies for enhancing lighting in various areas within the campus or building.

Over all, in order to achieve the optimal design goals and improve the overall performance of the building in terms of lighting conditions and interaction with the user's satisfaction, in addition to taking into account other factors like the client's health, safety, and wellbeing, the designer should also think sustainably in integrative process about the environment's influence. It has become essential to link the designers and their designs to the core meaning of sustainable interior design through integrative design process to achieve the holistic approach in the early stages of the design. As well as, in the physical environment, the function of interior designers is to produce environments that satisfy the requirements of their clients through a process of analytical reasoning, research, and inventive solutions.

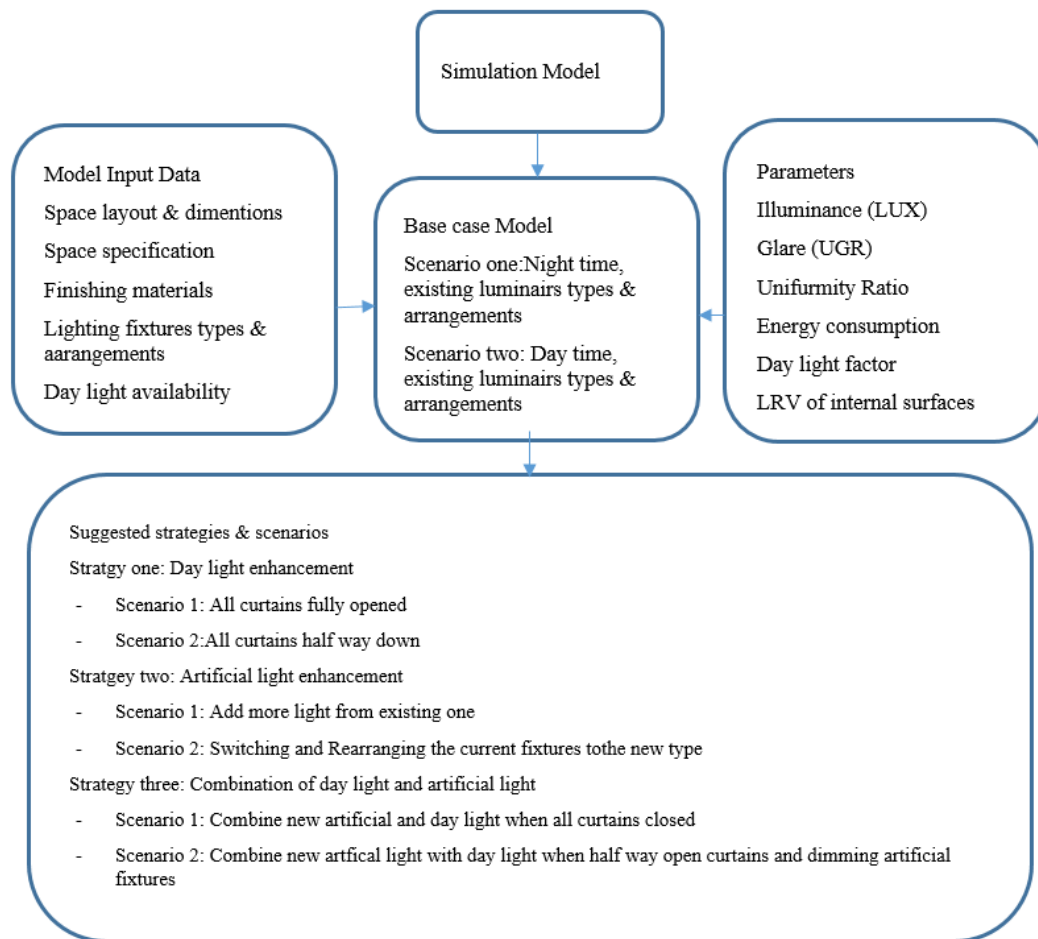


Figure 25: Model simulation framework

(Source: Author, 2023)

As a summary the methodological approach adopted in this research integrates multiple methods, each contributing uniquely to the comprehensive evaluation of lighting parameters within the campus environment.

- **Field Measurements:** Provided empirical data on lighting parameters such as lux values, uniformity ratios, color temperature, color render index and glare values across different spaces within the campus. This method offered objective quantitative data crucial for assessing the actual lighting conditions present in each location. Field measurements offer several benefits in research focused on assessing lighting parameters within a specific environment as :real-time assessment, identification of actual conditions, basis for comparison, informed decision-making to make informed decisions about potential improvements or modifications required to enhance the lighting environment, and validation of findings
- **Online Survey:** The choice of an online survey facilitated the collection of diverse perspectives from various campus users - students, academic, and non-academic staff. This method allowed for a wide-reaching data collection process, gathering insights on occupants' experiences and preferences regarding lighting conditions.
- **Computer Simulation Analysis:** Computer simulation analysis enabled the candidate to conduct predictive evaluations, simulating scenarios to optimize lighting parameters as per EN 12464-1 standards. This method offered a predictive element, allowing for the exploration of potential improvements and their impact on lighting quality. Also, its help to simulate different scenarios by adjusting variables such as fixture types, or daylight utilization. This ability to test multiple scenarios helps in identifying the most effective strategies for enhancing lighting conditions. Moreover, visual representation or renderings that depict how lighting changes could potentially impact the environment. These visualizations help stakeholders, including designers and decision-makers, better

understand the potential outcomes of proposed lighting modifications. Quantitative analysis provides quantitative data such as illuminance levels, light distribution, and glare values. These data points offer valuable insights into the expected performance of lighting designs, aiding in decision-making processes.

The inclusion of perspectives from diverse campus users was pivotal. Understanding the viewpoints of students, academic, and non-academic staff ensured a holistic assessment of the lighting environment. This approach acknowledged the varied needs and preferences of different user groups, aligning with the user-centric design philosophy critical for creating inclusive and accommodating educational spaces, and understanding their varied needs, preferences, and experiences with lighting directly contributed to tailoring recommendations that prioritize occupant satisfaction level. The analysis of lighting parameters, including daylight factors and artificial lighting parameters like lux value, uniformity ratio, and glare value, was conducted to align with EN 12464-1 standards. This alignment allowed for a systematic evaluation of lighting conditions against established benchmarks, enabling the identification of areas requiring improvement to meet industry standards and enhance the overall indoor environment. In essence, the combination of diverse methodologies and the consideration of multiple user perspectives ensured a comprehensive evaluation of lighting parameters.

The integration of different methodologies served as a validation mechanism for the findings. Combining quantitative data from field measurements with qualitative insights from surveys provided a more robust and reliable basis for analysis. Employing computer simulation analysis allowed for predictive evaluations of potential lighting improvements. This forward-looking

approach enabled the exploration of scenarios aligned with industry standards, offering insights into the potential impact of proposed changes. Aligning the analysis of lighting parameters with established standards such as EN 12464-1 ensured that the evaluation was grounded in recognized benchmarks. This alignment facilitated the identification of areas for improvement in line with industry best practices.

3.5 A Summary of Research Approaches:

In order to explore the same research themes from a different perspective, it is important to look into similar research topics. Or to investigate whether the same procedures and strategies that have been successful in one area have produced the same results or whether there have been changes that may have enabled us to understand the factors that influence these results. Instead than beginning from scratch and wasting time, this phase seeks to build on their accomplishments in order to further human understanding. The list of published papers in Table 5 that use the procedures described in this section and share the same research goals and conclusions would be appropriately considered when choosing and justifying the appropriate methodology for the case study of this research.

Table 5: Summary of methodologies to enhance the indoor environmental quality in terms of lighting and user's wellbeing, (source: Author,2023)

Paper Title: Personas for lighting'. Three methods to develop personas for the indoor lighting environment	
Location	Various buildings types in different location include: Norway, Poland, Italy.
Aims	Understand, discuss and contrast three alternative approaches to create "personas for lighting," which mimic the behaviors of users in an illuminated environment
Research Methods	Integration of three methods: Interviews, survey, field measurements
Findings	The developed personas could be used by designers to determine the lighting preferences, needs, and requirements of future users.
Citation	(Sokol et al. 2023)
Project Title: Profiling office workers based on their self-reported preferences of indoor environmental quality and psychosocial comfort at their workplace during COVID-19	
Location	Ten offices in the Netherlands
Aims	Aimed to organize home-based office workers into groups according to their self-reported preferences for IEQ and psychological comfort at their preferred workspaces and to determine these preferences and needs of workers during the pandemic.
Research Methods	Questionnaire, divided in to two models: the first one is related to variables focused on IEQ preferences. And the second model, focus on psychosocial comfort preferences
Findings	Claimed that, IEQ and psychosocial comfort preferences are situation to the space specifications
Citation	(Ortiz & Bluysen 2022)
Project Title: Visual comfort assessment of OLED lighting in an indoor office environment	
Location	Indoor office environment at Çankaya University, Faculty of Architecture
Aims	Examined how OLED lighting conditions affect visual comfort in an interior office environment, considering general comfort metrics such overall comfort, illuminance, brightness ratio, ceiling reflections, colour, flicker impact, and overall satisfaction.
Research Methods	Survey used to evaluate the general comfort of OLED lighting in an indoor workplace setting.

Findings	Show that, when compared to other lighting situations in the interior office environment, the illuminance level of OLED lighting was substantial to avoid ceiling reflections, to give good colour impressions under this lighting condition, and to do so.
Citation	(Avci & Akbay 2022)
Paper Title: Relationship of shading devices and its effects on daylight in Commercial buildings in Pune	
Location	Commercial buildings
Aims	The daylighting is important for designing a optimistic work atmosphere as it enhances productivity between occupants. However, research has shown that extreme natural light incoming across windows can lead to discomfort visual for users. To reduce this issue, the shading devices and their positions are working to relieve glare level, the goal is to decrease glare level and discomfort level for those working in indoor spaces.
Research Methods	Software simulation: Integrated Environmental Solutions (IES)
Findings	The shedding device used in a building where are spaced in a vertical way at different heights level, is able to give suitable effects for daylight distribution to enhance the uniformity level, and illumination levels. The space which can efficiently use the daylight can positively enhance generate healthy spaces and that is result to greater productivity, and decrease the artificial lighting loads.
Citation	(Joshi & Patki ,2022)
Paper Title: The case study on significance of daylight in classroom setting at Sarajevo Campus	
Location	Classroom Setting at Sarajevo Campus
Aims	To show the advantages of daylight design in a learning environment. The essay also focuses on identifying and analyzing the many conditions, traits, and elements that encourage the successful use of daylight design in classrooms. Additionally, it examines the daylight design of the structures on the Sarajevo campus.
Research Methods	Literature review method
Findings	By identifying the requirements and essential elements for successful daylight design as well as assessing the daylight design on the campus in Sarajevo, the study provides valuable information that will direct the construction of a comprehensive design manual. This recommendation will serve as a reference for future daylight design initiatives in educational facilities, ultimately assisting in the creation of the optimal learning environment for the students.
Citation	(Obralic & Jeghel 2021)

Project Title: Analysis of lighting performance in the Hall of the Faculty of Engineering, State University of Gorontalo by using the DIALux Evo 9.0 simulation.	
Location	Hall of the Faculty of Engineering, State University of Gorontalo
Aims	The purpose of this study is to analyze the performance of natural lighting, especially the daylight factor in the Hall of the Faculty of Engineering
Research Methods	Computer Simulation with DIALux Evo 9.0 software by comparing the existing model and the engineering design model which are changing materials of the handrail to transparent material, to change the reflectivity of the interior materials of the inner surface and add shading device such as light shelves inside the hall. The light shelf can proposal a shading besides that can redirect the major part of the incoming light flux
Findings	The outcome demonstrates that, although more engineering is still required, optimized design may optimize the direction of light according to the goal point and eliminate glare. And another way for increasing natural lighting can be consuming the daylighting systems through (blinds, light-shelves, louvers, ,etc.)
Citation	(Pratiwi & Djafar 2021)
Project Title: Simulation of artificial lighting using leading software to evaluate lighting conditions in the absence of daylight in a university classroom	
Location	Department of Environmental Engineering building located in Košice, Slovakia
Aims	To assess the lighting in a university classroom that is utilized for both daytime and evening classes
Research Methods	Simulation and measurement of lighting. The illumination on site was measured using a Radio Lux 111 lux meter., and computer simulation was carried out using the lighting design program DIALux EVO 10
Findings	In order to calculate and optimize lighting systems, this study highlights the advantages of using free computer software. The outcomes of the measurement and the two simulations were contrasted with one another and with the global standards
Citation	(Králíková et al. 2022)

Project Title: Lighting in higher education classrooms	
Location	Examines classrooms in higher education institutions located in Mexico City and Prague
Aims	To investigate the lighting conditions in educational settings, with a specific focus on visual comfort.
Research Methods	Adopted mixed mode method: On-site measurements were conducted using a lux meter, and data analysis was performed using lighting simulation software, namely DIALux EVO.
Findings	using natural light in educational settings improves students' performance in several ways, involving benefits to their overall comfort as well as their health. Furthermore, it helps energy saving and suggestions optimal lighting settings for user's vision.
Citation	(Alcaráz et al., 2018)

As discussed in the previous section, which outlines our research objectives, findings, and methods, case studies have been extensively utilized in the preceding chapter to provide a detailed analysis of indoor environmental quality. This analysis aims to enhance interior lighting parameters, leading to improved user satisfaction and increased student productivity and well-being.

Additionally, when selecting the optimal approach for our research case study, it is crucial to consider justifications. To explore our research themes from different perspectives, we must also delve into related research topics. This exploration helps us determine whether procedures and strategies that have proven successful in one context yield similar results or whether there have been changes that influence these outcomes. Rather than starting from scratch and wasting time, this phase seeks to build on previous accomplishments.

Based on these considerations, we have employed a mixed-mode research method in this study. The integration of various quantitative techniques has led us to conclude that the mixed-mode approach is the most effective methodology. This approach allows for a comprehensive

analysis and interpretation of the current case study situation and the evaluation of optimized case scenarios, incorporating diverse strategies and design techniques. In other words, our study's confirmation is achieved using a triangulation technique, offering a range of opportunities and advantages for enhancing the research. This involves integrating on-site measurements, surveys, and computer simulation findings. The mixed-mode approaches utilized in this project include on-site measurements, survey tools, and computer modeling tools (Kime and Alibaba, 2018). Their study highlights the substantial impact of lighting, whether natural or artificial, on how students respond and learn in classrooms, libraries, or offices.

This study will look into, evaluate lighting factors for educational campus building in a number of different spaces, including classrooms, library, corridors, auditorium, student lounge, group study room, individual offices, and shared open space offices. The purpose of this study was to assess comfort factors that influenced the user's satisfaction level, in the task area which going to be analyzed through the survey tool, because there are numerous factors and variables that affect the lighting quality in various measured areas, such as light type, quality, efficiency, finishing materials, and equipment. To gain insights into user satisfaction, student behavior, and the impact of lighting on different spatial conditions, an online survey was administered to students and staff at BUiD across various university settings. Participants were asked to share their perceptions of the indoor environment and evaluate the impact of interior lighting on their learning experiences. Consequently, analysis of the collected questionnaires will shed light on issues pertaining to user satisfaction, student behavior, and the influence of lighting on various space conditions. The study recognized the vital role of IEQ in shaping individuals' cognitive abilities and performance within academic settings. In terms of sustainability, energy-saving

lighting is considered optimum, with sunlight being the most efficient source. It is imperative that each area and room within the building is equipped with lighting that aligns with its intended function and meets the recommended illumination levels based on EN 12464-1 (2021) standards.

Moreover, the DIALux Evo 11 program was employed to conduct computer simulations for lighting performance analysis in order to simulate the base case and validate the gathered on-site information. Since in this study dealing with existing building, so the building façade cannot be changed, then solutions will be made internally. Furthermore, an additional simulation was carried out to assess both the base case and the suggested scenarios, allowing for a comparison of different options in order to identify the optimal scenarios. In the section that follows, each strategy's specifics, potential outcomes, and related discussions are displayed (DIALux 2016).

DIALux is a rapidly growing software solution for natural and artificial lighting that fulfills the information requirements of the latest lighting technology. It offers features such as automatic generation of technical reports and enhanced visual rendering capabilities. Various studies as highlighted in the previous section, have utilized DIALux simulations. These studies have employed numerical modeling based on the lighting standards, direct measurement data obtained on-site, and simulation technique. This study serves as a valuable contribution to the field of architecture and educational research, highlighting the importance of considering IEQ factors, particularly interior lighting characteristics, when designing and maintaining university campus buildings. By recognizing the significant impact of IEQ on users' satisfaction and well-being, stakeholders can work towards creating environments that promote effective learning,

improve academic performance, and enhance the overall quality of students' educational experiences.

3.6 Research Case Study

The British University in Dubai (BUiD) was chosen as the focal point for this research, serving as the case study site, with coordinates of 25.1266° N, 55.4109° W. Situated within Dubai International Academic City, BUiD was established in 2003 as a key component of a vibrant cluster of universities within the Academic City. The name itself, Dubai International Academic City, signifies its overarching goal of hosting esteemed educational institutions and fostering a conducive environment for academic pursuits. by the country's Vice President and Prime Minister Maktoum bin Rashid al-Maktoum. It is licensed by the UAE's Ministry of Education's Higher Education Affairs and all its programs are accredited by the Commission for Academic Accreditation (CAA). Moreover, The British University in Dubai is one of the top private universities in Dubai, United Arab Emirates (UAE). It is ranked 61-70 in Arab Region Rankings 2023. Which was named to indicate its purpose of hosting educational institutions.

BUiD stands as a prominent institution within this academic hub, offering a range of educational programs and contributing to the development of knowledge and expertise in various disciplines as shown in Figure 26. This study focuses on the Engineering campus located inside the main building. Furthermore, the LEED-based IEQ is not applied in the building, which influences efficiency and comfort of users. The purpose of using this for the research is to demonstrate the importance of using LEED ID+C to improve the lighting parameters.



Figure 26:BUiD location map and external views of the campus

(Source: google map,2023)

Even though Dubai Academic City is a relatively new development, the presence of educational institutions has significantly transformed the area into a vibrant and interactive environment. BUiD takes pride in being a top research university committed to producing knowledge that benefits governments, corporations, and communities around the world. BUiD was created to make it easier for Middle Eastern students to access outstanding training, education, and research. However, it is considered as one of the first postgraduate research institution in the Middle East, offering courses in education, business, engineering, and technologies, among other subjects. The university also collaborates with prestigious universities in United Kingdom (UK). BUiD aspires to the highest, internationally recognized British standards and provisions as reflected in its partnerships with the University of Edinburgh, the University of Manchester, the, Cardiff University and University of Glasgow.

All BUiD Masters and Doctoral programs have accreditation eligibility from Ministry of Education Higher Education Council. Moreover, BUiD is offering a bachelor degree in different disciplines such as: computer engineering, artificial intelligence, electro mechanical engineering, business management, accounting and finance, and law. On the other hand, the total student population on the campus comprises 434 students, with 263 of them being international students. Among the students, 65% are pursuing undergraduate degrees, while the remaining 35% are enrolled in postgraduate programs. Turning to the staff, there are a total of 37 faculty members, with domestic staff accounting for 3% and international staff representing the majority at 97%. The university campus encompasses two distinct blocks within the academic city complex. Block 11, the older of the two, consists of three floors, each of which accommodates various amenities, including classrooms, an auditorium, offices, meeting rooms, the Atkins lab, administration area, the main reception, a lounge room, a study area, a library, a pantry, IT room, a storage area, corridors, and other spaces. In contrast, block 10 features a renovated first floor, housing facilities such as science labs, a professional development and examination center, an architecture studio, and other related spaces. The focus of this work will be on block 11, which is situated on the first level of the university and encompasses various spaces.

The major objective of this study was to investigate the lighting parameters either natural or artificial light and its effect on user's satisfaction and their productivity. The case study as mentioned previously consist of three main blocks which categorized as per LEED based on the occupation settings of these spaces as following: Occupied vs. unoccupied spaces, regularly vs. no regularly occupied spaces, and Individual occupants vs. shared multi occupants' spaces.

- Shared regularly multi occupant:

First floor – block 11: Auditorium, classrooms (3 spaces), library, administration area, group study room, students lounge, female room, board room.

Second floor – block 11: Atkins DDS and IT lab, classrooms (7 spaces), meeting room, IT support, common room.

First floor – block 10: student administration, training center, class rooms (6 rooms) student lounge, science lab, professional development and examination center, architecture studio.

- Individual occupant's spaces:

First floor – block 11: offices (9 spaces).

Second floor – block 11: offices (31 spaces).

First floor – block 10: offices (3 spaces).

-Non-regularly occupied spaces:

First floor – block 11: common room, store (2 spaces), corridors.

Second floor – block 11: common room, server room, store, corridors, rest room, stairways.

First floor – block 10: store, DIAC service, mechanical room, corridors, stairways, rest room.

The British University in Dubai (BUiD) comprises three main blocks. Among these, the Old Block and the New Block are distinct structures that together form the core of BUiD. They serve as academic facilities for undergraduate and graduate programs, offering master's and doctoral degrees across a wide range of fields of study.

Figure 27 and Figure 28 illustrate the layout plans of the Old Block, providing a detailed overview of each floor. This block has played a significant role in the history of the institution, as it was one of the initial structures constructed when BUiD was established in 2003. Over the years, it has witnessed the expansion and growth of BUiD, solidifying its position as a prominent higher education center in Dubai. The Old Block-11 is equipped to support various postgraduate programs, offering a range of facilities such as classrooms, lecture halls, laboratories, and administrative offices. Despite its conventional design, this building provides students with a comfortable and conducive environment for learning.



Figure 27:Plan layout of the old block- 1st Floor - Block 11 BUiD

(Source: Buid,2022)



Figure 28:Plan layout of the old block- 2nd Floor - Block 11 BUID

(Source: Buid,2022)

In order to accommodate its growing student population for undergraduate students and improve the educational experience, BUID has recently upgraded its infrastructure as shown in Figure 29. Moreover, the new building serves as evidence of its development and renovation. The new block-10 features cutting-edge classrooms, specialized laboratories, collaboration areas, and interactive learning settings created for students. It is outfitted with cutting-edge amenities and cutting-edge technology. This facility exemplifies BUID's dedication to giving the students a modern and innovative educational environment. Furthermore, for lectures, practical sessions, group projects, and academic debates, local and international students can

attend in BUiD buildings. In order to support the extensive program, the university makes sure that these facilities are properly maintained and furnished.

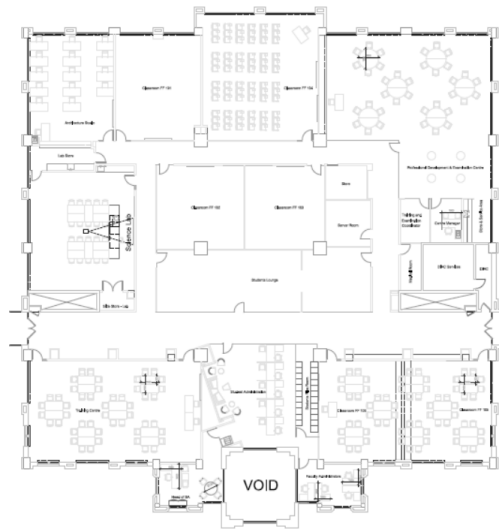


Figure 29:Plan layout of the new block 1st Floor - Block 10 BUiD

(Source: Buid,2022)

3.6.1 Overview of the Study Environment-Existing Conditions:

In this study, the data analysis involved a combination of mixed-mode methods. However, it is recommended to assess the existing conditions of each space based on its designated use. Many of the spaces within BUiD are utilized throughout the day by academic, non-academic, and administrative staff, in addition to the undergraduate students, who constitute the largest portion of the university's population. Furthermore, these spaces are also utilized at night by postgraduate students and academic staff.

In addition to that, a range of techniques were adopted to provide a holistic approach of evaluating the interior environment in terms of lighting and user satisfaction including: simulation, observations (walkthroughs and photographs, comments, etc.), site analysis, online questionnaires, illumination measurement, and behavioral analysis. This study goals to collect information that will assist fill these knowledge gaps. The major objective of this study was to investigate the lighting parameters either natural or artificial light at its effect on user satisfaction and productivity.

While, as shown in Figure 29 , the plan layout of the functions in the old block 11 first and second floors have almost the same environment, functions, and tasks, Thus, the focus of this work will be on the old block 11, located on the first floor of the university, which comprises multiple spaces such as: Classrooms, an auditorium, a student lounge, a reception and administration area, library, offices, and labs are among the building's amenities. To evaluate the existing situation and enhance the interior environment by applying different strategies and scenarios to improve the lighting and the user's productivity. As mentioned previously, the chosen space of this study will be the first floor of block-11 in the old building, which has a built-up area of roughly 1830 m², it is divided into the various zones categories as per LEED (ID+C) based on the occupation settings of these spaces as follows: Occupied vs. unoccupied spaces, regularly vs. no regularly occupied spaces, individual occupants vs. shared multi occupant's spaces. Figure 30 represents the various spaces as a shared regular multi-occupant space including: Auditorium, classrooms, library, administration area, group study room, students lounge, and the board room. Furthermore, Figure 31 shows the general circulation zones (corridors) as non-regular occupied space, and individual occupied spaces like offices.

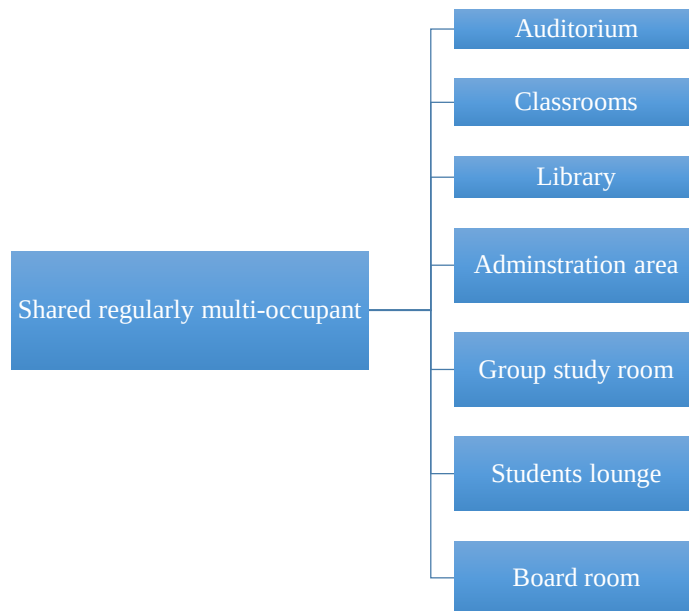


Figure 30: Spaces categories as per LEED ID+C guidelines- Shared regularly multi occupant spaces

(Source: Author, 2023)

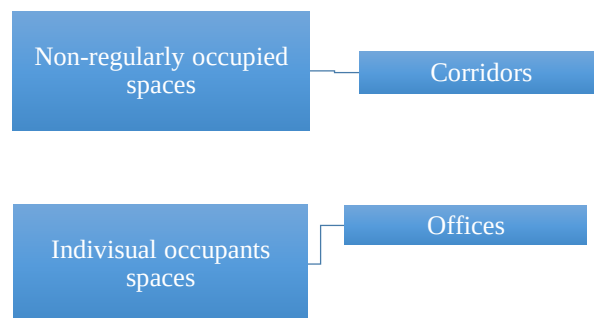


Figure 31: Spaces categories as per LEED ID+C guidelines- non- regularly occupied spaces and individual occupants' spaces

(Source: Author, 2023)

While the current situation of the study area information was collected through the site visit like the dimensions of the areas, the finishing of the walls, ceiling, and floors, lighting fixtures, and furniture materials are just a few of the specifics of the current location that will be documented and analyzed. Moreover, through the site visit, validation of the information was conducted through the field measurements on-site using light meter devices in specified task area. The studies areas can be summarized by the following:

- The reception zone includes the reception counter and two waiting areas with approximately a total area (50 m²), and general circulation corridors with almost a total area (of 340 m²)
- The student's lounge includes an activities area, a female room, and a store with approximately a total area of (of 150 m²),
- The administration zone includes an open plan office area in addition to six closed offices with approximately a total area of (220 m²).
- The library area including the reading parts, and bookshelves part, and the librarian office zone with approximately a total area of (310 m²).
- The auditorium space includes the stage zone and the audience area with an area of about (162 m²).
- The vice president's office, registration office, and receptionist office with total area of about of (93 m²)
- The board room (meeting room) with approximately an area of (33 m²).
- The group study room one and two and the common room of (180 m²).

- The classroom FF -1111 area including three classrooms one of them to be analyzed and simulated in this study has an area of around (240 m²).

In addition to that, each space from the different categories mentioned previously is going to be documented through photos, maps, and tables showing the specifications and the finishing of these spaces. Table 6 and Table 7 show the auditorium area plan layout and photos showing the furniture and other space specifications.

Table 6: Plan layout of the auditorium space, (Source: Author,2023)

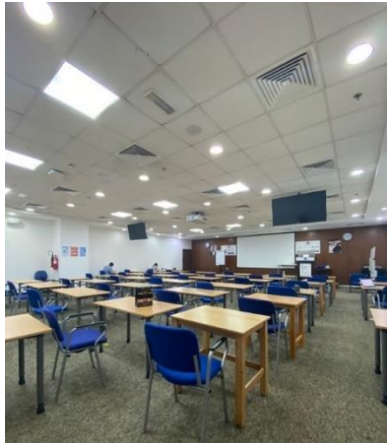
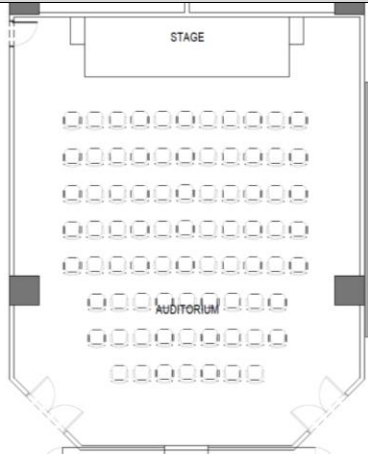
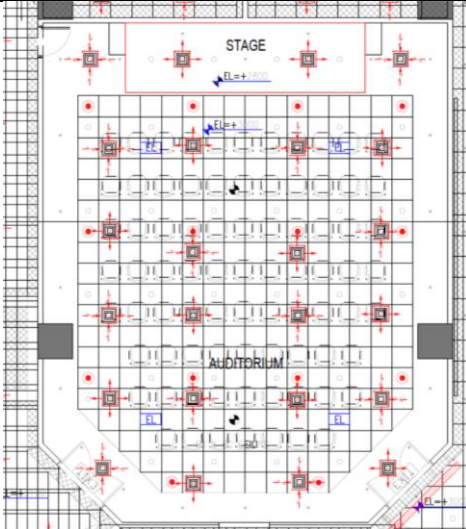
Plan layout- 1 st floor plan- Block 11 -BUiD- Auditorium plan	
	

Table 7:Plan layout and space specifications of auditorium space ,(Source: Author,2023)

Space specifications (finishing materials)		Space furniture layout
Floor	Carpet	
Ceiling	Nine florescent light (60 x60) cm & thirty-nine down light (20) cm	
Walls	One wall wooden & three walls with paint finish	
Doors	One single wooden door, and two double wooden doors	Lighting fixture distribution
Windows	NA	
Curtains or shading devices	NA	

Furniture layout and materials	Laminated MDF, glossy, Space capacity: 46 chairs	
--------------------------------	--	--

Educational lighting designers face a significant difficulty when designing lighting systems for lecture halls and auditoriums in campus building. To enable various settings, such as teaching, taking notes, entering and leaving the lecture hall, or presenting presentations, many lighting scenarios are required. Along with an expertly designed lighting strategy, light management systems are crucial. While it has no direct daylight and natural views, these areas only depend on artificial lighting and it's not possible for the occupants to use the space or function properly without the presence of one or both of the previously stated. The space is let

by nine fluorescent lights (60x60), and thirty-nine downlights. The walls were painted with a light reflection factor (LRV) of 49.4%, and the stage wall was covered with dark laminated wood finish material which resulted in a bright surface.

The floor was covered by a carpet with LRV of (15%), as these values represented by DIALux EVO manual inserted in the software after inserting the existing specifications of the internal finishing's of various surfaces. In addition to that, laminated glossy MDF (Medium Density Fiberboard) used for the furniture which result on glare and discomfort for users. In the following section, the lighting parameters measured on-site going to be analyzed and compared with the standard lighting manuals. After that defining the various functions for each zone, in order to be able to make the improvement.

Nowadays, the majority of learning is visual. Throughout the academic day, students can focus on reading and exams, and hear lectures from their lecturers. Flexible desk arrangements are common in campus buildings, thus the lighting in the classroom needs to be planned accordingly. When it is achievable, natural daylight is always desired and included in the planning. However, it has been discovered recently that luminaires with an adjustable light colour (adjustable white) produce favorable learning results. Students who are exposed to LED lights in the classroom with adjustable colour temperatures score better on tests and exhibit less stress. To achieve optimal visual comfort during learning, artificial light should be dimmable and bothersome glare should be minimized. As shown in Table 8 and Table 9, the students sitting arrangements in a U-shape with a capacity of around 15 students and the instructor's table.

Table 8: Plan layout of the classroom FF-111 space, (Source: Author,2023)

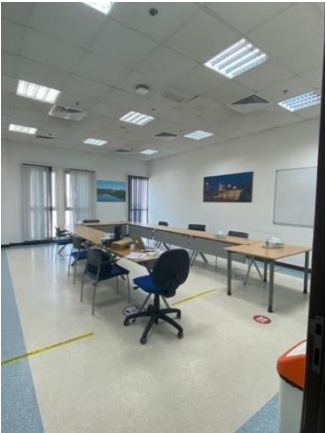
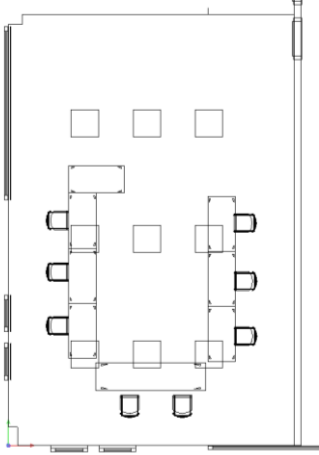
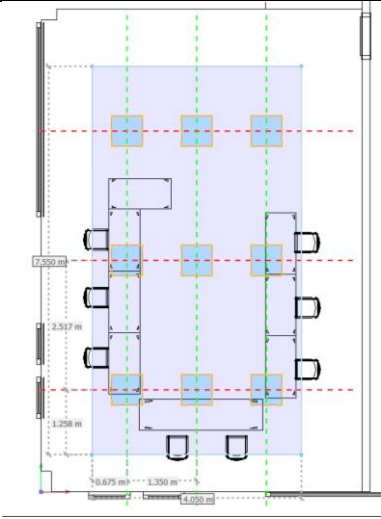
Plan layout- 1 st floor plan- Block 11 BUiD- Classroom-ff 111 plan	
	

Table 9: Plan layout & space specifications of the classroom FF-111, (Source: Author,2023)

Space specifications (finishing materials)		Space furniture layout
Floor	PVC-flooring	
Ceiling	Nine fluorescent lights (60 x60) cm	
Walls	Paint finish	
Doors	One single wooden door	Lighting fixture distribution
Windows	Three windows in one side, & 2 windows in top of other side	
Curtains or shading devices	Vertical blinds	

Furniture layout and materials	Laminated MDF, glossy, Space capacity: 16 chairs including the instructor, and 8 tables	
--------------------------------	---	--

While this type of arrangement offers numerous advantages, such as creating an interactive learning space that goes beyond traditional classrooms, fostering teacher-student engagement, and improving visual accessibility, there are some limitations to this style. These limitations may include class size, subject matter, and teaching style. The classroom features a floor covered with Polyvinyl Chloride or vinyl (PVC) material, while the ceiling comprises square tiles with a Light Reflectance Value (LRV) of 70%. Additionally, the old painted walls have an LRV of 49.5%, and the work surfaces are constructed from glossy wooden materials with an LRV of 25%. This glossy surface can lead to reflections and brightness discomfort for the students and may also affect the visual accessibility of presentation materials on the whiteboard.

BUiD library, located on the east side of the block towards the public open space area on the campus which contains the hybrid hub and the food court for the students and the staff which is considered as one of the most livable areas. While it supports the education and research activities of the university with its materials and information services. While, library spaces in

campus buildings are welcome places for students to learn independently or in groups where they should find it simple to focus and advance their knowledge in a calm setting.

This can be achieved by outfitting workstations and shelves with appropriate lighting, while also harnessing natural light to enhance energy efficiency and create a conducive learning environment. The library at BUiD boasts a collection of over 4,414 books, along with thousands of digital resources, all housed within a spacious area of 250 m². The library accommodates up to 45 seats and employs a combination of both natural and artificial lighting. The artificial lighting utilized in this space is of the fluorescent type, emitting bright white light, which may be excessive for the requirements of this area. The ceiling is composed of square tiles with a Light Reflectance Value (LRV) of 70%. To minimize glare resulting from the abundant daylight, the floor is covered with a dark gray carpet, which reduces light reflection in the area. Furthermore, the walls are painted with a light reflectance value of 49.5%, and the work surface materials possess an LRV of 25%, as indicated in (DIALux, 2016). A Plan layout of the library space is shown in Table 10 and the space specifications is shown in Table 11.

Table 10: Plan layout of the library space , (Source: Author,2023)

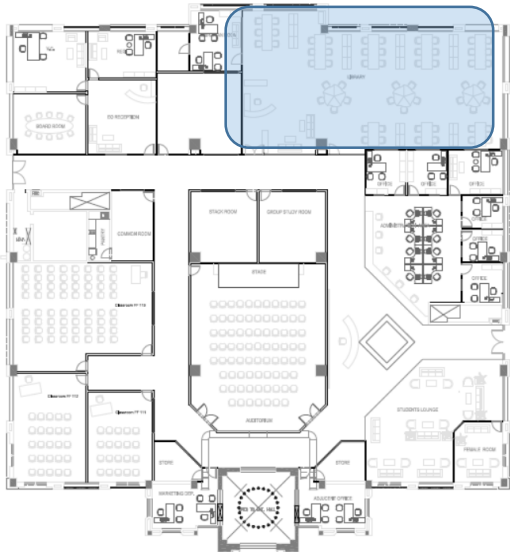
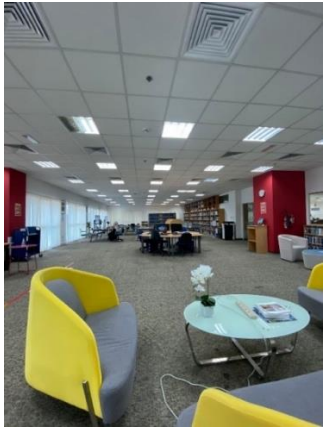
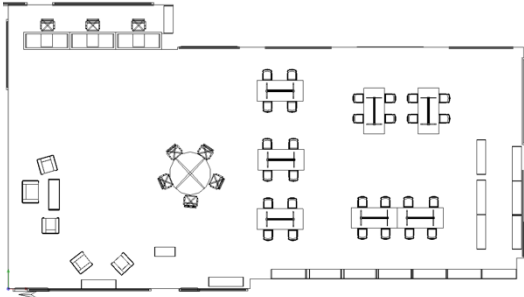
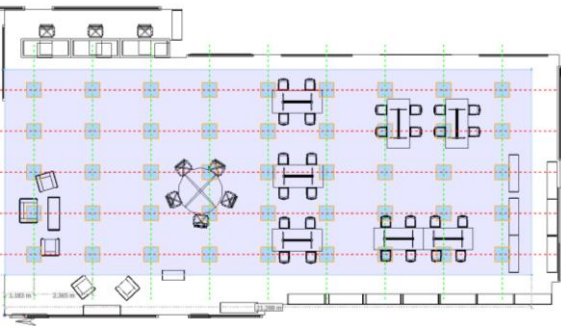
Plan layout- 1 st floor plan- Block 11 BUiD- library plan	
	

Table 11: Plan layout and space specifications of the library, (Source: Author,2023)

Space specifications (finishing materials)		Space furniture layout
Floor	Carpet	
Ceiling	47 fluorescent lights (60 x60) cm	
Walls	Paint finish	
Doors	1 double glass doors & 2 single glass doors	Lighting fixture distribution
Windows	8 full height windows	
Curtains or shading devices	Vertical blinds	

Furniture layout and materials	5 workstations (4 division) + 3 desks + 1 workstation (6 division) + 1 workstation (8 division) + book shelves & TV stands + Sitting Areas Finish: Laminated MDF in glossy finish & fabric	
--------------------------------	--	--

The administration area is designed as an open-plan office, offering a versatile working environment suitable for both individual and team work. This space comprises 15 workstations, each equipped with glossy wooden MDF desks and black chairs. The floor in this area is covered with glossy ceramic tiles (60x60), which can contribute to increased brightness and glare in the space. The ceiling is finished with square tiles (60x60) with a light reflection value of 70%. It features 19 fluorescent white lights and six spotlights over the information desk. The walls are painted with a light reflection value of about 49%. In an open-plan office, it is advisable to

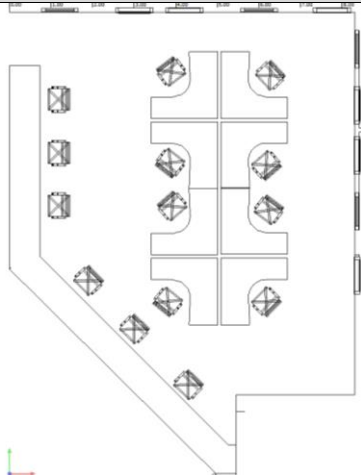
implement a direct/indirect light solution for general illumination. Pendant lights are also recommended for such spaces, as they provide a glare-free workspace. The Administration area plan layout and shape specifications are shown in Table 12 and

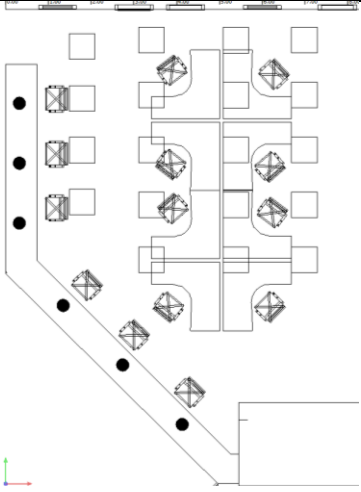
Table 13 respectively.

Table 12: Plan layout of the administration area , (Source: Author,2023)

Plan layout- 1 st floor plan- Block 11 BUiD- Administration area	
	

Table 13: Plan layout and space specifications of the administration area, (Source: Author,2023)

Space specifications (finishing materials)		Space furniture layout
Floor	Ceramic tiles 60 x 60 cm	
Ceiling	Tiles 60x60 Type: 19 florescent light and 6 spot lights under the reception desk only	
Walls	Paint finish	
Doors	6 wooden doors	Lighting fixture distribution
Windows	NA	
Curtains or shading devices	NA	

Furniture layout and materials	14 offices Wooden MDF tables Glossy materials.	
--------------------------------	---	--

A workstation can be lit in a variety of ways. Innovative workplace illumination and lighting design ideas that are specifically suited to the demands of each employee are created to enhance office lighting. Effective office lighting lowers the possibility of health issues, improves safety, and boosts productivity. It helps create a relaxing, adaptable, and interesting work environment.

Meanwhile, the limited availability of natural light is one constraint of the lack of sufficient nature features in indoor environments. Many interior spaces, such as office buildings, have few windows or access to natural light. This can have a negative impact on the well-being and productivity of the users. Natural light is critical for regulating circadian cycles, which affect our productivity, user's comfort, and overall health. Inadequate exposure to natural light can alter these rhythms, resulting in decreased alertness, weariness, and even mood disorders. Finally, it saves both money and energy.

The group study room, situated in front of the main library on the first floor of Block 11, is divided into two distinct areas. The first part is dedicated to bookshelves, while the other zone

features bright white laminated desks. During our visit, it was evident that the furniture layout in this area was quite crowded and not optimized for its intended purpose.

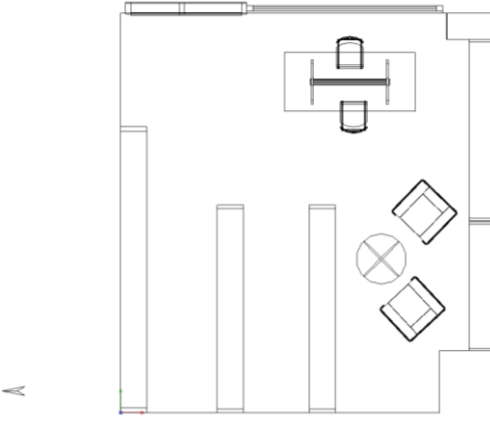
The lighting in this room is provided by five fluorescent white lights, as there are no natural light sources due to its central location within the block. This isolation from the surrounding landscape, in contrast to the main library, results in the absence of natural features within the indoor setting. This lack of natural light, plants, and other natural elements can lead to a decline in indoor environmental quality, potentially affecting mood, productivity, and overall performance.

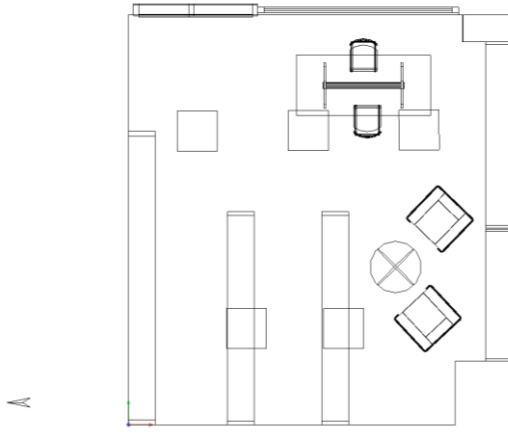
Furthermore, the choice of bright white lighting and the placement of fixtures did not take into account the furniture layout and the specific tasks conducted in each zone. The walls in this room were painted with a Light Reflectance Value (LRV) of 49.5%, and the ceiling was adorned with square tiles measuring 60x60 with an LRV of 70%. The only window in this area is situated in the upper part of the room's wall, facing the corridor. The group study room plan layout and shape specifications are shown in Table 14 and Table 15 respectively.

Table 14: Plan layout of the group study room ,(Source: Author,2023)

Plan layout- 1 st floor plan- Block 11 BUiD- Group study room	
	

Table 15: Plan layout and space specifications of the group study room, *(Source: Author,2023)*

Space specifications (finishing materials)		Space furniture layout
Floor	PVC floor matt finish	
Ceiling	Tiles 60x60 cm	
Walls	Paint finish	
Doors	1 wooden door	Lighting fixture distribution

Windows	1 window	
Curtains or shading devices	NA	
Furniture layout and materials	1 desk with white laminated Bright white chairs for the reading area	

Student lounge areas typically serve as flexible spaces without a specific purpose, offering a range of uses. For instance, after a class or workshop, students may gather in this area for a quick brainstorming session on a particular topic. It also serves as a place for preparation during meeting breaks or as a peaceful spot for focusing on essential professional tasks. Moreover, it's utilized for presenting students' work at conferences and hosting various on-campus activities.

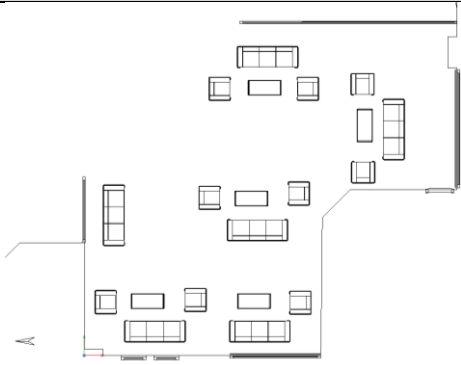
However, the student lounge is also designed to cater to employees looking for a break from their computer screens. With a view of the outdoor area and access to natural sunlight, it has the potential to be a relaxing space. Yet, the current atmosphere may not promote tranquility. The choice of color tones for the furniture and walls, instead of creating a serene setting, might induce feelings of restlessness or overstimulation. Overly bright or dark colors can be visually disruptive and hinder concentration and focus. Using neutral and soothing color palettes, such as soft pastels or earth tones, could help create a calm environment that encourages relaxation and study.

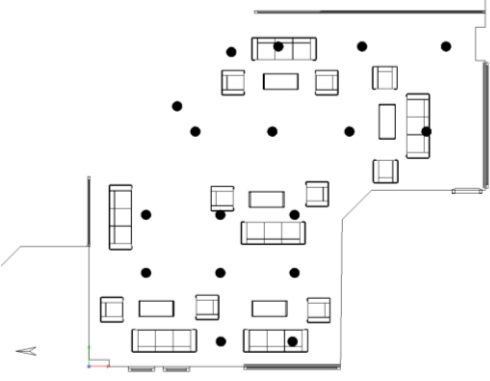
Furthermore, the lighting in the student area is overly bright and overwhelming, which may not be suitable for this type of environment. Harsh and intense illumination can impact students' ability to study and concentrate, leading to visual discomfort, eye strain, and fatigue. A more appropriate lighting solution would involve adjustable and dimmable lights, allowing students to tailor the light's intensity and warmth to their specific needs and preferences. This would enable them to create a comfortable lighting environment conducive to both studying and relaxation. The student lounge plan layout and area specification are shown in Table 16 and Table 17 respectively.

Table 16: Plan layout of the students lounge, (Source: Author,2023)

Plan layout- 1 st floor plan- Block 11 BUiD- students lounge	
	

Table 17: Plan layout of the students lounge, (Source: Author,2023)

Space specifications (finishing materials)		Space furniture layout
Floor	Ceramic tiles 60 x 60 cm – Glossy And rugs	
Ceiling	Tiles 60x60 19 spot light only	
Walls	Paint finish in both concrete walls or gypsum boards, other walls are fully glazed elevations towards the corridor from one side and the outdoor west elevation	
Doors	1 single wooden door +2 double glass door	Lighting fixture distribution
Windows	Three full height window & 2 others	
Curtains or shading devices	Vertical blend curtains	

Furniture layout and materials	7 sofas+4 tables+2 chairs	
-----------------------------------	---------------------------	--

Meeting rooms and board rooms require meticulous planning, as they host a variety of activities that demand different lighting setups. The lighting needed for one-on-one meetings is distinct from what is required for slide presentations or large gatherings. Moreover, the design and implementation of lighting serve as a reflection of a business's internal and external culture.

In the case of this area, the finishing materials are consistent with those used elsewhere, except for the gypsum board ceiling with indirect blue lighting and ten spotlights. This lighting arrangement may lead to excessive brightness in the space relative to its size, making it challenging to achieve the desired level of darkness during presentations. This limitation arises because there is no light control system in place to dim the lights in such spaces in the old block.

A more appropriate lighting solution would involve the installation of adjustable and dimmable lighting solutions. These solutions allow users to customize the light's intensity and warmth to suit their specific needs and preferences. This approach can greatly enhance the

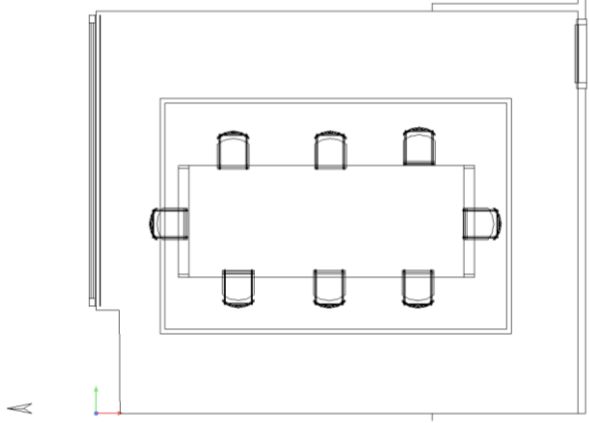
adaptability and functionality of the space. The board room plan area and specifications are shown in Table 18 and

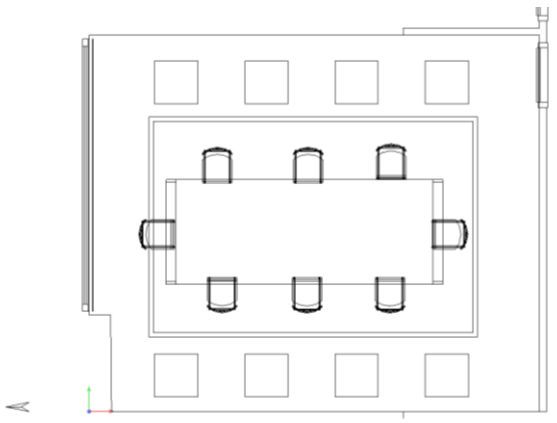
Table 19 respectively.

Table 18: Plan layout and photos of the board room, (Source: Author,2023)

Plan layout- 1 st floor plan- Block 11 BUiD- Board Room	
	 

Table 19: Plan layout and specifications of the board room, (Source: Author,2023)

Space specifications (finishing materials)		Space furniture layout
Floor	Carpet finish	
Ceiling	Gypsum board with 10 spotlight & indirect light	
Walls	Paint finish	
Doors	-1 wooden single door	Lighting fixture distribution

	-1 double wooden door	
Windows	1 window in the top	
Curtains or shading devices	NA	
Furniture layout and materials	Big meeting table With 8-12 chairs -TV -Small board -Cabinet	

While open-plan offices have gained popularity, traditional individual offices continue to be prevalent in both older and newer buildings. The location of this particular office offers a connection to the natural view, overlooking the main court on the campus. This provides abundant natural sunlight to the space. However, as observed in the images below, the area near the windows experiences high glare, which not only affects visual comfort but also introduces excess heat, leading to increased energy consumption. The office space is lit both by natural and artificial light sources. In the following section, we will assess the lighting conditions using on-site light meters and validate this information through computer simulations to establish a

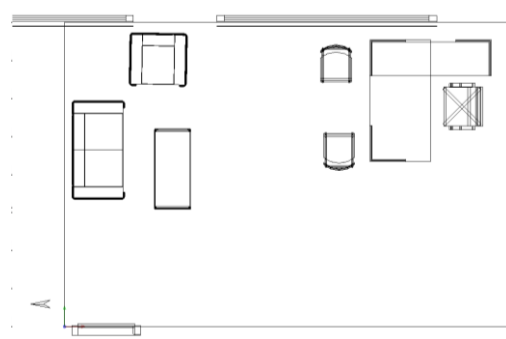
baseline scenario. This process is essential for identifying the optimal design options for these types of spaces. Individual offices typically benefit from a combination of direct and indirect illumination. The indirect component serves to expand the size and brightness of the individual office. Pendant lights positioned above desks are a common solution, while recessed lights in combination with task lights offer another option. For more flexibility, floor lamps and table lamps can be used, allowing employees to adjust both the light level and its position to suit their specific needs. The plan layout and area specifications for the individual office spaces are shown in Table 20 and Table 21 respectively.

Buildings are not only traffic zones but can also double as creative workspaces, providing opportunities for relaxation, idea exchange, team collaboration, and client meetings. Lighting in common areas plays a crucial role in accentuating different zones within these spaces without causing discomfort to users in adjacent rooms. For corridors, corner-mounted LED luminaires are utilized to deliver glare-free, asymmetric lighting on the walls and ceilings. Indirect lighting is applied to create the impression of larger and more inviting corridors. A combination of direct and indirect lighting is employed to ensure proper illumination in conversation areas. Additionally, enhancing wall and ceiling lighting supports effective visual communication. In these traffic areas, the illuminance on the walls should be maintained at a minimum of 50 lux, while the ceiling should have at least 30 lux of illuminance. For seating groups and communication zones, higher illuminance levels are considered, taking into account cylindrical illuminance and the light's modeling effect. Plan layout and area specification of the general circulation areas (corridors) are shown in Table 22 and Table 23 respectively.

Table 20: Plan layout and photos of individual offices, (Source: Author,2023)

Plan layout- 1 st floor plan- Block 11 BUiD- Individual offices	
	

Table 21: Plan layout and specifications of individual offices, (Source: Author,2023)

Space specifications (finishing materials)		Space furniture layout
Floor	Carpet finish	
Ceiling	Gypsum board with 6 spot light	
Walls	Paint finish	
Doors	One wooden doors	Lighting fixture distribution
Windows	Two windows	
Curtains or shading devices	Vertical blend curtains	

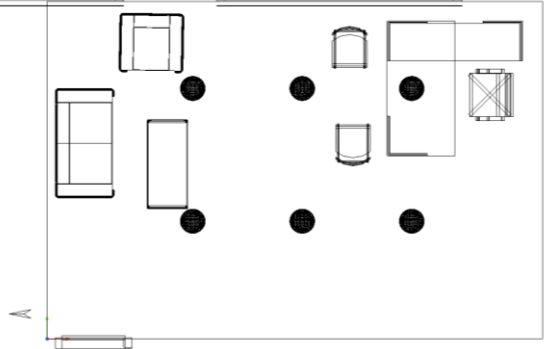
Furniture layout and materials	Office desk -1 chair -3 sofas - 2 tables - 1 cabinet	
---------------------------------------	--	--

Table 22: Plan layout and photos of general circulation areas (Corridors), (Source: Author,2023)

Plan layout- 1 st floor plan- Block 11 BUiD- General circulation areas (corridors)	
	

Table 23: Plan layout and specifications of general circulation areas, (Source: Author,2023)

Space specifications (finishing materials)		Space furniture layout and lighting fixture distribution
Floor	Ceramic 60x60 tiles	
Ceiling	Gypsum ceiling, paint finish (Down lights)	
Walls	Gypsum wall in the paint finish, and glass 6mm partition	
Doors	Double main entrance glass door & single glass door	
Windows	NA	
Curtains or shading devices	NA	
Furniture layout and materials	NA	

3.7 Methodological Framework

The methodological framework in Figure 32, represent the steps to evaluate and enhance the current lighting system in existing building. While a methodology for creating environmentally friendly lighting systems was carried out. The approach is based on current regulations and

standards for the inspection and evaluation of lighting systems in terms of ensuring visual comfort, user satisfaction, and considering the illuminating values in accordance with each space's purpose of use. The key components of this methodology are broken down into separate branches of the flow chart, whose combination results in a list of steps to be discussed on the following chapters.

The study's findings shed light on the critical relationship between user happiness and well-being in various parts of a university campus building, with a particular emphasis on the influence of interior lighting features as a component of indoor environmental quality (IEQ). This study aims to provide significant insights into the significance of developing conducive learning environments by assessing user satisfaction and its relationship to IEQ in terms of lightings. (IES 2000).

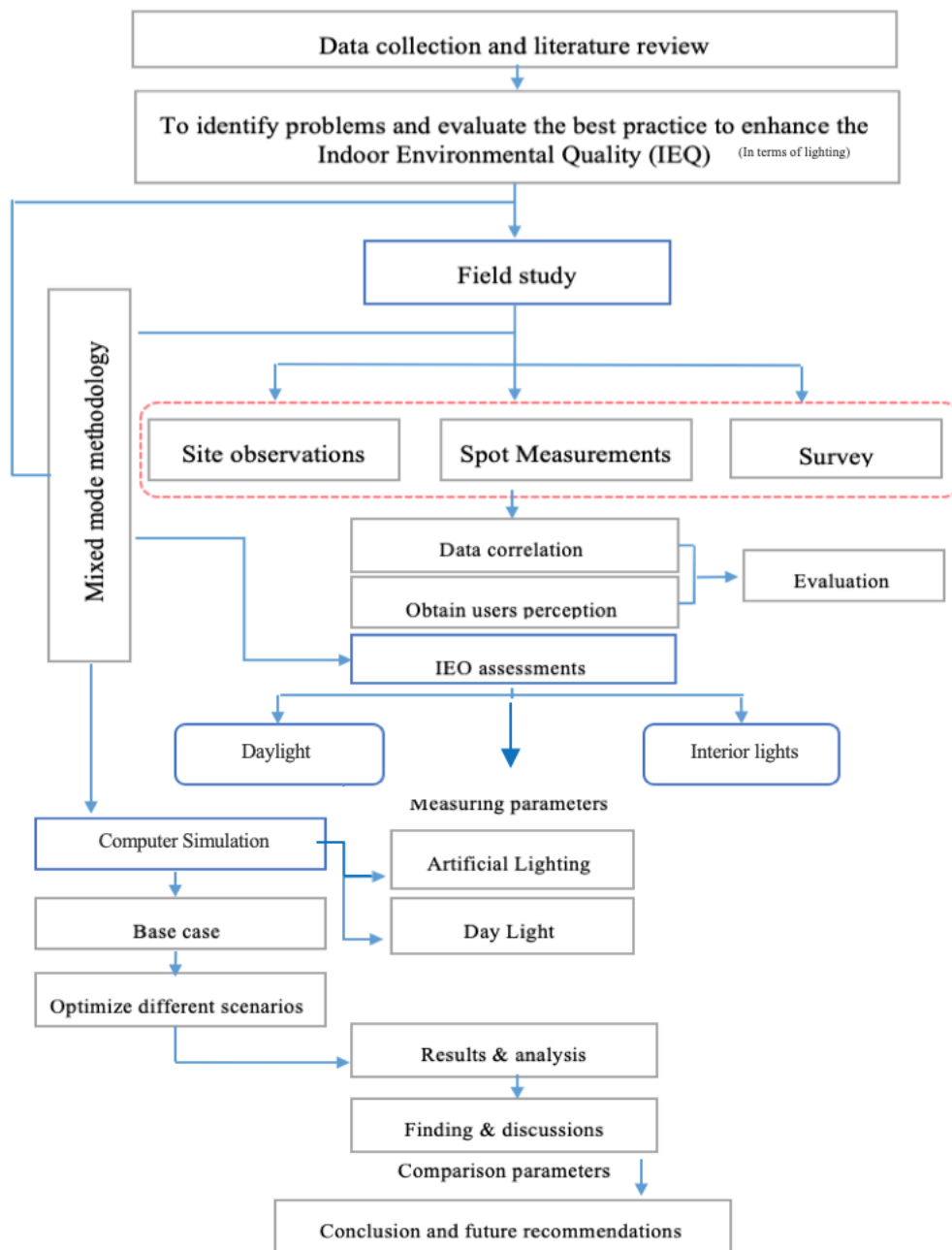


Figure 32: Chart of the methodological framework of the study

(Source: Author,2023)

To summarize, in educational facilities, lighting design considerations are crucial for creating an optimal learning environment. Key characteristics to address include the integration of daylighting and lighting system control, achieving both horizontal and vertical illuminance, ensuring appropriate surface light distribution, minimizing direct glare, and maintaining uniform light distribution on the project plane. The use of higher color temperature LED lamps can enhance the effectiveness of various activities and attitudes within a campus environment. To enhance the lighting design in educational spaces, several solutions can be implemented, ultimately improving the overall quality and user comfort in these areas. Additionally, it is imperative to ensure that instructional spaces are free from glare, as excessively bright electric or natural light sources can lead to discomfort and visual impairment.

The chart above outlines the process of the study's analytical framework, which will be applied to the selected case study in this research. The process commences with an understanding of the current situation, followed by an investigation of each space within the context of different LEED (Leadership in Energy and Environmental Design) categories. Spaces are then classified based on the tasks associated with each area. A critical aspect of this analysis is the examination of the finishing materials in each space, aligned with their lighting reflectance factor. This factor plays a key role in enhancing the interior lighting quality of the campus building.

Subsequently, the data collected on-site is validated and integrated as input data into DIALux EVO software, facilitating the analysis of the base case scenario. This analysis leads to the suggestion of various strategies and scenarios, including lighting fixture selection and improvements to finishing materials. The lighting of various surfaces within the typical field of

view is a crucial consideration, and it must be maintained within an acceptable range. Additionally, minimizing visible brightness disparities between the ceiling and the luminaires is essential to ensure a comfortable environment. On the other hand, many educational facilities, like the BUiD campus, are utilized after dark, and it is essential to illuminate them for nighttime services to ensure the safety and security of the user.

Chapter 4 : Analysis and Results

4.1 Introduction

The initial phase of the analysis provides a comprehensive overview of the selected case study, aiming to gain insights into the current state of the physical and visual aspects within campus buildings' interior environment, with a specific emphasis on lighting parameters. The process commences with the selection of a campus building as the focal point for proposing innovative lighting strategies in this thesis. The selected campus building must possess the following capabilities:

- 1- Focus on the learning environment to enhance the lighting conditions, consequently affecting the user's well-being and productivity.
- 2- A variety of spaces ranging from the classroom, library, auditorium, offices, etc. required different lighting levels per the task area.
- 3- The researcher will have access to the campus, and get the measurement devices from the university.
- 4- Ability to implement the suggested strategies to enhance the indoor environment in terms of lighting as the proposed scenarios related to the finishing materials and types of lighting fixtures without the need for major changes in the building facade.

Then, the next stage involved a detailed analysis of the BUiD campus building through conducting a field study as discussed in the previous chapter and observing the area in terms of spaces categories, layout, finishing materials of the walls, ceiling, floors, furniture

measurements of different lighting parameters such as: illuminance, glare, color render index, and color spectrum. Lighting settings can be calculated using a variety of approaches or by using computer software. It is important in the event of rebuilding to examine the current lighting conditions in terms of energy efficiency and quality. Also, to determine whether the lighting system meets the legislative and regulatory standards for the type of area and activity. The lit spaces are examined after assessing the existing situation.

4.2 Lighting Assessment in the University Spaces

When designing lighting solutions for academic buildings, it is essential to take into account the diverse range of activities conducted within each space, whether by students, academic staff, or administration personnel. This includes considering the specific tasks associated with each area, such as their interaction with computer screens, as well as spaces dedicated to reading and writing tasks. The campus serves as a space for educating university students during the day and evening during the school year. In this study, we focus on evaluating and improving lighting conditions in various zones during evening and day hours. In the previous chapter, each zone specification was analyzed in terms of different factors like spaces categories, dimensions of each space, finishing material, furniture layout, wall textures, floors, and ceiling materials to understand and validate the information through a site visit to the campus, then model the base case with all existing features on the DIALux Evo software. Lighting can have a significant influence in promoting learning and behavior in the classroom.

This study aims to investigate, measure, and analyze various lighting factors in educational buildings across diverse spaces, including classrooms, libraries, corridors, study areas, offices,

auditoriums, and more. The primary objective of this research is to assess and understand how lighting conditions impact users' performance, productivity, and well-being in specific task areas. It involves an examination of multiple factors and variables that influence light quality in different measured areas, encompassing aspects such as light type, quality, efficiency, finishing materials, and spatial layout.

To achieve this, the study incorporates measurements of lux levels, brightness, light spectrum, color temperature, and color rendering index, all of which are compared with recommended settings based on LEED V4. The IES lighting handbook serves as a valuable reference for establishing lighting standards and defining lighting zones. Light measurements are conducted using specialized light measurement devices in designated task areas, with lux levels recorded at a work plane height of 80 cm, reflecting the existing conditions. Subsequently, the study categorizes different functions and zone types, enabling the development of enhancement strategies and facilitating a comparison between the current state and proposed improvement strategies for each zone.

4.3 Field Measurements

In this study, the measured spaces have been categorized into three groups, as previously discussed in the preceding chapter. These categories are based on the LEED V4 interior spaces classification, comprising shared regularly multi-occupant spaces, non-regularly occupied spaces, and individual occupant spaces. The subsequent chapter will delve into the various parameters that were measured on-site for each of these spaces. The analysis of these parameters will involve comparing them with established standard values to identify the unique lighting

characteristics of each space and assess their suitability for different task areas, ultimately aiming to enhance user productivity and well-being.

It is worth noting that this study, in its exploration of lighting parameters, conditions, and characteristics in educational campuses, has drawn upon previous research and documents. Furthermore, artificial light measurements were conducted in the specified spaces in April 2022 during morning working hours, which represent peak campus activity hours when the spaces are most heavily utilized. These measurements were taken using a Sekonic C-7000 lighting device, and the results encompassed data on LUX, luminance, and measurements per area for other factors, including color temperature, color rendering index, and illuminance distribution of the light source.

To ensure that each space and room in the building is adequately lit for its intended function and meets recommended levels, the illuminance reference values [lux], glare, uniformity ratio, and color render index values were based on the IES lighting handbook, and used to create a comfortable environment for all users and lighting zones of each task and space characteristics (IES, 2000) as shown in Table 24.

Table 24: Lighting reference as per EN124641 standards, (Source: IES, 2000)

Space Type	Illuminance (lux)	Glare (UGL)	Uniformity (U)	Color render®
Shared regularly multi-occupant				
Auditorium	500 lux	19	0.6	80
Classroom	500 lux	19	0.6	80
Library	500 lux	19	0.6	80
Open space office	300 lux	22	0.6	80
Group study room	500 lux	19	0.6	80
Students lounge	300 lux	19	0.4	80
Board room	500 lux	19	0.6	80
Non-regularly occupied spaces				
Corridors	100 lux	28	0.4	40
Individual occupants' spaces				
Registration office	300 lux	19	0.6	80

4.3.1 Artificial Lighting Parameters Analysis

4.3.1.1 *Illuminance and Luminance Measurements*

Lux measurements done in various spaces by using Sekonic C-7000 machine to measure the amount of light falling onto a surface or a point through taking many readings in one space in order to measure the uniformity ratio. Moreover, many factors affected the result like old or new fixtures, finishing and furniture LRV affect the light brightness level, object characteristics such as texture, color, and reflectance values. Furthermore, various Lux values measured within each space due to lighting quality, brightness of the source, sufficiency and intensity, which going to be compared with the standard value as per IES lighting handbook (IES, 2000).

In addition to the parameters mentioned earlier, the reflectance value of each surface plays a significant role in influencing the lighting conditions within a space. This value represents how much light is reflected off or passes through a surface, and it directly impacts the comfort, visual needs, and cognitive abilities of the occupants.

Under the LEED v4 standards, specifically concerning "Interior Lighting Quality," the goal is to enhance the quality of lighting in indoor spaces within campus buildings. To achieve this, certain requirements are established for light reflectance values. According to these standards, ceilings should have a minimum reflectance value of 85%, walls should have a value of at least 60%, and floors should maintain a minimum reflectance value of 25%. Meeting these reflectance standards is essential for creating a well-lit and visually comfortable environment in indoor spaces. High luminance in a space is associated with increased brightness, and the perception of glare can be influenced by a multitude of factors. These factors include:

1. Room Size and Shape: The dimensions and geometry of the room can impact how light is distributed and perceived.
2. Room Surface Reflectance: The reflectance properties of the surfaces in the room, including walls, ceilings, and floors, play a crucial role in light distribution and glare.
3. Luminaire Characteristics: The type and design of light fixtures, as well as the characteristics of the light sources used, can affect the distribution of light.
4. Number and Location of Luminaires: The placement and quantity of light fixtures can influence the uniformity and intensity of lighting.
5. Nature of the Given Surface: Different surface materials can absorb or reflect light differently, affecting the overall lighting conditions.
6. Observer Location: Where an individual is positioned within the room can impact their perception of glare and brightness.
7. Line of Sight and Viewing Angle: The angle at which a person views a light source or a reflective surface can influence glare.
8. Luminance of Other Surfaces: The luminance of all other surfaces in the environment, including objects and other surfaces, contributes to the overall perception of brightness and glare.
9. Body Shadow Effects: The presence of individuals in the room can create shadows, affecting how light is perceived.

It's important to consider and balance these factors when designing lighting systems to ensure that they provide adequate illumination without causing discomfort due to glare. Consistency in

measurements, such as taking readings at similar heights on walls, is essential to accurately assess and manage lighting conditions in a space (Makaremi et al.,2017).

4.3.1.2 *Shared Regularly Multi Occupants Spaces*

A. Auditorium

The auditorium within the BUiD campus building serves as a versatile facility accommodating a variety of activities throughout the year, including large conferences, presentations, and meetings. This auditorium consists of a stage zone and an audience area, as depicted in Figure 33. The arrangement of students' desks varies, with rows set up for exams, lectures, and other events, which can be modified according to the specific requirements of each event. To ensure the auditorium's adaptability and functionality, it is recommended to employ a flexible lighting approach with efficient control systems. This approach is well-suited to support the diverse functions that the auditorium serves for conferences and meetings.

The auditorium is situated in the middle of block 11 on the first floor, covering an area of approximately 162 m². Three of its walls (North, South, and East) are bordered by internal corridors, while the West wall adjoins the student study rooms, making it inaccessible to daylight. The auditorium's dimensions are 14.35 meters in length, 11.5 meters in width, and 2.8 meters in height (L x W x H). The auditorium's walls are painted white, and the stage wall is covered with laminate dark brown glossy cladding. A whiteboard is hung in the middle of the stage wall for presentations and other purposes. The ceiling comprises mineral fiber false ceiling tiles (60x60 cm) with embedded luminaires. The artificial lighting in the area consists of nine fluorescent tube lights (60x60 cm) and thirty-nine downlights (20 cm).

Measurements were taken on the student desks, which have a height of approximately 80 cm, in accordance with the indoor lighting standard EN 12464-1-1. However, as indicated in Table 25, the lux values over the student's desks did not meet the recommended value of 500 lux. The minimum measured illuminance in the auditorium was 112 lux, which was recorded on the presenter's table. Most of the student desk rows had lux readings ranging between 300 and 400 lux, primarily provided by the fluorescent lights. However, desk number 33 relied solely on the downlights and had a minimum illuminance value of 199 lux, explaining the lower lux value in comparison to other desks. The luminance readings on the walls, taken at a height of 1.75 meters, indicated that the reflectance value of the wall paint was around 45%, which falls within the category of medium Light Reflectance Value (LRV). However, this LRV was below the recommended standards by 15%. This deviation can have significant effects on the appearance of the room and the feelings of the users.

The LRV of interior surfaces, such as walls, ceilings, and floors, plays a crucial role in visual comfort. Appropriate LRV values for these surfaces can enhance the reflectance of light. Higher LRV values can contribute to more efficient light distribution throughout a space, improving visibility and reducing shadows. This, in turn, reduces eyestrain and enhances visual comfort in the environment. Surfaces with higher LRV values, especially on walls, can create a sense of brightness and openness, fostering a positive and cheerful atmosphere and mood. However, in the case of the auditorium, the ceiling was covered with mineral fiber boards with an LRV of 60%, which is 85 % is the standards. As a result, the room might experience glare, as indicated by the vertical illuminance readings, with all surface readings exceeding 100lx.

The presence of fluorescent and downlights in the space, without considering the arrangement of student desks and the glossy material of the walls with a lower LRV of about 25%, which is considered a darker color, can result in light absorption rather than reflection. Additionally, the lack of a control system in the area is a significant limitation, particularly during presentations and conferences. A control system is necessary to manage the lighting system and achieve comfortable vision for the audience.

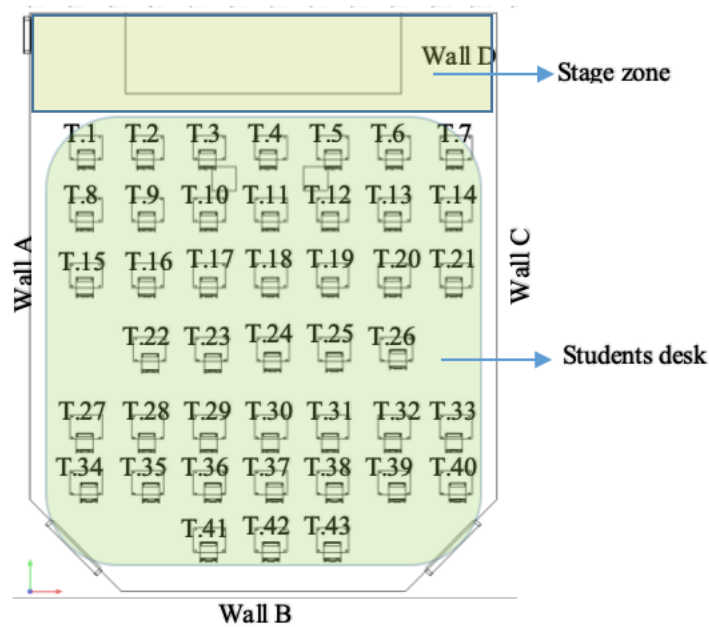


Figure 33: Auditorium furniture layout plan drawing, illuminance value

(Source: Author,2022)

Table 25: Illuminance[lux]values for auditorium, and presentation area, (Source: Author,2022)

No. of table	Horizontal LUX value	No. of wall	Vertical LUX value
Podium table	112	A.1	157
T.2	388	A.2	227
T.13	304	B	208
T.24	388	C.1	166
T.33	199	C.2	333
T.41	416	D	91.41

B. Classroom FF-111

The use of university classrooms for a variety of purposes, from lectures and presentations to group discussions and multimedia activities, necessitates a well-designed lighting system that can provide appropriate illumination for these diverse learning scenarios. It is essential for the lighting design in a classroom to adapt to the multiple needs of instructors and students of different age groups while accommodating the changing lighting conditions throughout the day and night.

A well-lit classroom can have several positive impacts. It can enhance learning outcomes, promote well-being, and create an environment conducive to both academic performance and personal development. In this specific classroom, there are eight tables for students and one desk

for the professor arranged in a U-shape, fostering a welcoming environment for discussion and the exchange of ideas, as depicted in Figure 34. As a part of the lighting assessment, illuminance measurements were taken over the eight student tables, and multiple readings were also obtained above these tables in the classroom. The use of the Sekonic -C7000 instrument not only helped confirm the accuracy of the data but also minimized the margin of error. This precision is critical when designing lighting schemes, particularly in an educational setting where lighting needs can change due to various activities and furniture layouts.

Furthermore, taking Lux measurements at multiple points within the classroom supports the identification of areas with uneven illumination levels. This information is valuable for adjusting lighting fixtures or confirming the uniformity of the lighting design, in line with the findings of Gleason et al. (2019). It ensures that the lighting in the classroom is not only functional but also contributes to a positive and effective learning environment. Tables at the working plane of 80 cm were measured, and fluorescent lamps are used for lighting in the classroom. The classroom features three windows, with one on wall A, facing the corridor side. The corridor lights being on at times can lead to glare on the classroom wall from that side, creating an uncomfortable lighting zone. The second and third windows are situated on wall B, allowing daylight into the classroom. This explains the high lux value of 699 lx measured on Table T.4, even with the curtains closed during the measurement, which is above the target value of around 500 lx. This results in excessive brightness in that area and potential heat gain due to indirect sunlight passing through the curtains during the day. The other student desks measured around 444 to 505 lx, which is mostly close to the target value for illuminance on student tables. Table 26 shows the measured illuminance and luminance values in classroom FF-111

On the other hand, the arrangement of lighting fixtures in this classroom resulted in a uniform lighting distribution, which explains the varying lux values in different zones. The lighting system in place utilizes fluorescent light fixtures, a common choice in traditional classrooms, although not necessarily the most optimum. The measurement device was positioned above the student desks at a height of approximately 80 cm from the floor. To assess the uniformity of the lighting, eight measurements were taken at various points within the space. This allowed for the calculation of the uniformity value, providing insights into the distribution of different lighting fixtures.

In terms of the classroom's finishing, it exhibits older features. The wall paint has a reflectance factor of around 45%, and the ceiling tiles have a 60% LRV. Both the walls and ceiling fall within the category of medium LRV, which means they reflect an average amount of light. However, these values are below the recommended standards. Other factors contributing to the lighting conditions in the classroom include the presence of a whiteboard, old and dusty fixtures, and desks made of laminated wooden MDF with a glossy surface material. These desks have a light reflectance factor of nearly 25%, while the standards suggest values closer to 45%. This difference in reflectance can lead to glare in the task area, particularly when students need to use computer screens, as it absorbs lighter than it reflects.

Furthermore, vertical illuminance measurements were taken during the same visit on the specified date, at the same height as the other spaces, which is approximately 1.75 meters. These measurements indicate the brightness level and the potential for glare in the area. However, all the readings exceeded 100 lx. The illuminance measurements were conducted four times for the walls, with one reading per wall. The readings were taken in the middle of each wall, except for

the reading for wall D, which was near the ceiling and closer to the lights, making that area brighter.

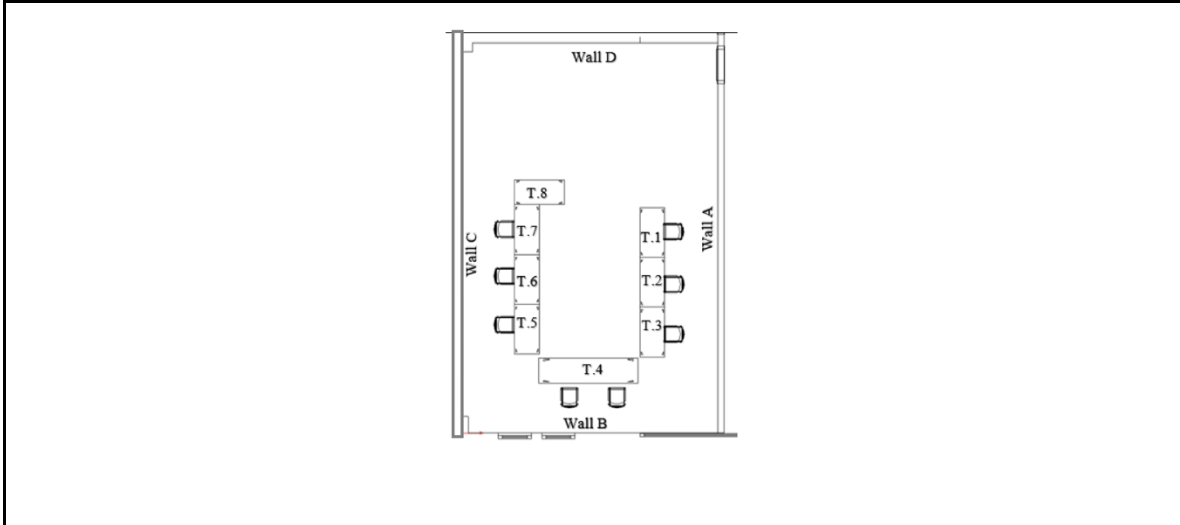


Figure 34:Classroom FF 111 furniture layout plan drawing, illuminance values

(Source: Author,2022)

Table 26: Illuminance[lux] for classroom FF-111, *(Source: Author,2022)*

No. of table	Horizontal LUX value	No. of wall	Vertical LUX value
T.1	495		
T.2	491		
T.4	699		
T.5	505	A	281
T.6	444	B	271
T.8	491	C	302
		D	303

C. Library

Libraries on college campuses serve as communal spaces where lighting is crucial for creating a welcoming and pleasant environment. Balancing artificial and natural light is a complex task that requires precise light control, but the outcome is a comfortable and enjoyable setting for reading and study.

The library is divided into multiple zones, each with distinct lighting needs. One zone caters to reading and computer work, while the other zone houses the bookshelves. Reading areas within the campus building demand robust task lighting, with an average illuminance of at least 500 lux, characterized by high uniformity and minimal glare. Achieving this requires luminaires that emit both direct and indirect light, offering efficiency and ensuring that each reading spot benefits from glare-free illumination. The inclusion of desk lamps at each reading location adds

adaptability and saves space, facilitating glare-free reading. In the bookshelves zone, a vertical illuminance of 200 lux is essential for finding the right shelf and book with ease. Consistency in lighting is key to ensuring that books on the shelves are uniformly visible from all angles. This meticulous approach to lighting design creates an atmosphere in the library that encourages concentration and provides a comfortable and well-illuminated space for reading, working, and exploring the collection.

Figure 35 represents the BUiD library space, which is situated at the corner of block 11, between the intersecting corridors leading to the main food court building in the academic city. This library occupies the first floor and has an approximate area of 310 square meters. It is subdivided into four distinct zones, each serving specific purposes. The first zone is dedicated to reading, while the second zone is designated for bookshelves. The third zone is designed to accommodate computer workstations, and the fourth zone houses the librarian's office.

The library space features three noteworthy wall elevations. Wall A [West] faces the main corridor in the campus and is primarily constructed with full glass, allowing natural light to stream into the space. The integration of natural light with artificial light is particularly important in such spaces. Wall C [East] incorporates eight full-height windows, serving as a source of natural light from the eastern side of the space. Wall B [South] is mostly enclosed by bookshelves, creating a partition at the end of the space, and wall D [North] is located adjacent to the library office. The combination of these architectural elements, including the use of glass walls, windows, and the various functional zones within the library, contributes to a dynamic and well-lit environment. This design ensures that the library space caters to a range of activities

and user needs, while the integration of natural and artificial light enhances the overall ambiance of the space, creating a welcoming and functional library for students and library visitors.

The library has dimensions of 22.4 meters in length, 10.5 meters in width, and 2.8 meters in height (L x W x H). The walls of the library are painted white with a medium Light Reflectance Value (LRV) of 45%, and some walls include glass windows covered by vertical curtains. The ceiling consists of mineral fiber false ceiling tiles (60x60 cm) with a medium LRV of 60%, in which the luminaires are mounted. The specifications of the lighting fixtures indicate that the artificial lighting sources are distributed in the area, with forty-seven fluorescent tube lights (60x60 cm).

The measurements were taken at the desks, and the tables have a height of about 80 cm, following the indoor lighting standard EN 12464-1.

Table 27 summarizes the illuminance measurements taken on eight tables: T1 to T6 are used for reading or computer work by students, table 7 is primarily used for meetings, student discussions, and computer work, while table 8 is designated for library staff. The lux values over the student's desks in the reading zone and the librarian staff's desks vary, with some areas meeting the target value of 500 lux, while others fall below the target illuminance levels. The measurements of this space were conducted during the daytime with all curtains closed. The

minimum measured illuminance value in the library is 297 lux, recorded on table number six. Table four and table seven yielded nearly identical values, ranging between 480 to 483 lux. The remaining tables had illuminance readings ranging from 300 to 400 lux. It is evident that the distribution of light in the reading zone is relatively darker compared to other areas in the library, where the illumination is somewhat lower.

Regarding vertical illuminance readings on the wall surfaces, which were taken at a height of 1.75 meters, it is apparent that there is a presence of glare in the library, as indicated by the readings. All surface luminance readings exceed 100 lx. The presence of glare on the wall surfaces suggests that there may be areas in the library where excessive brightness or discomfort can affect the visual experience of the library's users. Addressing this issue may involve adjusting lighting fixtures, window treatments, or the arrangement of furnishings to create a more comfortable and visually pleasing environment.

Despite the presence of a dark gray floor carpet, which aids in absorbing a significant amount of the reflected light from various surfaces, there are some noteworthy considerations. The lighting fixtures in the space are fluorescent and are distributed without taking into account the arrangement of furniture. Additionally, the furniture features a glossy wooden material with a low Light Reflectance Value (LRV) of 25%, which falls short of the recommended standards by 20%. This variance in LRV can impact the lighting conditions in each zone and the corresponding activities.

It is also worth noting that there is no control system in place within the area. The absence of a control system means there is no way to adjust or manage the lighting system to achieve a

comfortable and visually pleasing environment for the users. Implementing a lighting control system could provide the flexibility needed to adapt to different tasks and preferences, ensuring an optimal and adjustable lighting experience throughout the space.

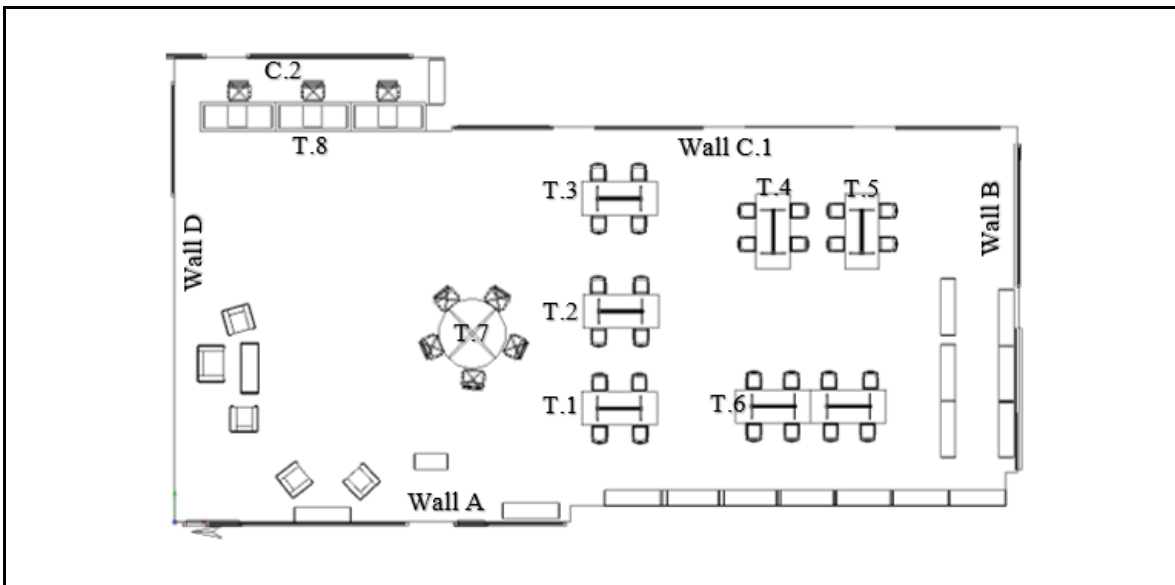


Figure 35: Library furniture layout plan drawing, illuminance values

(Source: Author,2022)

Table 27: Illuminance[lux] for the library, (Source: Author,2022)

No. of table	Horizontal LUX value	No. of wall	Vertical LUX value
T.1	384		
T.2	451		
T.3	458		
T.4	483	A	124
T.5	381	B	165
T.6	297	C.1	157
T.7	480	C.2	152
T.8	337	D	256

D. Administration Area

As depicted in Figure 36, the administration area within the campus is designed with an open-plan office layout, a popular choice in contemporary office design. This space is surrounded by individual offices along the back elevation, and it features an open counter for user interactions.

The central area is arranged with staff offices in connected workstations. This layout provides users with the flexibility to adjust lighting levels according to their tasks and preferences. For example, areas with computer workstations may include a control system to regulate lighting and reduce glare, while collaborative workstations could have brighter lighting, especially when they open to the corridor zone. Furthermore, the circadian cycles of the users have been considered when designing the lighting. This is particularly important in areas where individuals spend a significant amount of time, as it can promote better concentration, productivity, and overall well-being.

The measurements were conducted during daylight hours, and the open-plan office area covers approximately 220 square meters. The main elevation faces the main corridor in the campus and features fully open workstations. Wall A [East] is closed with painted wall and has three wooden doors leading to three individual offices and two glass windows. Wall B [South] is also a white-painted wall with three wooden doors and three glass windows leading to three individual offices. Wall C [West] is closed by a gypsum wall next to a closed area. The dimensions of the open-plan office are 9.2 meters in length, 7.5 meters in width, and 2.8 meters in height (L x W x H). The ceiling consists of mineral fiber false ceiling tiles (60x60 cm) with a medium Light Reflectance Value (LRV) of 60%, in which the luminaires are mounted. The specifications of the lighting fixtures reveal that artificial lighting sources are distributed in the area, including nineteen fluorescent tube lights (60x60 cm) and six downlights over the open collaborative desk area. The measurements were taken at the desks, with the tables at a height of approximately 80 cm, in accordance with the indoor lighting standard EN 12464-1.

As shown in Table 28, illuminance measurements were taken on nine tables (T1 to T9) used by administration staff for various tasks, including reading, writing, and computer work. Desk stations 1 to 5, primarily used by staff members who directly interact with students and visitors to assist with administrative or registration tasks, are illuminated by white downlights positioned directly over the working area. In this area, the illuminance levels measured approximately 308 lux, which meets the recommended values for such a working zone. However, it is worth noting that the area is considered excessively bright, and the glare value is high due to the lighting coming from the corridor area in front of it. Desks 6 to 9 are designated as individual workstations and are illuminated by fluorescent lighting. The horizontal illuminance Lux values at these workstations range from 549 to 735 lux, falling short of the recommended value of 300 lux for an open office space.

The measurements for this space were conducted during daylight hours, and there are no windows to introduce natural daylight into this zone. The significant difference in lux values within the same zone is attributed to the inappropriate distribution of lighting fixtures over the workstations and in the circulation zone around the office stations, as well as the type of light fixtures used. The vertical illuminance measurements were taken on the wall surfaces at a height of 1.75 meters. All surface readings exceeded 100 lx, ranging from 266 lux to 383 lux. Additionally, the light reflectance factor in this area varies from low to medium values (25-60%).

It is also important to note that there is no control system in place within the area, which is needed to manage the lighting system and achieve a comfortable visual environment for the

users. Implementing a lighting control system could help address the issues of excessive brightness and glare, allowing for a more comfortable and adjustable lighting experience.

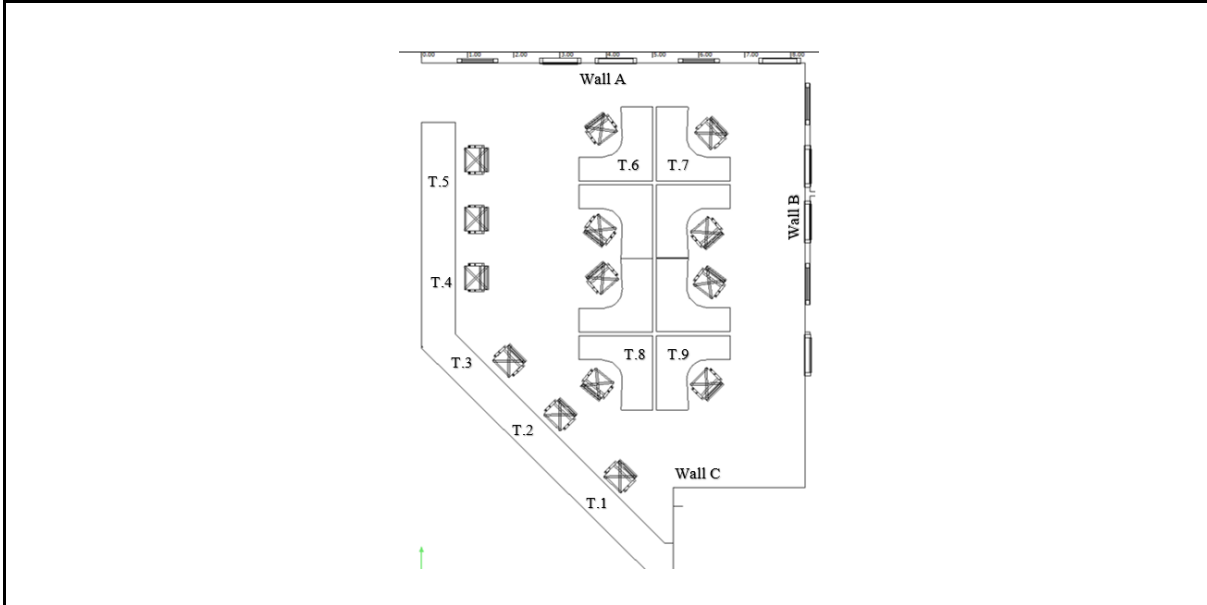


Figure 36:Administration area furniture layout plan, illuminance values

(Source: Author,2022)

Table 28: Illuminance[lux] values for the administration area, (Source: Author,2022)

No. of table	Horizontal LUX value	No. of wall	Vertical LUX value
T.5	308	A	368
T.6	735	B	266
T.9	549	C	383

E. Group Study Room

The group study room, depicted in Figure 37, requires careful planning due to the presence of various zones, such as the reading or studying zone and the bookshelves zone. As previously discussed, integrating natural light is crucial as it helps regulate the body's natural circadian rhythm, particularly during the daytime. Additionally, the appropriate distribution of artificial light with the right color temperature, such as white during the day and warmer tones during the night, can help maintain alertness, promote concentration, and enhance overall performance.

The area of the group study room is approximately 35.34 square meters. Wall A [East], features a white-painted wall with one wooden door and one full-height glass window. There is also another window positioned at the top of the wall facing the corridor in front of the library. Wall B [South] is also a white-painted wall and is lined with bookshelves. In front of this wall, there is a reading area with two sofas and a glass round table. Wall C [West], the back elevation, is painted with a white finish, and wall D [North] is enclosed by bookshelves. These architectural elements, combined with the careful consideration of lighting design, aim to create a conducive environment for group study, reading, and concentration, offering users the flexibility to adapt to different tasks and lighting needs. The integration of natural and artificial light, as well as the appropriate color temperature, can enhance the overall experience in the group study room

The group study room has dimensions of approximately 5.7 meters in length, 6.2 meters in width, and 2.8 meters in height (L x W x H). The ceiling is constructed with mineral fiber false ceiling tiles measuring 60x60 cm, where the luminaires are mounted. The lighting fixtures in this area consist of five fluorescent tube lights measuring 60x60 cm. Illuminance measurements were conducted in the reading area, particularly over tables 1 and 2, with the tables positioned at a height of approximately 80 cm, in accordance with the indoor lighting standard, EN 12464-1. Table 29 shows the measured values of illuminance and luminance in the group study room

The measurements revealed that Table 1, positioned near the glass window facing the corridor, achieved an illuminance level of approximately 526 lux. This represents the highest level of illuminance in the area and can be attributed to the effect of lighting from the corridor. Importantly, it closely approaches the recommended target value for this type of space, as outlined in the relevant standards. Table 2, which is a round table, registered an illuminance level of about 427 lux. While this value falls short of the target value by 73 lux, it still provides sufficient lighting for the tasks conducted at this table. Zone L1, situated between the bookshelves, recorded an illuminance level of 216 lux, aligning with the recommended value per the standards. These measurements were taken during daylight hours. It's important to note that there are no windows in this zone to introduce natural daylight. The combination of artificial lighting and thoughtful design considerations ensures that the group study room offers adequate illumination for various tasks, enhancing its functionality.

On the other hand the vertical illuminance was measured on the wall surfaces at a height of 1.75 meters, and the results revealed high glare values. All surface readings exceeded 100lx, ranging between 293 lux on wall B and 177 lux on wall C. Several factors contribute to the

brightness and uniformity of light levels, including the type and arrangement of fixtures, light color and temperature, surface reflectance values, room shape and area, furniture layout and specifications, the intended tasks or activities in each zone, as well as the light reflectance factor of different surfaces, such as walls (45%), floor (15%), ceiling (60%), and working surfaces (25%). These factors did not meet the target values as specified in the LEED V4 ID+C guidelines.

Similar to other areas, it is evident that there is no control system in place within this area, which is essential for managing the lighting system and achieving comfortable vision for users. This lack of control can lead to suboptimal lighting conditions and potential discomfort for those using the space.

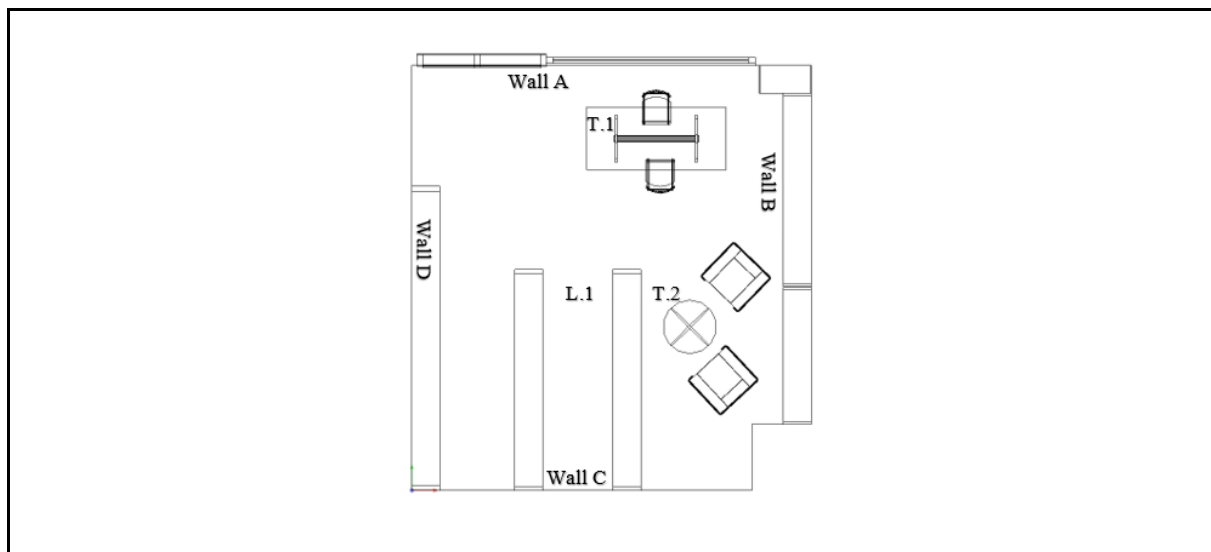


Figure 37:Group study room furniture layout plan, illuminance values

(Source: Author,2022)

Table 29: Illuminance[lux], and luminance values for the group study room, (Source:

Author,2022)

No. of table	Horizontal LUX value	No. of wall	Vertical LUX value
		A	255
T.1	526	B	293
T.2	427	C	177
L.1	216	D	202

F. Student Lounge

The students' lounge serves as a versatile space for entertainment, gathering, and quick brainstorming sessions to find solutions to particular tasks. It also functions as a staff break area. Such break areas are open spaces that can be used for a variety of activities, including the display of student projects and posters during conference days or the annual sustainable spring school hosted on campus. These flexible and easily accessible break areas require effective, user-friendly lighting controls to adapt the lighting to specific needs. Additionally, the integration of natural light and outdoor views is essential to enhance the indoor environment and improve user satisfaction in these spaces

The student lounge area encompasses approximately 150 square meters. It is prominently positioned, with its main elevation facing the campus's main reception and the corridor leading to the administration zone. As shown in Figure 38, the zone's features, including surfaces, furniture, and lighting layout, are described as follows: Wall A [West] is a white-painted wall with a glass facade that allows natural light to enter the space. Wall B [South] is also a white-painted wall with a large window located beside the prayer room. Wall C [East] and wall D [North-east] feature fully internal glazed elevations facing the general circulation zone, with double glass doors. Wall E [North] is finished with white paint and also has a double glass door. The dimensions of the area are approximately 12.2 meters in length, 10.6 meters in width, and 2.8 meters in height. The ceiling is covered by mineral fiber false ceiling tiles (60x60 cm) where the luminaires are installed.

The lighting in this area is a combination of artificial light and daylight, a strategy that enhances the well-being of users in the indoor environment while also reducing energy consumption on campus. The measurements were taken in different zones, as presented in Table 30. Zone one, used as a reading and sitting area, recorded a minimum illuminance value of 161 lux, which falls 139 lux short of the target value. Zone two, designed for gaming, had partially opened curtains during the measurements, resulting in a higher illuminance value of 386 lux, exceeding the target value by 86 lux. In zone three, an illuminance level of 255 lux was measured, slightly below the recommended target value of 300 lux for the student lounge, considering its various tasks and activities.

On the other hand, vertical illuminance measurements taken on the wall surfaces, at a height of 1.75 meters, revealed moderate to high glare values. All surface readings exceeded 100 lx,

ranging from 155 to 245 lux. The highest values were recorded on walls D, A, and E, largely due to the influence of sunlight from the windows on wall A, as well as factors related to luminaire types and interior materials used. These results can be attributed to numerous variables that impact the brightness and uniformity of light levels, including window specifications, curtains and shading devices, luminaire types and arrangements, light color and temperature, surface reflectance values, room shape and area, furniture layout and specifications, the specific tasks or activities carried out in each zone, and the light reflectance factor of different surfaces. It's important to note that the light reflectance values (LRV) in this area were lower than the target values mentioned in LEED V4 (ID+C) guidelines. Walls were painted with an LRV of 45% instead of the recommended 60%, and the ceiling tiles had an LRV of 60% instead of the optimal 85%, which would have provided an appropriate task area and a comfortable indoor environment for all users.

Like other areas, it's also worth mentioning that there is no automated lighting control system in place, which could play a vital role in managing the lighting system during occupied hours, reducing energy consumption, minimizing operational costs, and ensuring optimal lighting levels. Such a system could also help harness natural light during the day, enhancing user comfort and indoor environmental quality, while promoting a positive atmosphere, mood enhancement, and reduced reliance on artificial lighting during daytime gatherings.

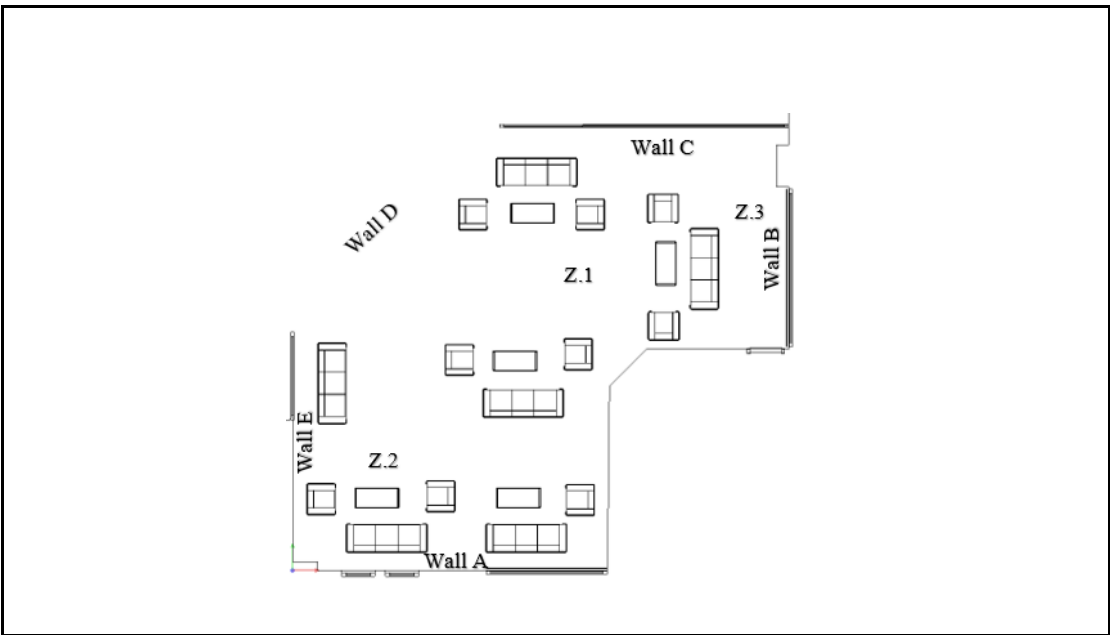


Figure 38: Students lounge area furniture layout plan-illuminance values

(Source: Author,2022)

Table 30: Illuminance[lux]values for the students lounge, *(Source: Author,2022)*

No. of table	Horizontal LUX value	No. of wall	Vertical LUX value
		A	228
		B	191
Z.1	161	C	155
Z.2	386	D	245
Z.3	255	E	212

G. Board Room

Meeting rooms, like other interior spaces, require meticulous lighting design considerations right from the initial stages of the design process. This is crucial to ensure the dependability of the indoor environment and enhance the overall user experience in such spaces. The boardroom at BUiD's campus serves as a critical space primarily utilized by academic staff and the university's senior management. It accommodates various functions such as presentations, conference calls, discussions, and more. To support the diverse requirements of a conference or meeting room, an adaptable lighting concept is essential, particularly for video conference rooms, and it should incorporate effective control systems.

In order to grasp the current scenario, it is imperative to analyze the specifications of the spaces, which include factors such as the area, finishing materials, and spatial dimensions. The boardroom at BUiD covers an area of approximately 33 square meters and lacks access to outdoor surroundings. This space is enclosed by four internal walls, making it void of natural

daylight. As depicted in Figure 39, this space comprises wall A [South], which features white paint and a wooden door; wall B [East], also painted white with a window at the top; wall C [North], displaying a white wall with a black screen; and wall D [West], completed with white paint and double wooden doors. Notably, all these walls have a moderate Light Reflectance Value (LRV) of 45%, although standards recommend an LRV of 60%. The spatial dimensions are approximately 6.2 meters in length, 5.2 meters in width, and 2.8 meters in height. The ceiling design incorporates gypsum board with indirect blue lighting on the sides, featuring about 10 downlight fixtures. However, the ceiling has an LRV of 65%, whereas the required value should ideally be around 85% to align with the standards.

The measurements in various zones within the boardroom, as indicated in Table 31, show that the illuminance levels over the meeting table are below the target values. Specifically, the minimum illuminance recorded was around 298 lux, falling short of the target value by 202 lux. Another reading in a different zone over a table registered the highest value at approximately 350 lux, also lower than the target value by 150 lux. As per the standards, the recommended target value for the boardroom should be 500 lux, catering to different tasks and activities.

Furthermore, illuminance measurements on the wall surfaces were taken at a height of 1.75 meters, revealing moderate to high glare values. All the surface readings exceeded 100 cd/sqm, with values ranging between 162 lux and 335 lux. The highest values were observed on walls B and D, attributed to direct light reflectance from the downlights. Wall B may have been influenced by the top window, especially as the lighting fixtures were switched on during the measurements on the other side of the wall, increasing the lighting on this surface.

The results are influenced by several factors impacting brightness and uniformity of light levels. These factors encompass window specifications, fixture types, arrangements, light color and temperature, surface reflectance values, room shape and area, furniture layout and materials, the specific task or activity within the space, and the light reflectance factor of various surfaces, including walls, floors, ceilings, and working surfaces. These factors do not meet the target values outlined in the LEED V4 (ID+C) guidelines, which were also incorporated into the software as part of the base case.

Moreover, in spaces like boardrooms, the ability to adjust lighting settings based on different meeting scenarios is vital. Therefore, the consideration of an intelligent lighting control system for these spaces is recommended. Such a system would facilitate monitoring of lighting during occupied hours, reduce energy consumption and operational costs when meetings are not in progress, and help maintain optimal lighting levels to enhance focus and attentiveness during meetings.

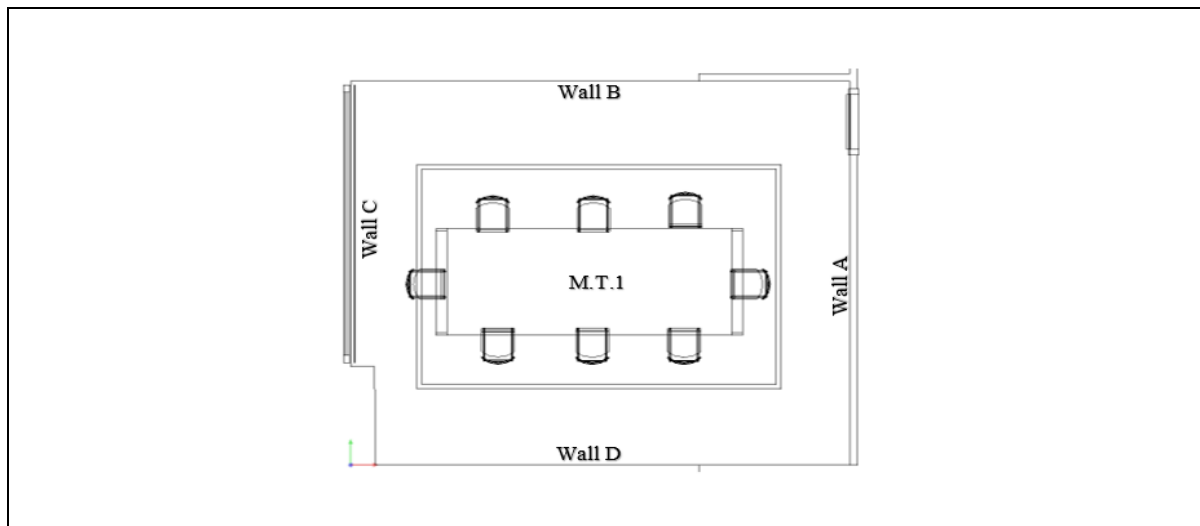


Figure 39: Board room furniture layout plan- illuminance values

(Source: Author,2022)

Table 31: Illuminance[lux] values for the board room, *(Source: Author,2022)*

No. of table	Horizontal LUX value	No. of wall	Vertical LUX value
		A	175
		B	332
M.T.1	298	C	162
M.T.2	350	D	335

4.3.1.3 *Non -Regularly Occupants Spaces:*

A. General Circulation Areas- Corridors

In campus buildings, the general circulation zone area serves not only as pathways but also as creative workspaces for relaxation, idea exchange, team collaboration, and social interaction. Consequently, adequate lighting in this zone is essential to ensure safety and create a conducive environment for various activities.

To comprehensively assess this area, measurements were divided into various zones to obtain accurate results. Analyzing the space's specifications, such as its shape, dimensions, and finishing materials, is crucial. The corridor area covers approximately 340 square meters and lacks any direct connection with outdoor areas, resulting in a lack of natural daylight. As depicted in Figure 40, the space is characterized by its surfaces, materials, and lighting layout. The walls are finished with white paint, having a light reflectance value (LRV) of 45%, which falls short of the recommended 60% as per the standard. The dimensions of the area are approximately 3.0 meters in width and 2.8 meters in height. The ceiling is covered with gypsum

board and features approximately 13 downlight fixtures. The ceiling's LRV is 65%, whereas the required value for optimal luminance should be around 85%.

The measurements were conducted in various zones as shown in Table 32. In the middle of the corridor, the minimum illuminance values were measured in zones 2, 3, and 4 (133 lux, 149 lux, 119 lux), which nearly meet the target value of around 100 lux. This result can be attributed to the unique characteristics of this area, situated in the middle of the block and surrounded by different spaces on both sides. It receives no direct sunlight, except for zones 2 and 3, which are influenced by the glass elevations of the library and the group study area, increasing the illuminance levels in these zones more than in zone 4.

On the other hand, measurements were obtained in other zones (1, 5, 6) with illuminance levels of (186 lux, 175 lux, 180 lux) respectively, and these values didn't meet the target of 100 lux, making them considered over-lit zones. For example, in zone one, the highest illuminance value was recorded because it receives more light from the adjacent area (students' lounge). As discussed previously, this also explains the high glare value in the administration area, especially in the front workstations that are open to the corridor.

Furthermore, vertical illuminance measurements were taken on all wall surfaces at a height of 1.75 meters. The results indicated normal to high glare values, with the highest values measured on walls A and B due to direct light reflectance from the downlights and, as previously mentioned, natural sunlight from the windows in the adjacent student lounge area. Generally, these two walls in zone one is brighter and exhibit some glare in comparison to the other corridor walls, with all other readings measuring below 100 lx.

These results can be attributed to various factors affecting the brightness and light reflectance on surfaces, including finishing materials, fixture types, arrangements, light color and temperature, surface reflectance value, room shape and area, ceiling and floor materials. In corridor areas, it is essential to consider lighting for exit and entrance zones and create transition areas to avoid sudden changes in illuminance between the interior and exterior during the day or at night. Moreover, implementing a control system with lighting sensors is advisable to reduce energy consumption and operational costs in such zones.



Figure 40: Corridors plan layout- illuminance values

(Source: Author,2022)

Table 32: Illuminance[lux]values for the corridor, (Source: Author,2022)

No. of zone	Horizontal LUX value	No. of wall	Vertical LUX value
		A	145
		B	171
		C.1	83.5
Z.1	186	C.2	69
Z.2	133	D.1	88
Z.3	149	D.2	98
Z.4	119	E	92
Z.5	175	F	95
Z.6	180	G	105

4.3.1.4 Individual Occupants Spaces

A. Registration and Chief Administrative Office

The registration office is situated between the library and the vice president's office and features a large glass elevation overlooking the campus court, providing the space with both views and natural light. The measurements were conducted during the day, and the office was illuminated by both natural and artificial light sources, although the curtains were partially closed during the measurements. To assess the illuminance values, the office was divided into two zones; zone T.1 over the chief officer's desk, and zone T.2 over the guest table

The registration office is depicted in Figure 41, showcasing its surfaces, materials, and lighting layout. The office's walls are covered with white-painted gypsum board with a light reflectance value (LRV) of 45%, whereas the standard specifies it should be 60%. The office has dimensions of about 5.8 meters in length, 4.0 meters in width, and 2.8 meters in height. The

ceiling, constructed with gypsum board, has an LRV of 65%, while the recommended value is around 85%. The lighting fixtures consist of indirect light sources, which provide additional brightness to the space, and six spotlights.

Table 33 shows the results of the illuminance measurements taken in different zones within the office. The measurements were conducted at the office desk and over a small sitting area table. In zone T.1, a minimum illuminance value of 896 lux was measured, which is very high for an office space and does not meet the target value. Conversely, zone T.2 recorded a measurement of 1441 lux, higher than T.1. This difference is due to direct sunlight falling on the table during the measurements, which also results in the office being frequently overheated.

Furthermore, the vertical illuminance values of the office surfaces were measured at a height of 1.75 meters. The highest values on walls A (around 1100 lux), wall D (about 981 lux), wall B (782 lux), and wall C (600 lux) due to direct sunlight from the windows. Hence, the office space is considered uncomfortable for working or any task due to the high lux values and glare. Additional measures may be required, such as altering the window specifications and adding shading devices to the external elevation. It's important to note that these measures can be challenging to implement using the DIALux EVO 11 software.

Table 34 shows a summarization of all spaces with the designated BUiD campus and their field measurement results including illuminance and uniformity values and the corresponding recommended values by the IES lighting handbook (IES, 2000).

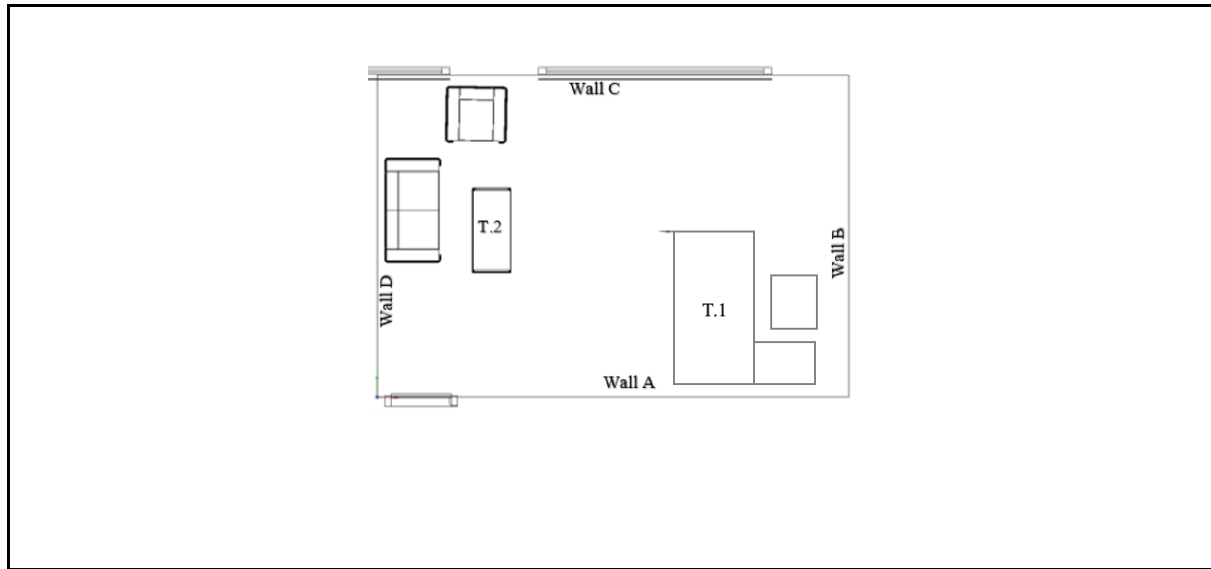


Figure 41: Registration and chief office furniture layout plan-illuminance values

(Source: Author,2022)

Table 33: Illuminance[lux] values for the registration and chief office, (Source: Author,2022)

No. of table	Horizontal LUX value	No. of wall	Vertical LUX value
		A	1100
		B	782
T.1	896	C	600
T.2	1441	D	981

Table 34: Horizontal illuminance Lux value measurements in different BUiD indoor spaces along with uniformity ratios, (Source: Author,2022)

Shared regularly multi occupants 'spaces							
	Auditor ium	Classroom FF111	Library	Admin. area	Group study room	Students lounge	Board room
	112	495	384	308	526	161	298
	388	491	451	735	427	386	350
	304	699	458	549	216	255	
	388	505	483				
	199	444	381				
	416	491	297				
			480				
			337				
Recommended horizontal (lux) value	500	500	200-500	300	500	300	500
Europe Uniformity (min/max)	0.47	0.64	0.62	0.41	0.41	0.41	0.85
Uniformity threshold	0.6	0.6	0.6	0.6	0.6	0.6	0.6

Non-regularly occupied spaces and Individual occupant spaces		
	Corridor	Registration office
	186	896
	133	1441
	149	
	119	
	175	
	180	
Recommended horizontal (lux)values	100	300
Europe Uniformity(min/max)	0.64	0.12
Uniformity threshold	0.4	0.6

4.3.1.5 *Color Temperature (Kelvin)*

When designing lighting, it's crucial to consider the color temperature and color rendering of the light sources. This aspect can significantly impact how we perceive different elements, such as furniture, screens, surfaces, and people, in terms of color. Moreover, there are several factors that influence color appearance, including the lighting, the finishing of the space, the furniture, the environment, and the intended use of the area (IES, 2000). Color temperature is a measure of the specific quality of visible light and is expressed in Kelvin (K). Table 35 (DiLaura et al., 2011), provides reference values for color temperature and illustrates the principles of color

appearance, differentiating between warm, neutral, and cold lighting. Table 36 presents values for correlated color temperature in various spaces, categorized as warm, neutral, and cold color appearances. These values are based on color temperature references specified as per color appearance standards. A correlated color temperature above 5,300 K is considered to create a cold space appearance, while the neutral color range of 3,300 to 5,300 K, and a warm color appearance is defined by a correlated color temperature below 3,300 K.

Table 35: Color temperature reference value. (*Source: DiLaura et al. 2011*)

Color appearance	Correlated color temperature (Kelvin)
Warm	Under 3,300 K
Neutral	3,300 K - 5,300 K
Cold	Over 5,300 K

During on-site measurements conducted in various spaces, several color temperatures were observed. The auditorium had the highest color temperature at around 5,692 K, classifying it as having a cold appearance. The classroom FF111, with its old fluorescent lighting and space finishings, had a color temperature of approximately 5,614 K, categorizing it as a cool area. The color temperature of lighting fixtures in different areas typically falls within the range of 2,700 to 6,500 K, depending on factors like space type, finishing materials, and surface colors (DiLaura et al., 2011).

It's worth noting that cooler color light exposure can enhance cognitive abilities in an educational campus. As a result of these color temperatures, the color appearance of various objects, furniture, screens, surfaces, and people are influenced to appear more natural with correct colors. However, most of the spaces considered in this analysis are characterized as too bright with a cold appearance. The students' lounge and the boardroom, in contrast, exhibit a neutral color appearance with measured values ranging from 5,247 to 4,056 K.

4.3.1.6 *Color Spectrum*

The lighting parameters that determine the color quality and appearance of indoor illumination are significant in creating a comfortable indoor environment and have a direct impact on the well-being of both staff and students. These factors are associated with the color spectrum of the indoor light, which defines the range of colors that can be generated by the light source. This spectrum plays a critical role in influencing visual comfort, concentration, and overall mood in interior spaces.

Table 36: Color temperature through various spaces (Kelvin), (Source: Author,2022)

Shared regularly multi occupant spaces							
Color appearance	Auditorium	Classroom-FF-111	Library	Administration area	Group study room	Students lounge	Board room
Warm							
Neutral						5,247 K	4,056 K
Cold	5,692 K	5,614 K	5,448 K	5,612 K	5,555 K		
Non-regularly occupied spaces and Individual occupant's spaces							
Color appearance	Corridors	Registration office					
Warm							
Neutral	5,336 K	5,016 K					
Cold	5,471 K 5,764 K						

The light spectrum can be categorized into two primary groups. The first group comprises warm colors, including red, orange, and yellow, which are considered energizing and can stimulate creativity and focus. The second group consists of cool colors, such as green, blue, indigo, and violet, which have a calming effect and can promote relaxation and enhance

attention. These characteristics make cool colors particularly suitable for classroom settings where focus and concentration are essential. Table 37 shows the colour spectrum measurements for each space, which were obtained during on-site visits using the Sekonic C-7000 measuring device.

Table 37: The color spectrum measurements in BUiD campus building spaces, (*Source: Author,2022*)

Area	Picture of Spectrum
Auditorium The predominant yellow color in the environment creates a warm, yellowish ambiance, which can have both positive and negative effects on users. On the positive side, it contributes to a welcoming and comfortable atmosphere. However, on the downside, the presence of yellow can impact color perception and visibility during presentations. As a result, it can affect how the audience perceives presentations and images	
Classroom FF-111 A balanced approach is evident in this graph, with a mix of yellow and blue tones indicating that the light is cool white. This balance between yellow and blue colors can be beneficial. Utilizing a combination of warm and cool hues to create a well-rounded environment that encourages both active engagement and focused learning may be advantageous in some classrooms	

Library The library also exhibits a balanced combination of yellow and blue colors, creating a blend of cool and warm tones. Given that the library benefits from a combination of artificial and natural light, it is considered a well-lit and cool space, which is suitable for younger students' classrooms. However, in our case, where the user age group is older students, it might be more beneficial to opt for calming colors that can enhance productivity.	 SEKONIC SPECTROMETER C-7000 Exposure Time: Auto Lux: 2561x Tcp: 5448K Juv: 0.0132 The image shows a color spectrum graph with a peak in the yellow-green region and a smaller peak in the blue region.
Administration area The administration area also demonstrates a balance between cool and warm colors. For spaces like these, it is recommended to incorporate a combination of natural colors and neutral light specifications (cool light) to enhance productivity and concentration.	 SEKONIC SPECTROMETER C-7000 Exposure Time: Auto Lux: 6711x Tcp: 5612K Juv: 0.0109 The image shows a color spectrum graph with a prominent peak in the blue region and a smaller peak in the yellow region.
Group study room The dominant color scheme in this space consists of yellow and blue, which creates an integration between a welcoming environment and enhanced sociability through the warm color. Simultaneously, the cool color contributes to increased productivity and improved concentration in the group study room.	 SEKONIC SPECTROMETER C-7000 Exposure Time: Auto Lux: 5481x Tcp: 5555K Juv: 0.0094 The image shows a color spectrum graph with a peak in the yellow-green region and a smaller peak in the blue region.

Student lounge The predominant color in this area is yellow, creating a warm color scheme. While this can make the space feel cozy, it may not offer the best visibility and can distort color perception. In such cases, a dimmable lighting system or the ability to adjust the color temperature can be useful to accommodate various needs and occasions.	
Board room As discussed earlier, colors have a significant impact on human emotions and behavior. Yellow is associated with creativity and can create a positive atmosphere in meetings. Green promotes a sense of harmony and cooperation, in line with the campus's environmental vision. Blue creates a professional atmosphere and enhances communication among board members	
Corridors In the corridor, there is mostly yellow color present, approaching the maximum level, while the blue color is minimal. This indicates a warmer atmosphere in the corridor, which may not provide a calm feeling and can distort the perception of true colors. In such spaces, it's essential to have a lighting system that ensures high visibility and alertness.	
Registration and chief office In this space, various colors are present in different proportions. Yellow is the dominant color, creating a welcoming and warm environment. Increasing the presence of blue color in this space can promote a more professional atmosphere and enhance productivity and concentration.	

4.3.1.7 *Color Rendering Index (CRI)*

Error! Reference source not found. represent the light source's capacity to render colors accurately and naturally, known as color rendering index (CRI), is also dependent on the light spectrum it emits. A pleasing condition is created by using a good color index, which displays items in their true colors. But at a value of 80, considered as an excellent color rendering index, by areas or in such spaces like over 80 considered as a good value depends on the task on that zone, but below 80 considered as not good average in showing the colors, and the color bars mean how good light showing different colors (every color). The recommended CRI value for educational spaces, a minimum color render of 80 was often suggested. A CRI of 80 confirms the equitably good color rendering, appropriate for most lecture halls and classrooms, and for auditoriums such cases, CRI values of 85 or higher may be recommended (IES, 2000).

Table 38: The General CRI values (Ra) for BUiD campus building spaces, (Source: Author,2022)

Area	Picture of CRI
Auditorium The General color rendering index (Ra) for this area is 74.2, which is not optimal. In the color bars, the light purple bar is the longest, indicating that the light performs best in displaying purple but is not effective in rendering the red color, as the red bar is absent. Therefore, in this area, audiences may have difficulty perceiving colors accurately during presentations and other activities	
Classroom FF-111 The Ra (General CRI) in this area is 74.8, indicating less than ideal color rendering. The color bars illustrate that the green bar is the longest, signifying that the lighting performs best with green tones. However, it does not render red colors effectively, as the red bar is absent. This deficiency could impact how students perceive colors within the classroom environment	
Library The Ra (General CRI) for this area is 76.4, indicating suboptimal color rendering. The color bars reveal that the green bar is the longest, signifying the lighting's best performance with green colors. However, it struggles to render red colors effectively, as indicated by the absence of the red bar.	
Administration area The Ra (General CRI) for this area is 72.0, signifying poor color rendering. In the color bars, the green bar is the longest, indicating that the light performs best in displaying green colors. However, it struggles to render red colors effectively, as the red bar is absent	

Area	Picture of CRI
Group study room The Ra (General CRI) for this area is 74.6, which is quite similar to the classroom CRI and is not considered ideal for this type of space. The absence of red colors in the light source is often associated with higher color temperatures. In such cases, cooler colors, like blues and greens, are prioritized, while warmer hues, such as reds and oranges, are de-emphasized. Consequently, the red hues within the illuminated environment may appear less prominent or vibrant.	
Student lounge The Ra (General CRI) for this area is 75.5, which is quite similar to the CRI values of other spaces and is not considered ideal for this type of area. The absence of red colors in the light source is often associated with higher color temperatures. Consequently, in the illuminated surroundings, the red hues may appear less prominent or vibrant.	
Board room The Ra (General CRI) for this area is 83.0, indicating a good color rendering index. The light source effectively represents most colors, with green being particularly well-rendered, and even red starts to become noticeable in the board room. This high CRI suggests that all colors appear natural and true to their actual appearance under this lighting condition, which is desirable for accurate color perception.	
Corridors The Ra (General CRI) for this area is 75.5, which is very close to the CRI of other spaces. This CRI is not optimal for accurately rendering the true colors of various objects, which can impact the students' experience, especially during poster presentations commonly held in the corridor area. The red color appears in very small portions, affecting the true color hue and appearance, and may result in less accurate color perception.	
Registration and chief office The Ra (General CRI) measured at 88.3, which is a good value. This indicates that all colors appear natural and true to their actual appearance under daylight conditions.	

4.4 Survey

The survey conducted by the British University in Dubai (BUiD) serves as a valuable tool for gathering data from the university's students and staff. Its primary aim is to gain insights into the demographics of the university community, assess their levels of satisfaction with various aspects of the campus, with a particular focus on lighting and indoor environmental conditions, and collect their suggestions for potential improvements. A total of 50 respondents participated in the survey, providing valuable insights into their satisfaction levels and the importance of factors such as daylight, natural views, artificial lighting, and overall environmental conditions in relation to their productivity.

The responses from the participants were categorized into five distinct levels: "Very Dissatisfied," "Not Satisfied," "Neutral," "Satisfied," and "Very Satisfied." In the following section, various analytical charts illustrate the responses of BUiD students and staff. The initial chart presents the distribution of responses by country, with the majority of respondents originating from the UAE. Subsequent charts offer demographic information about the respondents, including details regarding their age, gender, level of education, and job category. The survey also assesses the respondents' satisfaction with their working conditions, encompassing aspects like lighting, furniture layout, and the quality of materials used in their workspaces. These charts display the users' opinions concerning areas in need of improvement, with a significant portion expressing dissatisfaction. The questionnaire also solicits suggestions for enhancing the working environment. The responses point towards lighting improvements as a potential means of enhancing the effectiveness of workspaces. Finally, the survey collects data on the respondents' satisfaction levels regarding various facilities within the university, such as

the student lounge, the library, the auditorium, classrooms, group study rooms, offices, and meeting rooms. These charts reveal a noteworthy level of dissatisfaction with these facilities, highlighting the need for improvements.

The distribution of responses from the BUiD staff and student survey by nation is shown in Figure 42. The majority of responses came from the United Arab Emirates with a percentage of 76.54%. The United States had the second highest response rate at 9.88%, followed by Jordan at 8.64%. The lowest response rates were in Saudi Arabia, Syria, and Azerbaijan at 2.47%, 1.23%, and 1.23% respectively. This summarizes the presence of diverse cultures in BUiD as an educational campus which reflects the whole image of Dubai as a city which contributes to its multicultural perspectives and work practices. While, as discussed previously in the introduction chapter, this blending of cultures creates an inclusive environment and integration of people, understanding and dealing with different environmental factors in various sectors which brings more innovative approaches and creative solutions.

The age breakdown of BUiD employees and students is shown in the second graph. The age range of 35 to 44 accounts for the majority (39.58%). Ages 25 to 34 make up 29.17% of the population, making them the second-largest age group. The 45–54 age group, which makes up 25% of the population, comes next. The 18–24 age group, which only comprises 6.25% of the population, is the smallest group. Figure 43 shows the age distribution of staff and students at BUiD.

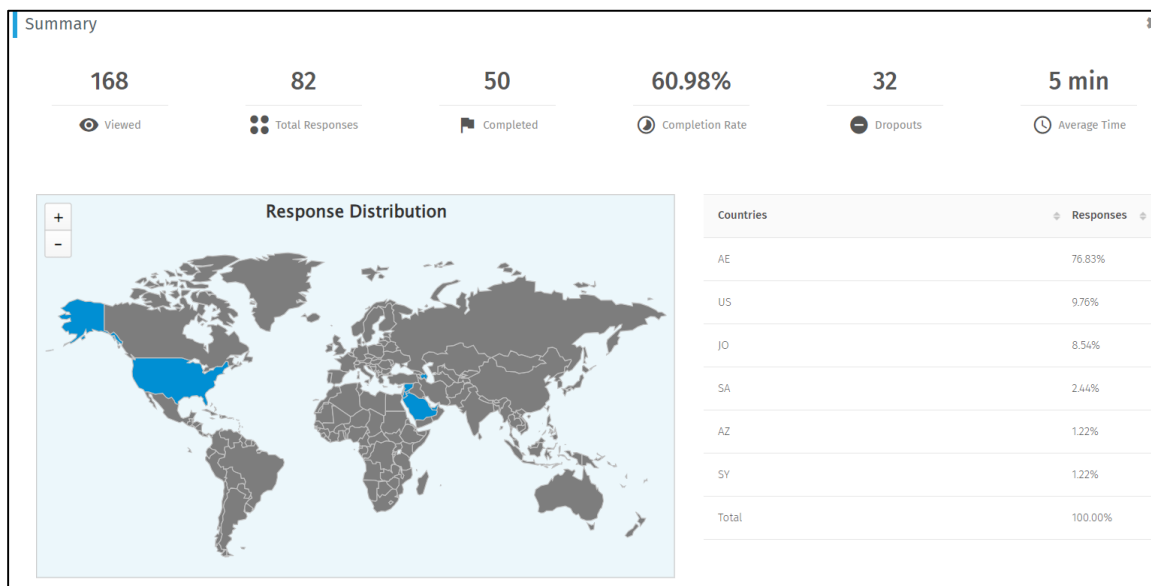


Figure 42: BUiD population distribution of students and the staff

(Source: Author,2022)

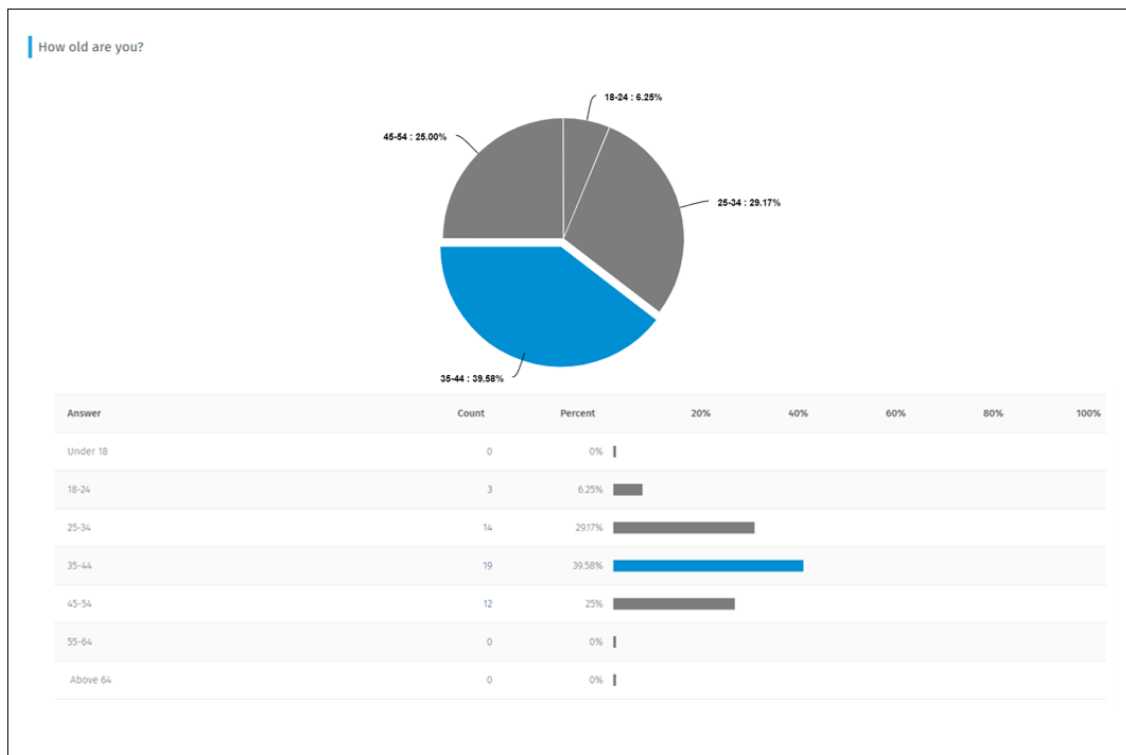


Figure 43: Age distribution of BUiD students and staff

(Source: Author,2022)

According to the BUiD students and staff survey, there are considerably more female students at the British University in Dubai (BUiD). Particularly, 31.25% of respondents identified as male, compared to 68.75% of respondents who identified as female. According to the findings of the survey, this implies a much higher percentage of women in the BUiD campus group. Figure 44 shows gender distribution among students and staff at BUiD.

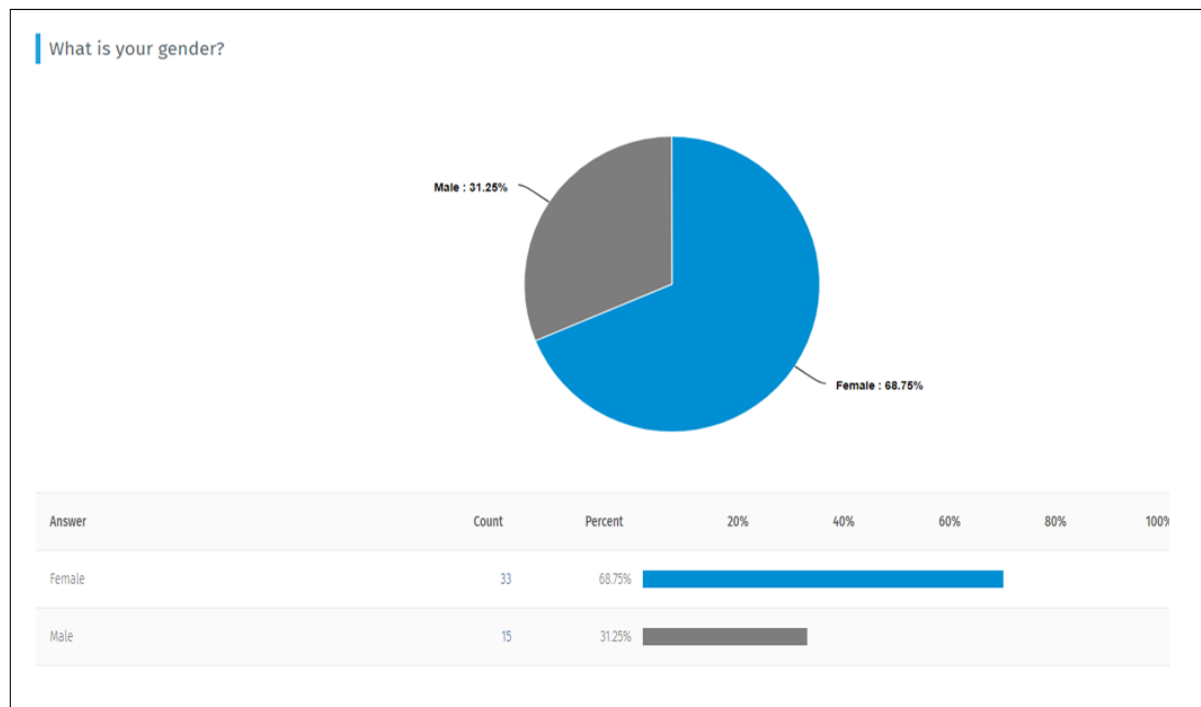


Figure 44: Gender distribution among students and staff at BUiD

(Source: Author,2022)

The questionnaire finds that post graduate students make up a majority of BUiD students, accounting for 72.92% of the people who participated. Graduate students make up the remaining 27.08%. There are no responders who fit into any other education level categories. This suggests that a large portion of the BUiD community is well educated. Figure 45 shows BUiD students' level of education.

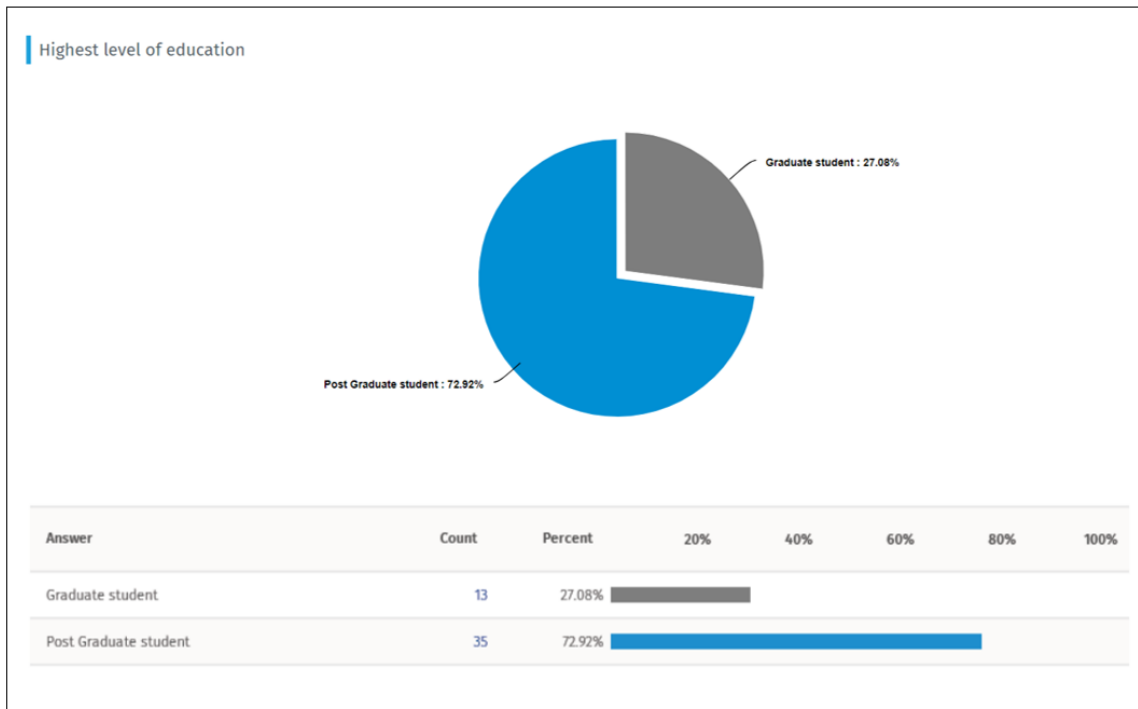


Figure 45: BUiD students' level of education

(Source: Author,2022)

According to the study done at the British University in Dubai (BUiD), there are two main groups of respondents based on their field of job: academic personnel and non-academic staff. While just 31.25% of the respondents were members of the academic staff, 68.75% of the responses were provided by non-academic workers. This shows that at the time of the survey, the majority of respondents were non-academic staff. Figure 46 shows BUiD staff job categories compromised between academic and non-academic staff.

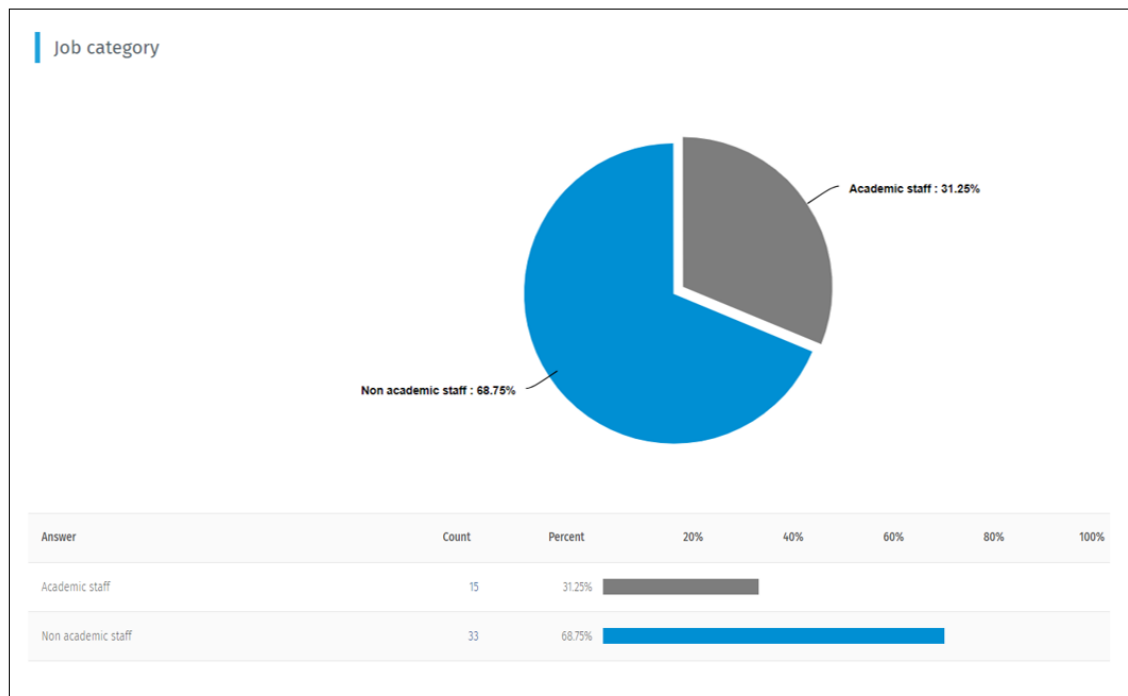


Figure 46: BUiD staff job categories compromised between academic and non-academic staff

(Source: Author,2022)

With respect to the time spent in BUiD campus, the survey's findings indicate that 53.19% of respondents, or the majority of BUiD students and employees, spend more than six hours each week in a classroom or office. The following largest group, comprising 29.79%, spends more than four hours each week. 17.02% of respondents, the smallest category, say they spend one to three hours a week in a classroom or office. Figure 47 shows the hours spent in the class room/ office per week at BUiD.

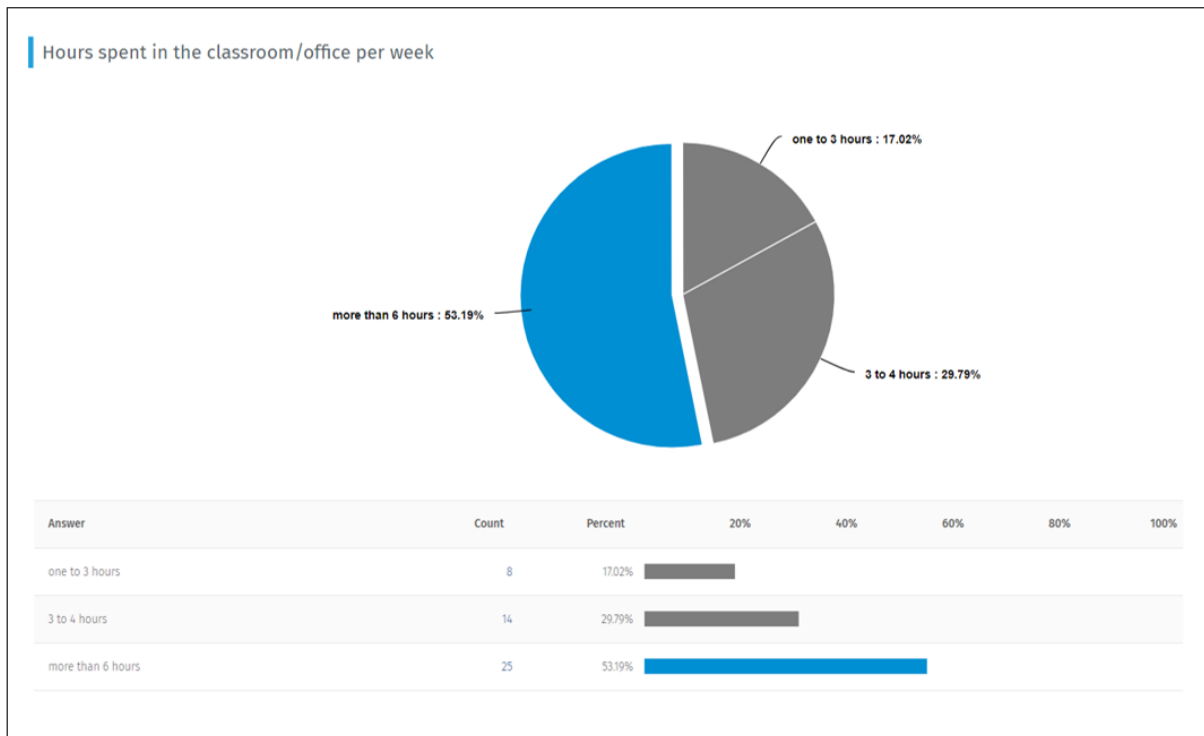


Figure 47: Hours spent in the class room/ office per week at BUiD

(Source: Author,2022)

The survey findings reveal a diverse range of opinions regarding the lighting conditions at BUiD, focusing on users' satisfaction with various aspects. These aspects include their contentment with their individual offices (for staff) or classrooms (for students), the extent to which the environmental conditions support and foster innovative workspaces, satisfaction with the existing artificial lighting and its impact on their mood, the quality of views from different areas and users' satisfaction with them, and the presence of daylight within spaces and its effects on their productivity and well-being.

As indicated by Figure 48, approximately 38.3% of respondents expressed neutrality regarding their working areas, with 29.79% reporting satisfaction, 21.28% indicating dissatisfaction, and a small 8.51% expressing strong dissatisfaction. These responses suggest that, while some individuals find the lighting conditions acceptable, there remains room for improvement in creating a more conducive working environment. This is consistent with the results obtained from field measurements, which indicate that most areas require enhancements in terms of lighting conditions, encompassing both natural and artificial lighting.

The survey results underscore the importance of addressing lighting concerns to enhance the overall well-being and satisfaction of BUiD's community. These insights can inform strategies for improving lighting conditions and creating more conducive and productive workspaces.

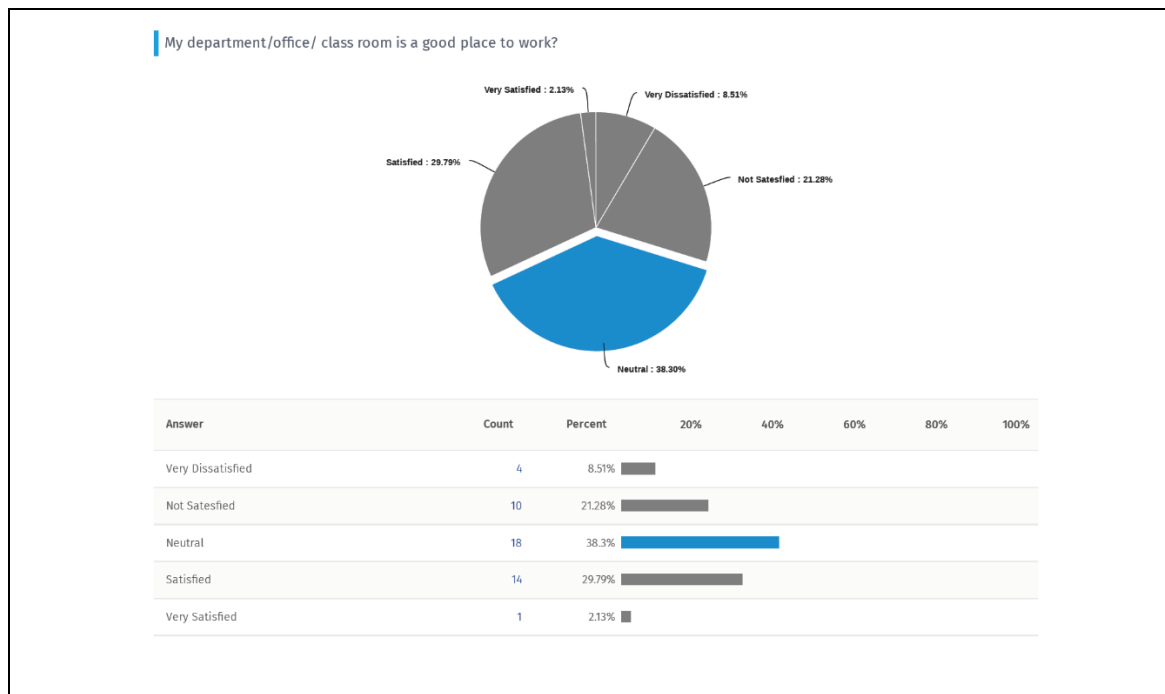


Figure 48: Lighting conditions: How do you feel about the working areas

(Source: Author,2022)

Environmental conditions play a significant role in influencing user satisfaction and productivity within indoor spaces, as people typically spend approximately 90% of their time inside buildings. The results of the survey reveal a wide spectrum of opinions on whether the working environment fosters individual productivity.

To break down the responses, Figure 49 shows that about 8.51% of participants expressed very low satisfaction, 23.40% were dissatisfied, 38.30% reported neutrality, 27.66% indicated satisfaction, and a small 2.13% reported very high satisfaction with their working environments. These findings imply that there is room for improvement in creating workspaces that better support the productivity of both students and staff. Recognizing the significance of the working environment in enhancing user satisfaction and productivity, addressing these concerns and striving for improvements should be a priority for BUiD to create more effective and user-friendly spaces.

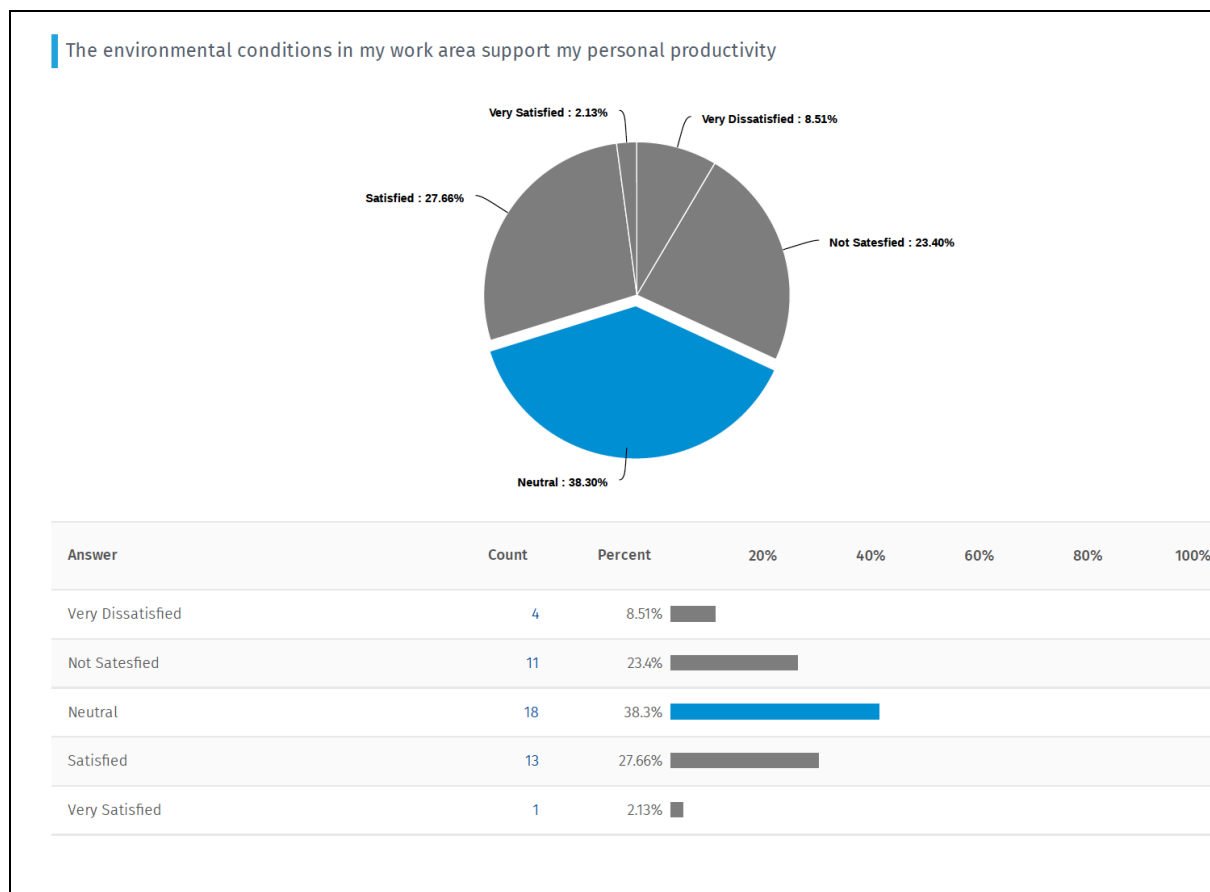


Figure 49: Environmental conditions: Its effect on the user's satisfaction

(Source: Author,2022)

The survey's findings show that opinions on the artificial lighting in the workspace are divided. Figure 50 shows that a considerable 27.66% of respondents were not satisfied, while 8.51% expressed extreme dissatisfaction. Equally as many people (27.66%) had a neutral opinion on the electrical lights. Positively, 31.91% of respondents said they were happy with the artificial illumination in their workspace, while 4.26% said they were really happy.

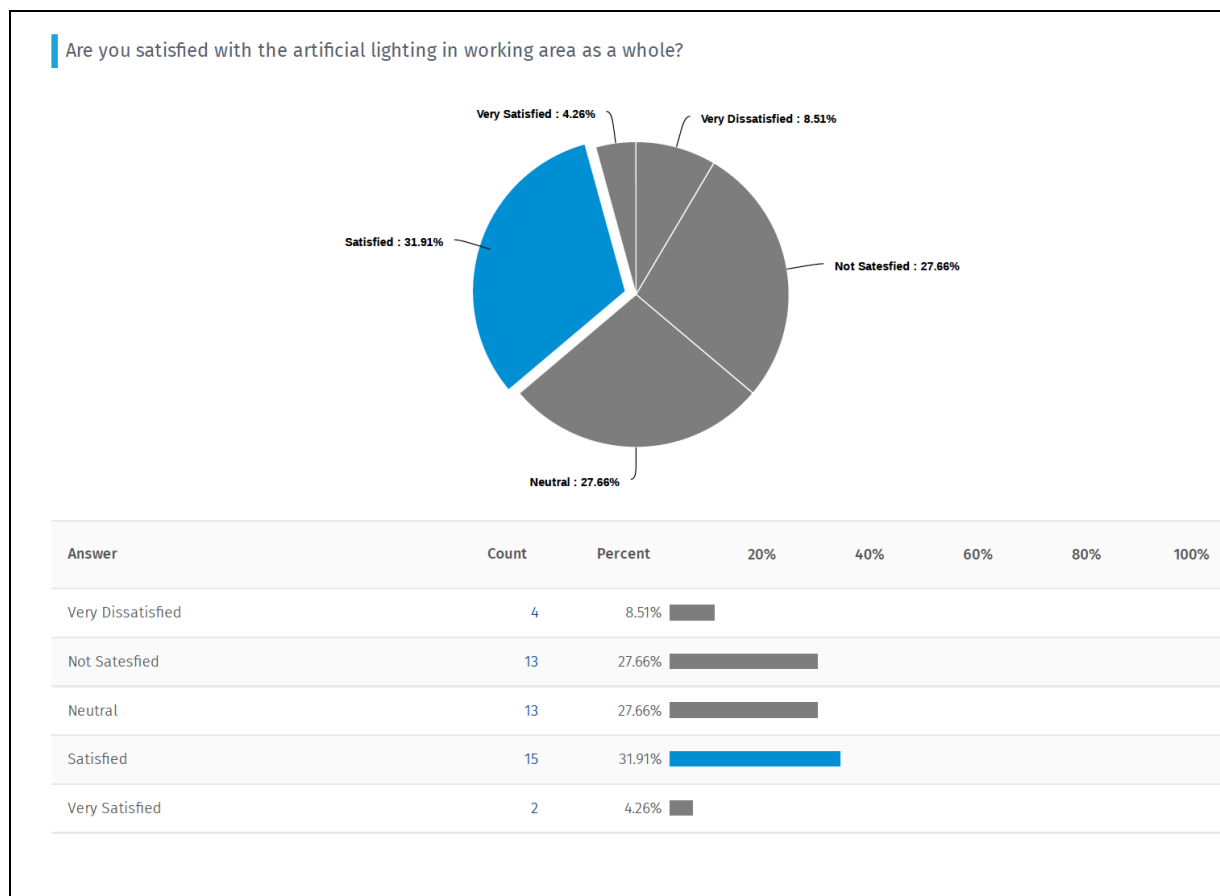


Figure 50: Satisfaction levels with artificial lighting in working areas

(Source: Author,2022)

The results of a study focused on people's perceptions of the outside environment from their separate locations are shown in the survey chart that is provided. sharing information on their satisfaction levels across the five aforementioned criteria. The outcomes presented in Figure 51 show a wide range of emotions among the responders. Notably, a substantial number of participants (10.87%) expressed a clear displeasure with the observable views. In addition, 34.78% of respondents reacted that they were "Not Satisfied" with the scenery in general. A quarter of the respondents (26.09%) had a neutral approach, indicating that there were no clear

good or negative feelings about the concept in the question. While a smaller group of 6.52% expressed being extremely delighted with their visual surroundings, as 21.74% expressed being pleased with the view. The findings highlight the diverse nature of human perception and takes advantage in connection with external environments and provide a variety of points of view to assist in our understanding of the significance people place on their immediate visual surroundings.

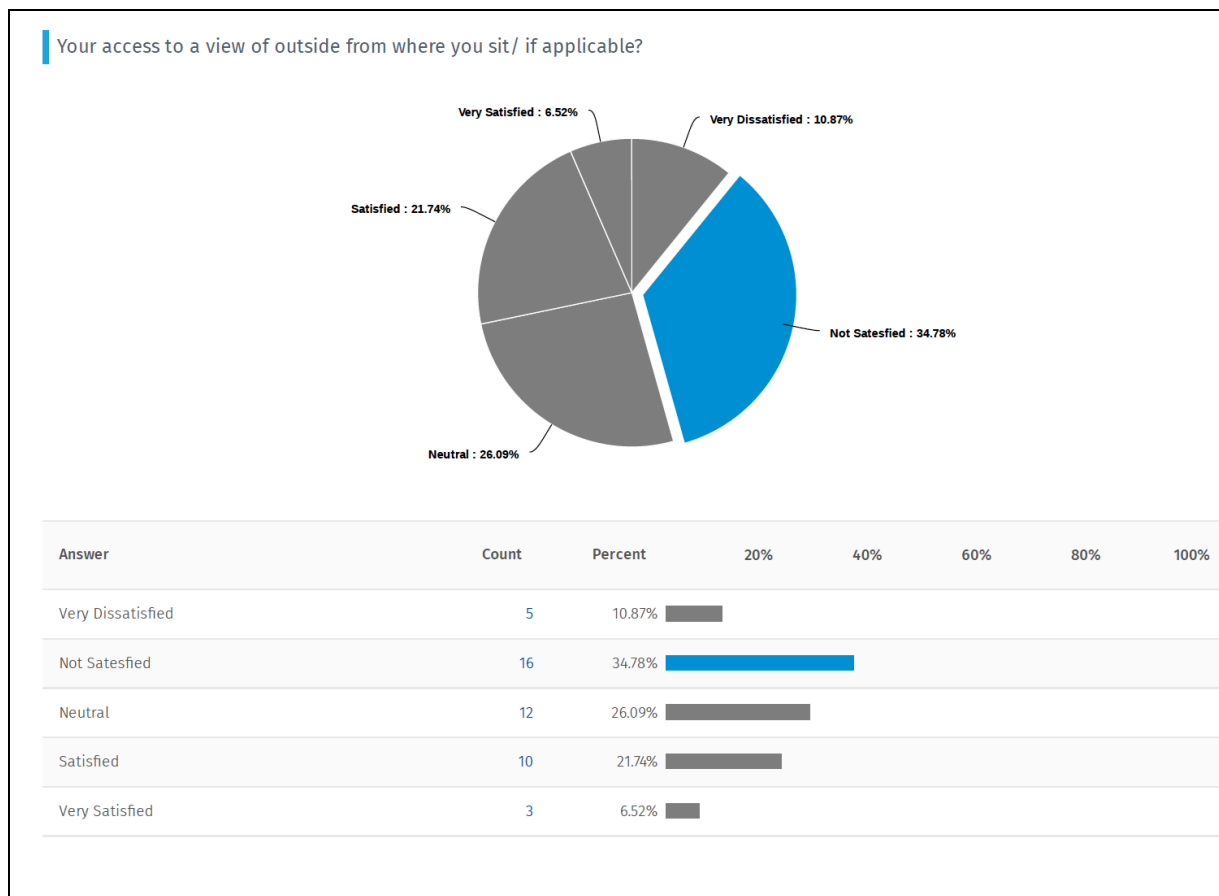


Figure 51: Accessibility of outside views in different spaces

(Source: Author,2022)

The evaluation of the overall quality of natural daylight in respondents' workspaces is shown in Figure 52. The results show a wide range of opinions on the subject. This highlights one of the main statements in regards to the people understanding and awareness about sustainability concept in buildings. The majority of respondents, at 38.30%, had a neutral approach, indicating that there were neither obviously good or negative opinions about the natural lighting. In contrast, 25.53% of respondents said they were happy with the daylight illumination, indicating a positive impression. Together, 31.92% of participants expressed "Very Dissatisfied" or "Not Satisfied" levels of dissatisfaction with the lighting quality. Notably, 4.26% of respondents indicated that they were "Very Satisfied" with the natural illumination, revealing a small but highly happy group. This study highlights the differences of how people perceive the natural lighting in campus building, direct sunlight and its distribution of satisfaction levels and the significance attached to this factor in a working and learning environment. Additionally, how does student awareness of daylighting in their learning environment effect academic performance relative to students who much they are aware of daylighting effect on their performance.

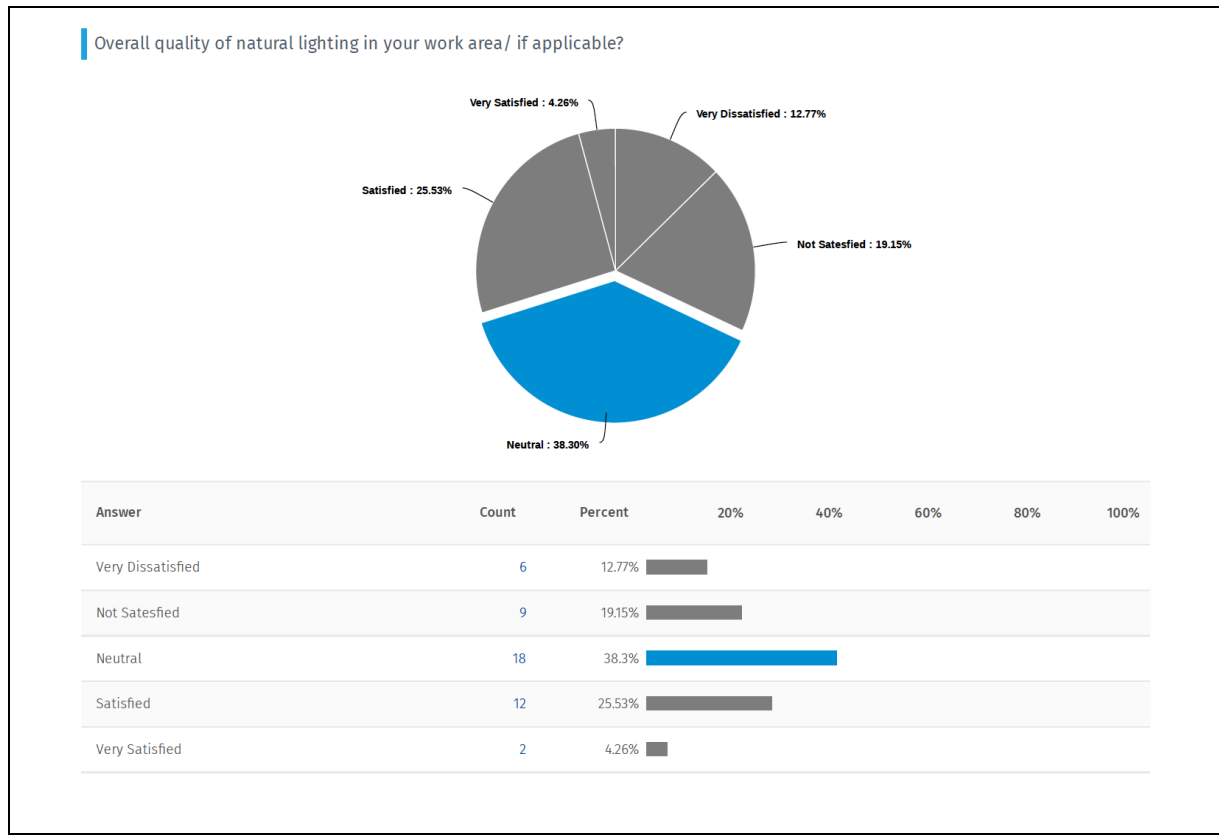


Figure 52: Quality of daylight in different spaces satisfaction levels

(Source: Author,2022)

The survey measures the frequency of glare witnessed on computer screens in different environments, including classrooms, study rooms, library, auditorium, and offices. As seen in Figure 53, the results show a spectrum of feelings regarding glare on computer screens. The majority, comprising 53.19% of participants, reported a neutral experience, indicating neither strong dissatisfaction nor satisfaction. Additionally, 21.28% expressed dissatisfaction with the glare, while 14.89% were satisfied with their experience.

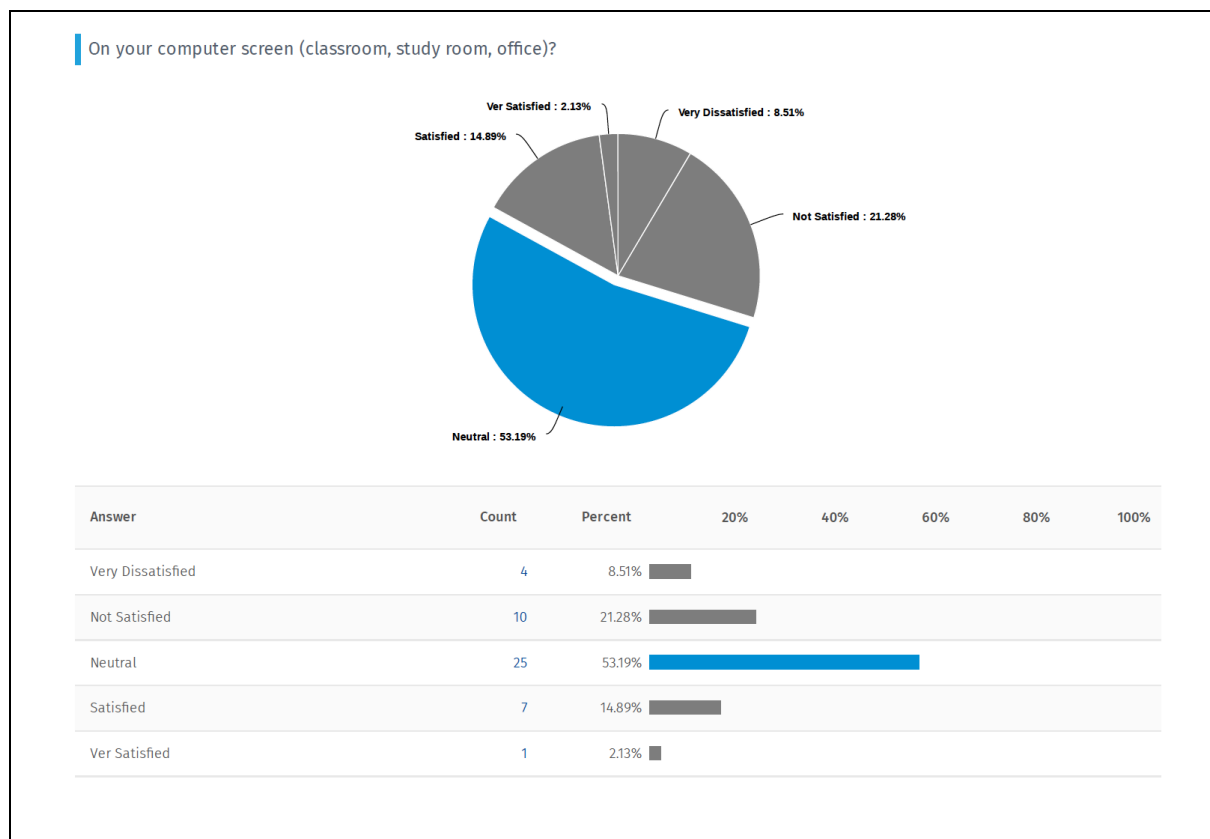


Figure 53: Glare on computer screens and how this effect the students' performance

(Source: Author,2022)

Figure 54 shows an evaluation of the respondents' encounters with glare resulted from the electric lighting fixtures in various contexts. 34.04% of the participants expressed unhappiness with the glare, and 10.64% expressed a strong dislike for it. A sizeable portion (40.43%) expressed neutrality, indicating that they weren't very satisfied or dissatisfied. 14.89% of a smaller group expressed pleasure with their exposure to glare. Notably, none of the individuals expressed being extremely satisfied. This research highlights a wide range of satisfaction levels and the need for future changes in addressing these problems by offering insights into the various opinions of respondents on glare difficulties associated to artificial lighting.

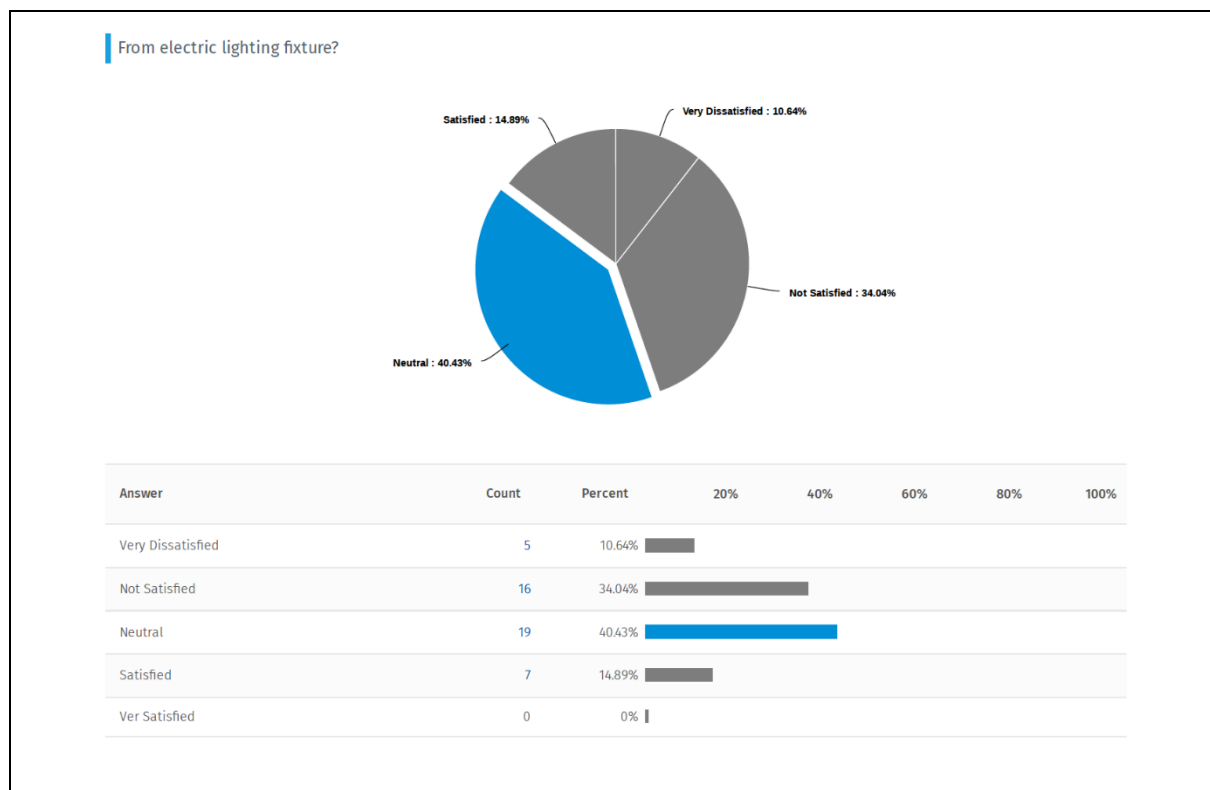


Figure 54: Glare produced from the electrical lighting fixtures

(Source: Author,2022)

Figure 55 relates to the experiences of the respondents with daylight-generated glare. Participants' reactions to daylight-induced glare ranged from very dissatisfied (6.38%) to unsatisfied (29.79%). A similar proportion of 29.79% said they were happy with their encounters. A total of 16 individuals, or 34.04%, maintained a neutral viewpoint, indicating that there was no clear preference for or against daylight-related glare. Notably, none of the respondents claimed to be extremely satisfied. These results demonstrate the variety of viewpoints on daytime glare and emphasize the necessity for efficient glare management and mitigation solutions.

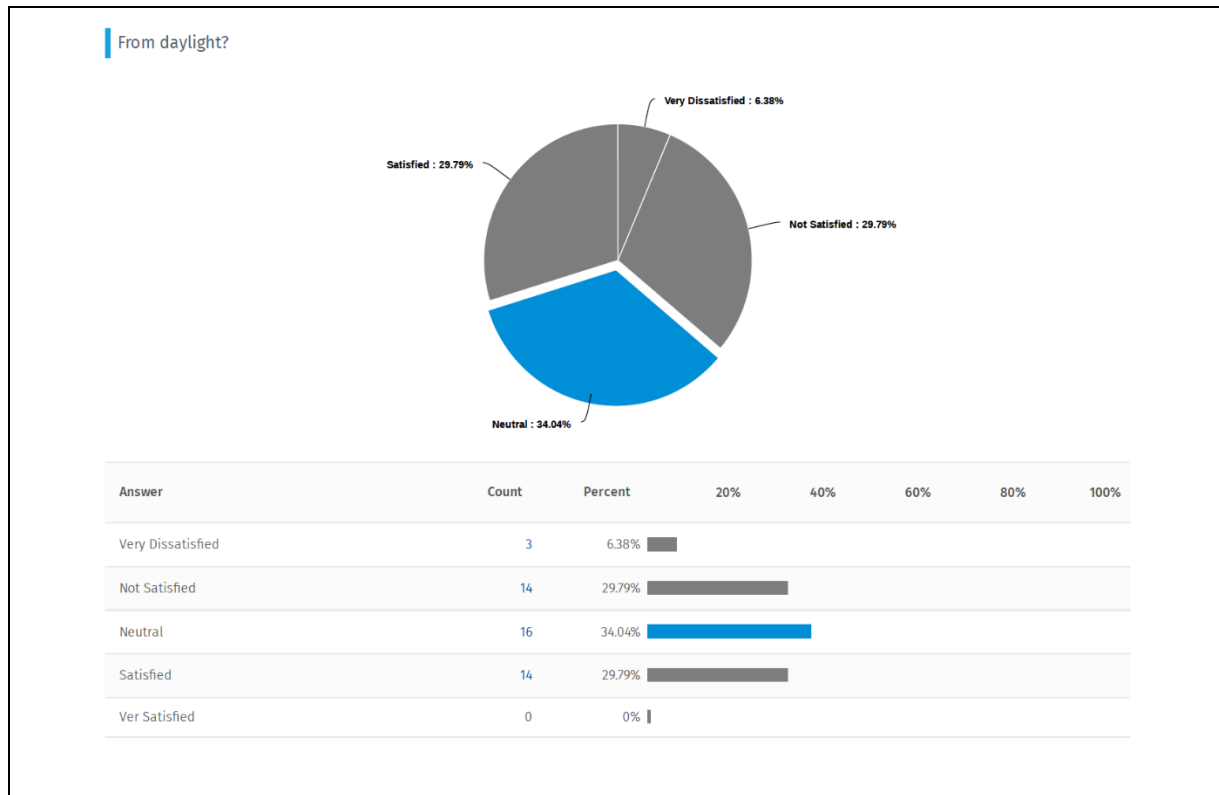


Figure 55: Glare produced from presence of daylight

(Source: Author,2022)

The data concern the respondents' evaluations of their capacity to perceive resources that are displayed in their classrooms is shown in Figure 56. Among the participants, 4.26% stated very disappointment with their capacity to see presented materials, while 17.02% were not satisfied. Additionally, 31.91% reported satisfaction with their capacity to see presented materials, and 8.51% reported satisfaction. Finally, 38.30% held a neutral viewpoint, indicating a lack of pronounced favorable or adverse feelings in the current setting.

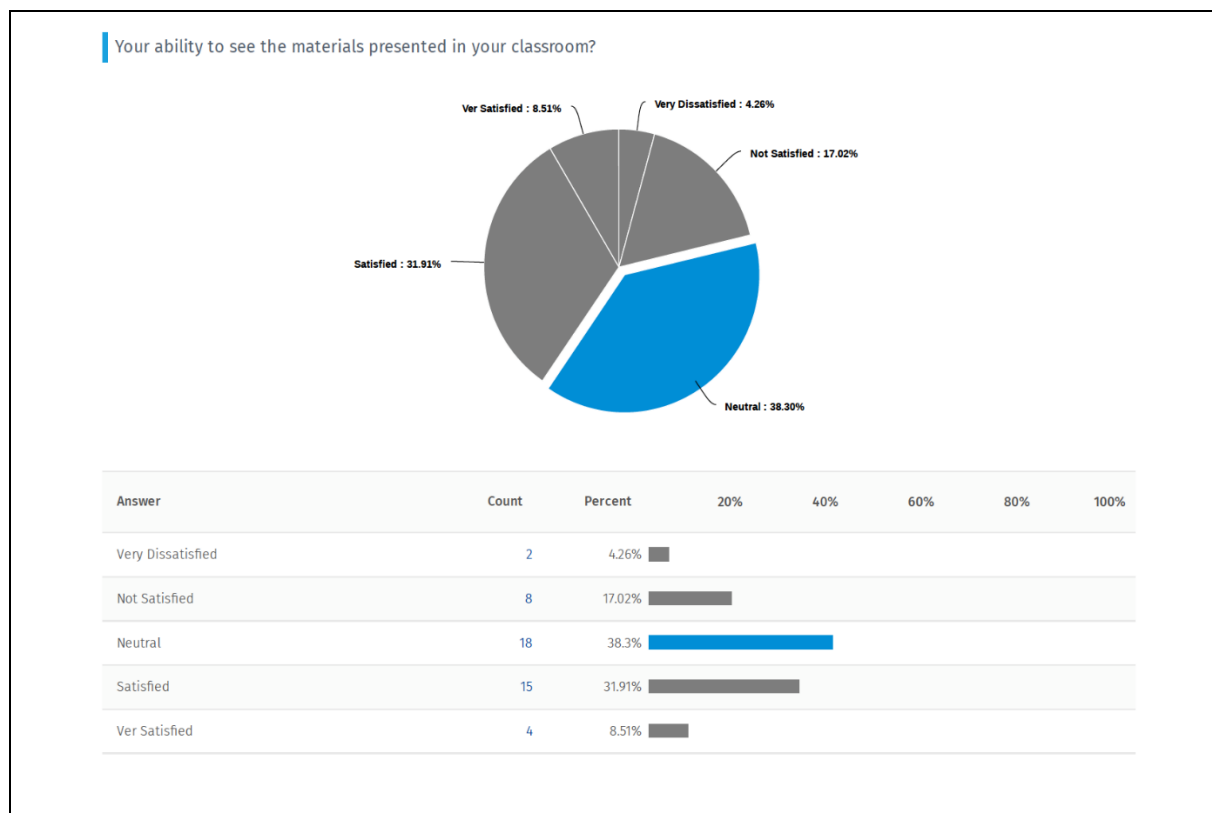


Figure 56: Glare and its effect on the student's abilities to see the presented materials

(Source: Author,2022)

To summarize how users experienced glare on different surfaces and its effect on their satisfaction. The results of the study show how often and from what sources respondents feel glare in various situations. 56.17 %of respondents expressed displeasure with computer screen glare in places including classrooms, study rooms, libraries, and offices, and 57.45% did the same with glare and brightness resulted from the direct sunlight. Dissatisfaction with glare caused by electric lighting fixtures was expressed by 51.91% of respondents. In addition, 64.68% of students expressed dissatisfaction with their capacity to understand the contents presented to them in class. On average, respondents rated their experiences with glare at 2.88, indicating a degree of overall dissatisfaction. These findings, presented in Figure 57, highlight

the widespread appearance of glare-related issues in a range of lighting conditions and lighting sources, highlighting the necessity of efficient glare reduction techniques in both natural and artificial lighting environments.



Figure 57: Summary chart of glare experience in different situation

(Source: Author,2022)

The survey measures participants' satisfaction with the campus spaces by asking, "How satisfied are you with the following spaces?". Figure 58 shows how satisfied those surveyed were with the library settings. 17.02% of the faculty and staff members and 4.26% of the students reported dissatisfaction with the library area. A neutral view was taken by about 36.17% of respondents, showing that there was no clear preference for or against library spaces. Furthermore, 4.26% of respondents said they were very pleased with the library spaces, while

38.30% said they were satisfied. These findings demonstrate the variety of viewpoints on library settings, highlighting a balance between areas of satisfaction and opportunities for development. In library contexts, good design and usage practices can help to increase user happiness.

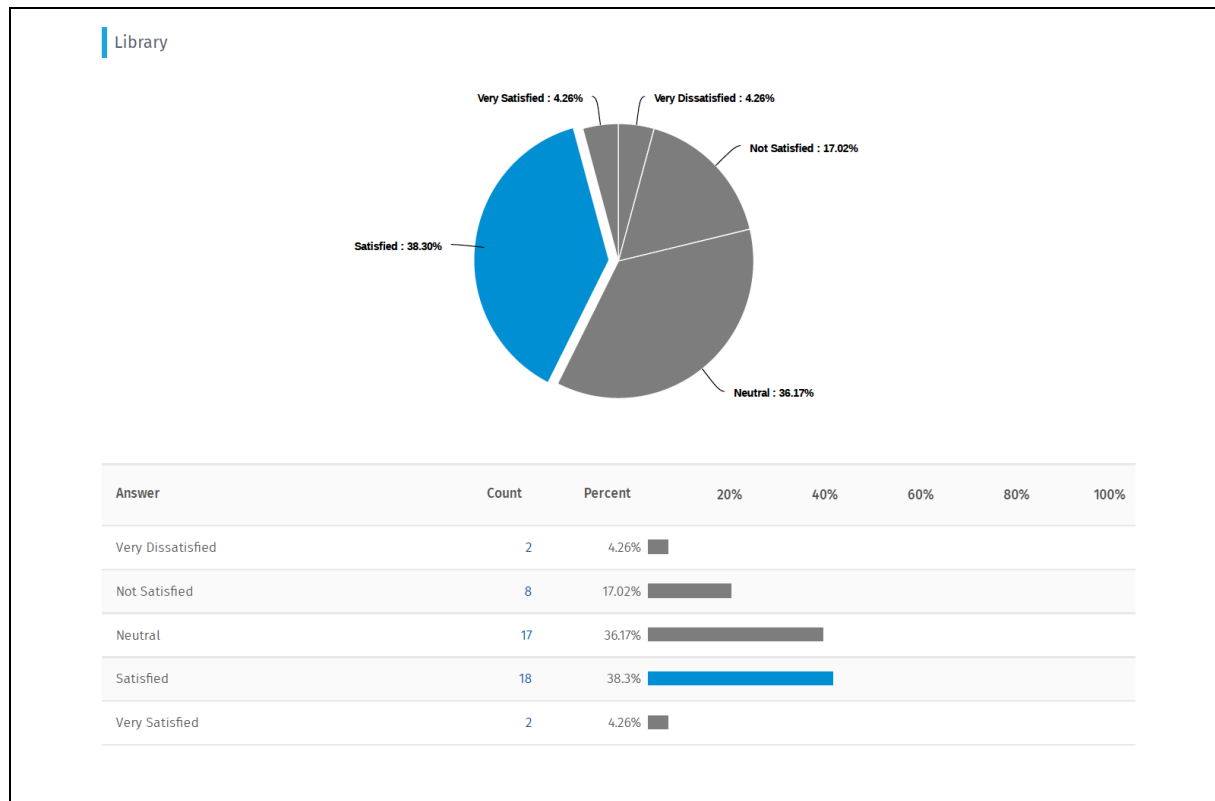


Figure 58: Satisfaction level of all users in the library

(Source: Author,2022)

Figure 59 reflects respondents' levels of satisfaction with student lounge areas. While 27.91% were not satisfied, 4.65% indicated extreme displeasure with the student lounge rooms. A sizable portion of 48.84% adopted a neutral posture, showing that there was no clear preference for or against these areas. Furthermore, 16.28% of respondents expressed pleasure

with the student lounge, with 2.33% of those saying they were extremely satisfied. These data demonstrate the conflicting viewpoints on student lounge areas, highlighting both places that might be improved upon and elements that increase contentment. These many viewpoints can be used as a basis for developing strategies to improve these areas' comfort and usability.

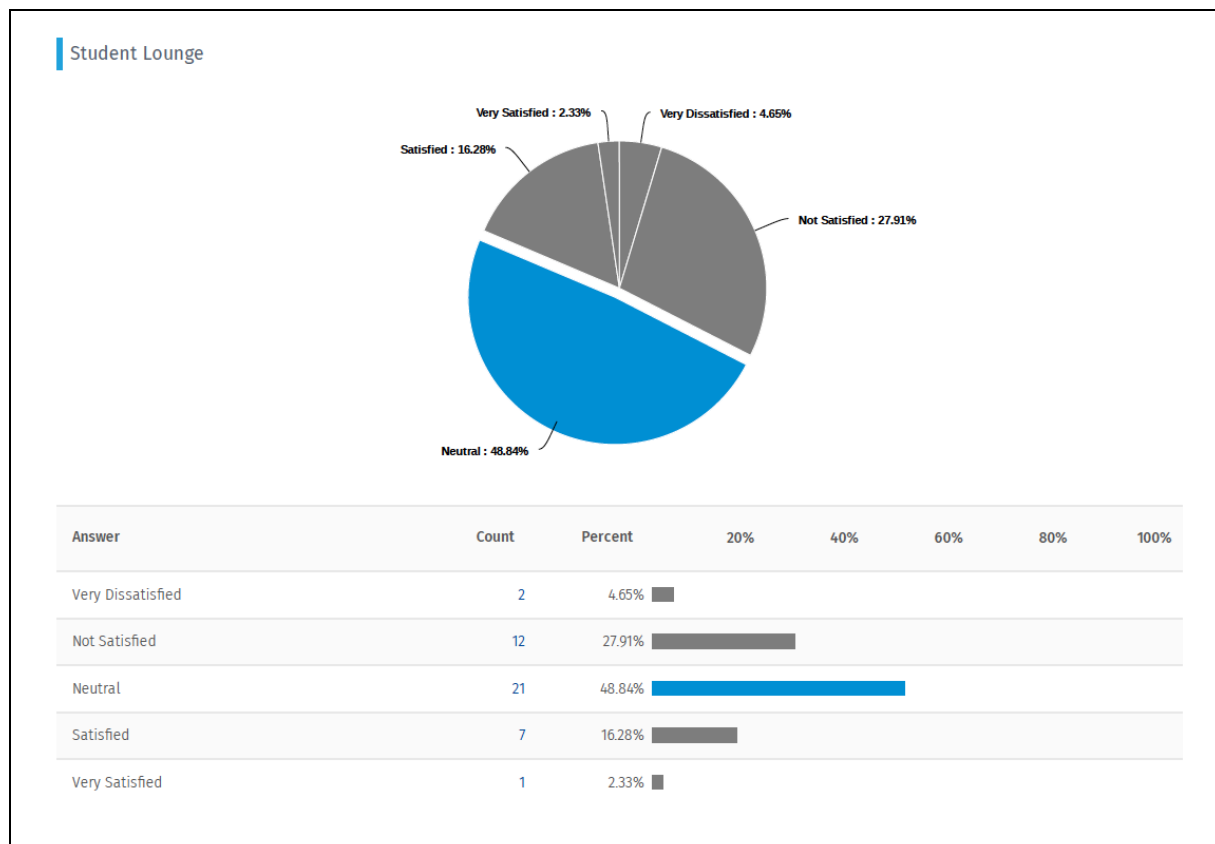


Figure 59: Satisfaction level of all users in the students lounge

(Source: Author,2022)

Figure 60 shows the satisfaction level of students in the group study room. According to the figure, 19.05% of respondents were not satisfied with the group study room facilities, while 9.52% voiced extreme displeasure. A neutral view was taken by over half of the respondents, or

47.62%, showing that there was no clear preference for or against these areas. Additionally, 21.43% of respondents expressed pleasure with the group study rooms, with 2.38% of those saying they were extremely satisfied. These findings highlight the diversity of viewpoints on group study rooms, highlighting both opportunities for development and factors that enhance user satisfaction. These various points of view can help to inform strategies for making the most of these areas.

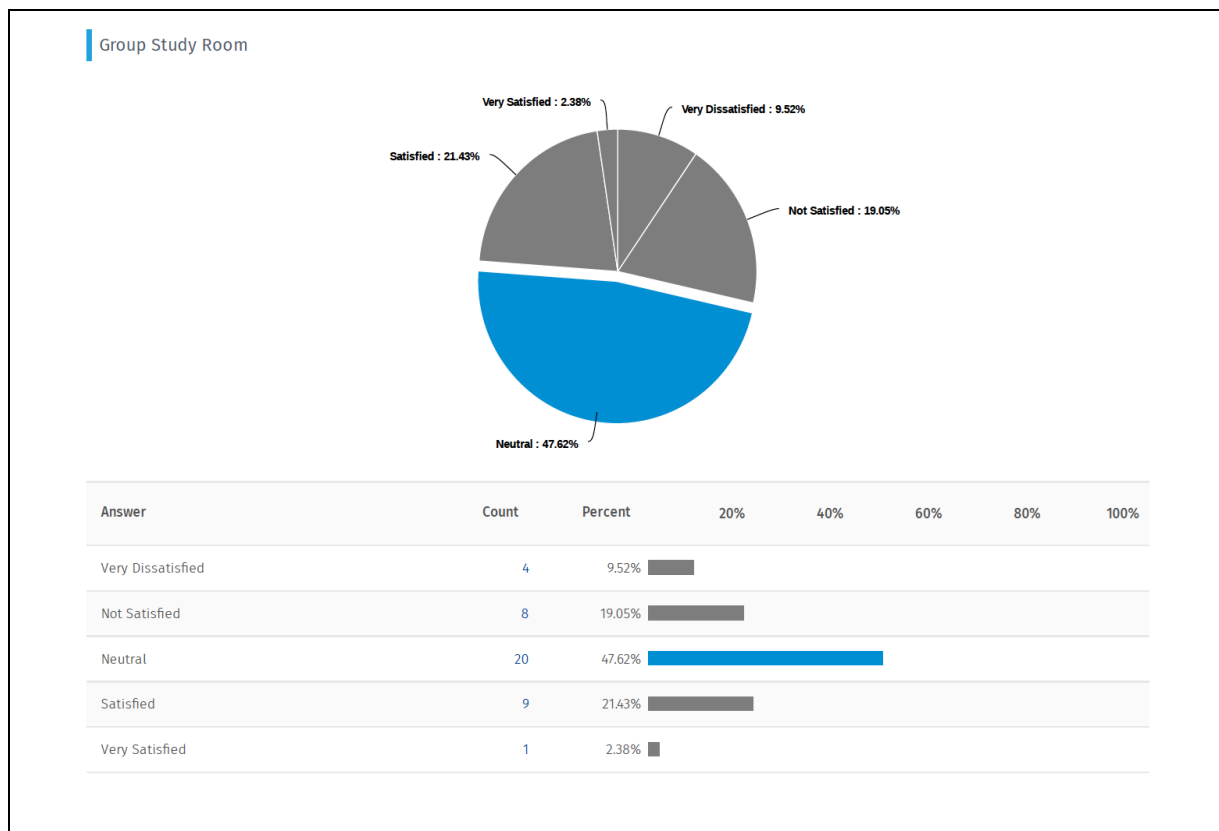


Figure 60: Satisfaction level of students in the group study room

(Source: Author,2022)

Figure 61 shows the satisfaction level in the board room. According to the information presented, 19.05% of respondents were not satisfied with meeting rooms, while 11.90% indicated extreme displeasure with them. A lack of visible positive or negative attitude toward these venues is indicated by the fact that over half of the respondents, or 47.62%, took a neutral perspective. Additionally, 7.14% of respondents (14.29%) said they were extremely satisfied with the meeting space. These results show a wide range of perspectives on meeting room settings, pointing out areas for development and factors that boost user satisfaction. These many viewpoints can be used to generate efficient design and utilization techniques.

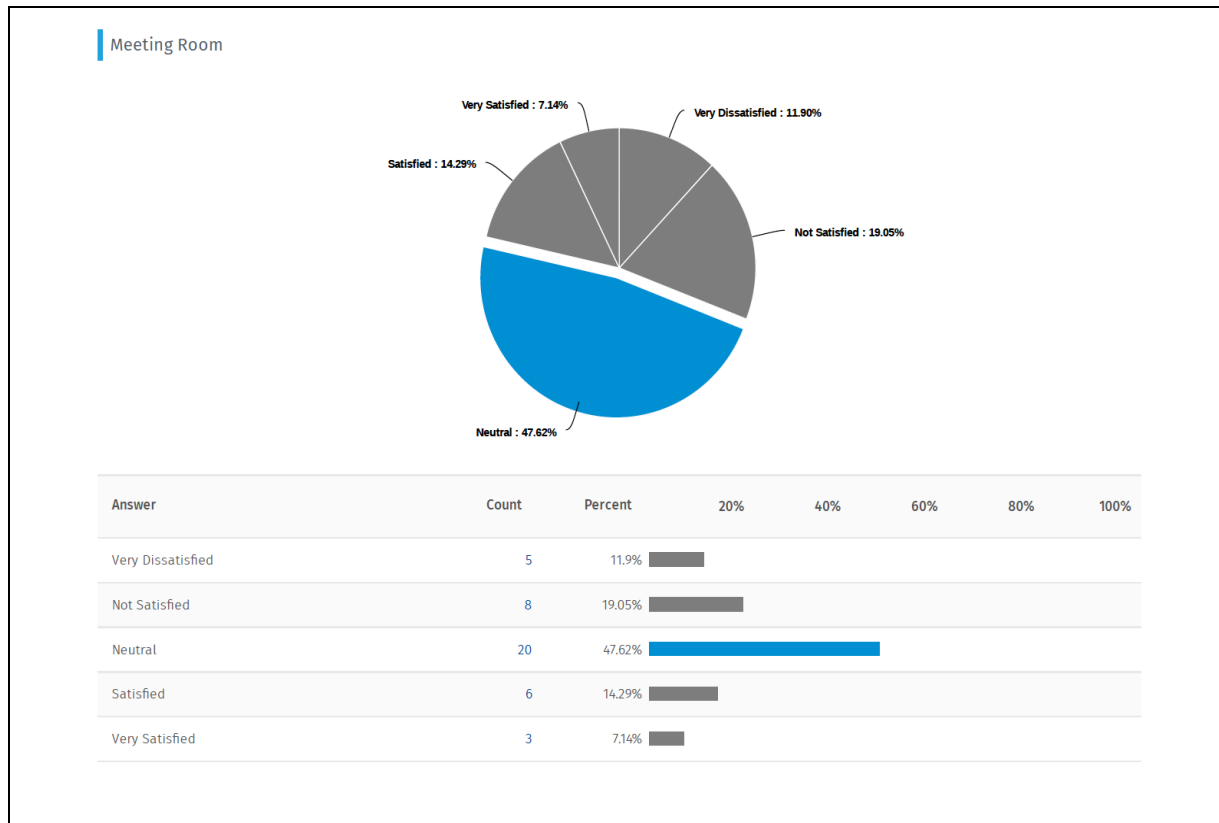


Figure 61: Satisfaction level in the board room

(Source: Author,2022)

Figure 62 shows the Satisfaction level of all users in the auditorium. According to the figure, it was found that 12.50% of respondents expressed very low levels of satisfaction with auditoriums, while 30.00% were not satisfied. 35.00% of respondents took a neutral attitude, showing that there was no clear preference for or against these areas. Additionally, 5.00% of respondents said they were extremely satisfied with the auditoriums, while 17.50% said they were satisfied. These findings reflect a variety of viewpoints on auditorium settings, highlighting both characteristics that might be improved and those that increase customer happiness. These various perspectives might serve as a guide for developing strategies aimed at maximizing these areas.

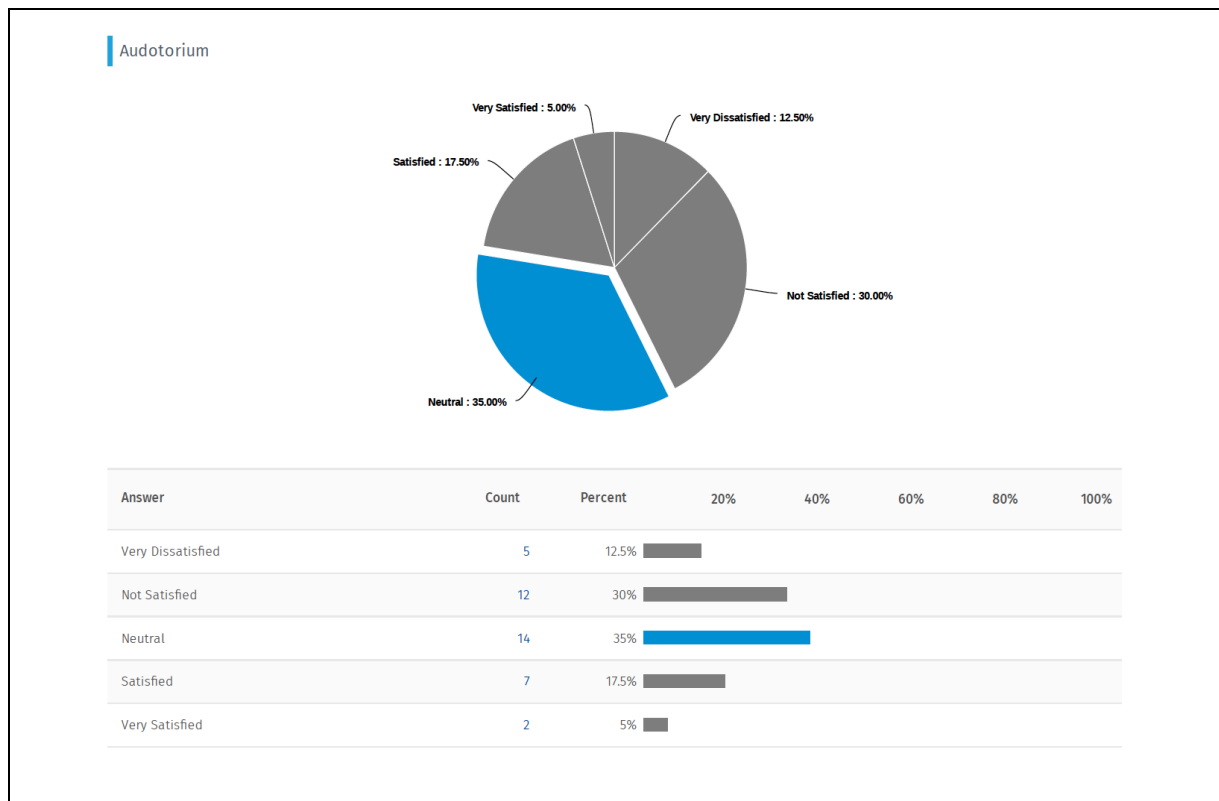


Figure 62: Satisfaction level of all users in the auditorium

(Source: Author,2022)

Parameters should be improved to enhance the performance in different working areas. The data that has been reported represents how participants felt about the need to increase the amount of daylight in their workspaces. These are the participants' responses shown in Figure 63, broken down as follows: 6.98% of responders thought that just minor daylight enhancement was needed. 9.30% of the participants said they could use some improvement. 18.60% of participants said they needed to improve in this area. A significant improvement, in the opinion of 25.58% of participants, was required. The majority (39.53%) thought that a significant improvement in the amount of daylight was crucial. The information as a whole emphasizes the value of natural lighting and the differing opinions among participants regarding the need to improve daylight conditions for a more optimum and effective working environment. These results match those observed in earlier study conducted by (Pulay, 2010), found that more students and faculty in the day lit facility were aware of daylighting than students in an educational facility not designed with daylighting techniques. This could be caused by various reasons and level of user's awareness and perception of the importance of natural lighting in indoor spaces, which, in turn, could promote students' academic performance.

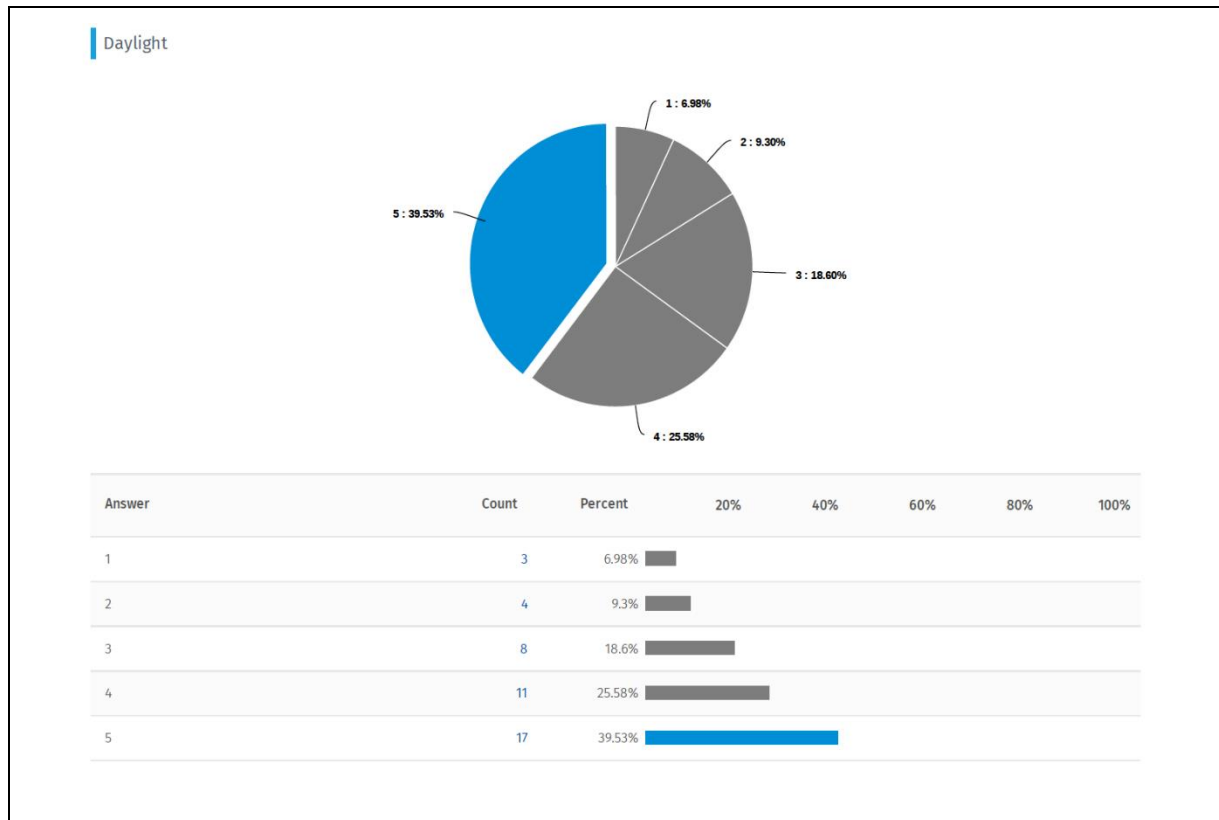


Figure 63: Daylight satisfaction level

(Source: Author,2022)

Figure 64 shows the artificial lighting satisfaction level. The data provided relates to how participants perceived the need for better artificial illumination in their workspaces. The participants gave ratings ranging from 1 to 5, with 1 denoting only a small amount of improvement required and 5 denoting a significant amount. The responses were distributed as follows: 4.44% of responders thought only a slight improvement was required. 13.33% of the responders said they could use some improvement. 37.78% of participants said they needed to improve moderately. 28.89% of participants thought there needed to be a significant improvement. 15.56% of responders thought artificial lighting needed to be much improved.

results demonstrate the many viewpoints on the need to improve artificial lighting in workplaces, highlighting the significance of improving lighting conditions to promote a conducive and efficient learning environment.

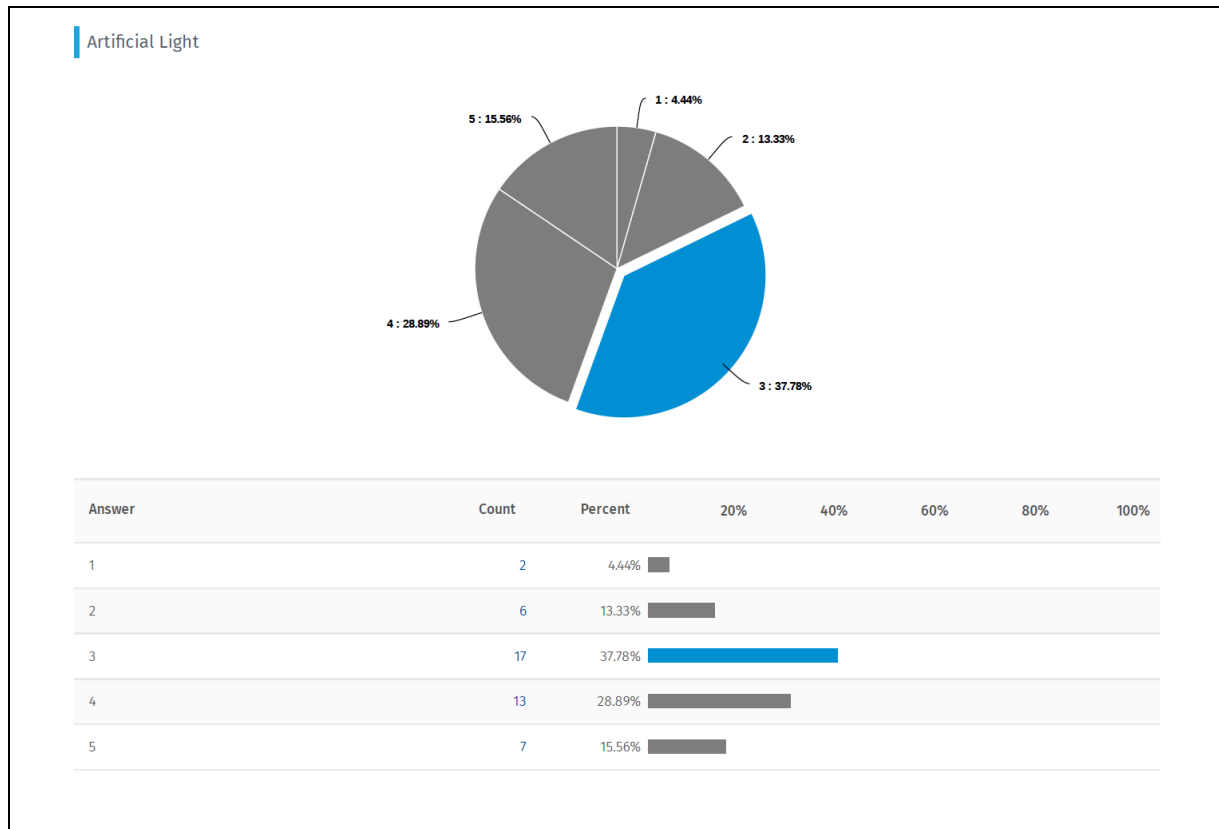


Figure 64: Artificial lighting satisfaction level

(Source: Author,2022)

4.4.1 Summary of Survey Findings

In general, the survey's concluding section, where participants share insightful comments, provides helpful information on ways to improve the indoor environment's quality in terms of lighting on campus. These insights offer valuable guidance for campus administrators and

designers seeking to enhance the quality of indoor spaces in terms of lighting, for fostering an environment conducive to productivity, well-being, and engagement. These recommendations and the rest of the survey results helps to understand the environmental conditions and make it possible to predict the user's satisfaction levels in the campus building in relation to the previous variables. Whereas, questions were designed to investigate and create more clear vision about the students and staff feelings and how they behave and their awareness of the importance of the interior environment and its effect on their performance and productivity.

It is encouraging to compare the above-mentioned results with those found by the U.S. Department of Energy (2010), which emphasized the significance of applying green building concepts to educational campuses due to their substantial energy consumption. This aligns with the importance of implementing sustainable design practices from the early stages of the design process. These practices should encompass not only architectural characteristics and building exteriors but also the integration of green materials in indoor spaces, thoughtful lighting design for both daylight and artificial lighting, furniture layout, and various other aspects. According to the findings of this study, interior space color and the appropriate use of lighting emerge as critical design elements that positively impact students' performance.

Despite the fact that interior room illumination and hue are crucial elements that support learning for students in accordance with different task and activities of each space. According to study conducted in the university of Sharjah as mentioned previously in the literature review chapter done by (Aljunaibi et al., 2018), it was stated that suitable lighting classroom can encourage students for improved learning. Users will be more comfortable, are not as sleepy, and are somewhat motivated to learn more in a classroom with decent lighting.

Additionally, the quantity and quality of light in classrooms considers how students concentrate on the tasks they are supposed to do or focused on. For pupils to study more effectively, good learning spaces that have the right lighting quality will act as a sort of intangible inspiration and encouragement. However, arranging light in workplaces or classrooms according to the subject is a crucial idea. This means that when students are required to write anything, the manner the light must be applied differs from when they are required to work on their screens or look on a board in the classroom. different lighting types selection will be necessary in many spaces, classrooms, library, offices, and auditorium, depending on the subject being utilized in these zones as stated by (Samani and Samani, 2012).

4.5 Computer Simulation

Following the manual illuminance measurement, DIALux EVO 11 lighting design software was used to generate a 3D model of the case study and calculate the illuminance as a base case to validate the collected measurements which conducted on site by using light meter device in specified task area. The dimensions, positions, and materials of surfaces and interior parts must be defined in the initial step of space modeling. Then, using the coordinate system, items like as windows, doors, and furniture are added to the space, so that the model accurately captures the current state of the area.

The first stage in designing a lighting system with software is to choose and insert the luminaires. The luminaires can be added to the project using the software library or online databases. After creating a 3D model of the space in the software, the lighting settings are calculated. Based on the entered data, the software can compute the illumination, uniformity,

glare rating, daylighting factor, and energy consumption. The calculations consider the latest European standards, EN 12464-1, and their recommendations and requirements of each task area. According to the results of the calculations, various suggested strategies were followed and measured by the software through the possibility to monitor the distribution of light and thus avoid the improper arrangement and installation of luminaires in the space. As well measure the daylight factor and interior material finishes reflectance factor to be enhanced through allowing the daylight in, or by changing the LRV factor of different surfaces of each space. Moreover, through changing the luminaires' arrangement or switching it to another type of power, it can easily monitor changes in lighting parameters. Based on the calculated illuminance values, it is possible to display isolines, false colors, value charts, or a 3D rendering of the simulated environment based on the determined illuminance values. Graphical outputs such as isolines represented in contour lines with numbers which means the lux value of each line, false colors showing color ranged from purple and blue which represent a low lux value reaching to the red color which means a high lux value, tables are supported with the software. The estimated values can then be compared to the needed guideline values for the space type.

4.6 Base Case Model

Figure 65 shows the model of the existing campus situation for all selected zones to be simulated and analyzed in this study reflecting the actual state of all spaces starting by the interior finishing material along with its reflectance values were done through matching the existing surfaces specifications with the same materials LRV inserted in the software catalogues wall paint (LRV 45%), ceiling (LRV 60%), floor (LRV 15%), furniture surfaces (LRV 25%),

luminaires types and arrangements. After defining the different zones and task area in the model for each zone, to be able to make the enhancements, first stage included calculating the current condition of lighting through the software checking the lighting level and compare it with the standards plugged into the software based on EN 12464-1. The following sections represents the graphical presentation produced by DIALux Evo associated with the lux levels in two scenarios the first one at night and the second scenario simulated during the day, and other parameters calculations to be discussed in the following sections along with luminaires list and specifications used in the existing model.

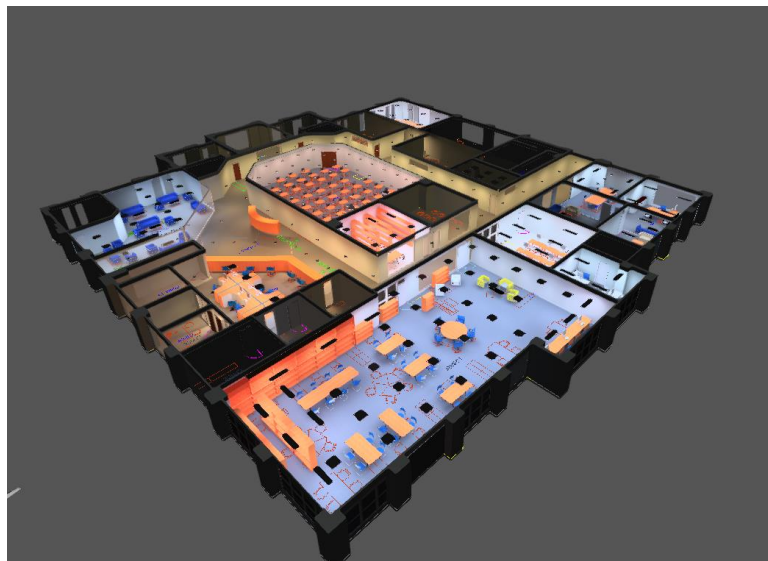


Figure 65: Campus building 3D model by DIALux EVO 11

(Source: Author,2023)

4.6.1 Scenario 1: Existing luminaries' types and arrangements -At night

The auditorium space shown in Figure 66. The auditorium represents the main area of the shared regularly multi occupant space where the most campus activities, conferences, and public presentation and speaking held in this space. The measured lux level around 318 which considered far from the target lux as per the standards. The space required more efficient lighting system to let the space in proper way and more appropriate uniformity ratio to be adequate to the activities held on it.

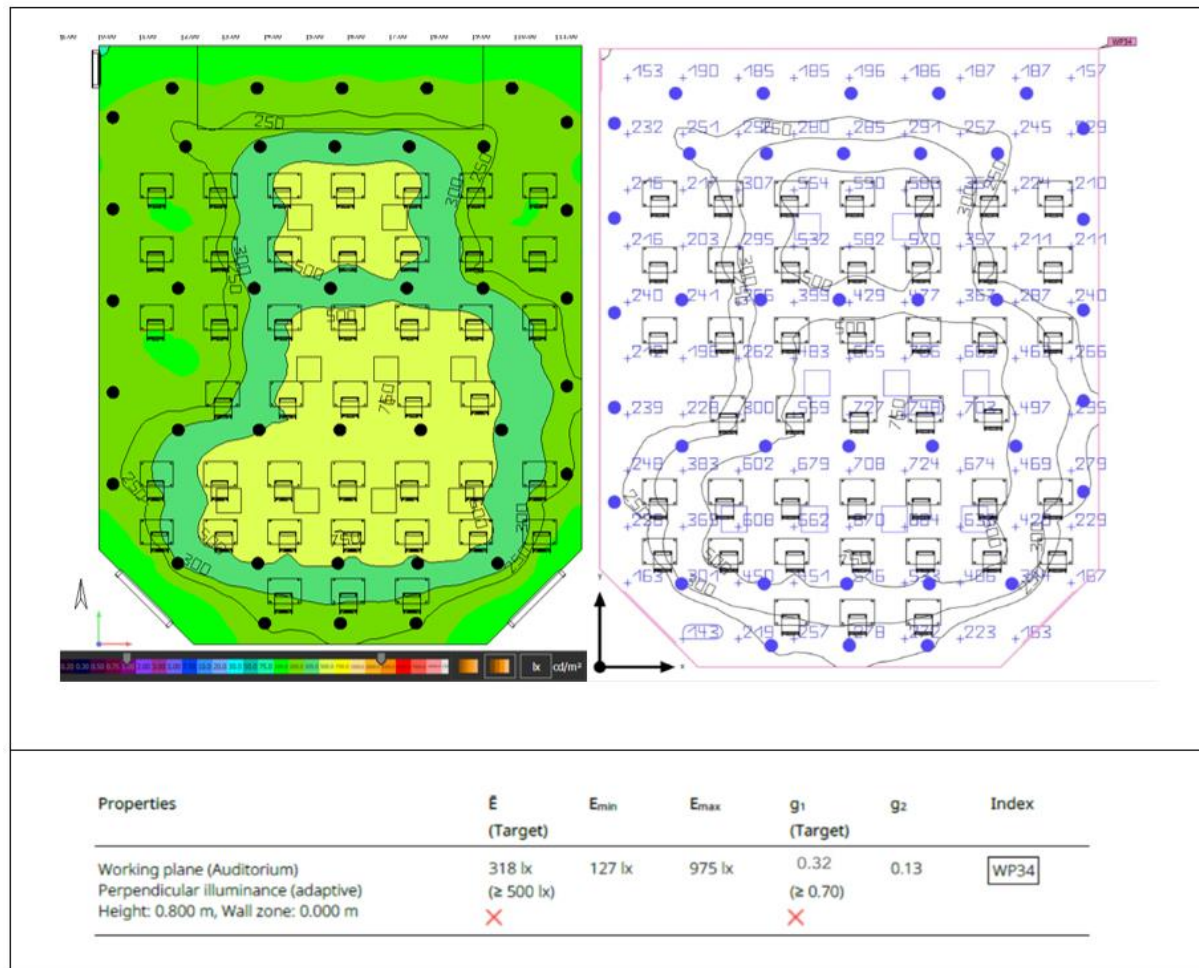


Figure 66: Auditorium light lux level and uniformity ratio

(Source: Author,2023)

The lux value in the class room highlighted in the green check mark indicate that lighting level meet the target but at the same time it's considered as over let space in the middle area which around 1000 lux, and the target in the classroom around 500 lux so this explain the low uniformity ratio in the space which make it uncomfortable for the required task either for the students or the lecturer causing high glare levels.

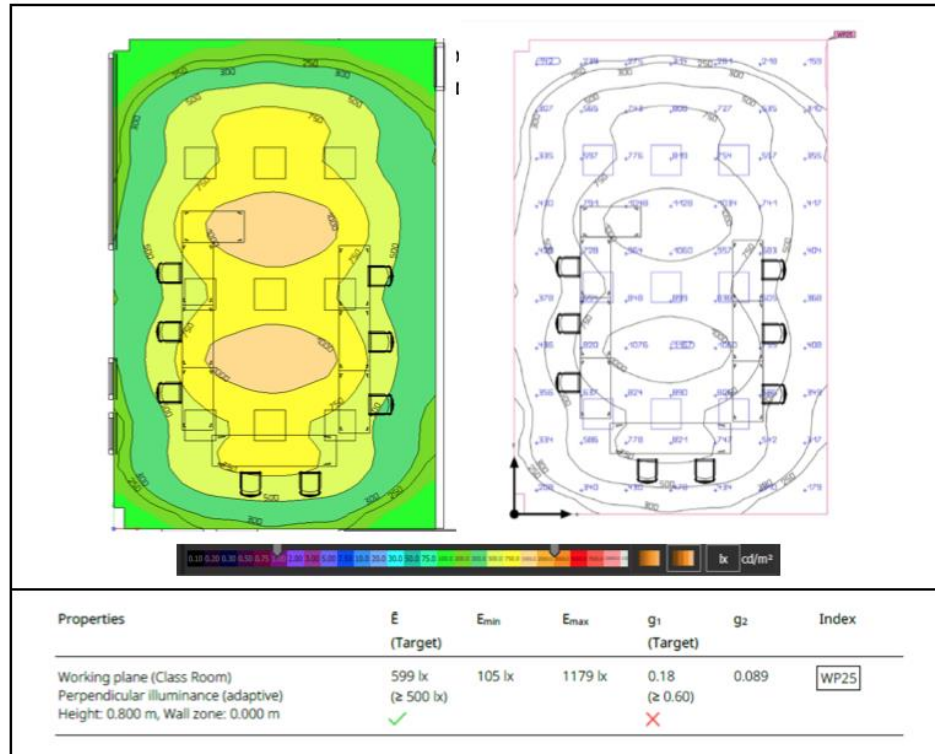


Figure 67: Classroom FF 111- light lux and uniformity ratio

(Source: Author,2023)

The library in BUiD located toward the main court in the academic city, includes three main areas one for reading, other for book shelves, and computer screens for public use, and the librarian officers. As mentioned previously each task zone required a specific light level to achieve the required task in a comfortable environment. As shown in Figure 68, the middle reading area considered as over bright with 600- to 1000 lx. While, the book shelves in the corner looks very dark as the target should be around 200 lx and the offices zone also considered as poor let zone.

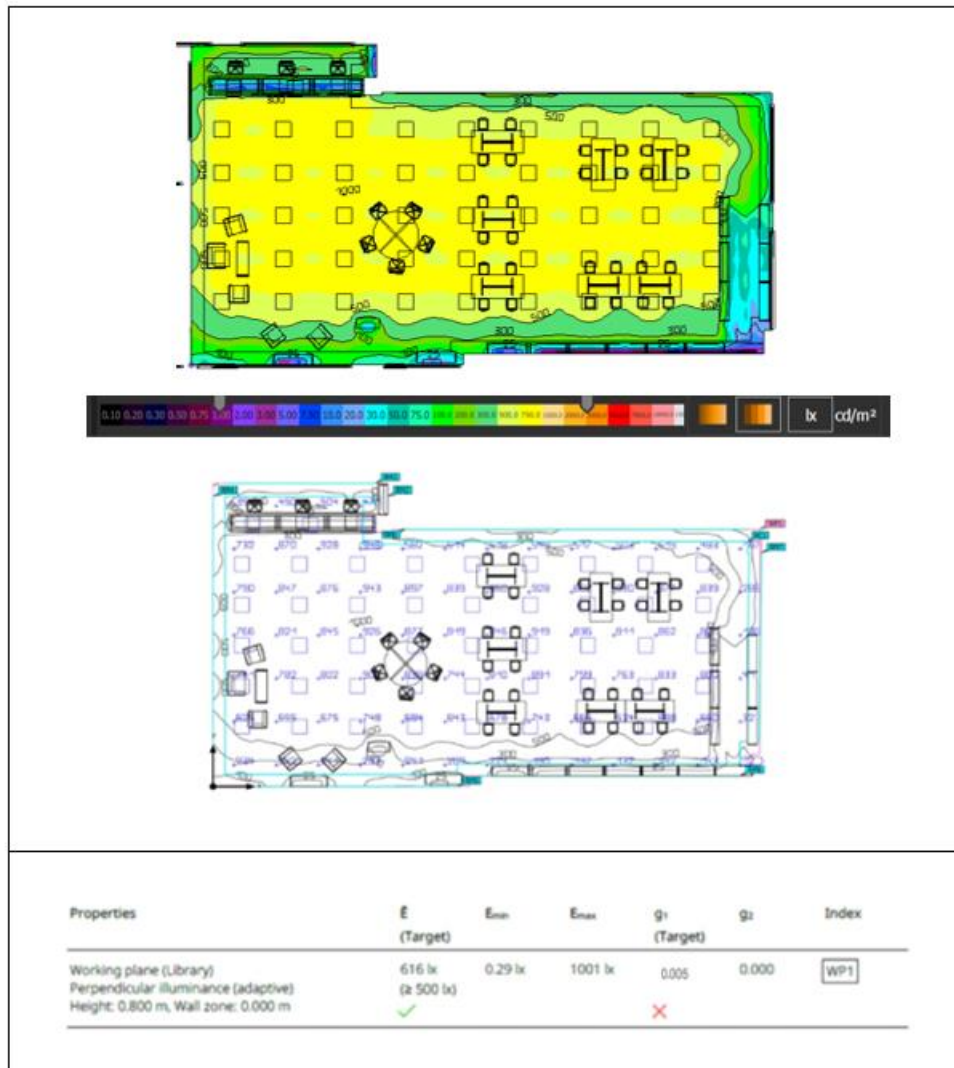


Figure 68: Library- light lux and uniformity ratio

(Source: Author,2023)

Figure 69 shows the administration room. The figures show the open office space as a dark area for the desk facing the corridor and the offices zones, at the same time the middle area (circulation zone) considered as over bright due to the use of fluorescent light tiles and down lights fixtures as it looks too much for that area causing brightness and uncomfortable working

zone. The same results founded it on site measurements and staff experience with high glare values on their screens.

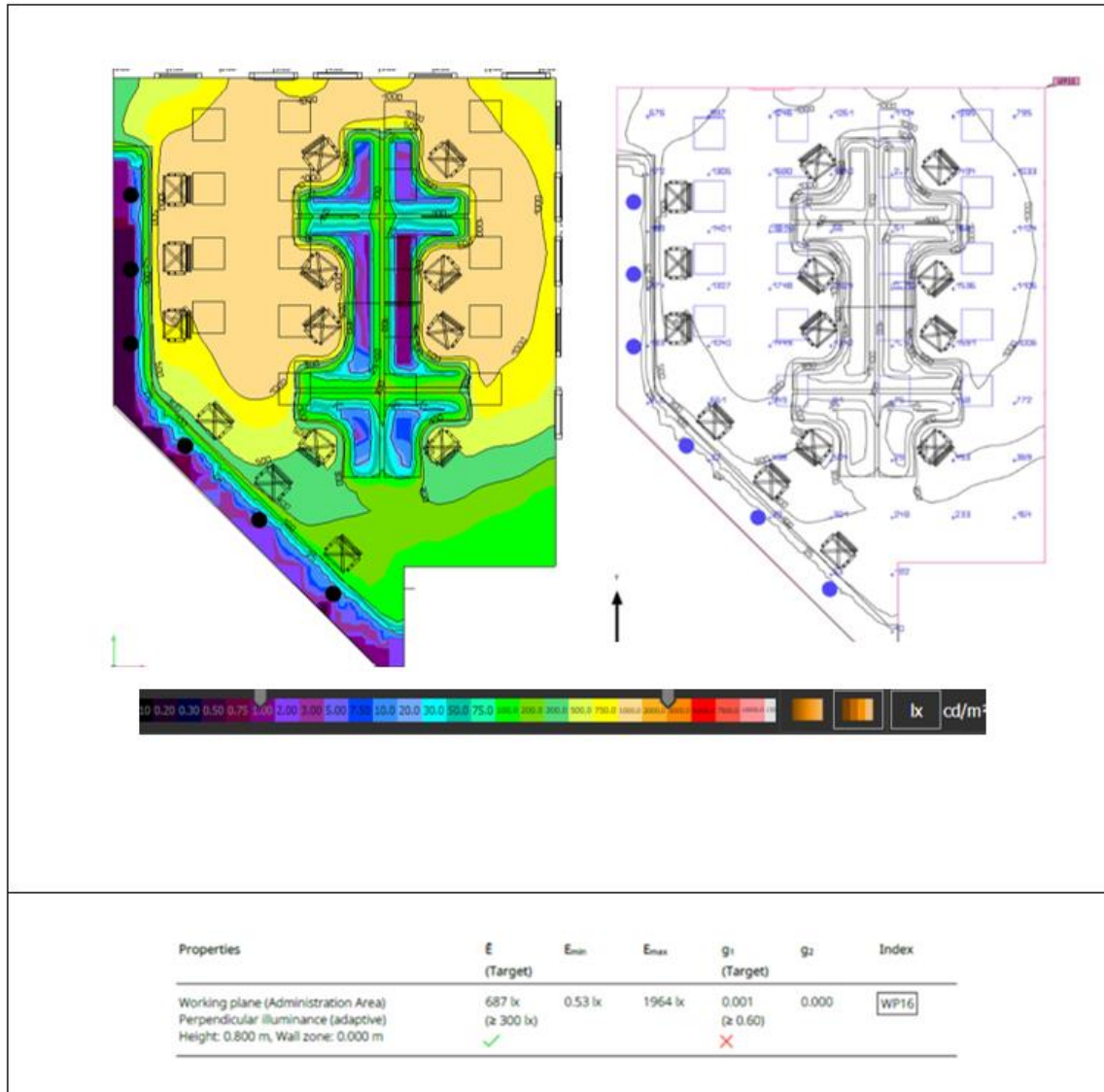


Figure 69: Administration area- light lux and uniformity ratio

(Source: Author,2023)

Figure 70 shows a group study room located in the main library zone. This room is unique in that it lacks any windows, meaning there is no access to natural daylight. The study room is divided into two primary sections: one intended for reading and the other for bookshelves. These two areas require different lighting conditions to ensure the comfort of users while studying. The red 'X' marked in the figure indicates that the reading area does not meet the targeted lux levels, with insufficient brightness. Moreover, the uniformity ratio in this area also falls short of the required standard.

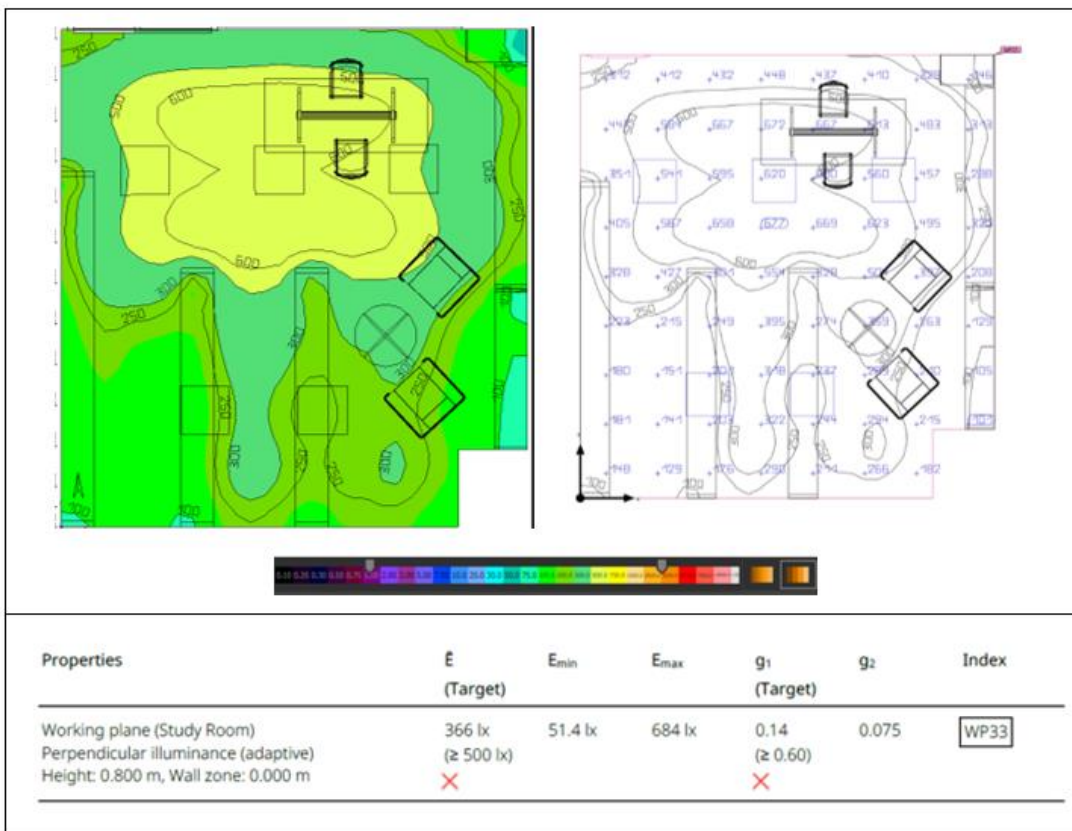


Figure 70: Group study room - light lux and uniformity ratio

(Source: Author,2023)

Figure 71 depicts the student lounge, designed as an interactive space on the campus, often utilized for student presentations such as posters and projects. However, there are certain issues with the lighting in this area. The measured lux value does not meet the target level of around 173 lux, closely resembling the value recorded on-site by the lighting meter. The lighting appears excessively bright with a stark white hue, which may not be the most suitable choice for this type of space. Consequently, the student lounge's design does not foster a quiet and calming atmosphere. The powerful color tones used for the furniture and walls may contribute to this problem.

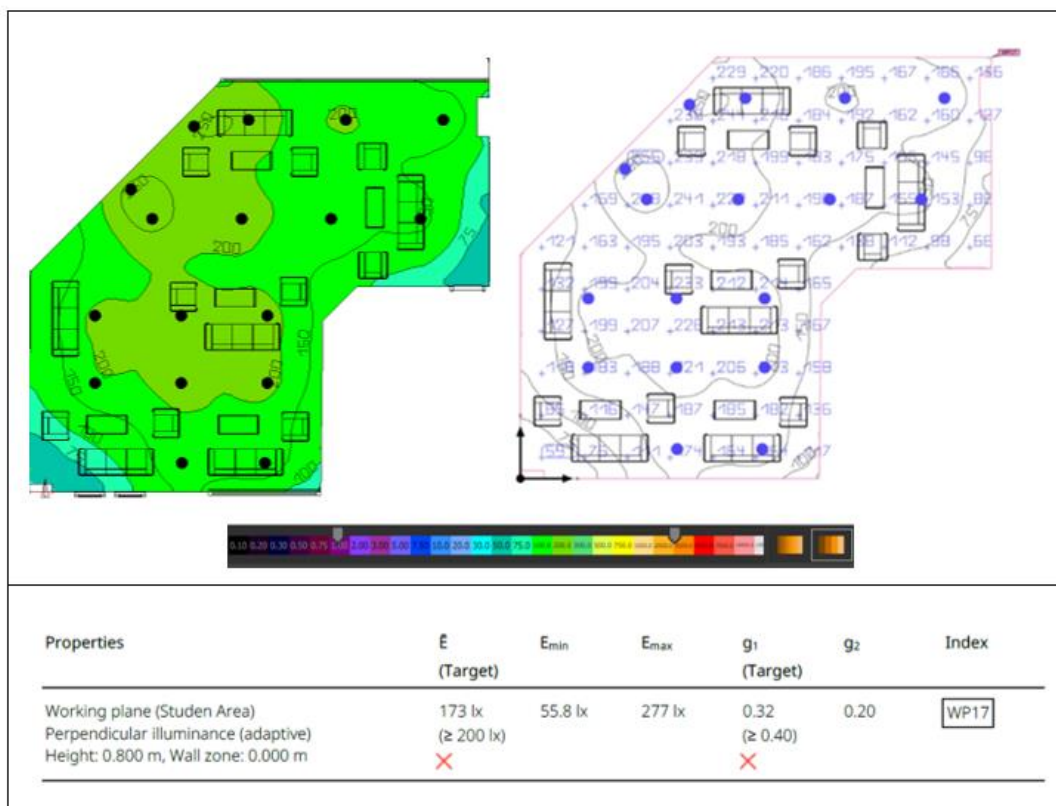


Figure 71: Student lounge room - light lux and uniformity ratio

(Source: Author,2023

Figure 72 displays the meeting room, a versatile space used for various meetings and presentations. The room features ten downlights and blue-colored indirect lighting. However, there are notable issues with the lighting. The excessive white light in the area creates significant glare, making the space uncomfortable for the audience, particularly during screen presentations. To mitigate the glare, the downlights are often turned off, resulting in a very dark area for the audience. Additionally, the glossy material of the meeting table reflects a significant amount of light into the audience's eyes, necessitating a change in both color and material to a matte finish for improved comfort and reduced glare.

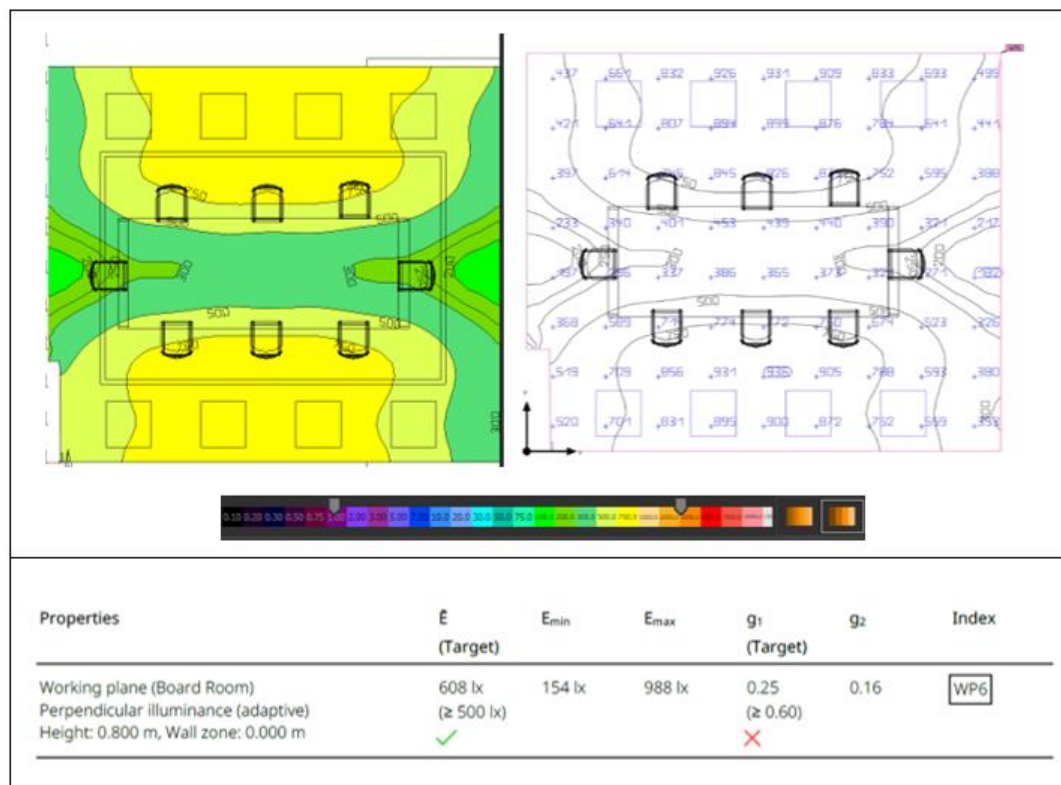


Figure 72: Board room - light lux and uniformity ratio

(Source: Author,2023)

In Figure 73, the educational campus passageways have been repurposed as creative workstations, facilitating presentations, idea discussions, group work, and interactions with students and staff. While it's beneficial to use lighting in common areas to delineate specific zones, it's crucial to ensure that it doesn't cause discomfort to users in adjacent rooms, as observed in BUiD. This issue arises due to the presence of windows on the upper side of the room's walls, allowing light to spill into the adjacent areas. Notably, the lux level in this space falls within the range of the target value, approximately 100 lux.

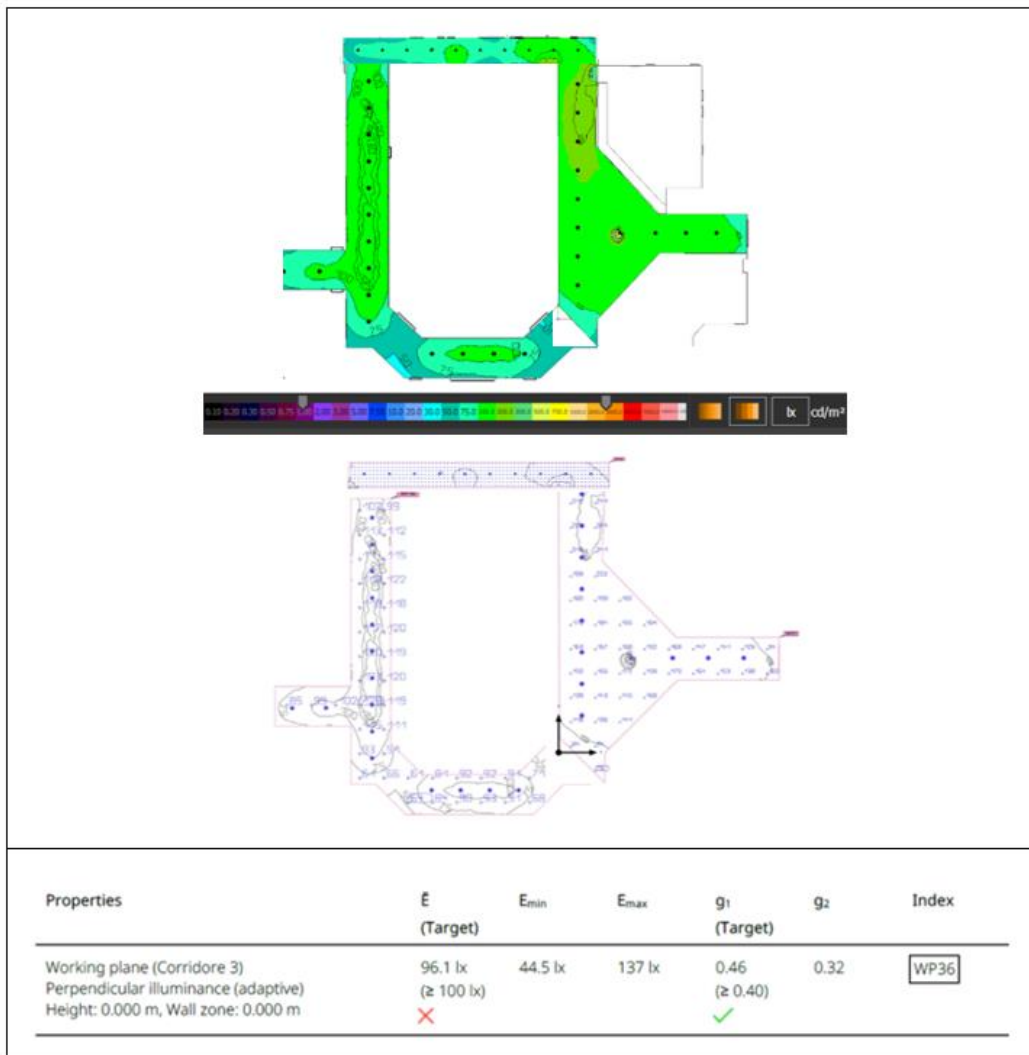


Figure 73: Corridor - light lux and uniformity ratio

(Source: Author,2023)

Figure 74 illustrates an individual office space designed for registration and chief officers at BUiD. The thoughtful integration of both daylight and artificial lighting within this setting offers users not only adequate views but also fosters a connection with the outdoor environment, aligning with scholarly principles that emphasize the significance of such integration. This

approach enhances user comfort and contributes to a productive and well-balanced work environment, underscoring the interplay between lighting and human well-being.

However, a critical assessment of the current lighting plan reveals insufficient lux values in this area. This issue arises from the inappropriate arrangement of downlights and is further exacerbated by surface reflectance values that impact the overall lighting quality in the space. In light of these observations, forthcoming strategies will be discussed to address these concerns. These strategies will encompass potential enhancements for daylight, artificial lighting, or a harmonious combination of both, in accordance with established academic norms and practices.

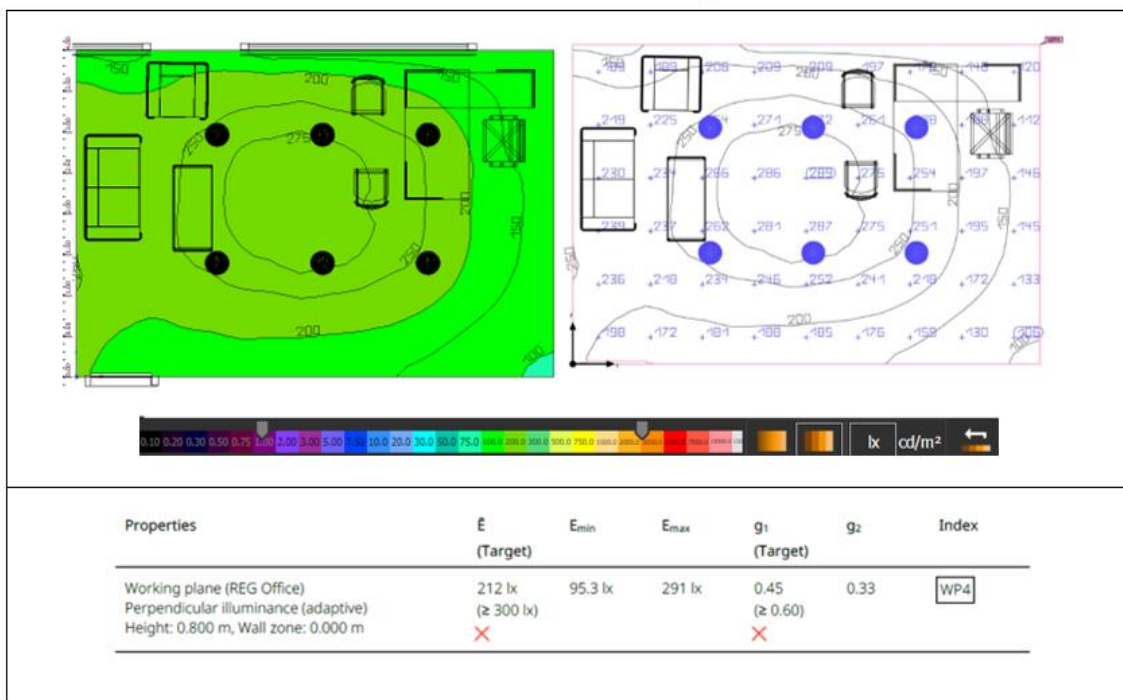


Figure 74: REG Office - light lux and uniformity ratio

(Source: Author,2023)

Figure 75 illustrates the artificial lighting fixtures used in the base case model. These fixtures accurately represent the existing luminaire types and have been incorporated into the software based on the plans and images gathered from BUiD. There are two primary types of fixtures distributed throughout Block 11, specifically on the first floor of the campus spaces: fluorescent lights and downlights.

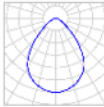
 		  	
Article No.	7150401	P	3.0 W
P	78.0 W	Φ_{Lamp}	400 lm
Φ_{Lamp}	5400 lm	$\Phi_{Luminaire}$	400 lm
$\Phi_{Luminaire}$	3870 lm	η	100.00 %
η	71.67 %	Luminous efficacy	133.3 lm/W
Luminous efficacy	49.6 lm/W	CCT	3000 K
CCT	4000 K	CRI	80
CRI	80		

Figure 75: Artificial lighting fixtures used in the base case model

(Source: Author,2023)

To summarize, four main spaces have met the target lux levels on average, including the library, classroom, administration area, and the boardroom. However, on-site measurements reveal results that do not align with established standards. Therefore, it is imperative to enhance the lighting conditions in these spaces to improve the overall experience of both staff and users. This involves addressing various lighting parameters to attain an optimal scenario, such as uniformity ratio, glare value, and the color scheme within the space. Conversely, the lux values

in the remaining zones fall below the required standards. Consequently, there is a need for improvement in terms of lux levels and other relevant parameters. Refer to Table 39 for specific measurements and data.

Table 39: Summary report of different zones in the campus, base case model, scenario1:at night, (Source: Author,2023)

Auditorium						Classroom FF-111					
	Symbol	Calculated	Target	Check	Index		Symbol	Calculated	Target	Check	Index
Daylight	D	0.000 %	-		DF34	Working plane	$E_{\text{perpendicular}}$	599 lx	≥ 500 lx	✓	WP25
Working plane	$E_{\text{perpendicular}}$	318 lx	≥ 500 lx	✗	WP34		g_1	0.18	≥ 0.60	✗	WP25
	g_1	0.32	≥ 0.70	✗	WP34	Glare valuation ⁽¹⁾	$R_{UG,max}$	17	≤ 19	✓	
Glare valuation ⁽¹⁾	$R_{UG,max}$	21	≤ 19	✗		Energy estimation ⁽²⁾	Consumption	[560.73 - 933.66] kWh/a	max. 2050 kWh/a	✓	
Energy estimation ⁽²⁾	Consumption	1404 kWh/a	max. 5650 kWh/a	✓							
Library						Administration area					
	Symbol	Calculated	Target	Check	Index		Symbol	Calculated	Target	Check	Index
Working plane	$E_{\text{perpendicular}}$	616 lx	≥ 500 lx	✓	WP1	Working plane	$E_{\text{perpendicular}}$	687 lx	≥ 300 lx	✓	WP16
	g_1	0.000	≥ 0.60	✗	WP1		g_1	0.001	≥ 0.60	✗	WP16
Room main surfaces	E_{ceiling}	1.26 lx	≥ 50.0 lx	✗	RC1	Glare valuation ⁽¹⁾	$R_{UG,max}$	21	≤ 22	✓	
	g_1 ceiling	0.27	≥ 0.10	✓	RC1	Energy estimation ⁽²⁾	Consumption	[2739.56 - 4347.75] kWh/a	max. 2650 kWh/a	✗	
	E_{walls}	7.15 lx	≥ 100 lx	✗	RM7						
	g_1 walls	0.005	≥ 0.10	✗	RM7						
Glare valuation ⁽¹⁾	$R_{UG,max}$	17	≤ 19	✓							
Energy estimation ⁽²⁾	Consumption	[8987.10 - 13478.40] kWh/a	max. 8550 kWh/a	✗							
Group study room						Students lounge					
	Symbol	Calculated	Target	Check	Index		Symbol	Calculated	Target	Check	Index
Working plane	$E_{\text{perpendicular}}$	366 lx	≥ 500 lx	✗	WP33	Working plane	$E_{\text{perpendicular}}$	173 lx	≥ 200 lx	✗	WP17
	g_1	0.14	≥ 0.60	✗	WP33		g_1	0.32	≥ 0.40	✗	WP17
Glare valuation ⁽¹⁾	$R_{UG,max}$	17	≤ 19	✓		Glare valuation ⁽¹⁾	$R_{UG,max}$	19	≤ 22	✓	
Energy estimation ⁽²⁾	Consumption	1404 kWh/a	max. 1200 kWh/a	✗		Energy estimation ⁽²⁾	Consumption	[340.24 - 539.96] kWh/a	max. 3200 kWh/a	✓	

Board room					
	Symbol	Calculated	Target	Check	Index
Working plane	$E_{\text{perpendicular}}$	608 lx	≥ 500 lx	✓	WP6
	g_1	0.25	≥ 0.60	✗	WP6
Glare valuation ⁽¹⁾	$R_{UG, \max}$	17	≤ 19	✓	
Energy estimation ⁽²⁾	Consumption	[979.04 - 1201.20] kWh/a	max. 1150 kWh/a	✗	

Corridor					
	Symbol	Calculated	Target	Check	Index
Working plane	$E_{\text{perpendicular}}$	96.1 lx	≥ 100 lx	✗	WP36
	g_1	0.46	≥ 0.40	✓	WP36
Glare valuation ⁽¹⁾	$R_{UG, \max}$	23	≤ 25	✓	
Energy estimation ⁽²⁾	Consumption	290 kWh/a	max. 4500 kWh/a	✓	

Registration office					
	Symbol	Calculated	Target	Check	Index
Working plane	$E_{\text{perpendicular}}$	212 lx	≥ 300 lx	✗	WP4
	g_1	0.45	≥ 0.60	✗	WP4
Glare valuation ⁽¹⁾	$R_{UG, \max}$	17	≤ 22	✓	
Energy estimation ⁽²⁾	Consumption	[171.55 - 272.25] kWh/a	max. 850 kWh/a	✓	

4.6.2 Scenario 2: Existing luminaries' types and arrangements- During the day (11:00AM)

In this scenario, the condition under consideration involves taking into account daytime conditions, with some daylight passing through the existing curtains at 11 AM. This time was chosen as it represents the peak hour on the campus, and the field measurements were conducted concurrently under clear sky conditions, reflective of the typical climatic conditions in Dubai.

Figure 76 shows classroom FF 111- light lux and uniformity ratio. It is clear that areas near the windows receive significantly more natural light, which leads to increased heat gain within the space and subsequently higher energy consumption. Although the lux value near the

windows registers at 739 lux, it's important to note that the strong lighting lux contour reveals excessive glare and an uneven distribution of light in the room. This results in an uncomfortable classroom environment.

Figure 77 depicts the lighting conditions in the library, focusing on both light lux and uniformity ratio. It is evident that there is a slight increase in lux levels compared to the nighttime levels, reaching approximately 650 lux, which exceeds the target level set by the standards. Particularly near the windows during the day, the space appears excessively bright. The increased temperature resulting from opened curtains leads to greater energy consumption and creates an environment that is less conducive to reading or work.

Furthermore, in the bookshelves area, the recommended task lighting levels range from 200 to 300 lux. However, the measured values in this zone vary, with some exceeding the target range and others falling below it. This disparity results in an inadequate task lighting zone that does not align with the standard values and fails to meet the required uniformity ratio.

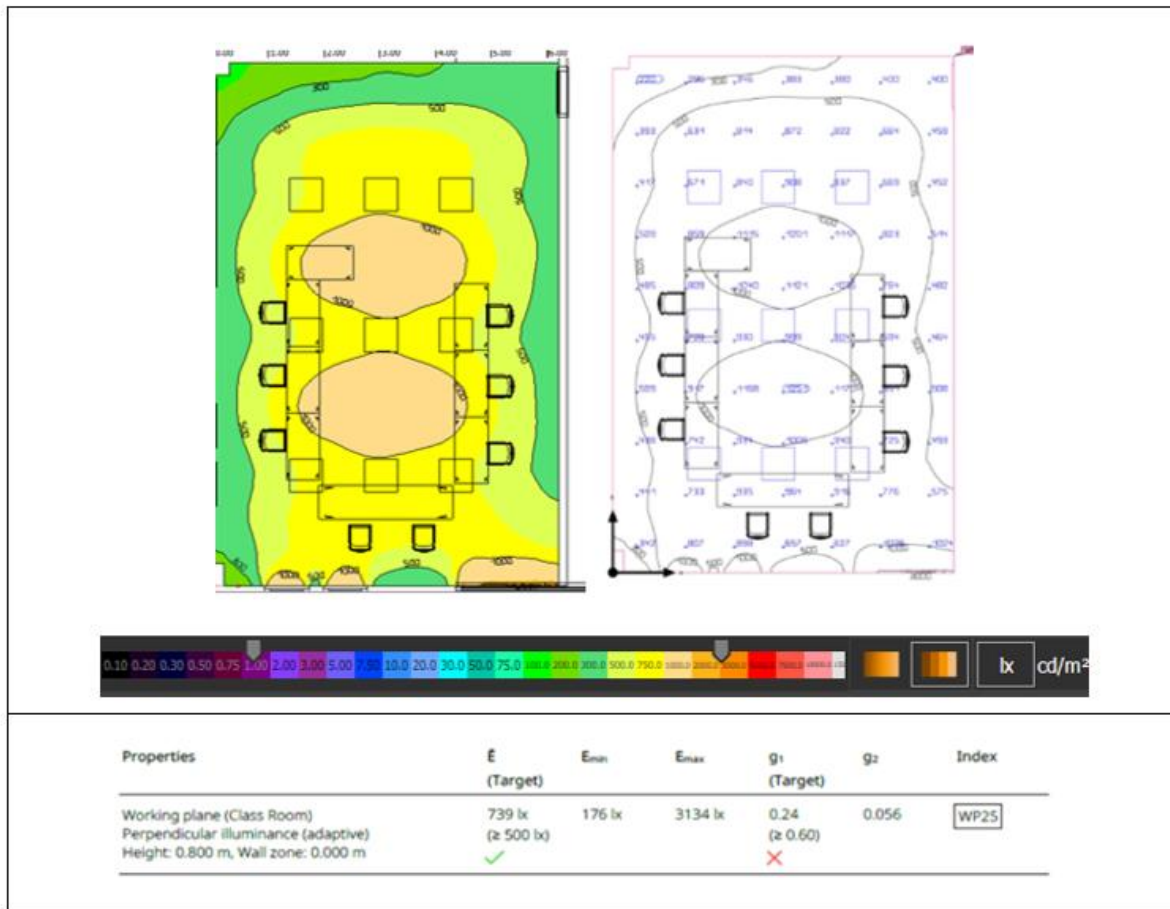


Figure 76: Classroom FF 111- light lux and uniformity ratio

(Source: Author,2023)

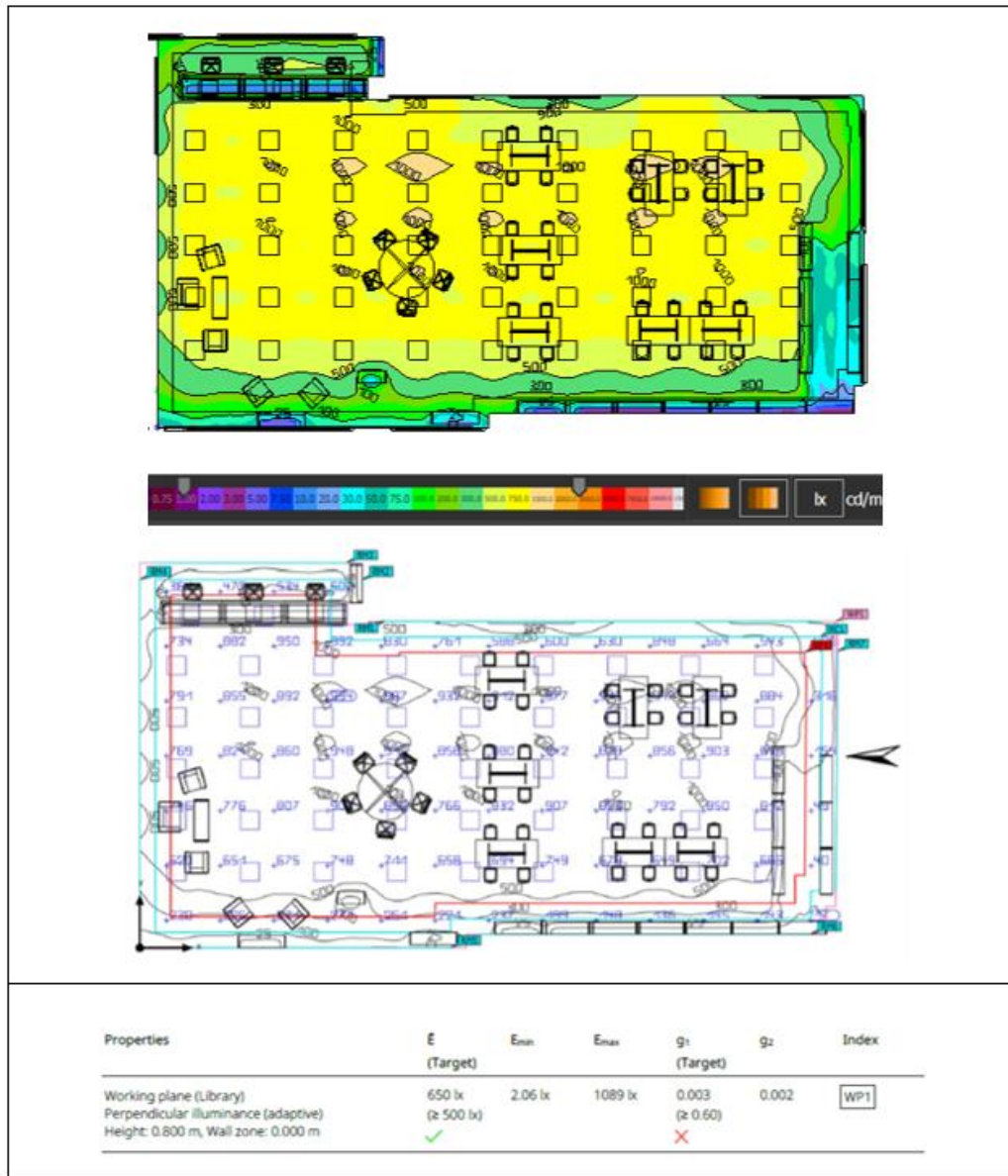


Figure 77: Library - light lux and uniformity ratio

(Source: Author,2023)

In Figure 78, the Student lounge area is assessed for its lighting conditions, particularly focusing on light lux and uniformity ratio. The simulation conducted under conditions where the curtains were closed reveals a moderate lux value, approximately 175. This level falls slightly below the recommended lux range of 200-300 for such areas according to established standards. The Student lounge is a versatile space with multiple potential uses. It serves as a flexible environment, suitable for activities such as brainstorming sessions, preparations during meeting breaks, or as a quiet space for dedicated professional work. Additionally, it functions as a break room for staff, providing them with a dedicated area to relax and unwind away from their workstations.

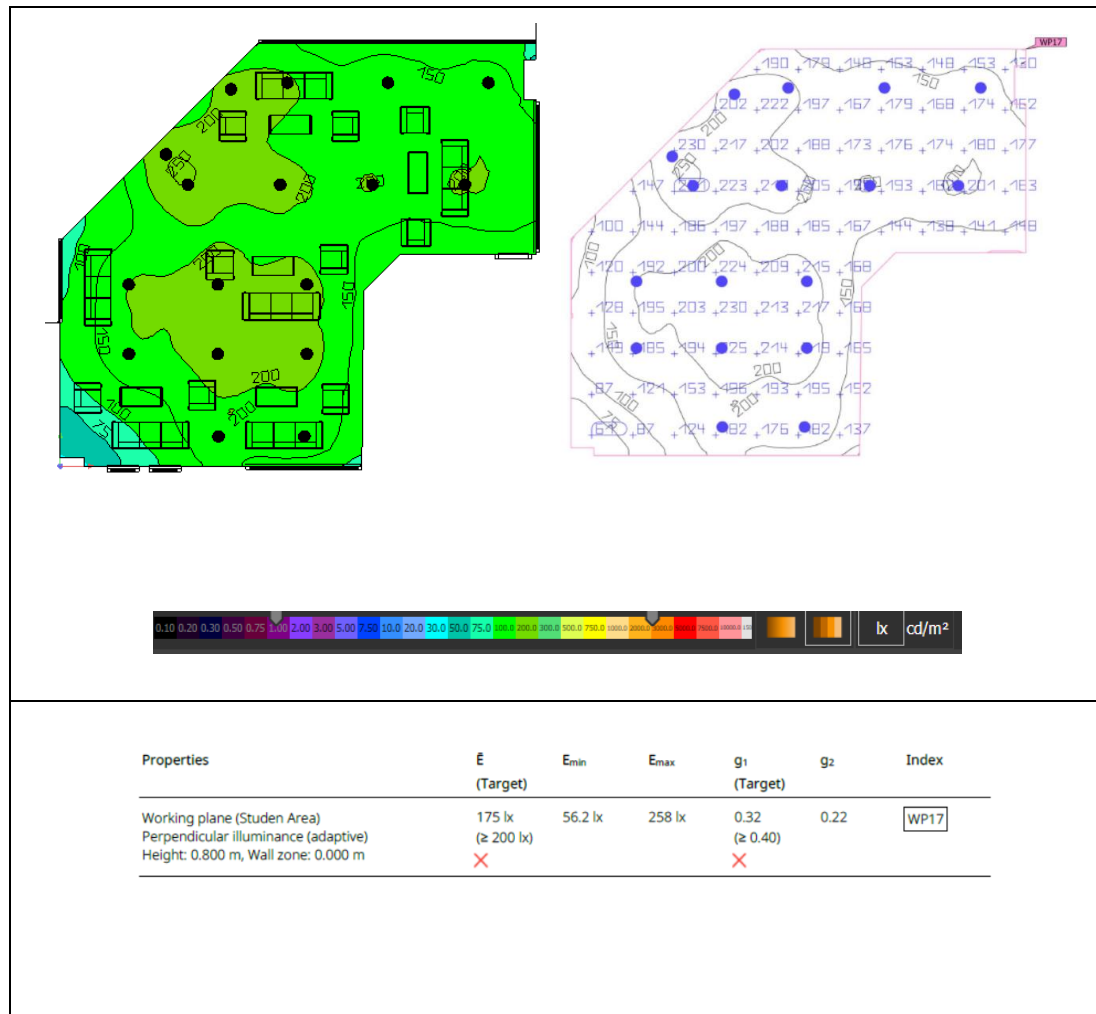


Figure 78: Student lounge - light lux and uniformity ratio

(Source: Author,2023)

Figure 79 displays the registration office space featuring six downlight fixtures and windows that face the main courtyard area. In this model, the curtains are kept closed. Unfortunately, the lux values in this setting do not meet the established target, resulting in a workspace that is inadequately illuminated for tasks like writing, reading, and other activities. However, a comparison with on-site measurements reveals a significant contrast. The lux level at the desk area was notably high, reaching around 700 lux. This discrepancy is primarily due to the desk's

proximity to the window, with the curtains partially open during the measurement. This resulted in increased temperature and screen glare, potentially compromising the functionality and comfort of the workspace.

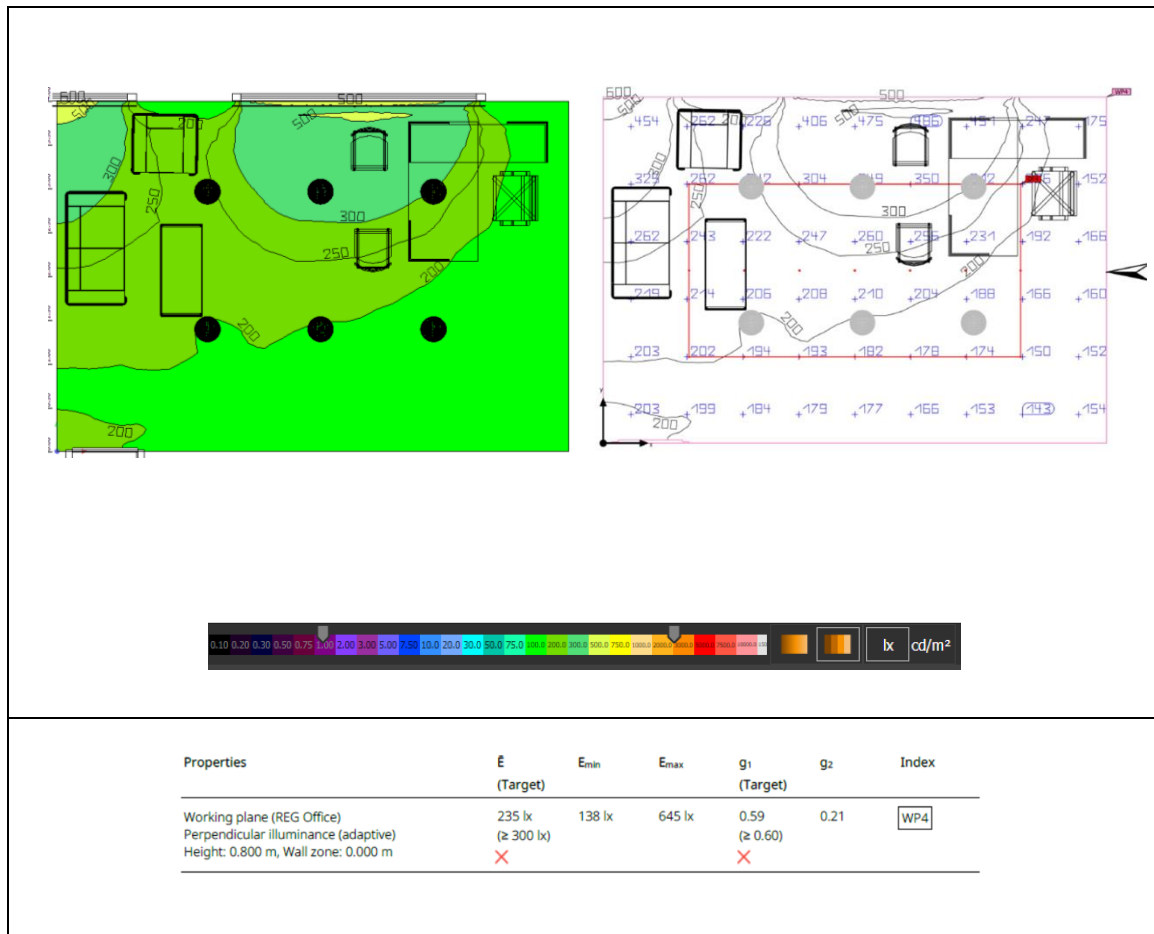


Figure 79: Registration office - light lux and uniformity ratio

(Source: Author,2023)

Table 40 presents a range of lighting parameter values that were measured during daylight hours, with a focus on capturing natural light within spaces containing windows, as previously

mentioned. While two of these spaces met the specified targets, it's worth noting that they lacked adequate light distribution across all task areas. This deficiency is highlighted by the non-compliance of the uniformity ratio, resulting in excessively bright spaces that cause glare and discomfort for those working within them.

On the other hand, drawing from the results outlined in the base case model, three distinct strategies have been proposed to explore the potential for enhancing the lighting conditions. These strategies are informed by a comprehensive review of relevant literature (Pratiwi and Djafar, 2021). Each proposed plan encompasses various scenarios aimed at realizing the best possible outcomes for each method. Subsequent sections will provide a detailed account of each strategy, its associated scenarios, the results achieved, and the ensuing discussion.

Table 40: Summary report of different zones in the campus- base case model, scenario2, During the day, (Source: Author,2023)

Classroom FF-111

Results

	Symbol	Calculated	Target	Check	Index
Working plane	$E_{\text{perpendicular}}$	739 lx	≥ 500 lx	✓	WP25
	g_1	0.24	≥ 0.60	✗	WP25
Glare valuation ⁽¹⁾	$R_{UL,max}$	17	≤ 19	✓	
Energy estimation ⁽²⁾	Consumption	[560.73 - 933.66] kWh/a	max. 2050 kWh/a	✓	

Students lounge

Library

	Symbol	Calculated	Target	Check	Index
Working plane	$E_{\text{perpendicular}}$	616 lx	≥ 500 lx	✓	WP1
	g_1	0.005	≥ 0.60	✗	WP1
Room main surfaces	E_{ceiling}	1.26 lx	≥ 50.0 lx	✗	RC1
	g_1 ceiling	0.27	≥ 0.10	✓	RC1
	E_{walls}	7.15 lx	≥ 100 lx	✗	RM7
	g_1 walls	0.005	≥ 0.10	✗	RM7
Glare valuation ⁽¹⁾	$R_{UL,max}$	17	≤ 19	✓	
Energy estimation ⁽²⁾	Consumption	[8987.10 - 13478.40] kWh/a	max. 8550 kWh/a	✗	

Registration office

	Symbol	Calculated	Target	Check	Index
Working plane	$E_{\text{perpendicular}}$	173 lx	≥ 200 lx	✗	WP17
	g_i	0.32	≥ 0.40	✗	WP17
Glare valuation ⁽³⁾	$R_{GL,max}$	21	≤ 22	✓	
Energy estimation ⁽³⁾	Consumption	[340.24 - 539.96] kWh/a	max. 3200 kWh/a	✓	

	Symbol	Calculated	Target	Check	Index
Working plane	$E_{\text{perpendicular}}$	235 lx	≥ 300 lx	✗	WP4
	g_i	0.59	≥ 0.60	✗	WP4
Glare valuation ⁽³⁾	$R_{GL,max}$	17	≤ 22	✓	
Energy estimation ⁽³⁾	Consumption	[171.55 - 272.25] kWh/a	max. 850 kWh/a	✓	

4.7 Strategies to Enhance Daylight and Artificial Light on the Campus

4.7.1 Strategy 1: Daylight Enhancement

The first strategy aimed to investigate the potential for improving lighting conditions by harnessing natural daylight through existing windows. This approach relied on the presence of the same artificial lighting fixtures which already present in areas with windows and views like the library, student lounge, classroom FF-111, and the registration office. Two distinct scenarios were developed to analyze this strategy without changing the space specifications in terms of surfaces LRV. The simulation was conducted in two scenarios, at 11 AM. The first one where all curtains are fully opened, and in the second scenario, the curtains were halfway down, with clear sky conditions selected as the reference sky type in Dubai. According to LEED standards, if the rate of daylight factors is less than 2%, the area appears dark and depressing overall. Electric lighting is frequently needed throughout the day, and electric lighting predominates the appearance during the day. If the percentage of the daylight factor is in the range of 2% and 5%, the amount of daylight from the windows has been significant, but occasionally additional electric lighting is still required; if the value of the daylight factor is 5% or higher, there would be enough light in the room and daytime electric lighting would rarely be required.

4.7.1.1 *Scenario 1- All curtains fully opened (At 11:00 AM)*

The first scenario for daylight focused on having curtains fully open to examine the enhancements without doing any change in the external elevation or the windows types as discussed previously. Based on the site visit and the staff experience their opening curtains cause heat in the spaces. Meanwhile, the change in windows or any external changes on the external façade is not discussed in this study as here the focus only on lighting parameters, interior finishing materials, and user's well-being.

in this scenario, the classroom exhibits an issue with excessive lighting in the student desk areas, creating a bright and glare-filled environment. Conversely, the areas near the windows are highly illuminated, with a daylight factor measuring around 1.57%, which falls below the acceptable value of 2 according to established standards. This imbalance in lighting results in both glare and uncomfortable heat, particularly in the vicinity of the windows. Classroom FF-111 results are shown in Figure 80.

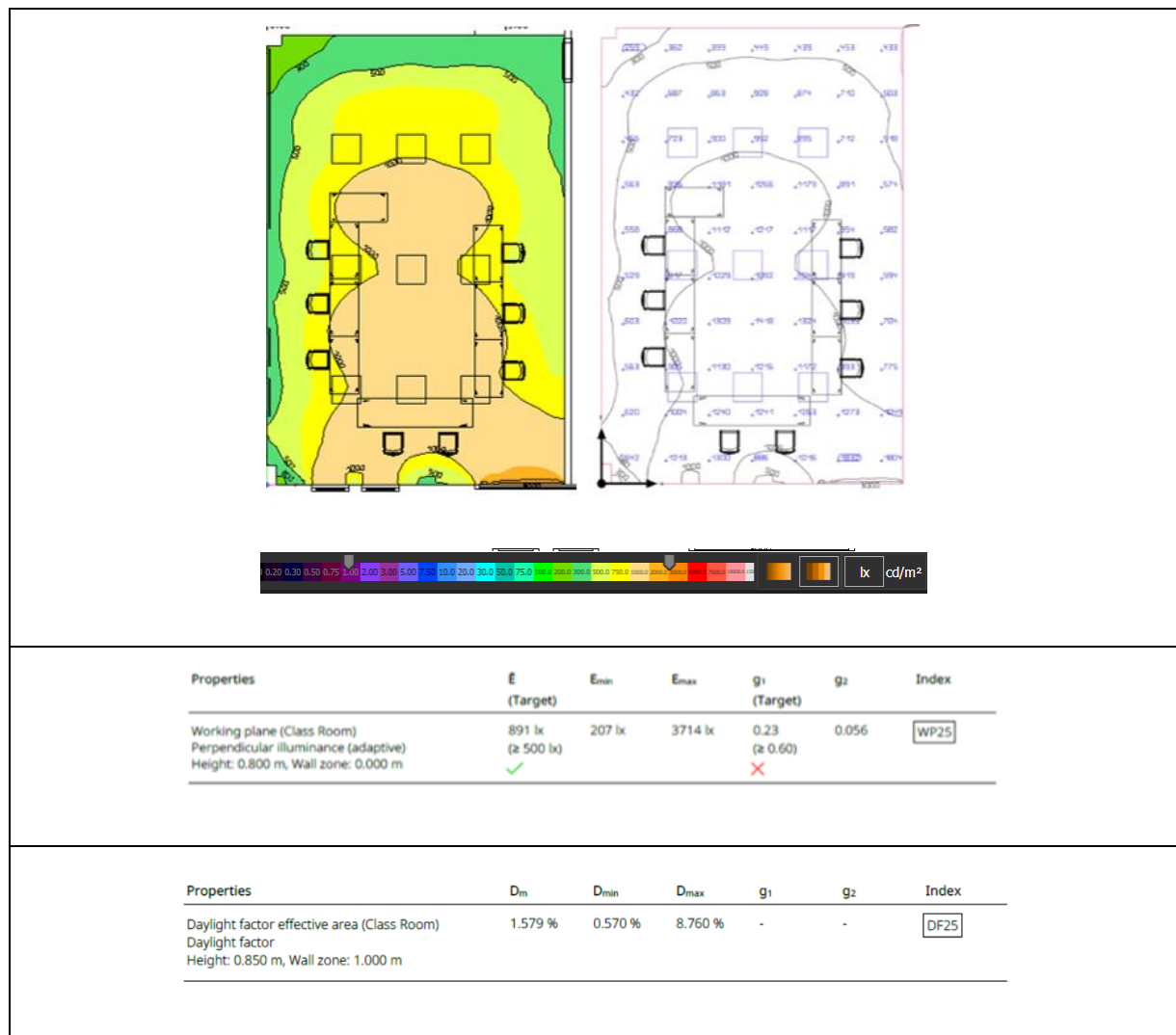


Figure 80: Classroom FF 111- daylight factor and lux value

(Source: Author,2023)

Results for the library under this scenario are illustrated in Figure 81, as shown in the figure, there is a notable issue with excessively high lux levels, reaching an astonishing 1844 lux, which significantly surpasses the established target. Particularly near the windows, all areas are marked in red and orange, signifying an excessive level of glare and rendering them unsuitable for any

form of tasks. Furthermore, the daylight factor is only 0.38%, which is considered an unacceptable value. According to established standards, a comfortable range for the Average Daylight Factor (ADF) should typically fall between 2% and 5%, as per LEED guidelines. The current conditions in this scenario do not meet these standards, resulting in an environment characterized by excessive brightness and discomfort.

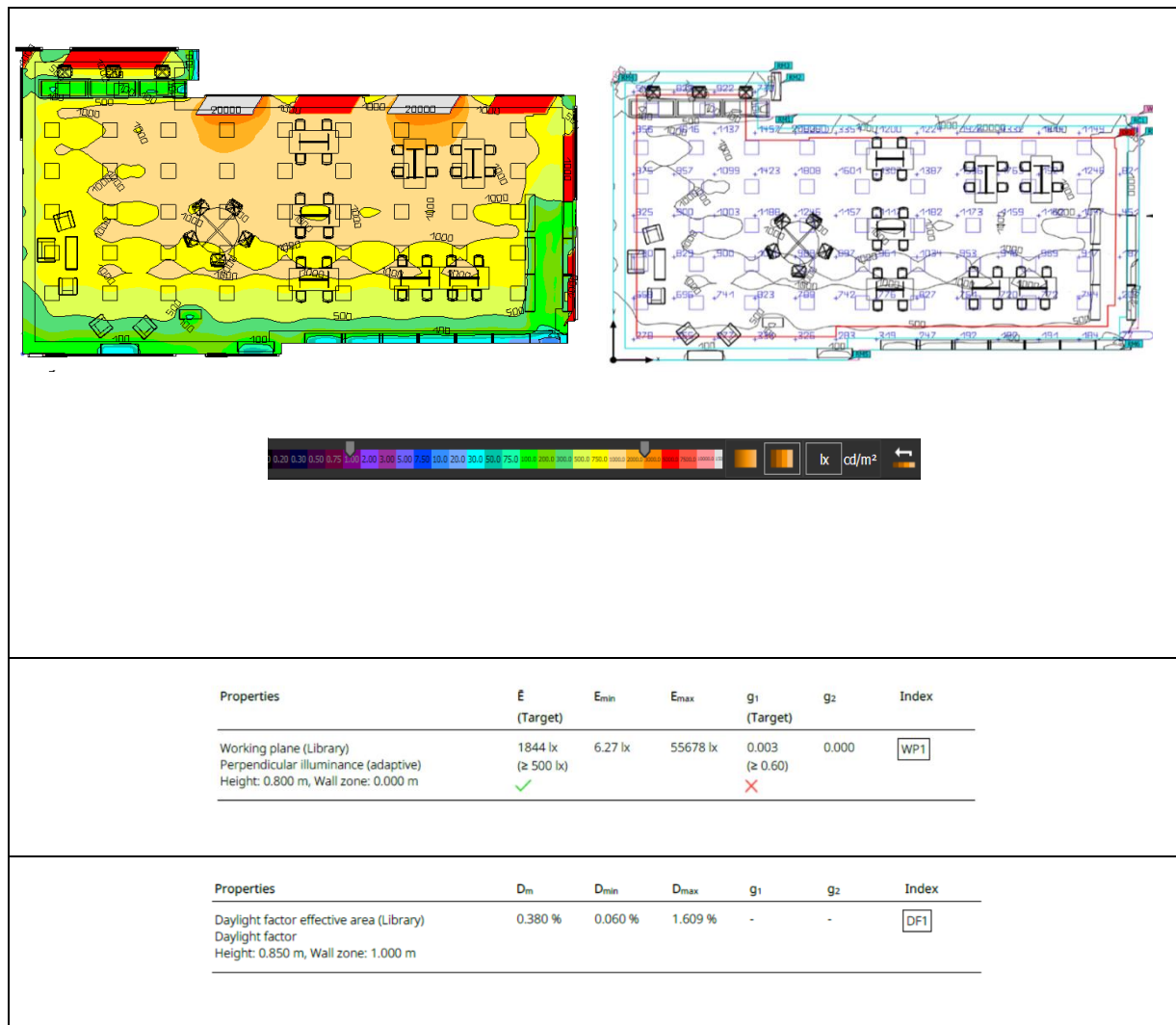


Figure 81: Library - daylight factor and lux value

(Source: Author,2023)

During the daytime in the student area, the lux level is measured at 1553, exceeding typical values. As depicted in Figure 82, the mean value of the daylight factor is calculated at 2.06%, indicating the potential need for electric lighting even during daylight hours. Notably, in the colored graph, the areas near the windows are highlighted in red, indicating a high level of sunlight exposure, while the rest of the zone is marked in green, representing relatively darker areas. This necessitates an increase in electric lighting lux in the green-highlighted zone, leading to the decision to add more lights as part of the second strategy.

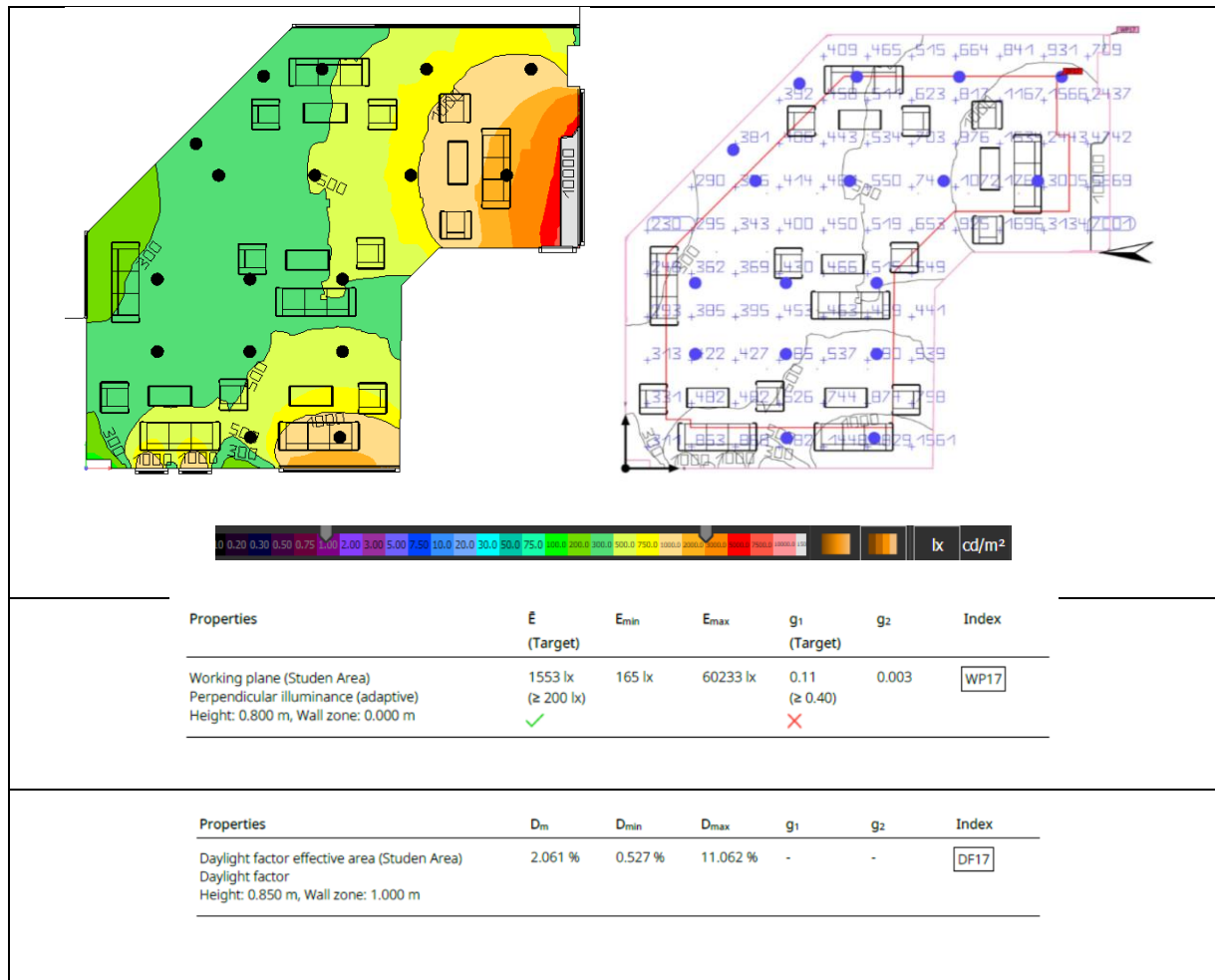


Figure 82: Student lounge- daylight factor and lux value

(Source: Author,2023)

As shown in Figure 83, the lux value in the registration office is extraordinarily high, measuring about 6188 lux, which significantly surpasses the target level of approximately 300 lux. Additionally, the average Daylight Factor (DF) is notably high at about 4.29%.

However, the areas near the windows are excessively illuminated by sunlight, resulting in a very bright and glary space that is not suitable for any type of tasks. Even in areas marked with a green checkmark, the lighting remains excessively bright, creating discomfort in both the office zone and the sitting area.

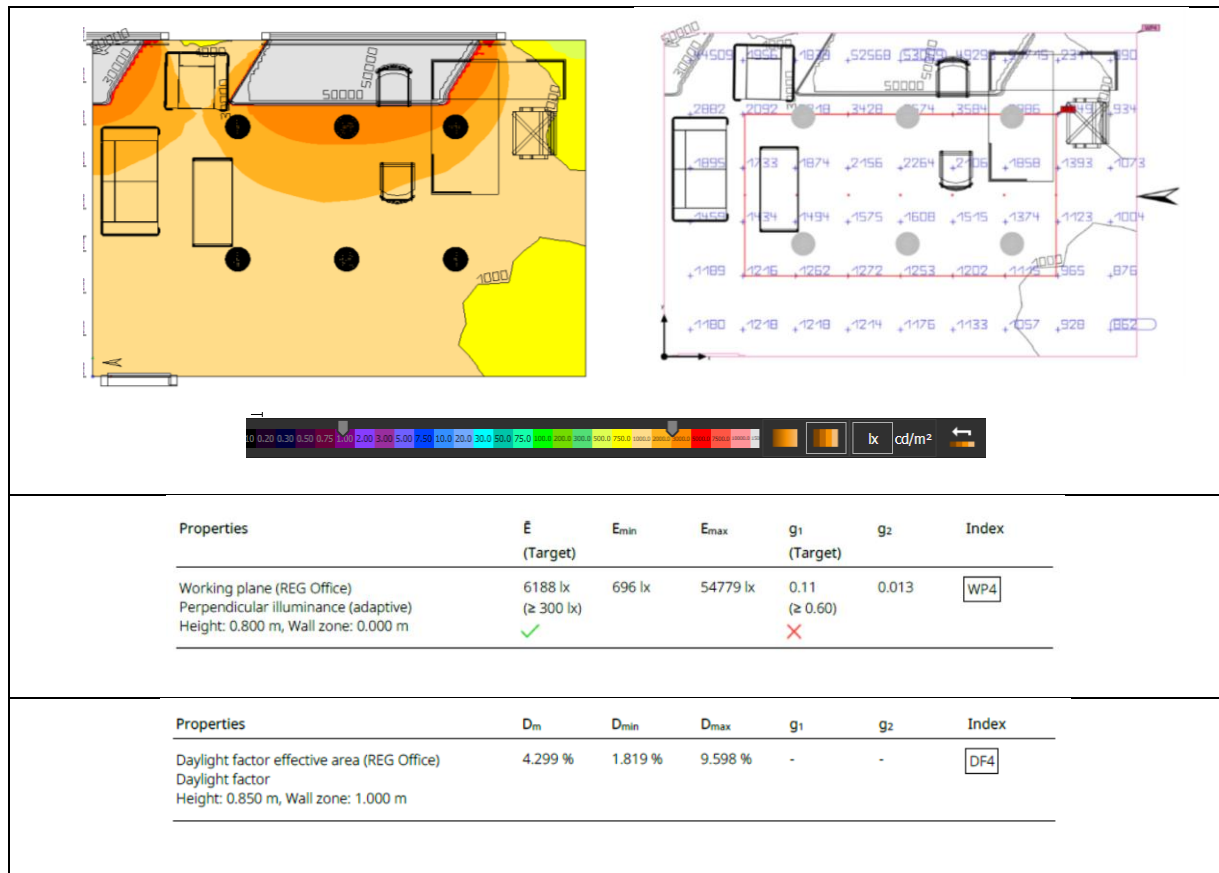


Figure 83: Registration office- daylight factor and lux value

(Source: Author,2023)

Table 41 provides a summary report of various zones within the campus, specifically in the context of Strategy 1, scenario 1, which involves fully opening all curtains during daytime. This scenario was aimed at harnessing natural sunlight in areas with windows, as mentioned earlier.

In this scenario, all the spaces mentioned, including Classroom FF 111, the library, the student lounge, and the registration office, have met the specified target Lux levels. However, it is worth noting that these spaces exhibit issues related to lighting distribution, particularly concerning uniformity. This condition results in specific spaces being overly bright and potentially uncomfortable due to glare. In such instances, the uniformity ratio of lighting within these areas does not meet the required target, and this discrepancy requires attention to ensure an optimal and comfortable lighting environment.

Table 41: Summary report of different zones in the campus- Strategy 1, scenario 1: All curtains fully opened, (Source: Author,2023)

Classroom FF-111					
	Symbol	Calculated	Target	Check	Index
Daylight	D	593 %	-		DF25
Working plane	$E_{\text{perpendicular}}$	891 lx	≥ 500 lx	✓	WP25
	g_1	0.23	≥ 0.60	✗	WP25
Glare valuation ⁽¹⁾	$R_{\text{UG,max}}$	17	≤ 19	✓	
Energy estimation ⁽²⁾	Consumption	[560.73 - 933.66] kWh/a	max. 2050 kWh/a	✓	

Library					
	Symbol	Calculated	Target	Check	Index
Daylight	D	0.380 %	-		DF1
Working plane	$E_{\text{perpendicular}}$	1844 lx	≥ 500 lx	✓	WP1
	g_1	0.003	≥ 0.60	✗	WP1
Glare valuation ⁽¹⁾	$R_{\text{UG,max}}$	17	≤ 19	✓	

Students lounge					
	Symbol	Calculated	Target	Check	Index
Daylight	D	2.061 %	-		DF17
Working plane	$E_{\text{perpendicular}}$	1553 lx	≥ 200 lx	✓	WP17
	g_1	0.11	≥ 0.40	✗	WP17
Glare valuation ⁽¹⁾	$R_{\text{UG,max}}$	21	≤ 22	✓	

Registration office					
	Symbol	Calculated	Target	Check	Index
Daylight	D	4.299 %	-		DF4
Working plane	$E_{\text{perpendicular}}$	6188 lx	≥ 300 lx	✓	WP4
	g_1	0.11	≥ 0.60	✗	WP4

4.7.1.2 *Scenario 2- All curtains halfway down- (At 11:00AM)*

As mentioned previously the focus of this study is to analyze the lighting performance in an existing campus building, so the strategies to enhance the interior performance in terms of lighting through different scenarios can be applied without any change in the building façade. The initial daylight scenario involved opening the curtains partially to assess the subsequent improvements without full exposure. Previous student observations revealed that opening the curtains increased the temperature within the library. As a result, the curtains were usually kept closed at all times. However, the objective in this situation was to position the curtains halfway down, with the assumption that specific adjustments to the existing windows would be performed to reduce heat gain. However, this study does not take into account window changes or heat gain decrease. The following spaces were measured and analyzed by the software as the only spaces having windows and daylight accessibility.

In the classroom where the curtains were halfway down based on this scenario, Figure 84 shows that the lux value is measured at approximately 470 lux, which is in close proximity to the target level. Additionally, the daylight factor registers at 0.59%, which falls below the 2% standard. These measurements indicate that while the lighting conditions are reasonably close to the target lux level, the space receives limited natural daylight, making it necessary to rely more on artificial lighting sources.

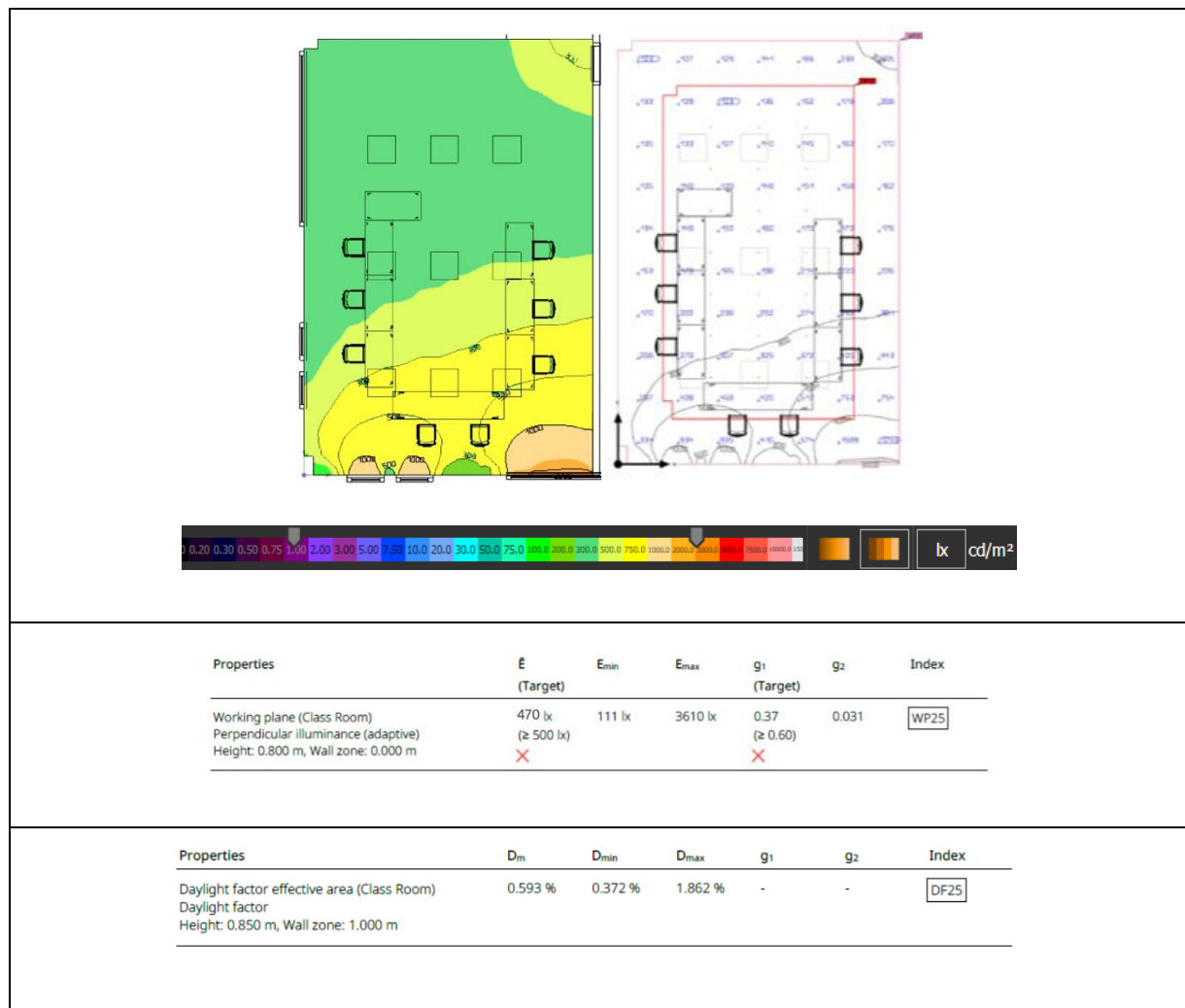


Figure 84: Classroom FF 111- daylight factor and lux value

(Source: Author,2023)

As shown in Figure 85, the library exhibits a high lux reading, with an overall level of approximately 1011 lux, nearly double the target value. This excessive brightness is particularly noticeable in the reading area near the window, leading to increased heat and an uncomfortably bright environment. However, despite the high artificial lighting levels, the daylight factor remains below the standard range at 0.079%, indicating a limited presence of natural daylight

in the space. This situation necessitates attention to create a more balanced and comfortable lighting environment.

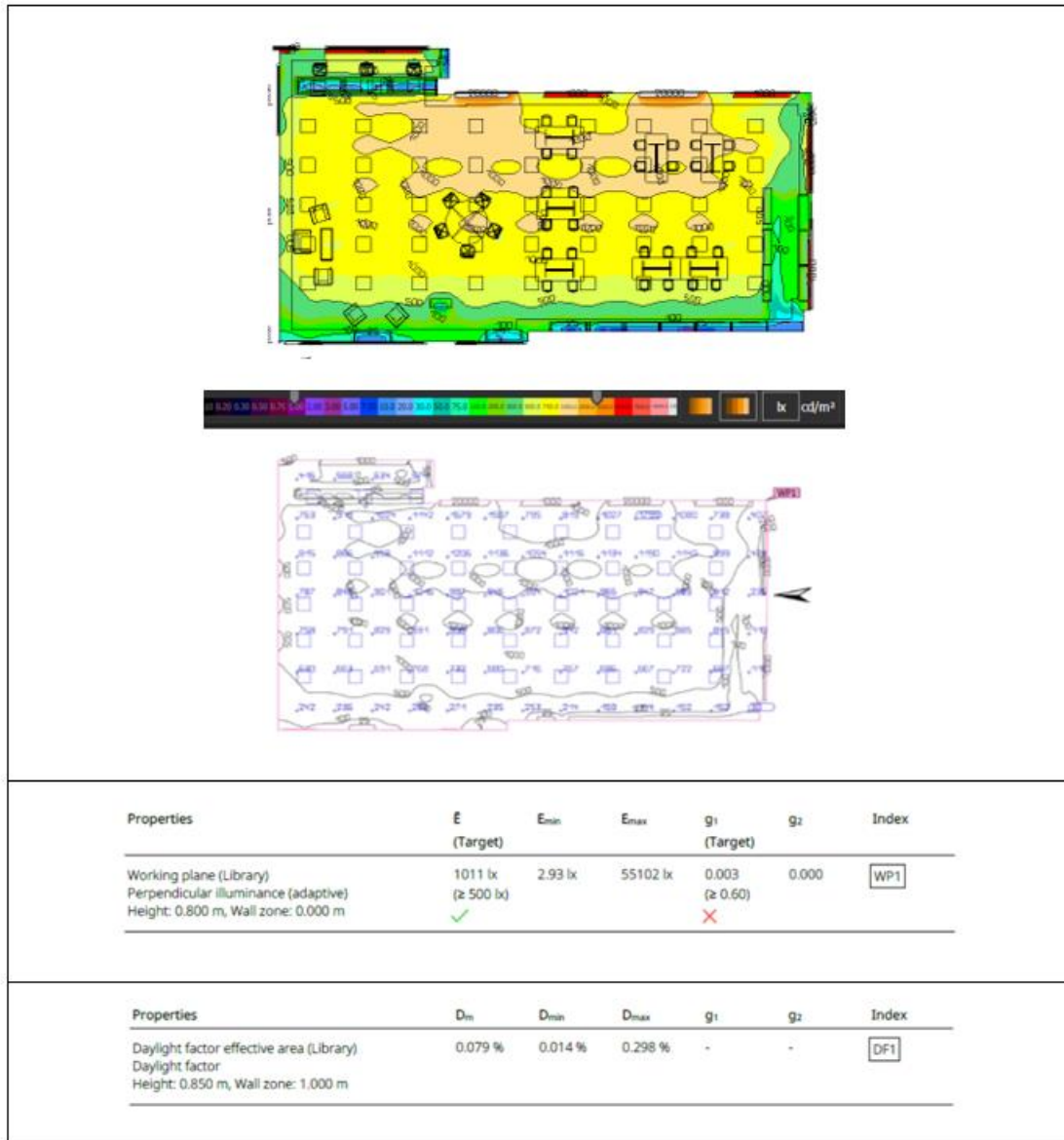


Figure 85: Library - daylight factor and lux value

(Source: Author,2023)

Similarly, in this scenario, the student lounge is impacted in a manner similar to the classroom, as both spaces are on opposite sides of the same block. Figure 86 illustrates that the

lux values require enhancement in certain areas, and the space appears dark in the middle while being overly lit near the windows. Additionally, the daylight factor is measured at a low 0.24%, indicating that natural daylight is limited in this space. Achieving a more balanced and comfortable lighting environment in these areas is crucial.

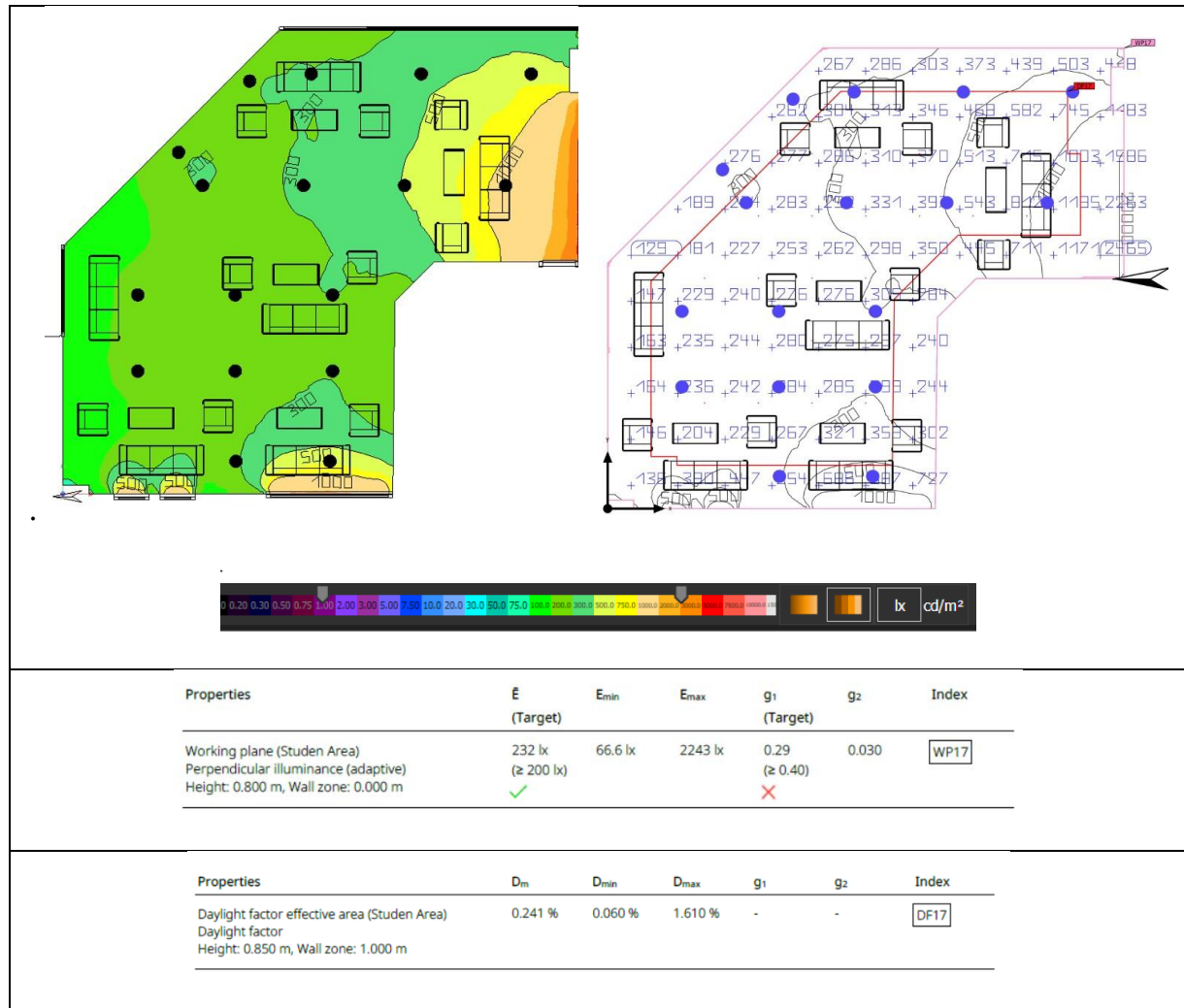


Figure 86: Student lounge- daylight factor and lux value
(Source: Author,2023)

Conversely, in the individual office space, the registration office records a lux value of approximately 1985, which significantly surpasses the required range of 300-500 lux. As depicted in Figure 87, this space exhibits high levels of lighting parameters and is excessively

bright, particularly near the windows. This excessive brightness results in glare and heat gain within the space, which can lead to discomfort and reduced productivity. Balancing the lighting conditions in this area is essential to create a more comfortable and conducive workspace. Table 42 presents a summary report of various zones within the campus, in the context of Strategy 1, Scenario 2, which involves having all curtains halfway down.



Figure 87: Registration office- daylight factor and lux value

(Source: Author,2023)

Table 42: Summary report of different zones in the campus- Strategy 1, Scenario 2, All curtains halfway down, (Source: Author, 2023)

Classroom FF-111					
	Symbol	Calculated	Target	Check	Index
Daylight	D	1.579 %	–		DF25
Working plane	$E_{\text{perpendicular}}$	470 lx	≥ 500 lx	✗	WP25
	g_t	0.37	≥ 0.60	✗	WP25
Glare valuation ⁽¹⁾	$R_{\text{GL,max}}$	17	≤ 19	✓	
Energy estimation ⁽²⁾	Consumption	[560.73 - 933.66] kWh/a	max. 2050 kWh/a	✓	

Library					
Glare valuation ⁽¹⁾	$R_{\text{GL,max}}$	17	≤ 19	✓	
Energy estimation ⁽²⁾	Consumption	[8987.10 - 13478.40] kWh/a	max. 8550 kWh/a	✗	
	Symbol	Calculated	Target	Check	Index
Daylight	D	0.079 %	–		DF1
Working plane	$E_{\text{perpendicular}}$	1011 lx	≥ 500 lx	✓	WP1
	g_t	0.003	≥ 0.60	✗	WP1

Students lounge					
	Symbol	Calculated	Target	Check	Index
Daylight	D	0.241 %	–		DF17
Working plane	$E_{\text{perpendicular}}$	232 lx	≥ 200 lx	✓	WP17
	g_t	0.29	≥ 0.40	✗	WP17
Glare valuation ⁽¹⁾	$R_{\text{GL,max}}$	21	≤ 22	✓	
Energy estimation ⁽²⁾	Consumption	[340.24 - 539.96] kWh/a	max. 3200 kWh/a	✓	

Registration office					
	Symbol	Calculated	Target	Check	Index
Daylight	D	0.835 %	–		DF4
Working plane	$E_{\text{perpendicular}}$	1985 lx	≥ 300 lx	✓	WP4
	g_t	0.14	≥ 0.60	✗	WP4

4.7.2 Strategy 2- Artificial Light

Given the diverse working hours on the campus, encompassing both day and night timings, this strategy involves testing multiple scenarios exclusively for the implementation of artificial lighting. Two distinct scenarios are explored within this strategy. The first scenario entails a transition to different types of lighting fixtures and a rearrangement of fixtures, incorporating new specifications for light types. Additionally, the second scenario involves improving the

Light Reflectance Value (LRV) of various finishing materials, encompassing walls, ceilings, floors, and furniture colors.

Subsequently, another simulation scenario is executed by merging the new artificial lighting arrangements with specifications in alignment with LEED standards for interior finishing materials. These parameters are integrated into the software alongside daylight factors. It's important to note that this scenario does not present any recommendations regarding the potential increase in heat gain through the existing windows.

The ensuing sections provide insights into the various scenarios designed for investigation and their respective results, taking into account both daytime and nighttime conditions, as these represent the two main periods when the university is occupied, either by students or staff.

4.7.2.1 *Scenario 1: Adding more lighting fixtures from the existing type- At Night*

In this scenario, we aim to explore the possibilities of improving lighting conditions by introducing additional light fixtures of the same type and model to achieve the target lux levels in each space. Consequently, we integrated extra lighting fixtures during the simulation to attain an optimal scenario. The number of fixtures added to each space is influenced by various factors, including furniture arrangements and the specific tasks conducted in each area.

As illustrated in Figure 88, the average lux level in auditorium based on this scenario measures around 527 lux, denoted by a green checkmark, indicating that it meets the target level. This outcome is achieved by adding approximately sixteen fluorescent lights in various task areas to align with the standards. Furthermore, the graphical colored map of the auditorium depicts a lux value of around 527 lux, which also meets the target value. On the contrary, in

some other areas, the uniformity ratio is calculated at 0.5, falling short of the recommended uniformity range of 0.6 to 0.7, as per the established standards.

In classroom FF-111, as depicted in Figure 89, the addition of five fluorescent lighting fixtures of the same type has significantly increased the lux value. The average lux level now stands at 983 lux, with the maximum lux value reaching a high of 1605 lux. This level far exceeds the target value of 500 lux. Simultaneously, the uniformity ratio has been improved, measuring around 0.2, although it is still well below the target value of 0.6. However, the classroom is now excessively bright, creating discomfort for both students and the professor. This excessive brightness can negatively impact their productivity and overall learning experience.

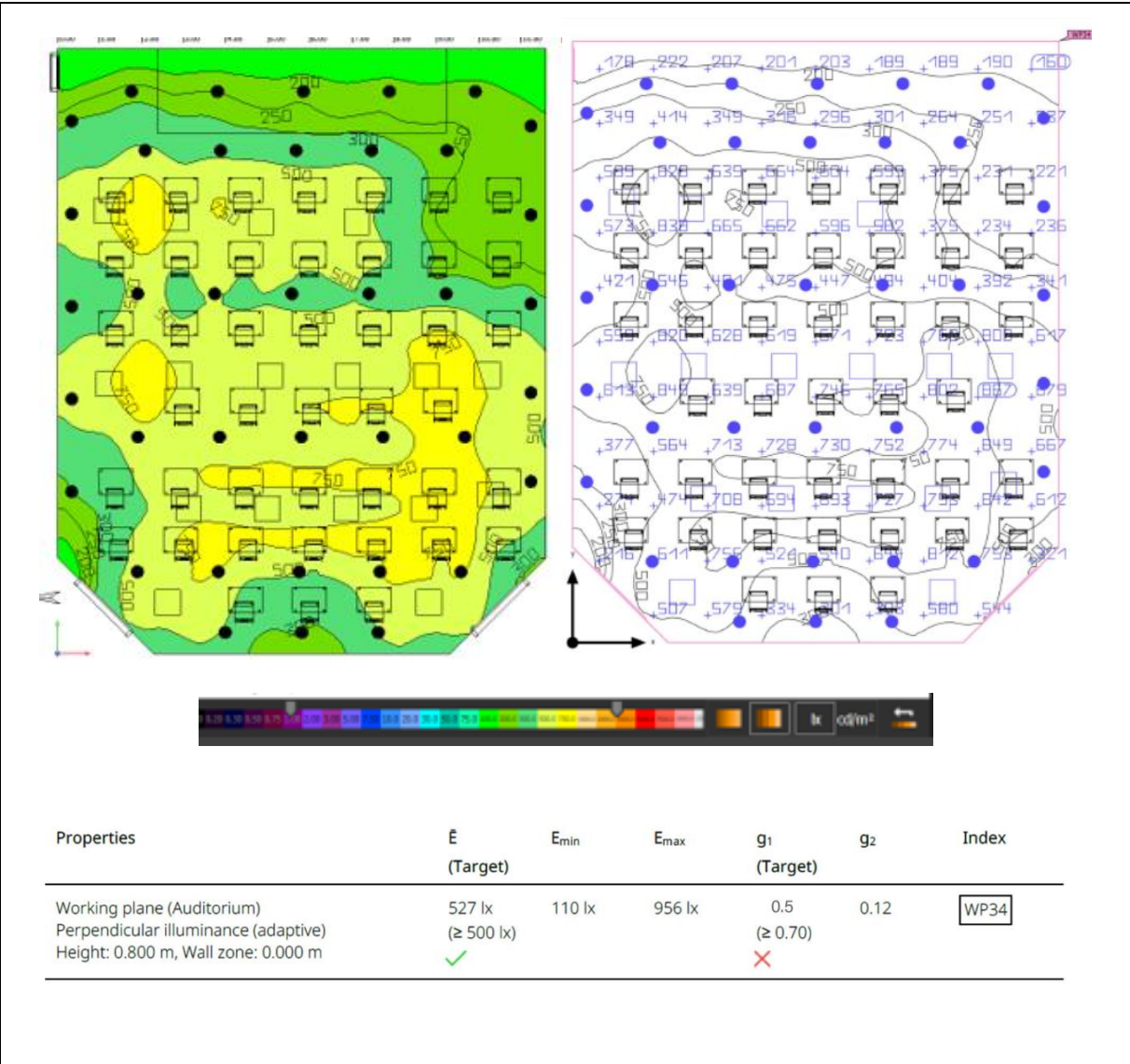


Figure 88: Auditorium- lux value and uniformity ratio

(Source: Author,2023)

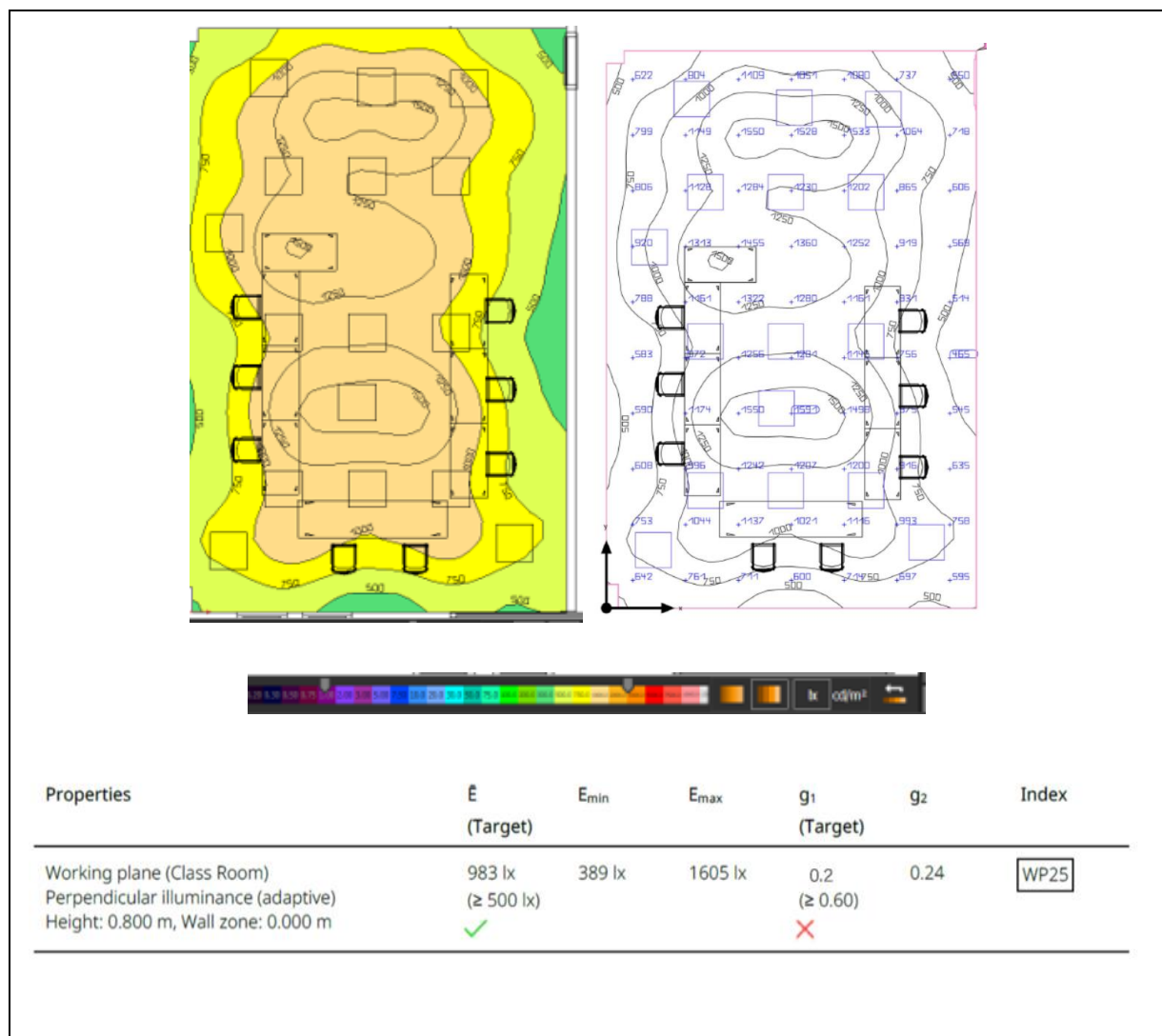


Figure 89: Class room FF 111- lux value and uniformity ratio

(Source: Author,2023)

In Figure 90, the library is depicted with its various task zones. By incorporating an additional sixteen luminaires of the same type, the lux value has significantly increased, measuring around 853 lux. This represents a notable improvement compared to the base case. The additional fixtures were strategically placed in the reading zone and the bookshelves zone. However, it's important to note that there is still room for improvement in terms of light

distribution and glare control. There remains a substantial difference in lux values within the area, and addressing this non-uniformity is essential to create a more balanced and comfortable lighting environment.

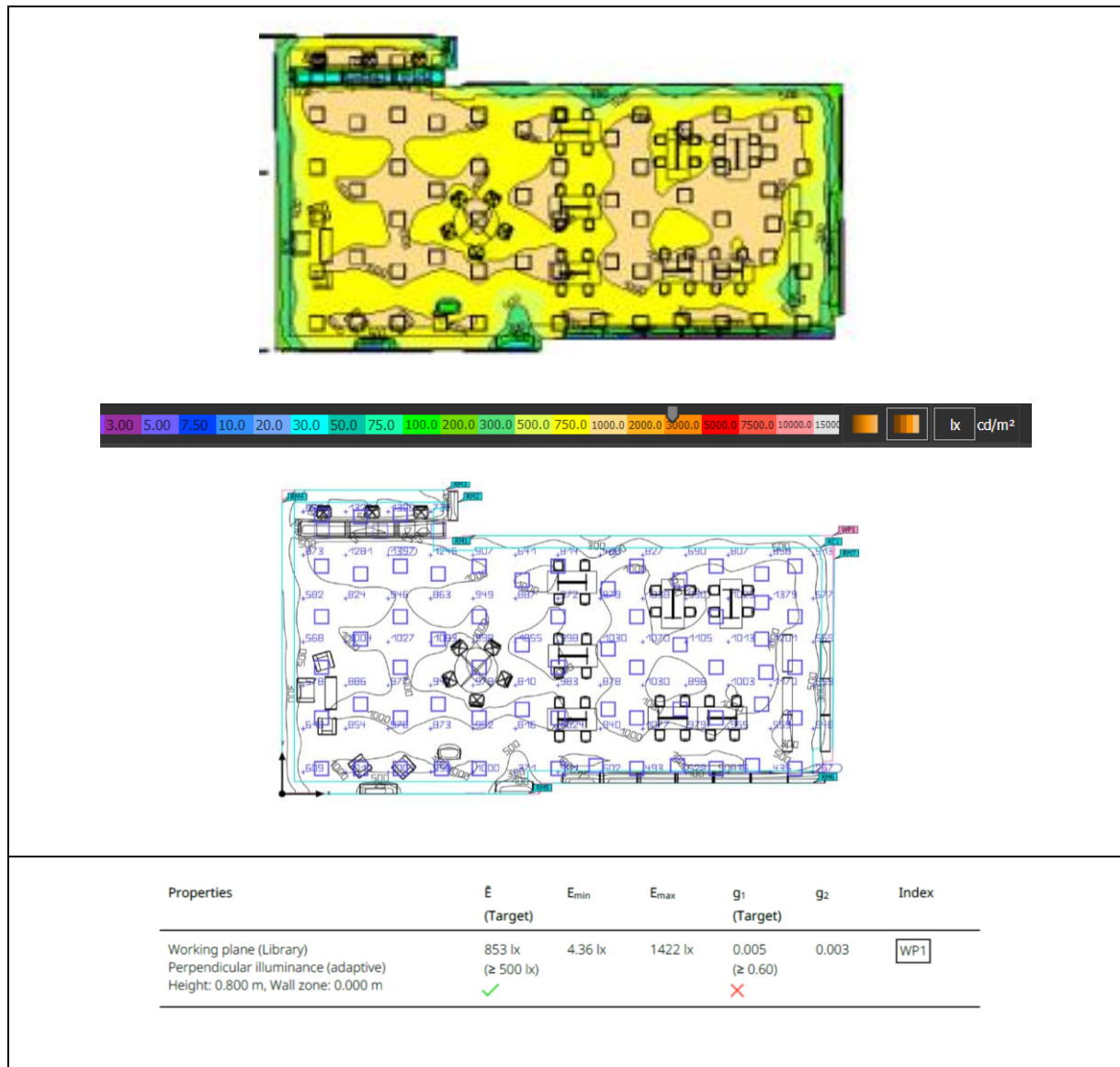
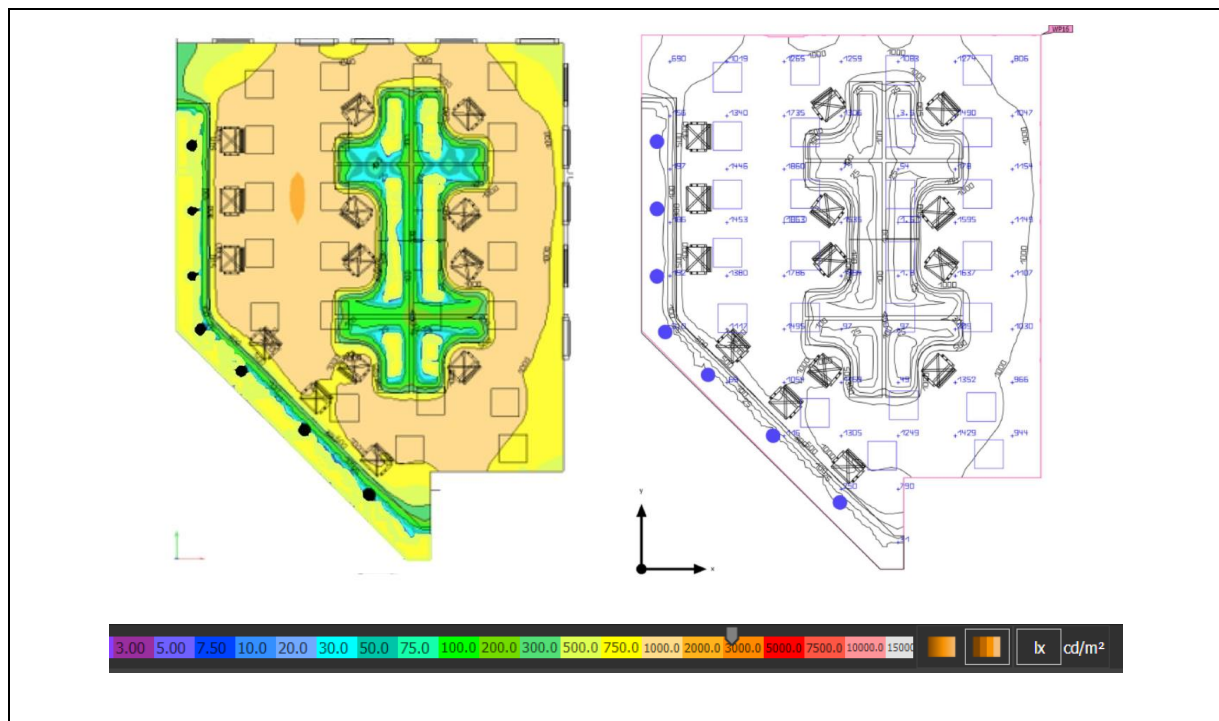


Figure 90: Library- lux value and uniformity ratio

(Source: Author,2023)

In the administration area, where artificial lighting plays a crucial role, additional fixtures were introduced, consisting of approximately six fluorescent fixtures and one downlight. This setup is part of an effort to investigate the impact on lighting parameters, as demonstrated in Figure 91. As a result of these additions, the lux value has increased to around 500 lux. However, it's evident that there is a lack of proper distribution of light, as indicated by the low uniformity ratio, which measures around 0.001.

To further enhance the lighting conditions in this area, a deeper analysis and the testing of various scenarios are planned for the following sections. These scenarios will explore changes in different parameters, including adjustments to the space's finishing specifications and the transition to new lighting types.



Properties	E (Target)	E _{min}	E _{max}	g ₁ (Target)	g ₂	Index
Working plane (Administration Area) Perpendicular illuminance (adaptive) Height: 0.800 m, Wall zone: 0.000 m	888 lx (≥ 300 lx) ✓	0.61 lx	2034 lx	0.001 (≥ 0.60) ✗	0.000	WP16

Figure 91: Administration area- lux value and uniformity ratio

(Source: Author,2023)

In the study room shown in Figure 92, the lux value has indeed increased, marked by a green check, reflecting an average value that meets the target. However, it's important to note that despite the increase in lux levels, the distribution of lux in the entire space has not changed significantly and still fails to meet the target values. Furthermore, other critical parameters such as uniformity ratio, glare, and energy consumption have not improved and remain at suboptimal levels.

What's notable is that the energy consumption has actually increased significantly due to the addition of four new fluorescent light fixtures, bringing the total to nine fixtures. This shift in energy consumption underscores the complexity of achieving a balanced and efficient lighting environment that meets various criteria and standards.

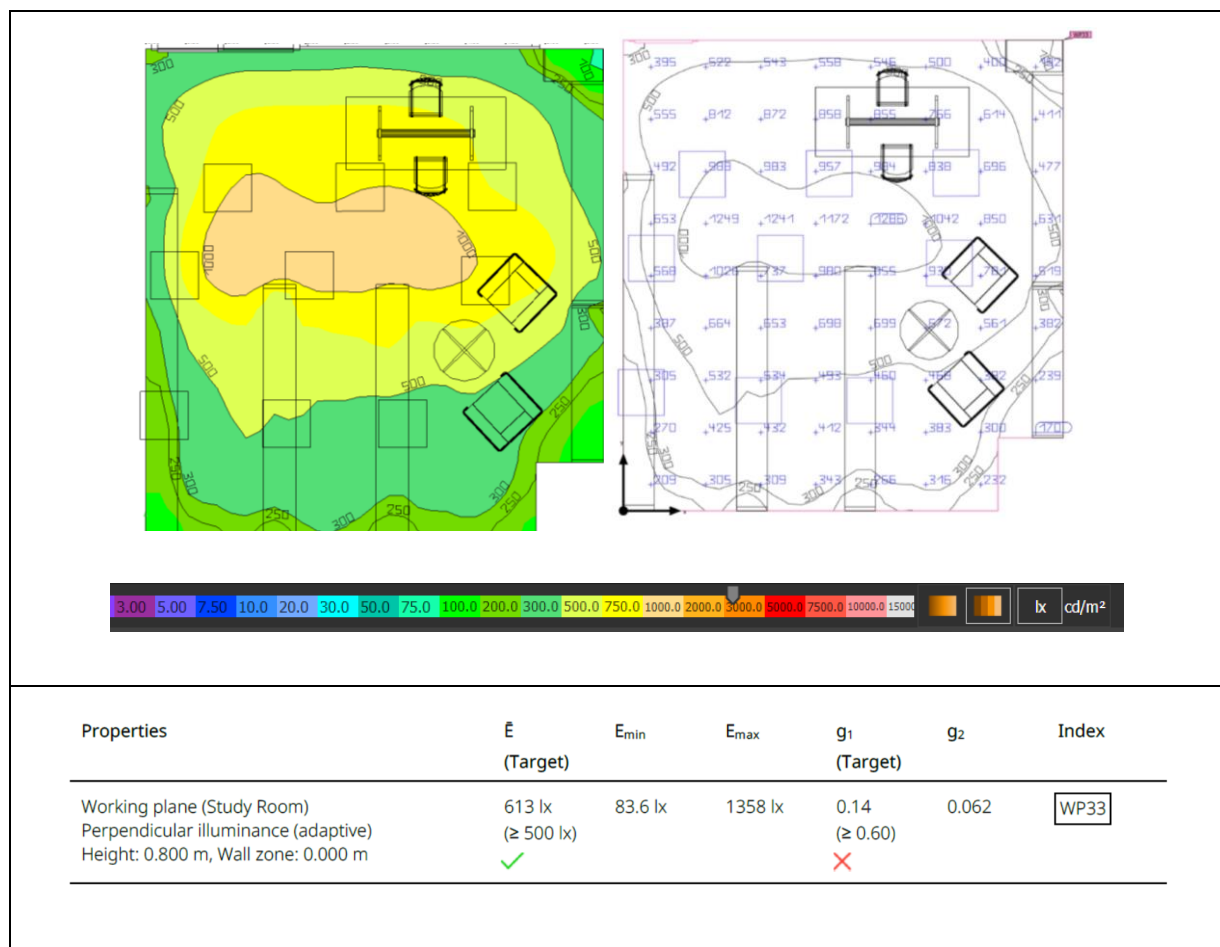


Figure 92: Study room- lux value and uniformity ratio

(Source: Author,2023)

In the students' lounge, where various activities take place, the addition of seven fluorescent lights has led to notable changes in the lighting conditions. As depicted in Figure 93, the lux value now measures around 367 lux, meeting the target value. In this space, similar to other areas, there is a range in lux values, with the minimum at around 101 lux and the maximum reaching 746 lux. The uniformity ratio is calculated at 0.37, which is in close proximity to the target value of 0.4. This suggests that the distribution of light in the students' lounge has been improved and aligns with the desired lighting standards.

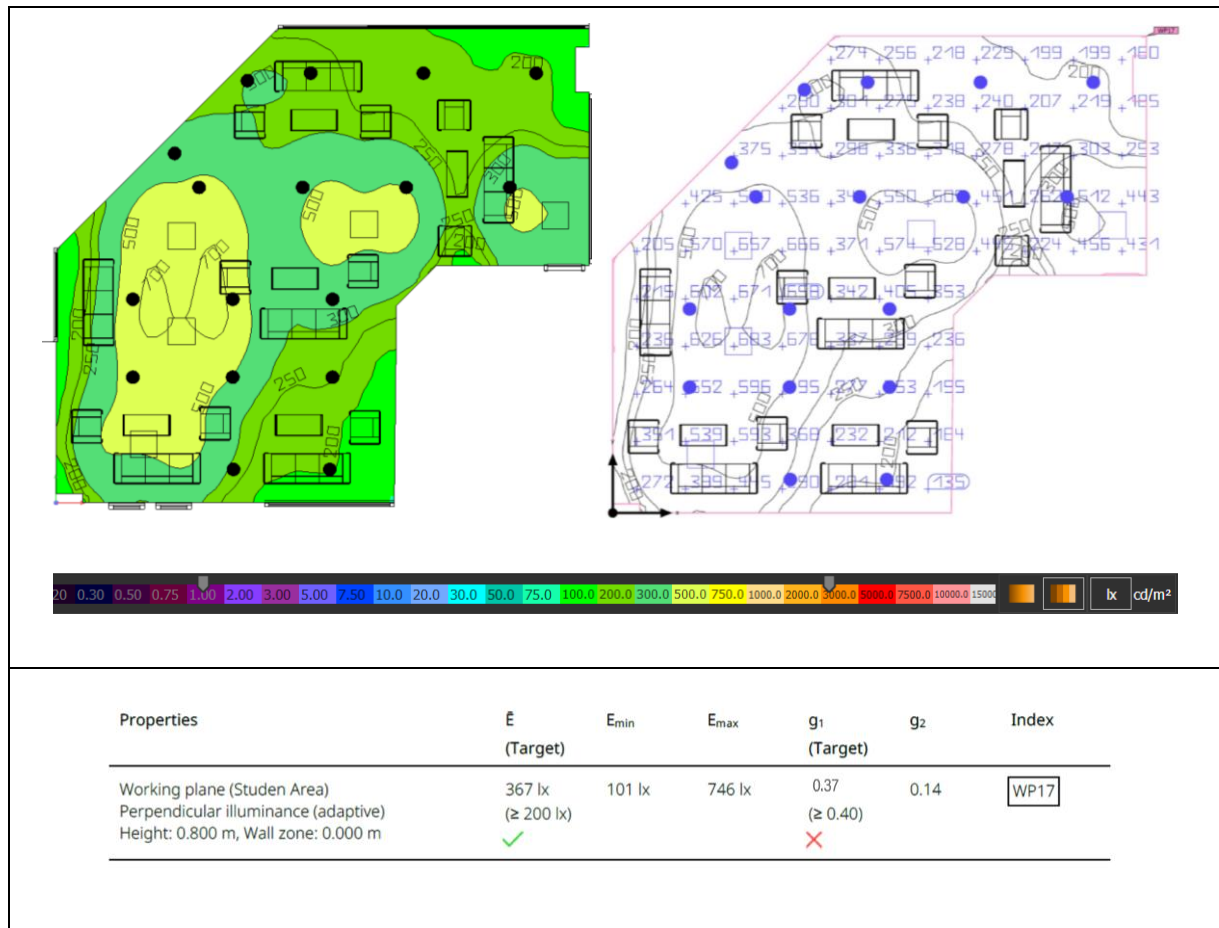


Figure 93: Student lounge- lux value and uniformity ratio

(Source: Author,2023)

In Figure 94, the meeting room is depicted with additional downlights. The average lux value in this room measures approximately 807 lux, exceeding the established standards. This higher level of illumination creates a very bright space, leading to increased energy consumption. However, this excessive brightness is not in line with the goals of LEED V4 ID+C, which aims to create sustainable and environmentally friendly spaces that ensure user satisfaction, productivity, and comfort. Achieving the right balance in lighting conditions is essential to meet these objectives.

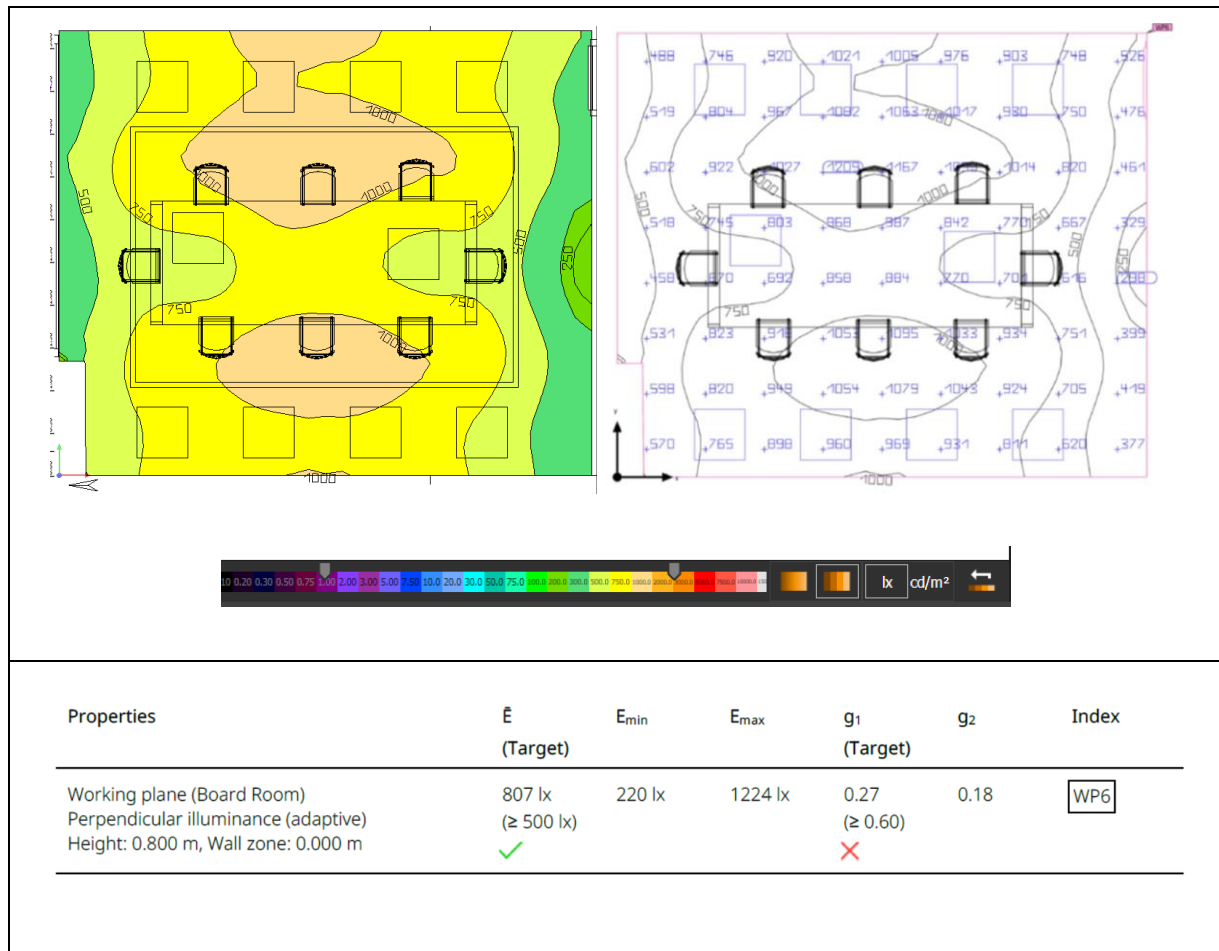


Figure 94: Board room- lux value and uniformity ratio

(Source: Author,2023)

In Figure 95, the general circulation zone (corridor) is depicted, where significant enhancements have been made in terms of various variables. The lux value in this space measures around 205 lux, slightly surpassing the target level. When assessing the space as a whole, particularly in terms of uniformity, the measurement registers at approximately 0.42, successfully meeting the target for lighting distribution. Importantly, these improvements have been achieved without a substantial increase in energy consumption in this area.

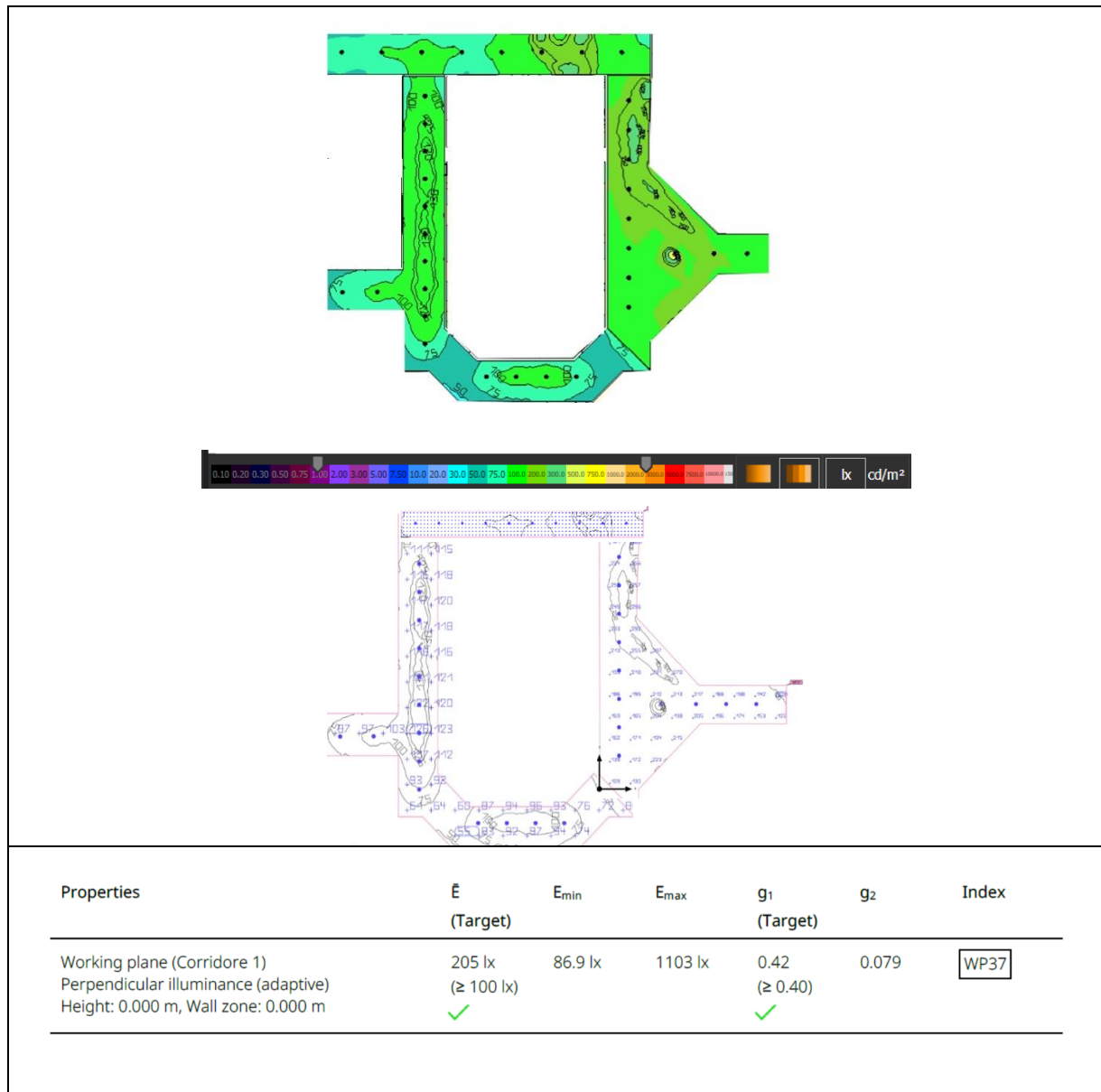


Figure 95: Corridors- lux value and uniformity ratio

(Source: Author,2023)

As depicted in Figure 96, the lux value in the office space has been increased by introducing an additional three fluorescent lights in the sitting area and beside the desk, as compared to the base case scenario. The lux level now measures around 469 lux. However, similar to other

spaces, the distribution of light in terms of various variables and conditions still requires further improvement to reach the optimal scenario. This improvement entails not only focusing on lux values but also enhancing the interior parameters of the space to ensure an overall comfortable and efficient lighting environment.

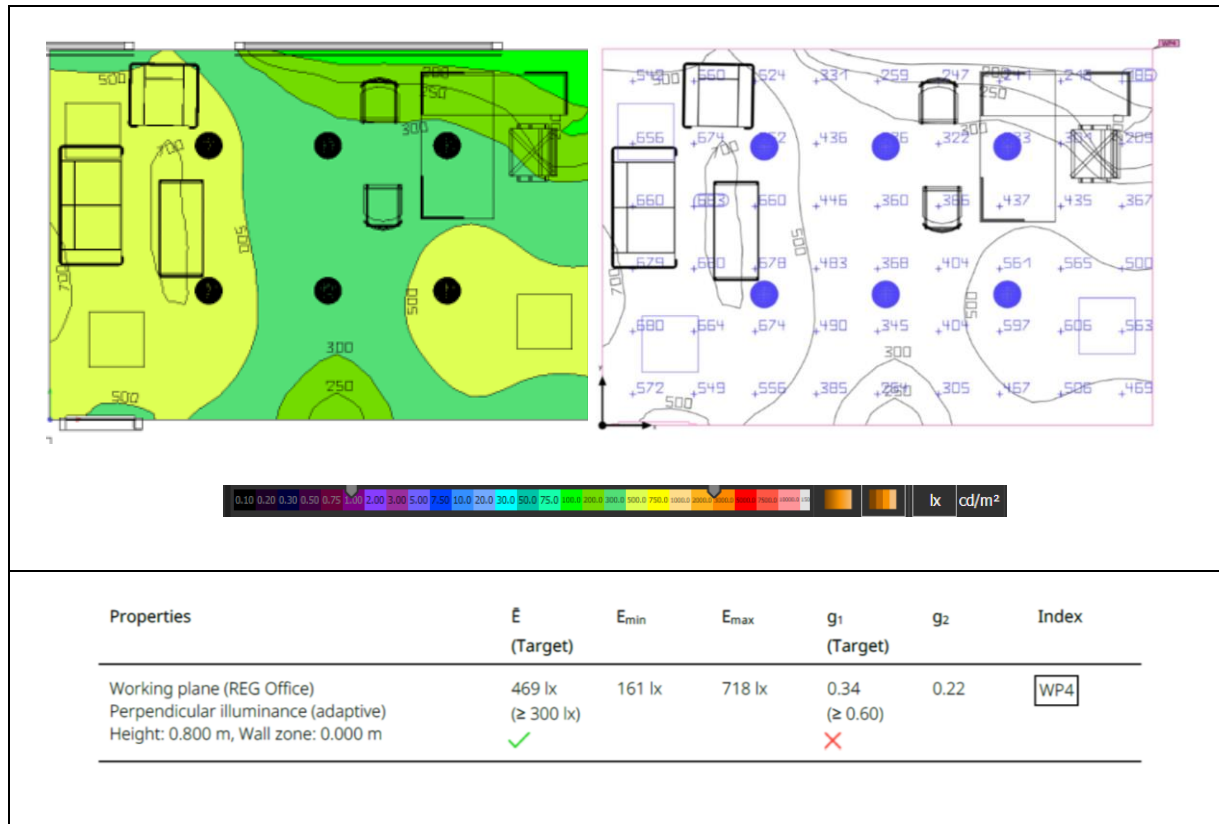


Figure 96: Registration office- lux value and uniformity ratio

(Source: Author,2023)

Table 43 offers a summary report of various zones within the campus, specifically in the context of Strategy 2, Scenario 1, which involves adding more lighting fixtures of the existing type.

Table 43: Summary report of different zones in the campus- strategy 2, scenario 1: Adding more lighting fixtures from the existing type, (Source: Author, 2023)

Auditorium					
	Symbol	Calculated	Target	Check	Index
Working plane	$E_{\text{perpendicular}}$	527 lx	≥ 500 lx	✓	WP34
	g_1	0.21	≥ 0.70	✗	WP34
Glare valuation ⁽³⁾	$R_{\text{UG,max}}$	19	≤ 19	✓	
Energy estimation ⁽²⁾	Consumption	2597 kWh/a	max. 5650 kWh/a	✓	
Classroom					
	Symbol	Calculated	Target	Check	Index
Working plane	$E_{\text{perpendicular}}$	983 lx	≥ 500 lx	✓	WP25
	g_1	0.2	≥ 0.60	✗	WP25
Glare valuation ⁽³⁾	$R_{\text{UG,max}}$	21	≤ 19	✗	
Energy estimation ⁽²⁾	Consumption	[996.85 - 1659.84] kWh/a	max. 2050 kWh/a	✓	
Library					
	Symbol	Calculated	Target	Check	Index
Working plane	$E_{\text{perpendicular}}$	853 lx	≥ 500 lx	✓	WP1
	g_1	0.005	≥ 0.60	✗	WP1
Glare valuation ⁽³⁾	$R_{\text{UG,max}}$	20	≤ 19	✗	
Energy estimation ⁽²⁾	Consumption	[5552.13 - 8326.80] kWh/a	max. 8550 kWh/a	✓	
Adminstration area					
	Symbol	Calculated	Target	Check	Index
Working plane	$E_{\text{perpendicular}}$	888 lx	≥ 300 lx	✓	WP16
	g_1	0.001	≥ 0.60	✗	WP16
Glare valuation ⁽³⁾	$R_{\text{UG,max}}$	23	≤ 22	✗	
Energy estimation ⁽²⁾	Consumption	[3579.10 - 5680.13] kWh/a	max. 2650 kWh/a	✗	
Group study room					
	Symbol	Calculated	Target	Check	Index
Working plane	$E_{\text{perpendicular}}$	613 lx	≥ 500 lx	✓	WP33
	g_1	0.14	≥ 0.60	✗	WP33
Glare valuation ⁽³⁾	$R_{\text{UG,max}}$	19	≤ 19	✓	
Energy estimation ⁽²⁾	Consumption	2527 kWh/a	max. 1200 kWh/a	✗	
Students Lounge					
	Symbol	Calculated	Target	Check	Index
Working plane	$E_{\text{perpendicular}}$	367 lx	≥ 200 lx	✓	WP17
	g_1	0.37	≥ 0.40	✗	WP17
Glare valuation ⁽³⁾	$R_{\text{UG,max}}$	21	≤ 22	✓	
Energy estimation ⁽²⁾	Consumption	520 kWh/a	max. 3200 kWh/a	✓	
Board room					
Corridor					

	Symbol	Calculated	Target	Check	Index
Working plane	$E_{\text{perpendicular}}$	807 lx	≥ 500 lx	✓	WP6
	g_1	0.27	≥ 0.60	✗	WP6
Glare valuation ⁽¹⁾	$R_{UG, \text{max}}$	19	≤ 19	✓	
Energy estimation ⁽²⁾	Consumption	[1168.27 - 1501.50] kWh/a	max. 1150 kWh/a	✗	

	Symbol	Calculated	Target	Check	Index
Working plane	$E_{\text{perpendicular}}$	205 lx	≥ 100 lx	✓	WP37
	g_1	0.42	≥ 0.40	✓	WP37
Glare valuation ⁽¹⁾	$R_{UG, \text{max}}$	23	≤ 25	✓	
Energy estimation ⁽²⁾	Consumption	290 kWh/a	max. 4300 kWh/a	✓	

Registration office

	Symbol	Calculated	Target	Check	Index
Working plane	$E_{\text{perpendicular}}$	469 lx	≥ 300 lx	✓	WP4
	g_1	0.34	≥ 0.60	✗	WP4
Glare valuation ⁽¹⁾	$R_{UG, \text{max}}$	19	≤ 22	✓	
Energy estimation ⁽²⁾	Consumption	[577.02 - 915.75] kWh/a	max. 850 kWh/a	✗	

4.7.2.2 Scenario 2: Switching and rearranging the current fixtures to the new type- At night

In this scenario, the approach involves replacing the existing lighting fixtures with a different type of lighting. This process would necessitate the installation of new fixtures in various configurations, which could entail adding more luminaires or reducing the overall number of lights to achieve the standard lighting levels for each space and task area. Detailed information about the chosen type of lighting and its specific properties is provided, as the lumens were sourced from DIALux EVO 11 and approved by factory manuals.

Furthermore, this scenario includes an enhancement of the Light Reflectance Value (LRV) of the internal surfaces to align with the values required by LEED guidelines for interior spaces.

This entails increasing the LRV of the ceiling to 85%, the wall paint to 60%, the floor to 25%, and the work surface to around 45%. These adjustments are essential to optimize the lighting conditions and create a more sustainable and comfortable environment.

In this scenario, the analysis involves switching and rearranging the lighting fixtures using the DIALux EVO manuals and its automatic features. This facilitates the distribution of luminaires based on the specific task areas within each zone. The selected lighting types were chosen based on a comprehensive literature review. Figure 97 provides detailed information about the selected lighting models in this scenario. These lighting fixtures used for each space, along with their associated lighting parameter can be summarized as:

- Pendant LED light: With a color temperature of 6500K and a Color Rendering Index (CRI) of 80, this lighting fixture is suitable for use in offices, reading areas, writing zones, and in the library's bookshelves area
- LED squared panel light: This type of light is utilized in the library, classroom, student areas, boardroom, and the open plan office.
- Down LED light: These lights are installed in the boardroom, auditorium, some areas in the administration area, and the registration office. They have a color temperature of 4000K and a CRI of 80.
- Round LED spot light: Equipped with a color temperature of 3000K and a CRI of 80, this lighting fixture is used in the circulation zone.

The selection of these lighting models is based on their compatibility with the specific needs and lighting requirements of each space.



P	54.3 W
Φ_{Lamp}	5468 lm
$\Phi_{Luminaire}$	5468 lm
η	100.00 %
Luminous efficacy	100.7 lm/W
CCT	6500 K
CRI	80



P	33.0 W
$\Phi_{Luminaire}$	4320 lm
Luminous efficacy	130.9 lm/W
CCT	6500 K
CRI	80



Article No.	3100172
P	16.5 W
$\Phi_{Luminaire}$	1305 lm
Luminous efficacy	79.1 lm/W
CCT	4000 K
CRI	80



P	35.0 W
Φ_{Lamp}	3539 lm
$\Phi_{Luminaire}$	3539 lm
η	99.99 %
Luminous efficacy	101.1 lm/W
CCT	3000 K
CRI	80

Figure 97: Luminaire list-DIALux EVO 11

(Source: Author,2023)

In this scenario, the objective in the auditorium is to achieve specific lux levels tailored to the various activities and tasks conducted in different areas of the auditorium. The primary target lux value is set at 317 lux. To achieve this, additional fixtures of LED downlights and two square lights have been introduced, as indicated in Figure 98. Designing the lighting for such a versatile space requires careful planning because it hosts a wide range of activities that demand different lighting solutions.

By implementing a lighting control system, the auditorium can seamlessly transition between different lighting scenarios, ensuring that the appropriate lighting levels are maintained for various events. This adaptability is crucial for accommodating presentations, meetings, performances, or general use. Furthermore, this flexibility not only enhances the functionality and user-friendliness of the auditorium but also contributes to sustainability by reducing energy consumption.

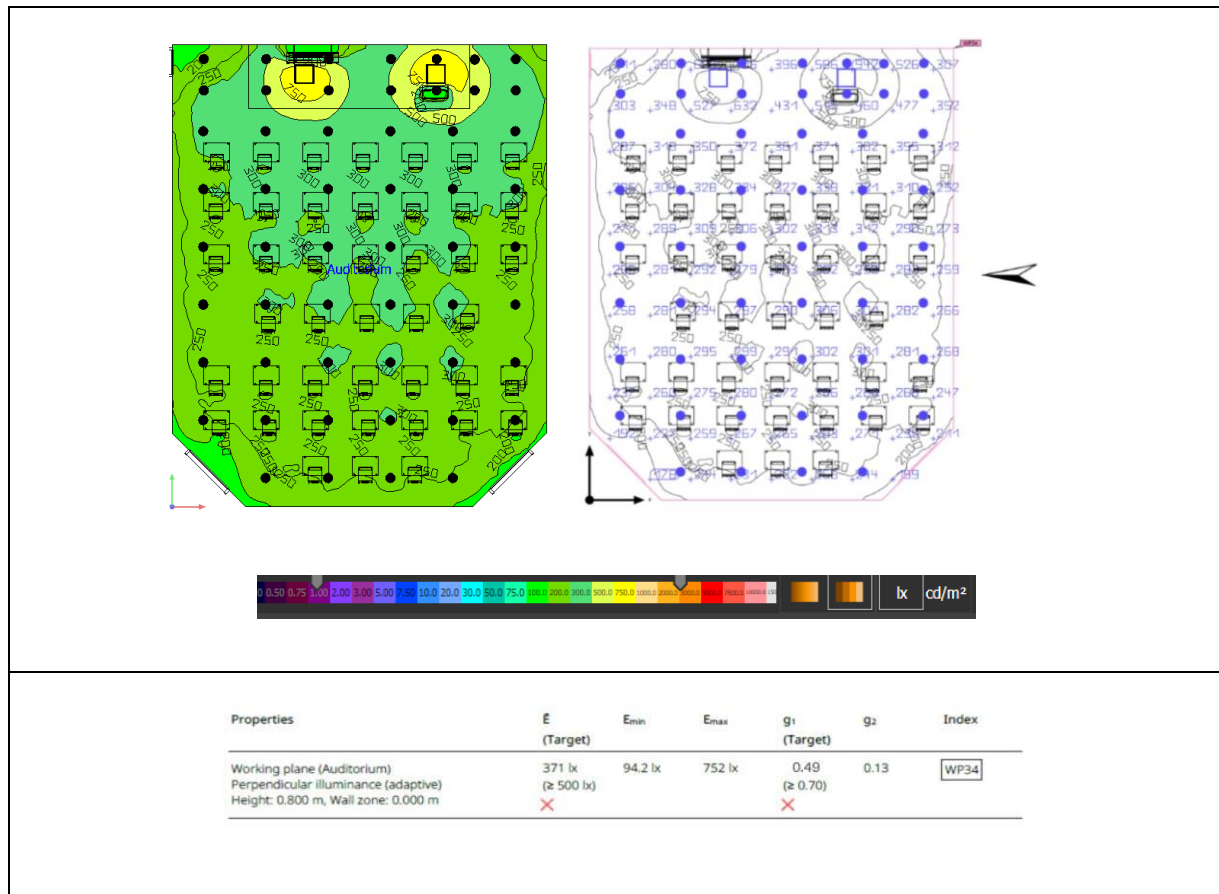


Figure 98: Auditorium- lux value and uniformity ratio

(Source: Author,2023)

Remarkably, the results, as displayed in Figure 99, reveal an improvement in the lux value within the classroom, particularly in terms of uniformity around the students' desks and the hall area. This improvement has been achieved while adhering to the standard value of approximately 500 lux. The transformation in lighting conditions was realized by replacing the existing luminaires with a new type, involving the insertion and rearrangement of eight LED square recessed panel luminaires in more suitable locations aligned with the furniture layout.

Additionally, the positive impact of enhancing the Light Reflectance Value (LRV) of the space's surfaces is evident in the overall results achieved in the classroom.

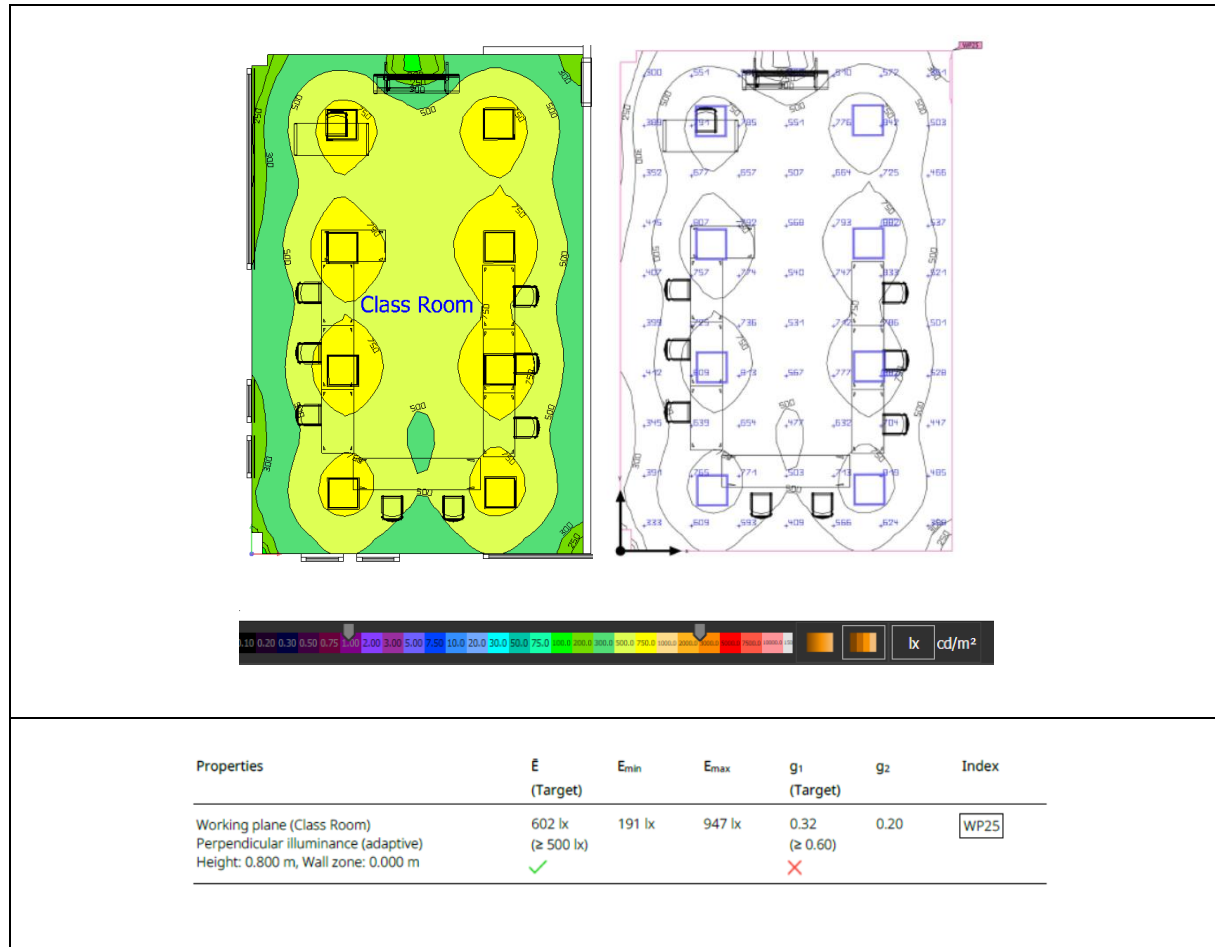
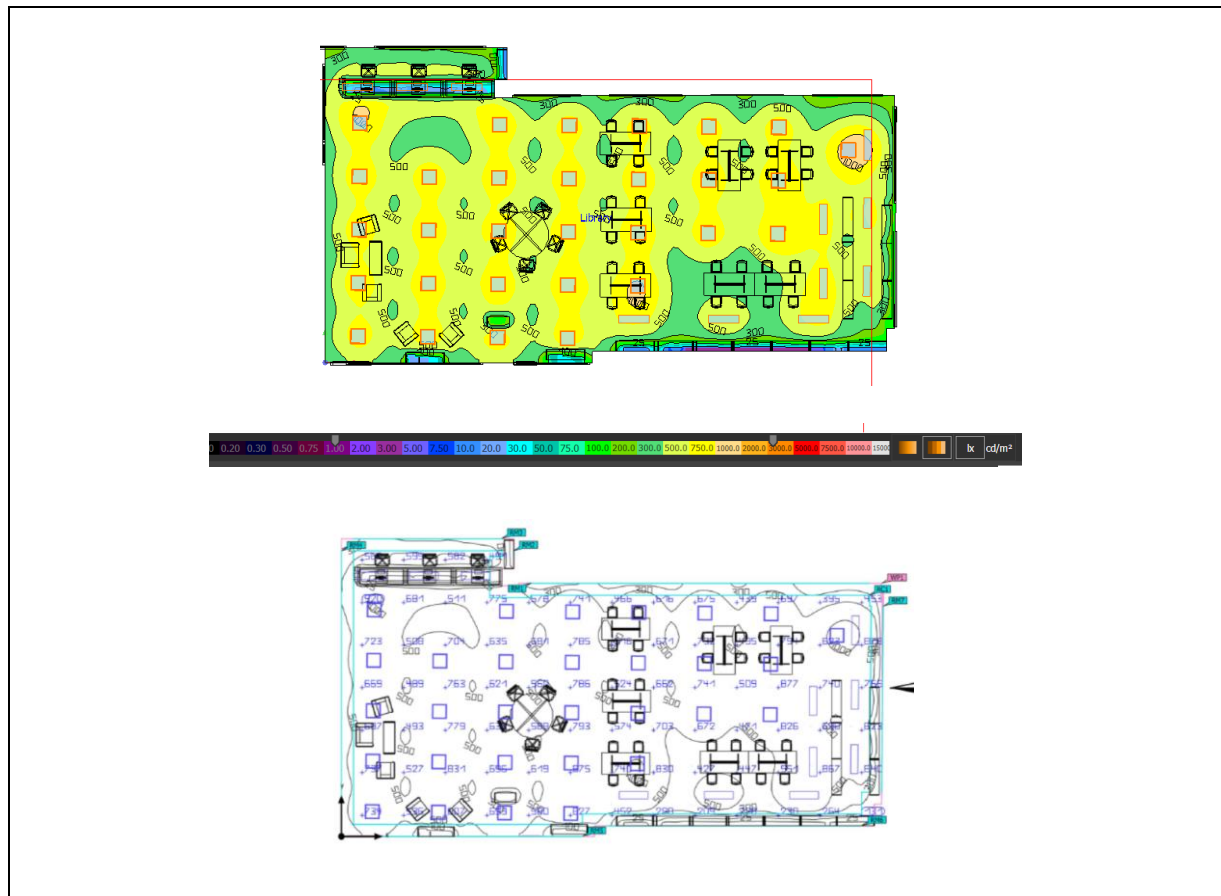


Figure 99: Classroom FF-111- lux value and uniformity ratio

(Source: Author,2023)

Further strong evidence of the positive impact of enhancing lighting parameters was discovered when the lighting fixtures in the library space were switched and rearranged to LED lights. As shown in Figure 100, improvements were made to the surface reflectance factor, aligning with LEED specifications for interior spaces. This strategic approach has resulted in

significant enhancements in the lux value throughout the campus building. These improvements have been achieved by simply adjusting these two factors, and they have contributed to enhancing user satisfaction and increasing student productivity. Whether for reading or using computer screens, inserting thirty square LED lights has made a notable difference. Moreover, the bookshelves zone has been enhanced by adding eleven pendant lights with specifications including a color temperature of 6500 K and a CRI of 80. The office zone has also seen remarkable improvements to meet the required reference values in accordance with the established standards.



Properties	E (Target)	E _{min}	E _{max}	g ₁ (Target)	g ₂	Index
Working plane (Library) Perpendicular illuminance (adaptive) Height: 0.800 m, Wall zone: 0.000 m	608 lx (≥ 500 lx) ✓	3.34 lx	1211 lx	0.05 (≥ 0.60) ✗	0.003	WP1

Figure 100: Library- lux value and uniformity ratio

(Source: Author,2023)

In Figure 101, the illustration demonstrates a significant improvement in lux values to meet the target standards in both areas. This enhancement involved the replacement of lighting fixtures with four LED square recessed panels and eleven LED downlights. Additionally, adjustments were made to the surfaces and furniture reflectance factor. As a result of these changes, the lux value in the task area now measures around 495 lux, aligning with the target value. Importantly, this was achieved without introducing glare, thanks to the appropriate distribution of light fixtures. This not only improves the overall lighting quality in these areas but also contributes to user comfort and productivity.

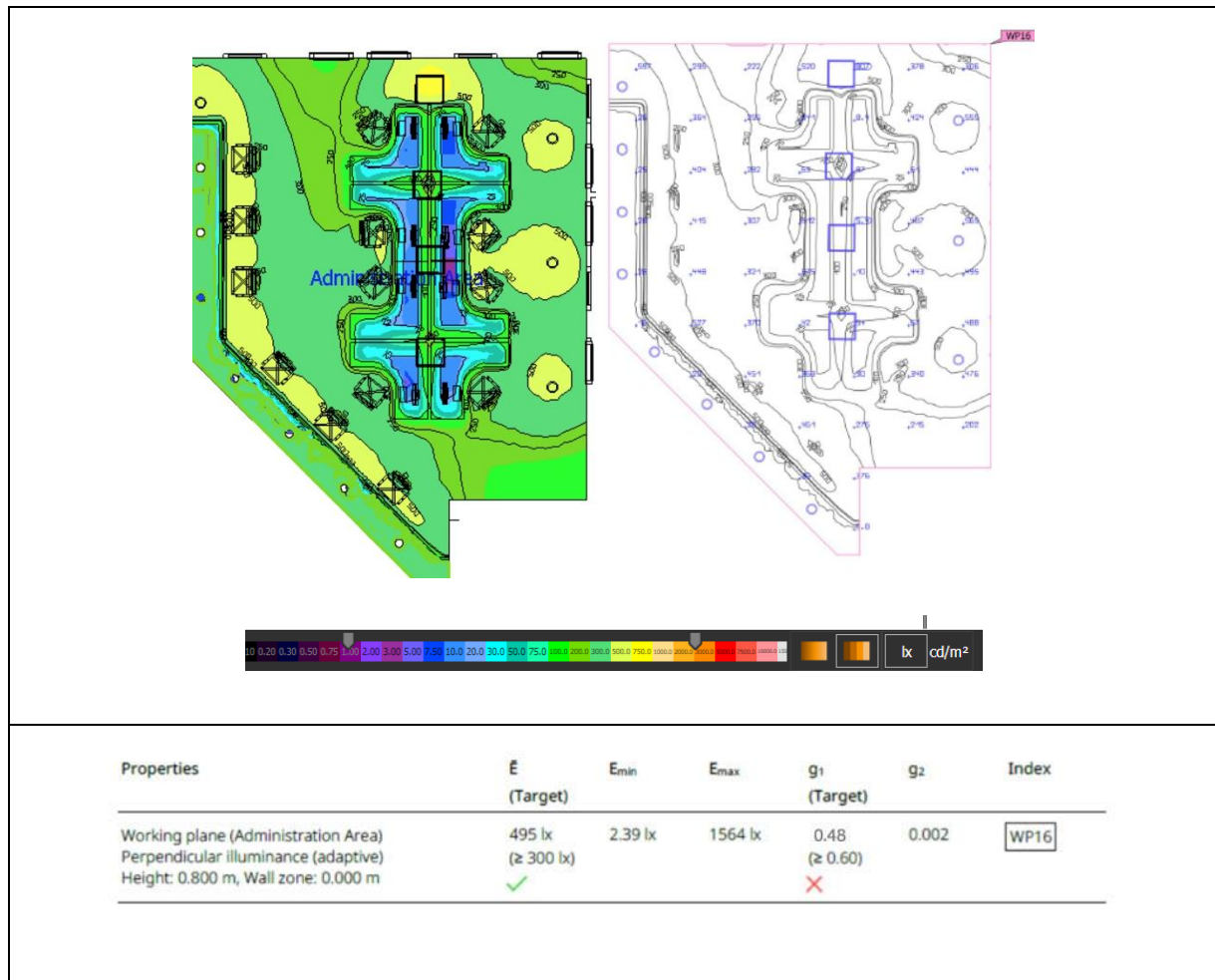


Figure 101: Administration area- lux value and uniformity ratio

(Source: Author,2023)

A significant difference is evident between the two simulated models and the resulting lux values before and after implementing the two enhancement strategies to improve the existing base case. Notably, the study room is now uniformly lit, aligning with the requirements of each task zone.

In Figure 102, a logical distribution of light is apparent around the reading zone, bookshelves, and the circulation area. Lux values in these areas now closely approach the target levels as defined by the standards. This significant improvement has been achieved by adding four LED square recessed panels and two pendant lights with a color temperature of 6500 K and a CRI of 80, strategically placed between the bookshelves. These enhancements have made the lighting in these areas more suitable for their intended purposes.



Figure 102: Group study room- lux value and uniformity ratio

(Source: Author,2023)

Furthermore, another space saw enhancements after applying the artificial lighting strategy. Figure 103 significantly represents the improved light distribution around the student lounge area, which entailed the addition of thirteen LED square recessed panel lights recommended by the software. This adjustment led to improved lighting levels, better distribution, reduced light contrast, and the creation of a more comfortable environment. The correlation between sustainable lighting strategies and internal finishing materials, based on LEED guidelines, is particularly interesting. These enhancements alone have effectively improved the uniformity ratio in different areas, all without the need for extensive changes to the external elevations, which could have incurred additional costs for an existing building.

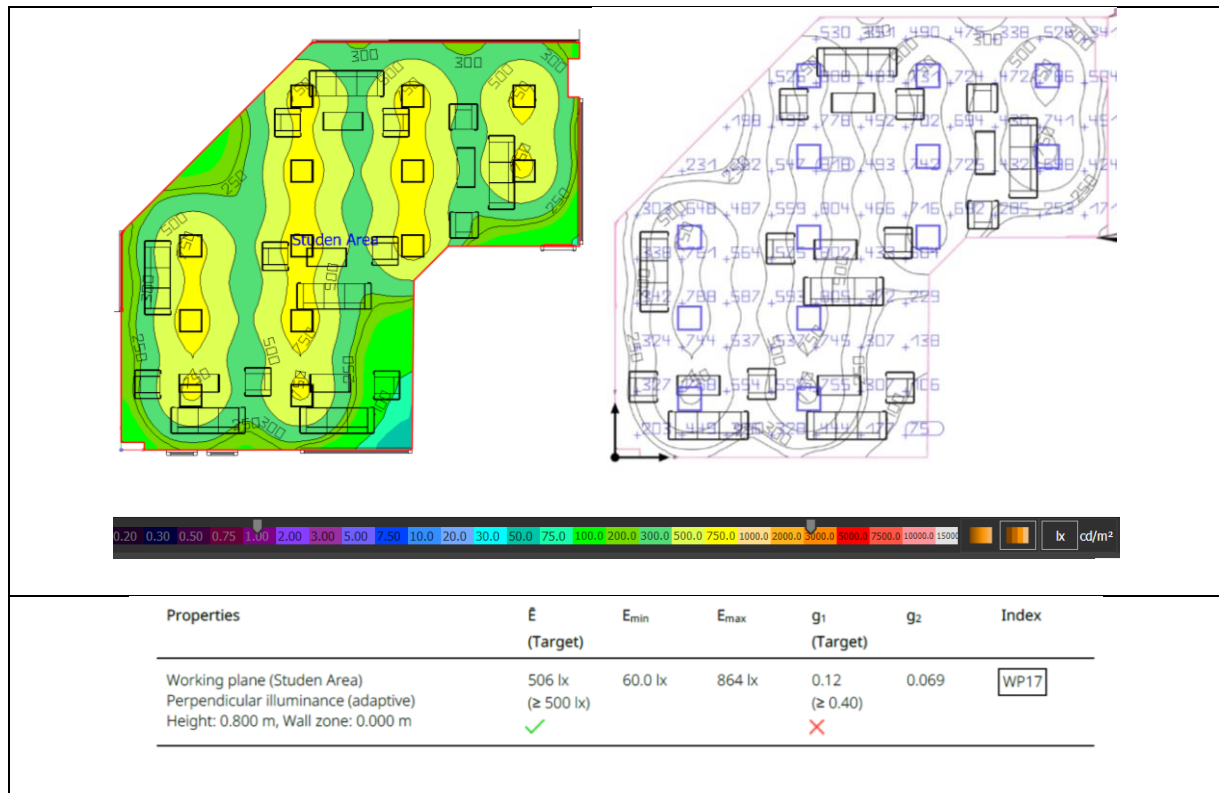


Figure 103: Students lounge- lux value and uniformity ratio

Moreover, the board room now boasts an average lux level of approximately 439 lx, which, while just slightly below the standard lux, has seen an improvement through the addition of four pendant lights with a color temperature of 6500 K and a CRI of 80, along with three downlights with 4000K and 80 CRI. As shown in Figure 104, the distribution of light in this area, much like other zones, has been enhanced, leading to a more uniform and comfortable lighting environment.

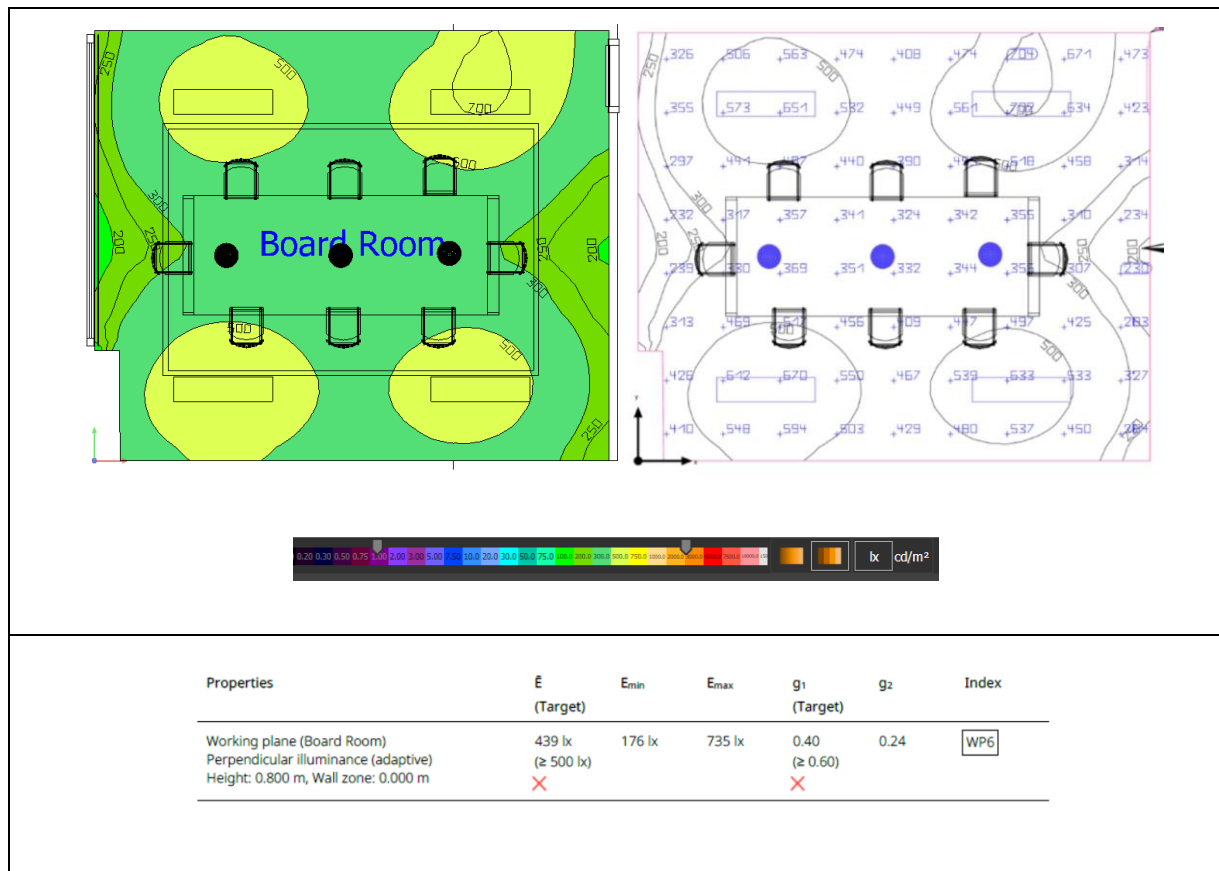


Figure 104: Board room- lux value and uniformity ratio

(Source: Author,2023)

Additionally, Figure 105 displays the general circulation zone, which has also seen improvement after implementing the artificial lighting strategy in a well-planned and uniform manner. LED luminaires placed at corridor corners produce glare-free, asymmetric light on the walls and ceiling, creating a more inviting and spacious atmosphere. Conversation areas have been adequately illuminated by a combination of direct and indirect lighting.

To further enhance the conditions for visual communication, thirty-four LED spotlights with a color temperature of 3000K and a CRI of 80 have been added to provide more light on the walls and ceiling. This not only contributes to the overall aesthetics of the space but also ensures that it is well-suited for various forms of interaction and communication.

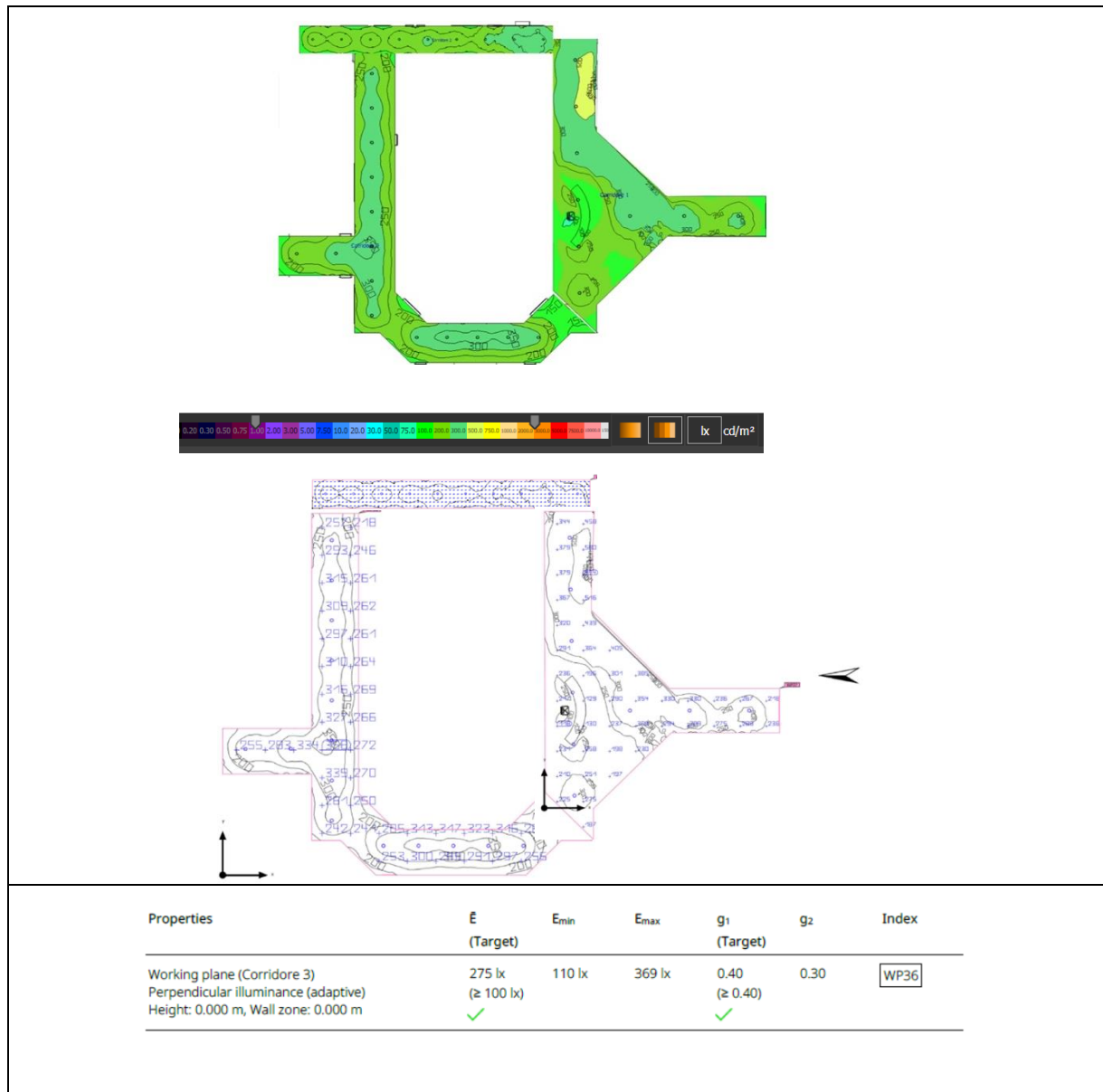


Figure 105: Corridors- lux value and uniformity ratio

(Source: Author,2023)

Figure 106 illustrates the layout plan for the registration office, demonstrating a significant improvement in lighting parameters compared to the base case scenario. This enhancement was achieved by replacing the down spotlights. Individual offices have greatly benefited from this

adjustment, with direct illumination playing a key role. Additionally, the indirect lighting component has contributed to increasing the size and brightness of the individual office spaces. Pendant lights positioned above desk areas have become a common solution, while recessed lights used in combination with task lights represent another viable option. Furthermore, floor lamps and table lamps offer employees the flexibility to adjust the light level and positioning to best suit their needs, enhancing their overall workspace experience.

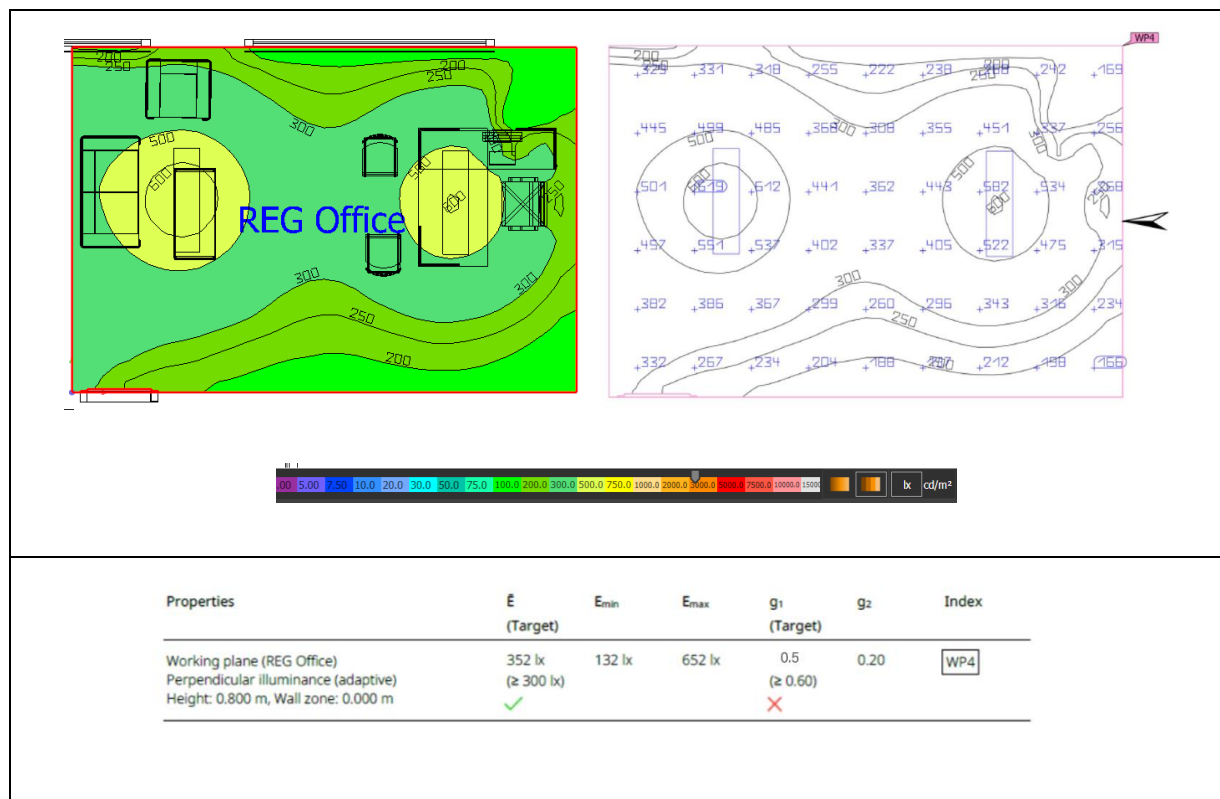


Figure 106: Registration office- lux value and uniformity ratio

(Source: Author,2023)

Table 44 provides a summary report of different zones within the campus, focusing on Strategy 2, Scenario 2. This scenario involves switching and rearranging the existing fixtures to a new type, particularly in the context of nighttime conditions.

Table 44: Summary report of different zones in the campus- strategy 2, scenario 2: switching and rearranging the current fixtures to the new type- At night, (Source: Autor,2023)

Audoturium						Classroom FF-111					
	Symbol	Calculated	Target	Check	Index		Symbol	Calculated	Target	Check	Index
Working plane	$E_{\text{perpendicular}}$	371 lx	≥ 500 lx	✗	WP34	Daylight	D	1.766 %	-		DF25
	g_1	0.43	≥ 0.70	✗	WP34	Working plane	$E_{\text{perpendicular}}$	602 lx	≥ 500 lx	✓	WP25
Glare valuation ⁽¹⁾	$R_{\text{GL,max}}$	18	≤ 19	✓			g_1	0.32	≥ 0.60	✗	WP25
Energy estimation ⁽²⁾	Consumption	1768 kWh/a	max. 5650 kWh/a	✓		Glare valuation ⁽¹⁾	$R_{\text{GL,max}}$	18	≤ 19	✓	
						Energy estimation ⁽²⁾	Consumption	[210.87 - 351.12] kWh/a	max. 2050 kWh/a	✓	
Library						Administration area					
	Symbol	Calculated	Target	Check	Index		Symbol	Calculated	Target	Check	Index
Daylight	D	0.024 %	-		DF1	Daylight	D	0.307 %	-		DF16
Working plane	$E_{\text{perpendicular}}$	608 lx	≥ 500 lx	✓	WP1	Working plane	$E_{\text{perpendicular}}$	495 lx	≥ 300 lx	✓	WP16
	g_1	0.05	≥ 0.60	✗	WP1		g_1	0.48	≥ 0.60	✗	WP16
Glare valuation ⁽¹⁾	$R_{\text{GL,max}}$	18	≤ 19	✗		Glare valuation ⁽¹⁾	$R_{\text{GL,max}}$	20	≤ 22	✓	
Energy estimation ⁽²⁾	Consumption	[3810.15 - 5714.28] kWh/a	max. 8550 kWh/a	✓		Energy estimation ⁽²⁾	Consumption	[895.86 - 1421.75] kWh/a	max. 2650 kWh/a	✓	
Group study room						Students lounge					
	Symbol	Calculated	Target	Check	Index		Symbol	Calculated	Target	Check	Index
Daylight	D	0.001 %	-		DF33	Daylight	D	0.078 %	-		DF17
Working plane	$E_{\text{perpendicular}}$	579 lx	≥ 500 lx	✓	WP33	Working plane	$E_{\text{perpendicular}}$	506 lx	≥ 500 lx	✓	WP17
	g_1	0.25	≥ 0.60	✗	WP33		g_1	0.12	≥ 0.40	✗	WP17
Glare valuation ⁽¹⁾	$R_{\text{GL,max}}$	17	≤ 19	✓		Glare valuation ⁽¹⁾	$R_{\text{GL,max}}$	22	≤ 22	✓	
Energy estimation ⁽²⁾	Consumption	866 kWh/a	max. 1200 kWh/a	✓		Energy estimation ⁽²⁾	Consumption	[520.36 - 825.83] kWh/a	max. 3200 kWh/a	✓	
Board room						Corridor					

	Symbol	Calculated	Target	Check	Index
Daylight	D	0.138 %	-		DF6
Working plane	$E_{\text{perpendicular}}$	439 lx	≥ 500 lx	✗	WP6
	g_1	0.40	≥ 0.60	✗	WP6
Glare valuation ⁽¹⁾	$R_{\text{gl,max}}$	18	≤ 19	✓	
Energy estimation ⁽²⁾	Consumption	[323.50 - 513.40] kWh/a	max. 1150 kWh/a	✓	

	Symbol	Calculated	Target	Check	Index
Daylight	D	0.149 %	-		DF36
Working plane	$E_{\text{perpendicular}}$	275 lx	≥ 100 lx	✓	WP36
	g_1	0.40	≥ 0.40	✓	WP36
Glare valuation ⁽¹⁾	$R_{\text{gl,max}}$	28	≤ 25	✗	
Energy estimation ⁽²⁾	Consumption	577 kWh/a	max. 4500 kWh/a	✓	

Registration office

	Symbol	Calculated	Target	Check	Index
Daylight	D	0.307 %	-		DF4
Working plane	$E_{\text{perpendicular}}$	352 lx	≥ 300 lx	✓	WP4
	g_1	0.5	≥ 0.60	✗	WP4
Energy estimation ⁽²⁾	Consumption	[188.18 - 298.65] kWh/a	max. 850 kWh/a	✓	

The results clearly illustrate that replacing the current lighting fixtures with new ones has the potential to create different lighting moods, enhancing the overall user experience and well-being. As a consequence, this can lead to increased productivity and concentration among both students and staff. Additionally, the suggested strategies have successfully improved and reduced the energy consumption estimates for all spaces, aligning them with the target levels specified in DIALux Evo 11. The addition of more fixtures has resulted in better lighting levels, and the choice of appropriate fixture types has enhanced the lighting distribution within the spaces. This reduction in dark-light contrast contributes to making students and staff more alert, ultimately optimizing the functionality of these areas.

4.8 Strategy 3: Combine Daylight with Artificial Light

In line with previous literature and case studies, this strategy primarily targets spaces with available daylight, as previously mentioned. The base case model assessed the presence of

daylight in these spaces using the same old lighting fixtures before any enhancements. However, the simulation results indicated very high lux values and excessive glare, especially in areas near the windows. It's important to note that this study focuses solely on the interior spaces of the existing building without any changes to the external envelope.

For this scenario, the strategy was expanded by collaborating with leading lighting manufacturers to gather information on the latest lighting fixture technologies for educational campus buildings worldwide. The manufacturer-approved manuals and catalogs were integrated into the DIALux EVO software, streamlining information accessibility for space designers.

The third strategy builds upon the previous one and includes two scenarios. The first scenario examines the impact of daylight in the enhanced spaces by closing all the curtains during the day and assessing the minimum and maximum lux values installed in these spaces. The second scenario revolves around the possibility of dimming some of the artificial lighting fixtures by up to 50% during the day by implementing a dimming system. It's important to note that this scenario has certain limitations, as the software only allows for dimming fixtures to a maximum of fifty percent.

4.8.1 Scenario 1: Combine artificial light and daylight while all curtains closed- Daytime (At 11:00AM)

As depicted in Figure 107, the classroom achieved a satisfactory lux value in this scenario. However, there is still an area near the window that exhibits an orange rendering, indicating increased heat gain. The daylight factor measured 1.76%, which falls below the standard.

Nevertheless, the light distribution has seen significant improvement compared to previous scenarios.

Figure 108 provides an analysis of the library, featuring both color graph analysis and an isoline map obtained from the software. In this representation, the reading area appears to be well-lit compared to previous values. Consequently, energy consumption has improved and aligns with the target value, as depicted in the summary Table 44.

As depicted in Figure 109, the student lounge exhibits a well-distributed lighting across all task areas. Furthermore, the circulation zone around the sitting area has successfully met the target values in terms of lighting. These achievements are a result of enhancing and replacing the old lighting fixtures with more efficient alternatives and improving the LRV of the internal surfaces.

Furthermore, Figure 110 shows the registration office space, which is used by individual occupants and differs from the shared office space in the administration area associated with various tasks. Notably, the uniformity ratio has been improved thanks to the effective distribution of lighting fixtures. This office space benefits from outdoor views and natural light, enhancing productivity and concentration during various tasks.

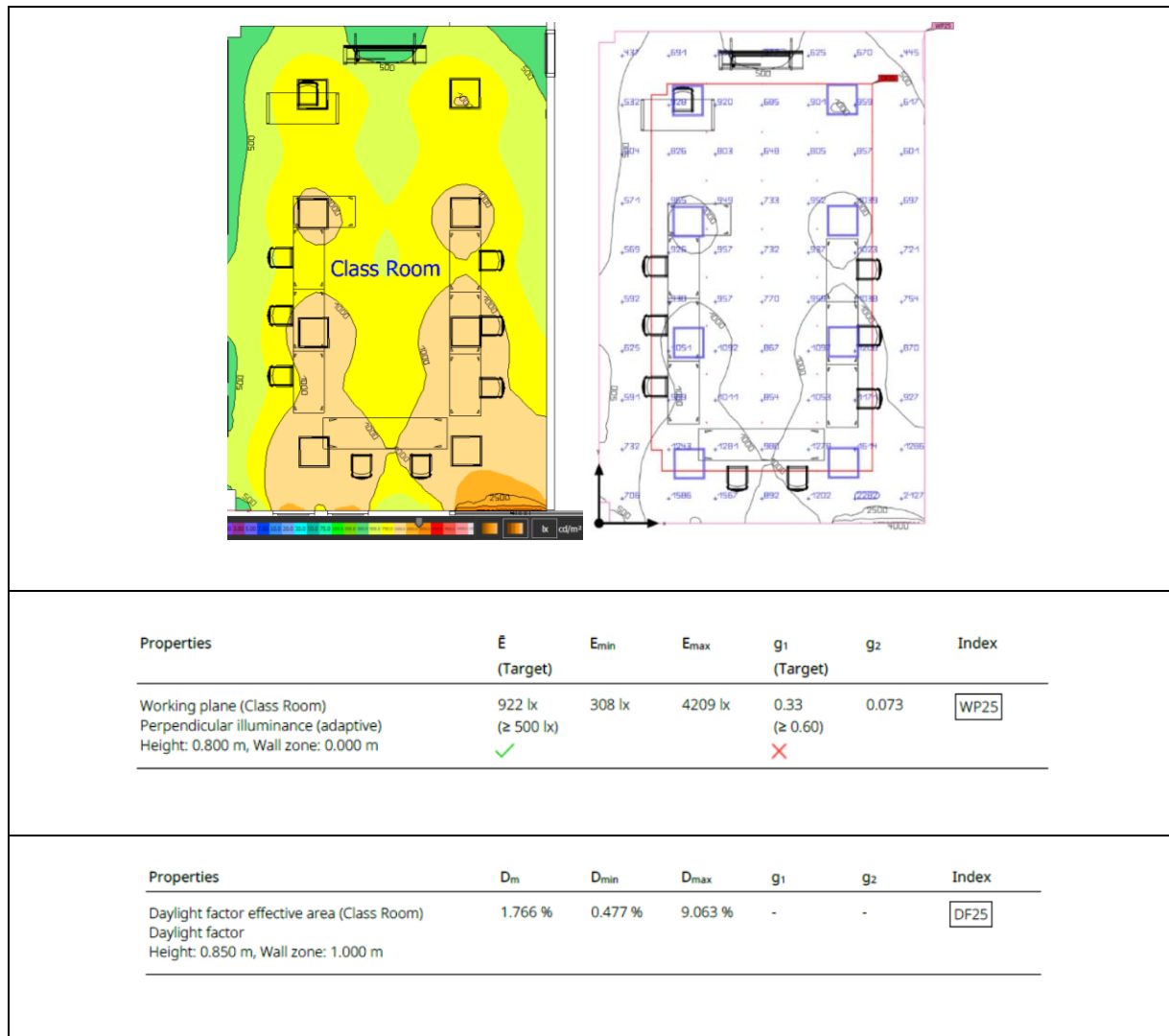


Figure 107: Classroom FF 111 - day light and lux value

(Source: Author,2023)

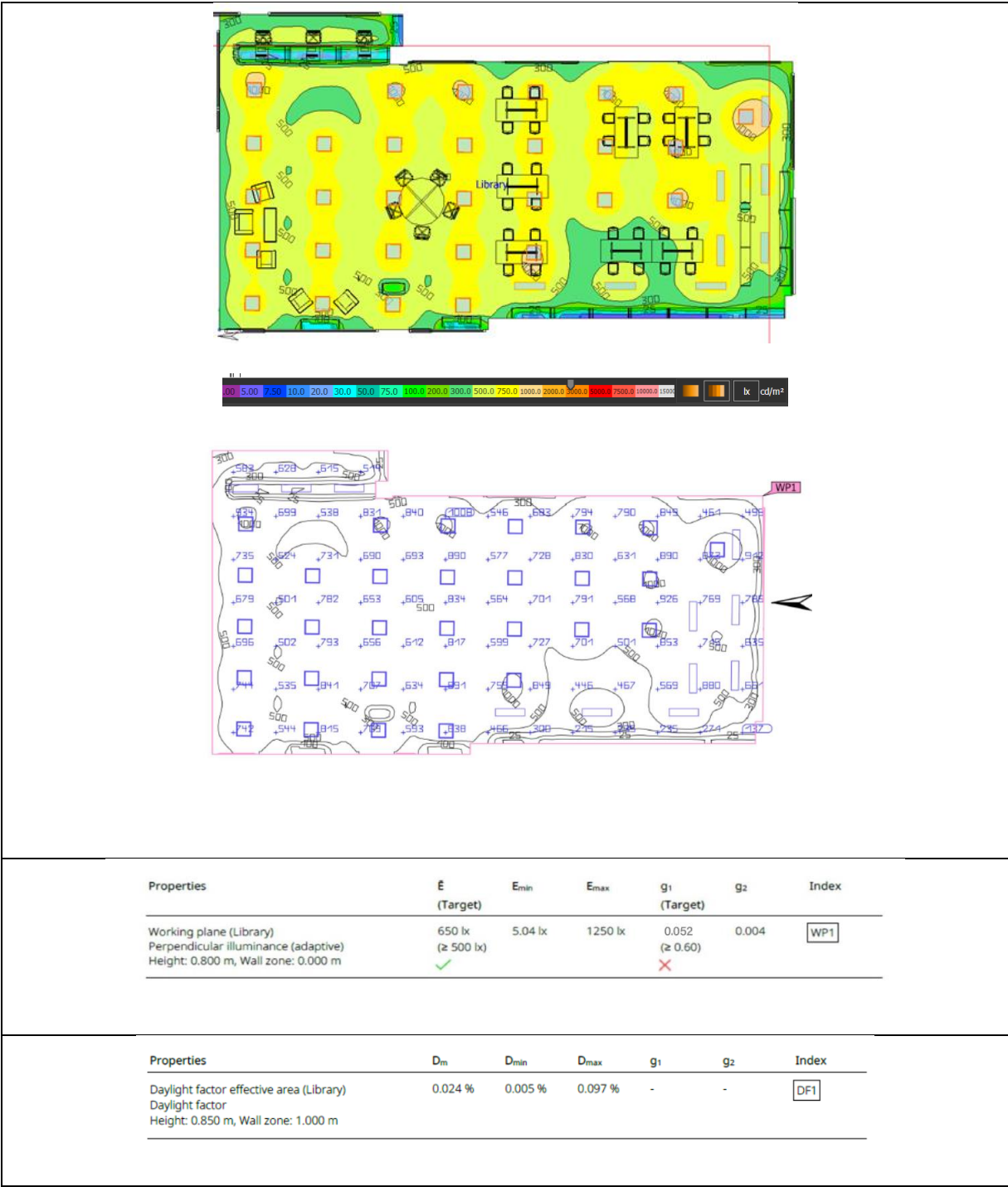


Figure 108: Library - day light and lux value

(Source: Author,2023)



Figure 109: Students lounge - day light and lux value

(Source: Author,2023)

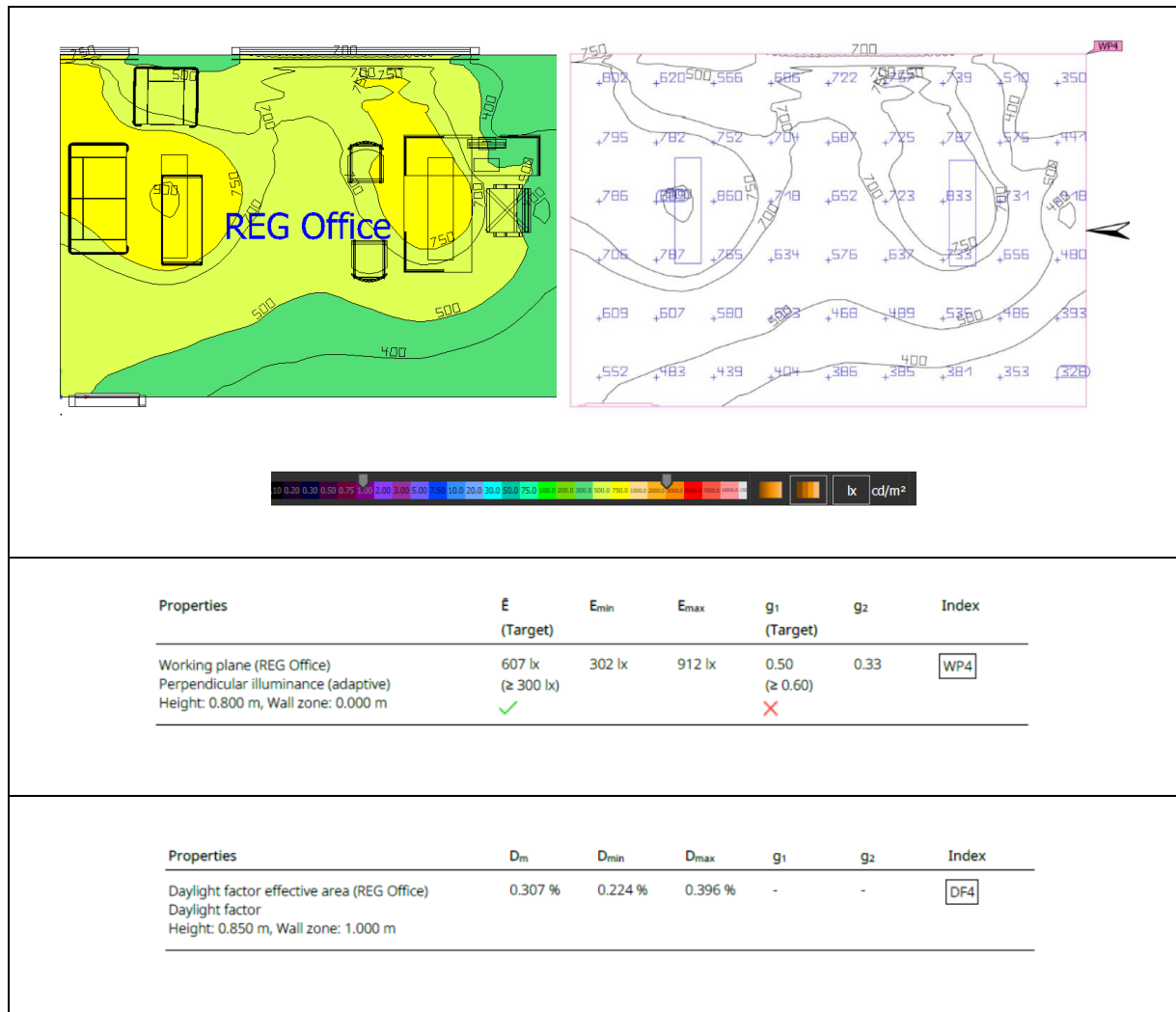


Figure 110: Registration office - day light and lux value

(Source: Author,2023)

Table 45 illustrates the results of combining daylight and artificial light. In all zones, the lighting lux levels meet the target standards. However, the daylight factor falls below the required standards, except in the classroom zone, where a normal daylight factor near the

window results in a slightly brighter space due to indirect sunlight. It's worth noting that the glare and uniformity ratio meet the required standards in some spaces.

As shown in the summary Table 44, the energy consumption values are within the target range, making this strategy an energy-saving approach.

To summarize the advantages and disadvantages of this strategy involving the current lighting fixtures and the enhanced reflectance values of interior surfaces in campus interior spaces, the following observations can be made. By adjusting the reflectance values, including ceilings (85%), walls (60%), floors (25%), and work surfaces (45%) in accordance with LEED standards via the DIALux Evo material manual, the quality and distribution of lighting within interior spaces are improved. This optimization ensures even illumination without causing glare in task areas and effectively meets the target lux levels during daylight hours. Moreover, the introduction of dimmable lighting fixtures offers flexibility in adjusting light levels based on specific tasks or activities. This not only enhances user comfort but also contributes to energy efficiency, reducing the reliance on artificial lighting when natural light is available.

On the other hand, some disadvantages pertain to limitations in the software, particularly concerning the integration of a lighting control system and sensors for managing artificial light during day and night. Additionally, when considering enhancements to the interior lighting environment in an existing building, the effective project cost should take into account external modifications required to mitigate heat gain through the windows. Addressing this may involve enhancing glazing specifications or incorporating shading devices into the building's elevations,

especially in hot regions like Dubai. It's worth noting that certain software limitations may impact the ability to optimize window types for heat gain reduction.

Table 45: Summary report of different zones in the campus- strategy 3,scenario 1:combine artificial light and daylight while all curtains closed, (Source: Author 2023)

Classroom FF 111					
	Symbol	Calculated	Target	Check	Index
Daylight	D	1.766 %	-		DF25
Working plane	$E_{\text{perpendicular}}$	922 lx	≥ 500 lx	✓	WP25
	g_1	0.33	≥ 0.60	✗	WP25
Glare valuation ⁽¹⁾	$R_{\text{GL,max}}$	18	≤ 19	✓	
Energy estimation ⁽²⁾	Consumption	[210.87 - 351.12] kWh/a	max. 2050 kWh/a	✓	

Library					
	Symbol	Calculated	Target	Check	Index
Daylight	D	0.024 %	-		DF1
Working plane	$E_{\text{perpendicular}}$	650 lx	≥ 500 lx	✓	WP1
	g_1	0.052	≥ 0.60	✗	WP1
Glare valuation ⁽¹⁾	$R_{\text{GL,max}}$	18	≤ 19	✓	
Energy estimation ⁽²⁾	Consumption	[3810.15 - 5714.28] kWh/a	max. 8550 kWh/a	✓	

Student lounge					
	Symbol	Calculated	Target	Check	Index
Daylight	D	0.078 %	-		DF17
Working plane	$E_{\text{perpendicular}}$	523 lx	≥ 500 lx	✓	WP17
	g_1	0.16	≥ 0.40	✗	WP17
Glare valuation ⁽¹⁾	$R_{\text{GL,max}}$	18	≤ 22	✓	
Energy estimation ⁽²⁾	Consumption	[520.36 - 825.83] kWh/a	max. 3200 kWh/a	✓	
Room	Lighting power density	4.71 W/m ²	-		
		0.90 W/m ² /100 lx	-		

Registration office					
	Symbol	Calculated	Target	Check	Index
Daylight	D	0.307 %	-		DF4
Working plane	$E_{\text{perpendicular}}$	607 lx	≥ 300 lx	✓	WP4
	g_1	0.50	≥ 0.60	✗	WP4
Energy estimation ⁽²⁾	Consumption	[188.18 - 298.65] kWh/a	max. 850 kWh/a	✓	

4.8.2 Scenario 2: Combine artificial light with daylight when curtains half way open and dimming artificial fixtures (At 11:00AM)

In this scenario, with the curtains halfway opened and the artificial light dimmed by approximately 50%, we aimed to assess the impact of daylight and its potential to replace

artificial lighting during the day for energy savings and improved indoor quality. However, as depicted in Figure 111, the lux levels in classroom FF-111 based on this scenario were found to be considerably low. Daylight only adequately illuminated the area next to the window, with an average of 1.4%, leaving the rest of the classroom in shades of blue and green, indicating a darker environment that may negatively affect user satisfaction and productivity during tasks.

Additionally, the library appeared to have lower light levels as indicated in Figure 112, especially in the section closer to the indoor area of BUiD. However, the area near the windows was comparatively brighter, with an average of 420 lux and an overall daylight factor of 0.024%. This discrepancy in lighting may result in variations in user experience within the library.

In Figure 113, which shows the student lounge results, the lux distribution around the area did not meet the target levels. The maps indicate that the blue color predominated in this area, covering most of the space, signifying low light levels. This could have a negative impact on users, including students and staff, who may find this space less conducive for relaxation or as a break room.

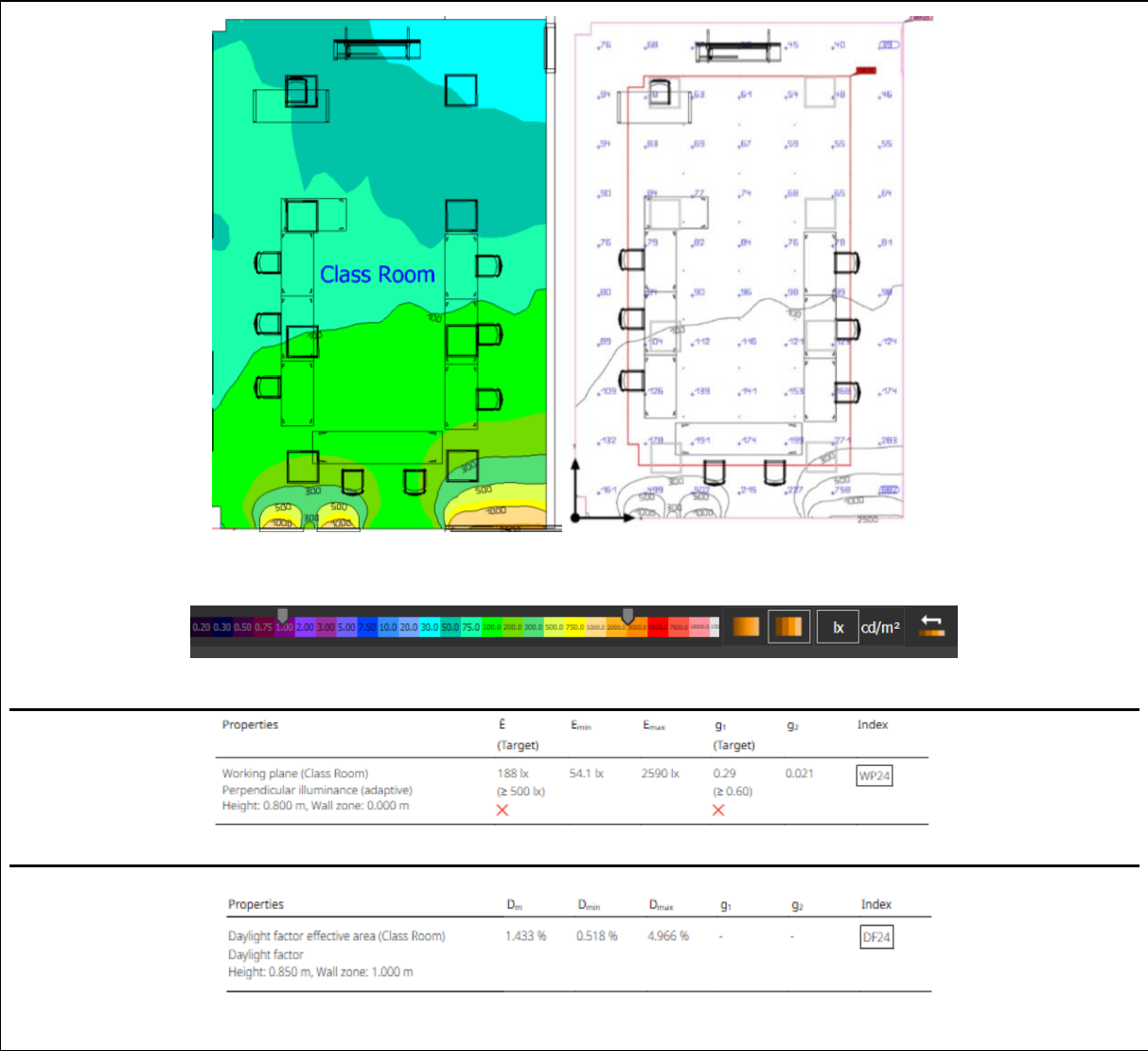


Figure 111: Classroom 111- day light and lux value

(Source: Author,2023)

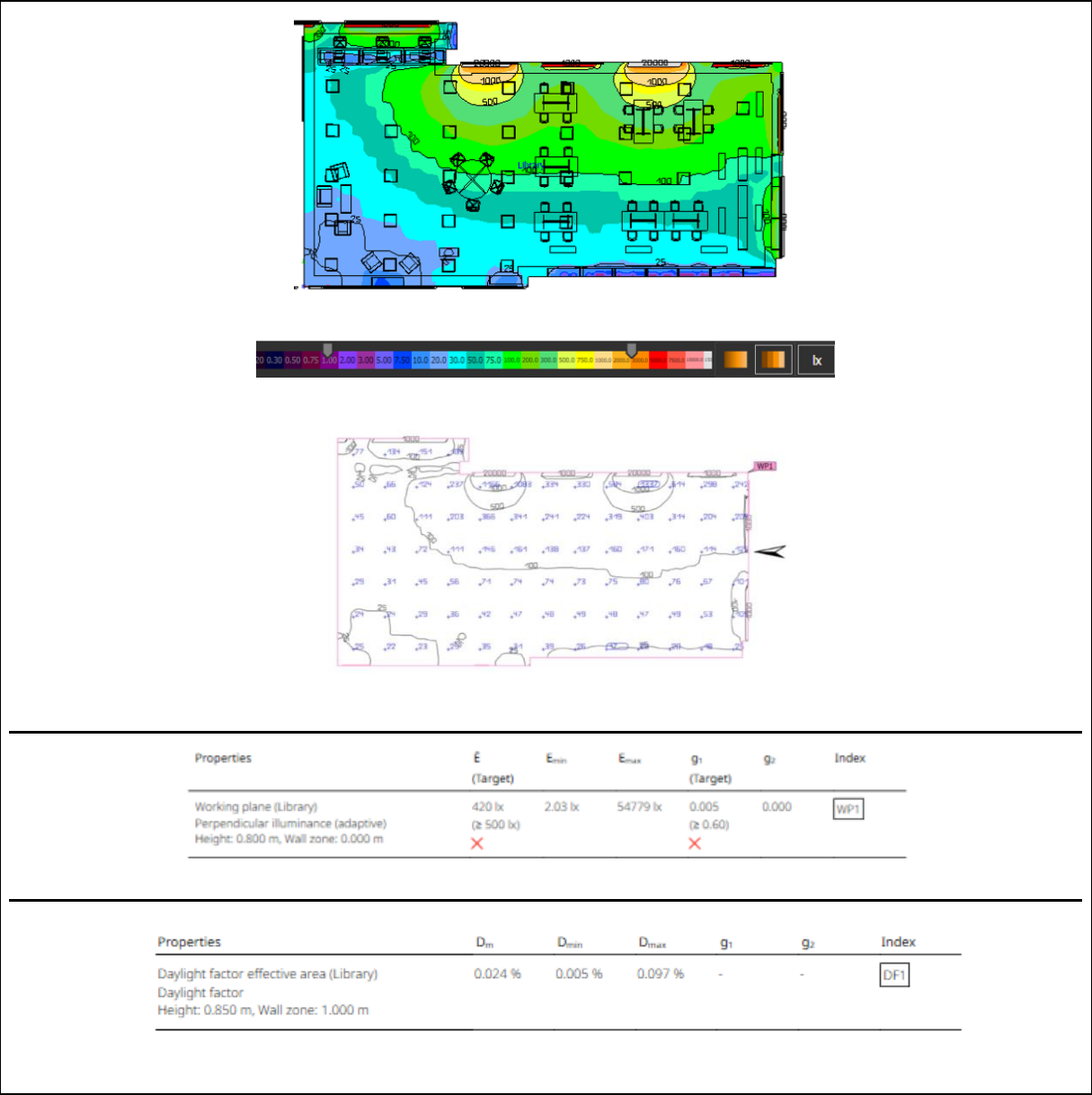


Figure 112: Library - day light and lux value

(Source: Author,2023)



Figure 113: Students lounge - day light and lux value

(Source: Author,2023)

The registration office is also affected by the daylight coming in from the windows, resulting in a high lux value of around 2052 lx and causing a very bright space as shown in Figure 114. This is primarily due to the large window area relative to the total space. As a result, energy consumption is likely to increase. However, it's important to note that the software doesn't

provide the capability to calculate energy savings in the presence of dimmers, as explained previously.



Figure 114: Registration office - day light and lux value

(Source: Author,2023)

Table 46 provides a summary of the different zones in the campus, considering the combination of artificial light with daylight when curtains are halfway open and artificial fixtures are dimmed. In this scenario, the library, students' lounge, and classroom FF-111 had lux values below the target average, while the registration office exhibited a high level of lux.

However, the daylight factor in these spaces did not meet the required standards. The spaces near the window experienced excessive brightness and heating, leading to discomfort in these areas. The Daylight Factor (DF) is an essential metric in lighting design, as it assesses the amount of natural daylight relative to the total illumination level within a space. Specifically, it measures the ratio of natural light (daylight) to the total light, including both natural and artificial light, in an interior space. This metric helps evaluate the impact of daylight on the overall lighting environment and assess its effectiveness in contributing to energy savings and user comfort.

Table 46: Summary table of different zones in the campus, strategy 3-scenario 2: Combine artificial light with daylight when curtains half way open and dimming artificial fixtures,

(Source: Author ,2023)

Classroom FF 111					
	Symbol	Calculated	Target	Check	Index
Daylight	D	1.433 %	-		DF24
Working plane	$E_{\text{perpendicular}}$	188 lx	≥ 500 lx	X	WP24
	g_1	0.29	≥ 0.60	X	WP24
Library					
	Symbol	Calculated	Target	Check	Index
Daylight	D	0.024 %	-		DF1
Working plane	$E_{\text{perpendicular}}$	420 lx	≥ 500 lx	X	WP1
	g_1	0.005	≥ 0.60	X	WP1
Student lounge					
	Symbol	Calculated	Target	Check	Index
Daylight	D	0.078 %	-		DF17
Working plane	$E_{\text{perpendicular}}$	378 lx	≥ 500 lx	X	WP17
	g_1	0.054	≥ 0.40	X	WP17
Registration office					
	Symbol	Calculated	Target	Check	Index
Daylight	D	0.307 %	-		DF4
Working plane	$E_{\text{perpendicular}}$	2052 lx	≥ 300 lx	✓	WP4
	g_1	0.14	≥ 0.60	X	WP4

4.9 Analysis Chapter Summary

The previous strategies and scenarios aimed to enhance the interior lighting parameters within the indoor campus building for educational purposes, with the goal of improving the users' experience and well-being while increasing the productivity of students and staff. The data analysis covered various interior spaces within the campus building and evaluated the indoor environment based on natural and artificial lighting parameters.

The analysis demonstrated that enhancing the lighting design in an existing building can be a challenging endeavor, requiring a holistic approach to address all aspects of lighting, including factors such as light lux value (illuminance), glare value (luminance), uniformity ratio, color render index, color temperature, and energy consumption. These parameters need to meet the required standards for each zone and task, highlighting the importance of considering these aspects in the early stages of the design process.

The importance of improving the interior finishing specifications, particularly in terms of Light Reflectance Value (LRV), cannot be overstated in the context of enhancing lighting strategies. This becomes evident when we consider the second scenario of strategy two, where increasing the LRV value in compliance with LEED standards led to improved lux values and overall lighting conditions in most of the tested zones.

It's important to note that several factors can impact the campus building, students' lives, and their learning processes. These factors, in turn, influence the lighting parameters, space design, and the users' overall experience. In cases where natural daylight is unavailable, as seen in spaces like the auditorium, administration area, group study rooms, and general traffic zones,

the second strategy becomes particularly relevant. This strategy focuses on enhancing artificial lighting by switching and rearranging luminaire types and upgrading surface specifications to match the standards, ensuring a better and more efficient lighting environment in these areas.

Chapter 5 : Result and Discussion

5.1 Introduction

This study set out with the aim of assessing the importance of lighting design in indoor environmental quality enhancements associated with occupant's comfort and satisfaction in an educational building in Dubai, UAE. A strong relationship between interior lighting design and user's well-being and satisfaction has been reported in the literature. As stated by Alhamad and Saraiji (2022) and Ticleanu (2021), lighting solutions aim to enhance visibility and clarity in various settings depends on the task and activity of each zone. However, it is important to note that certain spaces, such as classrooms, libraries, auditorium also consider aesthetic requirements to improve the overall appearance of the environment, individuals, and objects within it. This perspective aligns with the common assumption that the main function of light is to support visual perception and satisfaction by providing appropriate lighting conditions for safe, accurate, efficient, and comfortable performance of human tasks.

However, very few studies have been conducted in the literature to address the question of enhancing lighting parameters, whether natural or artificial, in existing campus buildings, encompassing various spaces such as libraries, classrooms, auditoriums, meeting rooms, offices, and lounge areas for students. Most studies have focused on a single category of space, particularly in the Gulf region, and have examined the impact of these parameters on user productivity and performance. One of the most interesting findings, as highlighted by Pratiwi and Djafar (2021), is that factors like the positioning of windows, the ratio of windows to walls, room proportions and shape, the arrangement of surfaces (including furniture layout), and the

reflectivity of inner surface materials all significantly affect how light is distributed within a space. This variability can be observed from one space to another and is influenced by the building's location and orientation. Therefore, it is essential to consider these design parameters in the early stages of the design process. Additionally, another important discovery was made by Sulaiman et al. (2013), indicating that lighting plays a crucial role in shaping the overall campus experience. However, poor lighting design can have adverse effects on the ambiance of a space, as well as on the health and productivity of its occupants.

Poor lighting design can negatively impact a space's atmosphere, the health and productivity of its occupants, and both aspects simultaneously. When it comes to electrical lighting in educational facilities, it should be tailored to the specific function and purpose of each room, taking factors such as the intended use of the space and the time of day into consideration. Furthermore, creating a pleasant and comfortable environment requires careful consideration of the categories of spaces based on LEED (Leadership in Energy and Environmental Design) standards, as previously mentioned. Striking the right balance between daylight and artificial light is essential in achieving this goal. In the discussion section of this chapter, we aim to go beyond presenting raw numbers and charts by delving into the interpretation and understanding of the results. This involves investigating the meaning and significance of the findings, as well as explaining the various parameters, relationships, and trends detected in the data results. These insights are then placed in context to provide a comprehensive analysis of the study.

This chapter comprehensively explores the outcomes resulting from the utilization of the DIALux EVO software. These results are derived from the implementation of different strategies and scenarios within the selected spaces in Block 11 of the campus, which encompass

a range of areas such as the auditorium, classroom, library, group study room, administration area, student lounge, boardroom, corridors, and registration office. The study involves the application of suggested strategies and scenarios during both daytime and nighttime settings. These suggested strategies and scenarios include:

A. Strategy One: Daylight Enhancement:

- Scenario 1: All curtains fully opened.
- Scenario 2: All curtains halfway down.

B. Strategy Two: Artificial Light Enhancement:

- Scenario 1: Adding more light from existing sources.
- Scenario 2: Switching and rearranging the current fixtures to a new type.

C. Strategy Three: Combination of Daylight and Artificial Light:

- Scenario 1: Combining new artificial and daylight when all curtains are closed.
- Scenario 2: Combining new artificial light with daylight when curtains are halfway open and dimming artificial fixtures.

Subsequently, a detailed analysis is conducted for each lighting parameter within each specific space, whether it is during nighttime or daylight hours. These analytical parameters encompass Lux values, uniformity ratios, and glare levels, providing a comprehensive understanding of the lighting performance within each space. Additionally, a holistic evaluation is performed by comparing these parameters against the standards outlined in the study, adhering to the EN12464-1. This comparison entails measuring the results of the base case scenarios for each space with those of the alternative strategies across all aspects of lighting.

Finally, based on this comprehensive evaluation, decisions are made regarding the optimal scenarios for each space and its respective tasks. The lighting parameters are assessed in accordance with the established standards, ensuring that the selected scenarios meet the required criteria and performance expectations.

5.2 Discussion of Computer Simulation Results

The provided auditorium chart for nighttime scenarios shown in Figure 115 illustrates three distinct lighting strategies. The first strategy, which serves as the base case, maintains the existing luminaire types and arrangements in the auditorium. Strategy two, scenario one, involves enhancing the existing lighting by increasing the light output from current fixtures. The third strategy, scenario two of strategy two, revolves around replacing the existing luminaires with new types and rearranging their placement to improve illumination. These strategies are tailored to optimize nighttime lighting in the auditorium, taking into account the absence of daylight. They encompass varying approaches to luminaires, their arrangements, and artificial lighting enhancements, with the additional consideration of the Light Reflectance Value (LRV) of internal surfaces in scenario two of strategy two. This analysis allows for a comprehensive comparison of these strategies based on various lighting parameters assessed using DIALux EVO 11.

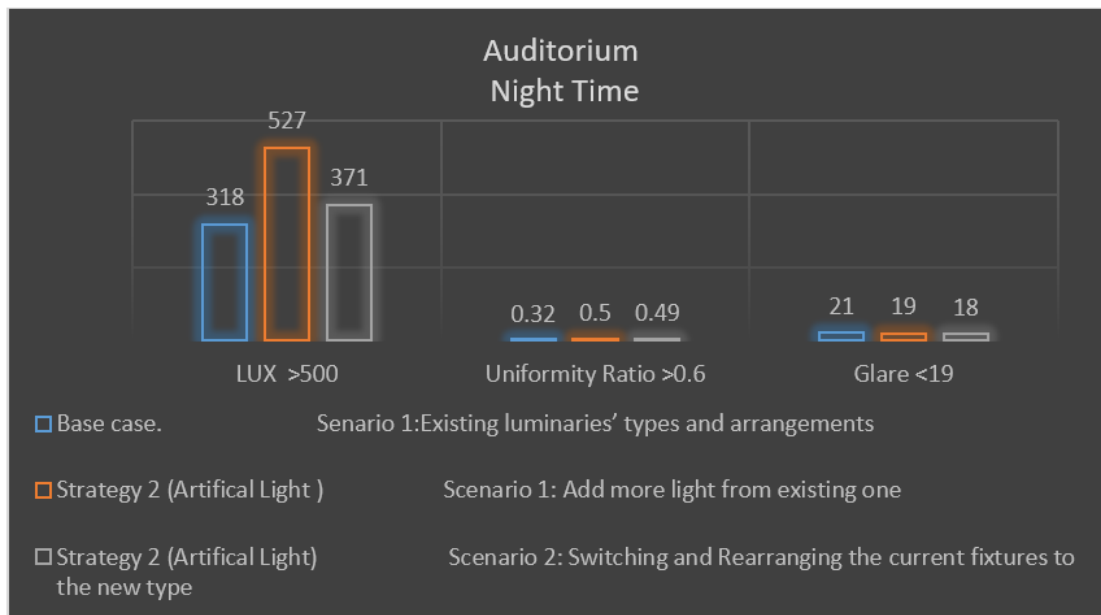


Figure 115: Auditorium chart- Night time scenarios

(Source: Author,2023)

The below describes the results for other lighting parameters:

- **Illumination Intensity (Lux):** As shown in Figure 115 and Figure 116, the "Add more light from existing luminaires" strategy (Scenario 1) within strategy two provides the highest illumination intensity among the options, with an adequate illumination level of 527 lux. Notably, the lux level above the podium area falls within the range of 200-250 lux, as depicted in the iso-line map from the previous chapter. According to EN 12464-1 standards for auditorium spaces, the required illuminance value typically falls within the range of >500 lux, approximately between 500 and 700 lux. However, it is important to ensure that the lighting is controllable and adaptable to accommodate various tasks

performed within this space. Moreover, the lux level on the podium area ranges from 200-300 lx, providing suitable lighting conditions. Scenario two of the same strategy, "Switching and rearranging current fixtures," offers a lower illuminance level of 371 lux, falling below the target level. In contrast, the base case records the lowest average value at 318 lux, with the minimum value primarily at the stage area and the maximum value in the audience zone. This distribution creates uncomfortable visibility, especially during presentations.

- **Uniformity Ratio:** The base case exhibits a uniformity ratio of 0.32, while both scenario 1 and scenario 2 show higher uniformity ratios of 0.5 and 0.49, respectively. These scenarios offer improved uniformity in lighting distribution, ensuring a more consistent visual experience throughout the auditorium. This is depicted in Figure 115 which provides a graphical representation of the auditorium's lighting.
- **Glare:** Strategy 2 of the second scenario effectively reduces glare to meet the target value of 18. In contrast, the base case registers a glare level of 21, and scenario 1 results in a glare level of 19. Both scenario 1 and scenario 2 ensure a comfortable visual environment by minimizing discomfort caused by excessive brightness.
- **Energy Consumption:** The base case consumes the least energy, with an annual consumption of 1404 kWh. However, in strategy 2, for both scenarios (1 and 2), energy consumption increases compared to the base case, reaching 2597 kWh/year in scenario 1 and 1768 kWh/year in scenario 2.

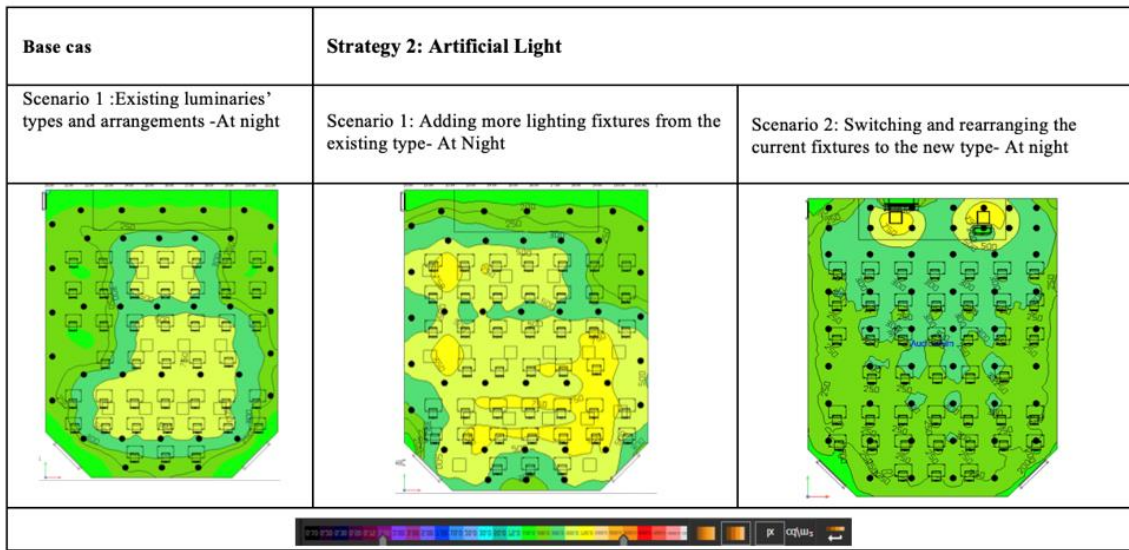


Figure 116: Auditorium graphical colored maps-Night scenarios

(Source: Author,2023)

The strategies for illuminating the auditorium at night involve trade-offs in illumination intensity, uniformity, glare, and energy consumption. Adding more light from existing luminaires (Scenario 1) provides the desired intensity and glare levels while enhancing uniformity compared to other scenarios and the base case. On the other hand, switching and rearranging fixtures (Scenario 2) results in lower intensity and higher energy consumption compared to the base case. The base case prioritizes energy conservation but compromises on illumination levels, uniformity, and glare. The choice of strategy should align with the specific lighting requirements and energy efficiency goals for the auditorium, considering the diverse activities hosted in this space throughout the year.

Figure 117 presents two distinct lighting strategies for achieving optimal illumination in Classroom FF111 during nighttime, allowing for a comparison with the base case scenario.

These strategies encompass a range of approaches to luminaire types, their arrangements, artificial lighting enhancements, and the improvement of the lighting reflectance value of internal surfaces. The following comparison elucidates the disparities between the parameters in each scenario.

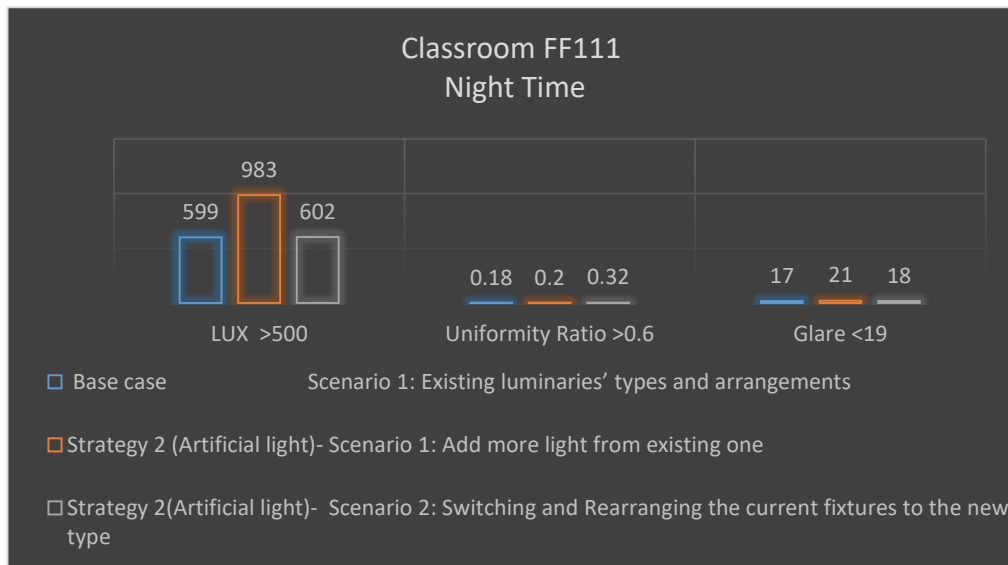


Figure 117: Class room FF-111 chart -Night time scenarios

(Source: Author,2023)

- **Illumination Intensity (Lux):** As shown in Figure 117 and Figure 118, among the strategies, the "Add more light from existing luminaires" strategy 2 (scenario 1), without any changes in the interior finish materials, achieves the highest illumination intensity at 983 lux. However, this falls significantly above the target value of 500 lux. In comparison, the base case provides 599 lux, and the "Switching and rearranging current fixtures" strategy 2 (scenario 2) offers 602 lux. Scenario 2 produces the best overall illumination, evident when examining various lux values on the isoline map from the

previous chapter and the graphical colored map presentation below. This improvement in lux values across the entire space enhances visibility and contributes to an improved learning environment.

- **Uniformity Ratio:** In terms of uniformity ratios, the base case records a ratio of 0.18, primarily due to the significant differences in lux values across the area. Scenario 1 exhibits a ratio of 0.2, although it still maintains notable differences in lux values within the same zone, resulting in excessive brightness in the student's area. On the other hand, scenario 2, as measured by DIALux EVO, achieves a uniformity ratio of 0.32. This scenario, as depicted in the graphical map presentation, showcases an improved distribution of light throughout the entire space, resulting in the most uniform lighting distribution. This indicates a consistent and evenly lit classroom environment.
- **Glare:** The UGR (Unified Glare Rating) glare level is 17 for the base case, which falls within an acceptable range. In contrast, scenario 1 of strategy 2 records a glare level of 21, exceeding the average requirement for this space based on EN12464-1. However, scenario 2 within strategy 2 achieves a glare level of 18, which ensures a good, comfortable, and visually pleasing environment for the users.
- **Energy Consumption:** The base case consumes 560.73 kWh per year, while scenario 1 demands significantly more energy at 906.85 kWh/year. In contrast, scenario 2 stands out as the most energy-efficient option, with a consumption of only 210.87 kWh per year. This suggests that the approach of switching and rearranging fixtures in scenario 2 results in lower energy usage, making it a more energy-efficient choice.

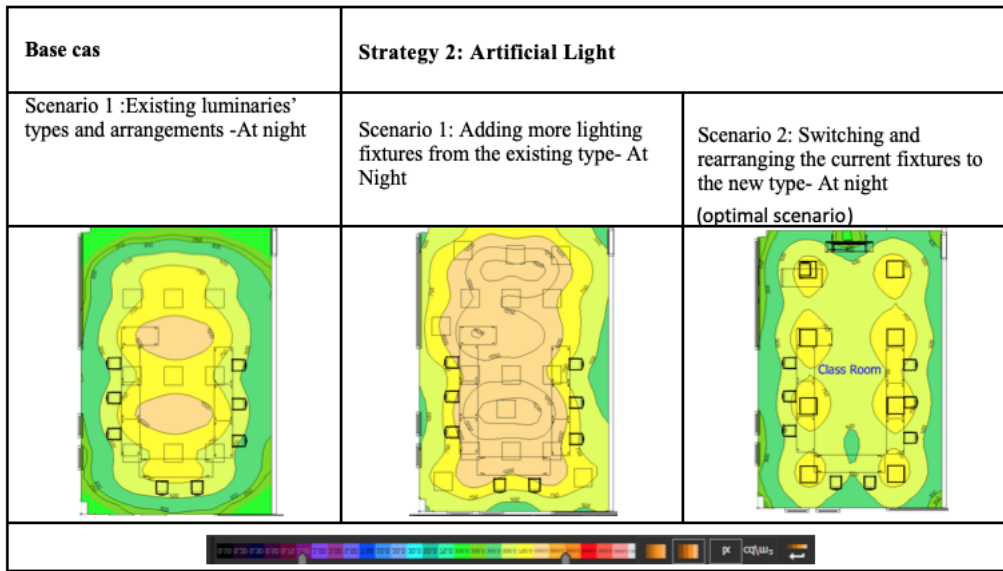


Figure 118: Classroom FF-111 graphical colored maps-Night scenarios

(Source: Author,2023)

The strategies for illuminating Classroom FF111 present clear trade-offs among illumination intensity, uniformity, glare, and energy consumption. Strategy 2, involving the addition of more light from existing luminaires (scenario 1), provides the highest intensity but results in increased energy consumption for the space. On the other hand, Strategy 2, which focuses on switching and rearranging fixtures (scenario 2), prioritizes energy efficiency while maintaining the target illumination level, glare, and uniformity across the space. This strategy strikes a balance between these factors, ultimately creating a comfortable and visually pleasing lighting environment, making it the optimal scenario.

Figure 119 introduces four distinct lighting strategies in Classroom FF-111. The base case, represented in Scenario 2, maintains the existing luminaire types and arrangements. Strategy 1,

focused on daylight, includes Scenario 1 with all curtains fully opened and Scenario 2 with curtains halfway down. Strategy 3 combines daylight and artificial light, offering Scenario 1 with a mix of new artificial and daylight when curtains are fully closed, and Scenario 2, which combines new artificial lighting with daylight when curtains are halfway open, along with dimming artificial fixtures. These strategies cater to different lighting scenarios, providing flexibility and options to ensure optimal illumination in Classroom FF-111 by harnessing both natural daylight and artificial lighting enhancements as needed.

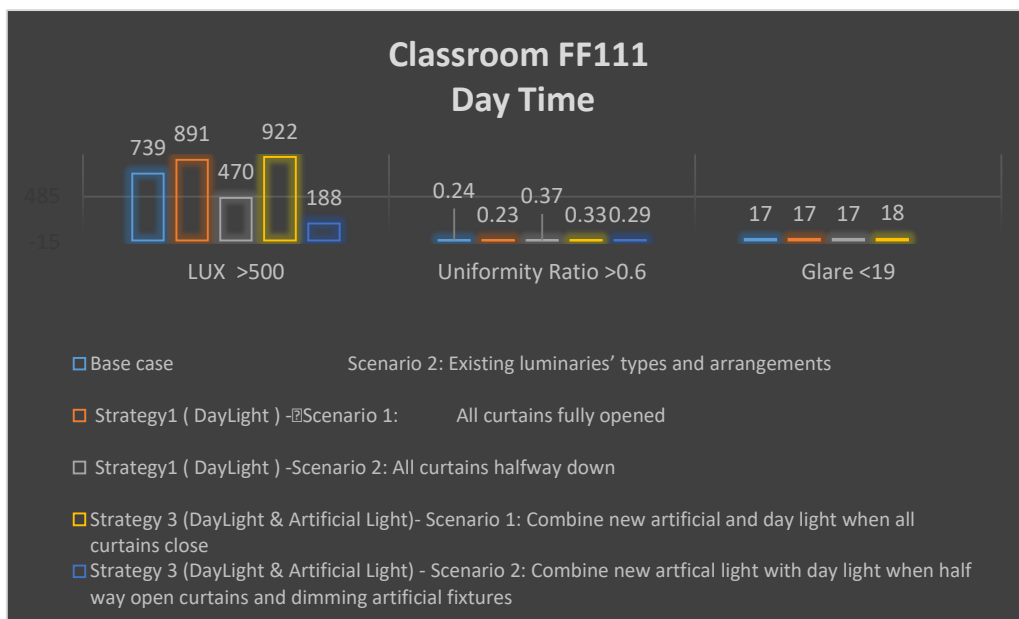


Figure 119: Class room FF 111 chart at day time scenarios

(Source: Author,2023)

For achieving optimal illumination in classroom -FF111 during daytime activities and compare them with the base case. These strategies encompass various approaches to utilizing

natural daylight and artificial lighting, curtains, and energy consumption. Here is a summary and comparison of these strategies:

- **Illumination Intensity (Lux):** As shown in Figure 119 and Figure 120, the strategies demonstrate varying illumination intensities, with Strategy 3 (Scenario 1) providing the highest Lux value at 922 lux, particularly near the student's desks close to the windows where some sunlight filters through even with the curtains closed. Meanwhile, Strategy 1 (Scenario 1) offers 891 lux, exceeding the target value of >500 lux. In contrast, the base case (Scenario 2) with fully opened curtains provides 739 lux. On the other hand, the most moderate Lux values were measured in Strategy 1 (Scenario 2), with curtains halfway down and the same types and arrangements of luminaires, yielding 470 lux. The lowest Lux value is found in Strategy 3 (Scenario 2), measuring 188 lux. These varying values highlight the impact of different lighting strategies on the illumination levels in Classroom FF-111.
- **Uniformity Ratio:** Strategy 1 (Scenario 2) and Strategy 3 (Scenario 1) also offer relatively reasonable uniformity ratios of 0.37 and 0.33, respectively. These values suggest a fairly even distribution of natural light within the classroom, as depicted in the graphical map in Figure 119. In contrast, the base case, Strategy 1 (Scenario 1), and Strategy 3 (Scenario 2) exhibit lower uniformity ratios of 0.24, 0.23, and 0.29, respectively. These lower ratios result in an uncomfortable learning environment in the classroom, characterized by uneven lighting conditions.
- **Glare:** Most strategies maintain a consistent glare level of 17, as observed in the base case and Strategy 1 for both scenarios (1 and 2). This is because these scenarios maintain the

same type of artificial lighting throughout the space. The software DIALux EVO primarily measures glare levels in response to artificial lighting. However, the impact of daylight in this space is visualized in the graphical colored maps in Figure 120, which allow for an assessment of lighting uniformity. In Strategy1 (Scenario 2), lower glare levels are observed from daylight, contributing to a more comfortable and visually pleasing learning environment. Extreme glare from daylight can be uncomfortable and distracting for both teachers and students, as seen in the base case, Strategy 1 (Scenario 1), and Strategy 3 (Scenario 1) in the graphical colored maps. Strategy 3 (Scenario 1), which combines new artificial and daylight when all curtains are closed, generates a slightly higher glare level of 18. Strategy 3 (Scenario 2) does not report glare values due to the presence of dimmer controls, reflecting a limitation of the software. The consideration of glare levels is essential for creating a conducive and comfortable learning environment in the classroom.

- **Energy Consumption:** The energy consumption for artificial lighting remains constant at 560.73 kWh per year for all scenarios of Strategy 1 and the base case because there are no changes in lighting types. In Strategy 3 (Scenario 1), the light fixtures are changed to LED lights, which consume less energy at 210.87 kWh per year. However, Strategy 3 (Scenario 2) does not report energy values due to a limitation of the software, likely related to the presence of dimmer controls or specific lighting configurations. The transition to LED lighting in Strategy 3 (Scenario 1) reflects an energy-efficient choice, contributing to reduced energy consumption in the classroom.

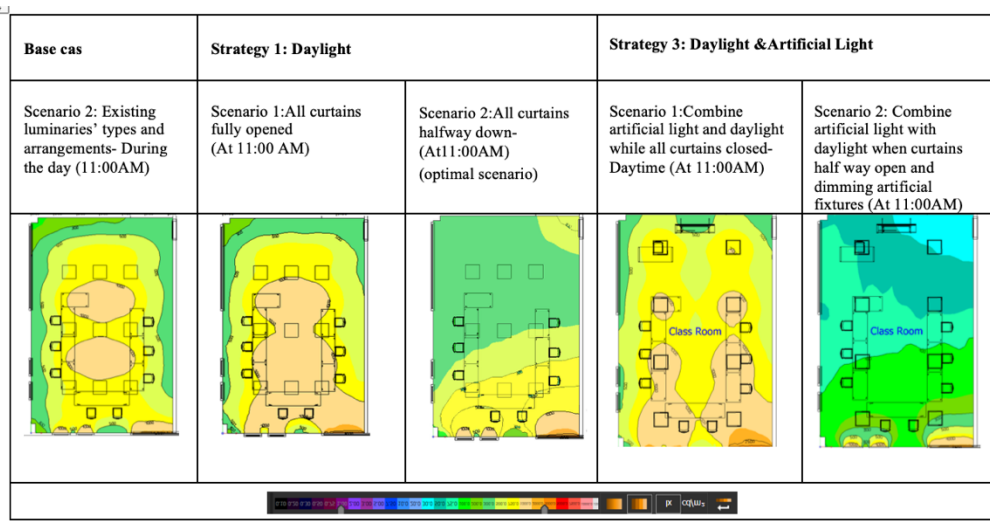


Figure 120: Classroom FF-111 graphical colored maps-Day time scenarios

(Source: Author,2023)

The base case and the suggested strategies, including Strategy 1 (Scenario 1) and the combined daylight and artificial lighting (Scenario 1), provide higher illumination levels but lack proper light distribution within the space, potentially resulting in increased heat gain during the day. The choice of strategy should consider factors such as illumination intensity, uniformity, glare, energy efficiency goals, and user satisfaction. Strategy 1 (Scenario 2) may be considered as an optimal choice, depending on specific lighting requirements and the desired balance between natural and artificial light for the classroom, offering a more balanced and comfortable lighting environment.

Figure 121 shows the library in nighttime scenarios and presents two distinct lighting strategies designed to achieve optimal illumination in a library during nighttime activities. These

strategies employ varying approaches to luminaire types, arrangements, and artificial lighting enhancements.

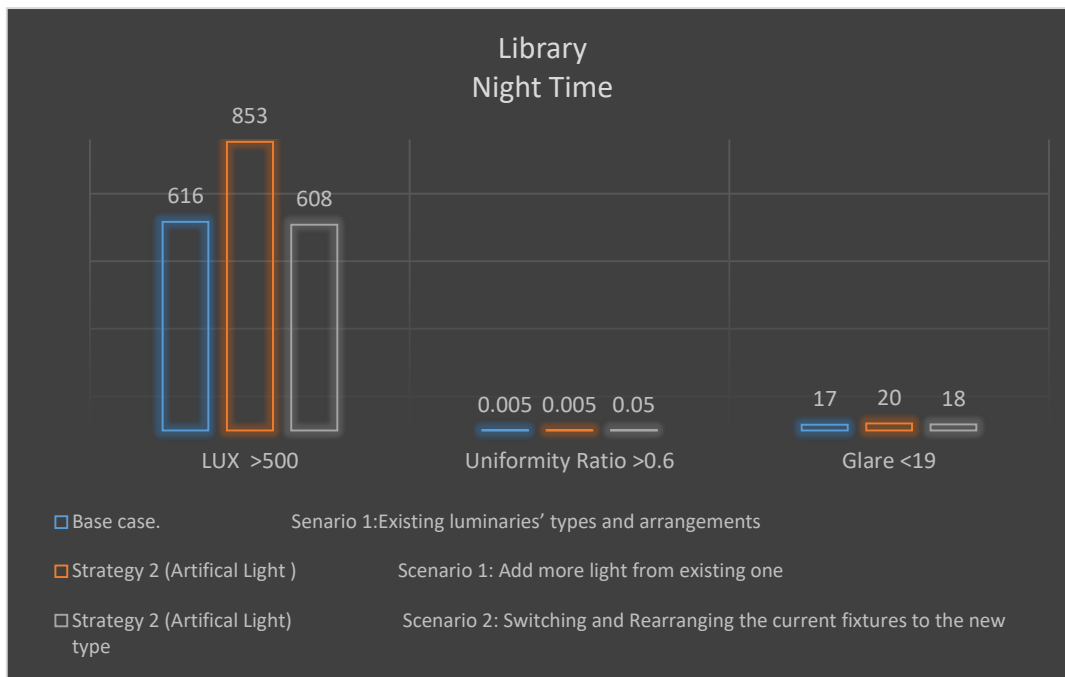


Figure 121: Library chart- Night time scenarios

(Source: Author,2023)

The following provides a summary and comparison of the results obtained from the DIALux EVO software for these strategies:

- **Illumination Intensity (Lux):** As shown in Figure 121 and Figure 122, the "Add more light from existing luminaires" strategy 2 (scenario 1) provides the highest illumination intensity at 853 lux, surpassing the target level, but it may lead to increased glare in that area. The base case offers 616 lux, and the "Switching and rearranging current fixtures" strategy 2 (scenario 2) provides 608 lux, which is closest to the target value of >500 lux,

in accordance with EN12464-1 standards. This strategy, particularly in the reading zone, achieves a balanced lux value distribution across the library zones, including reading areas, bookshelves, and staff offices, as indicated in the isoline map from the previous chapter.

- **Uniformity Ratio:** The uniformity ratios are remarkably low for Strategy 2 (Scenario 1) and the base case, both measuring at 0.005. A low uniformity ratio indicates that the lighting in the library or space is not distributed uniformly or evenly across the entire area. In contrast, Strategy 2 (Scenario 2) exhibits a uniformity ratio of 0.05, signifying an improvement in light distribution within the space when compared to the other scenarios, as illustrated in the figures below.
- **Glare:** In Strategy 2 (Scenario 1), the glare level is measured at 20, which is the highest among the scenarios and exceeds the target value according to EN 12464-1 standards. The base case records a glare level of 17, while Scenario 2 in Strategy 2 reports a glare level of 18, which falls within the target value, indicating a more comfortable and visually pleasing lighting environment.
- **Energy Consumption:** The base case and Strategy 2 (Scenario 1) have the highest energy consumption, with 8987 kWh per year and 15552 kWh per year, respectively. These values are relatively high. In contrast, Strategy 2 (Scenario 2) consumes less energy, totaling 3810 kWh per year. This lower energy consumption is attributed to the improved lighting efficiency resulting from enhancements made to the lighting parameters in Scenario 2 (strategy 2).

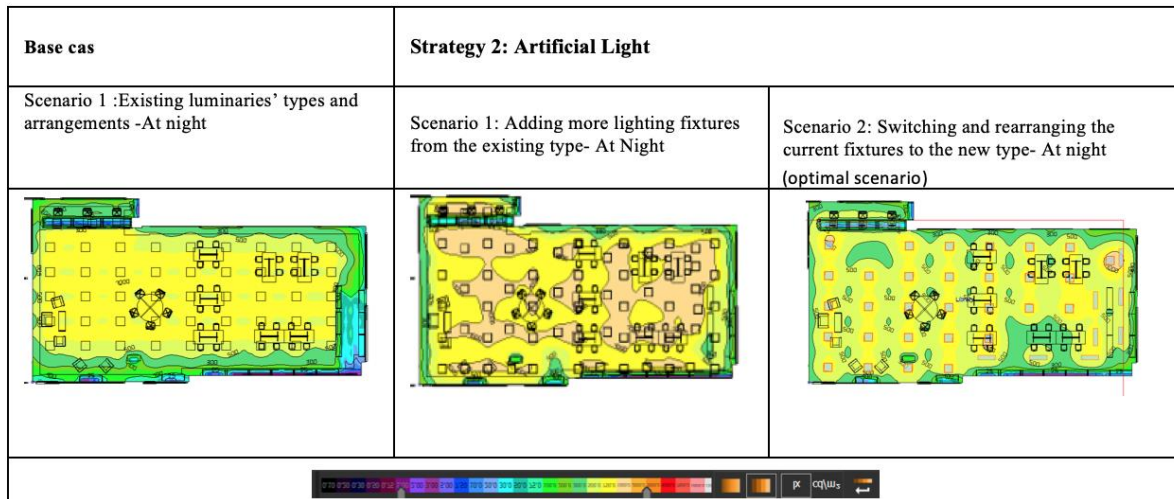


Figure 122: Library graphical colored maps-Night time scenarios

(Source: Author,2023)

The strategies for illuminating the library at night present trade-offs among illumination intensity, uniformity, glare, and energy consumption. Adding more light from existing luminaires (Scenario 1) results in the highest intensity but may lead to increased glare and energy usage. On the other hand, switching and rearranging fixtures (Scenario 2) strike a balance between intensity, glare level, and lighting distribution, particularly in the reading zone and bookshelves area, making it a more energy-efficient scenario. Consequently, the base case exhibits the highest energy consumption among these scenarios. The choice of strategy should align with specific lighting requirements, energy efficiency goals, and the desired visual comfort and usability of the library space.

Figure 123 presents the Library daytime Scenarios chart, outlining four distinct lighting strategies designed to achieve optimal illumination in a library during daytime activities. These strategies involve different combinations of natural daylight and artificial lighting.

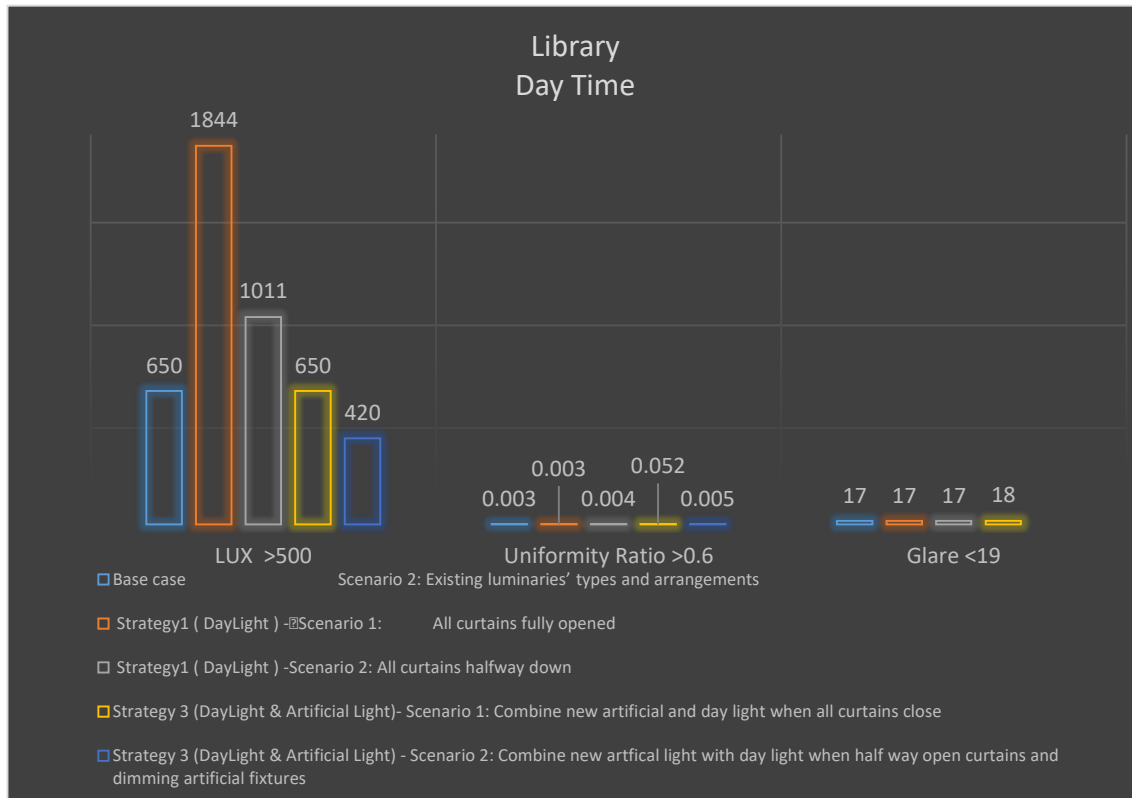


Figure 123: Library chart -Day time scenarios

(Source: Author,2023)

The following provides a summary and comparison of these strategies.

- **Illumination Intensity (Lux):** As shown in Figure 123 and Figure 124, the strategies exhibit varying levels of illumination. In the first strategy (Scenario 1), with all curtains

fully opened, the Lux level is the highest at 1844, significantly exceeding the target Lux level for this type of space, which is typically around 500 Lux. In Strategy 1 (Scenario 2), with curtains halfway down, the Lux measurement is 1011, which still significantly surpasses the target Lux level. In the third strategy (Scenario 1), which involves the integration of new artificial lighting with daylight when all curtains are closed, the Lux level is maintained at 650, coming closest to the target Lux level. However, in Scenario 2 of the third strategy, lower Lux levels are observed. These variations reflect the impact of different strategies on the illumination levels in the library during daytime activities.

- **Uniformity Ratio:** The uniformity ratios for the base case, Strategy 1 (Scenario 1 and 2), and Strategy 3 (Scenario 2) range between 0.003 and 0.004. These low uniformity ratios suggest that the lighting in the space is not evenly distributed uniformly across the entire area. However, Strategy 3 (Scenario 1) presents a higher uniformity ratio of 0.052, indicating a more even and uniform distribution of light within the space.
- **Glare:** The base case scenario, both scenarios in Strategy 1, and Strategy 3 (Scenario 1) maintain a consistent glare level of 17, as they employ similar artificial lighting throughout the space. DIALux EVO predominantly measures glare levels in response to artificial lighting. However, the impact of daylight in this space is visualized in the graphical colored maps in Figure 123 allowing for an assessment of lighting uniformity. In Strategy 3 (Scenario 1), the glare level is slightly higher at 18, but it falls within the glare level target based on EN12464-1 standards. This scenario also exhibits lower glare levels from daylight compared to the base case and Strategy 1 (Scenario 1 and 2), contributing to a more comfortable and visually pleasing learning environment. It's worth

noting that excessive glare from daylight can be uncomfortable and distracting for both teachers and students. However, Strategy 3 (Scenario 2) does not report glare values, likely due to software limitations related to the presence of dimmer controls. Consideration of glare levels is crucial for creating a conducive and comfortable learning environment in the library.

- **Energy Consumption:** Energy consumption varies across the scenarios. It's worth noting that Strategy 3 (Scenario 2) does not provide energy consumption values due to software limitations related to the presence of lighting dimmers in the space. However, the base case and Strategy 1 (Scenario 1 and 2) exhibit relatively high energy consumption at 8987.1 kWh per year. On the other hand, Strategy 3 (Scenario 1) consumes significantly less energy, totaling 380.15 kWh per year. This lower energy consumption in Strategy 3 (Scenario 1) demonstrates the potential for energy savings through the integration of efficient lighting solutions and the proper management of lighting resources in the library.

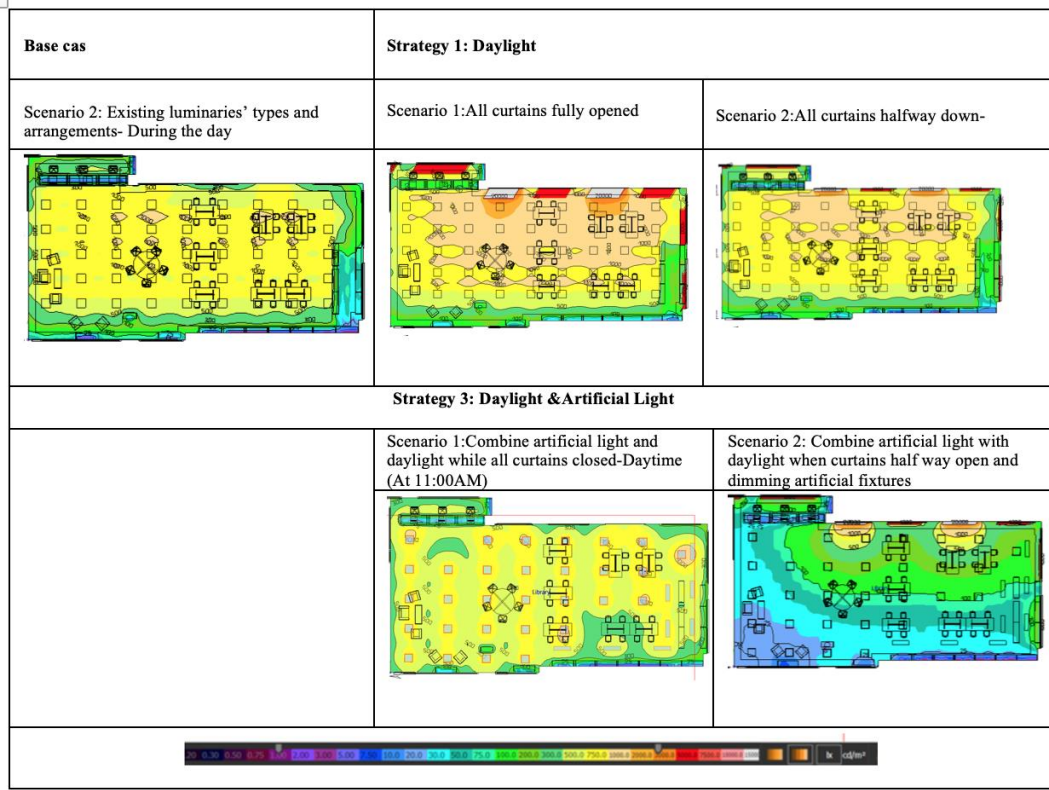


Figure 124: Library graphical colored maps-Day time scenarios

(Source: Author,2023)

The strategies for illuminating the library during the daytime offer a range of options for leveraging natural daylight and artificial lighting. The choice of strategy should consider various factors, including illumination intensity, uniformity, glare, energy efficiency goals, and the Lighting Reflectance Value (LRV) of internal surfaces. The optimal strategy depends on the desired lighting conditions and the desired balance between natural and artificial light in the library. Strategy 3 (Scenario 1), which involves the integration of daylight and artificial lighting, presents the potential for energy savings, improved Lux values, and enhanced uniformity,

making it a promising choice for achieving an efficient and effective lighting environment in the library.

Figure 125 presents the chart for the Administration area, outlining two distinct lighting strategies designed to achieve optimal illumination in an open plan office (administration area) during nighttime activities, as natural daylight is not available in this zone. These strategies involve different combinations of luminaires, arrangements, artificial lighting enhancements, and improvements in the Lighting Reflectance Value (LRV) of internal surfaces.

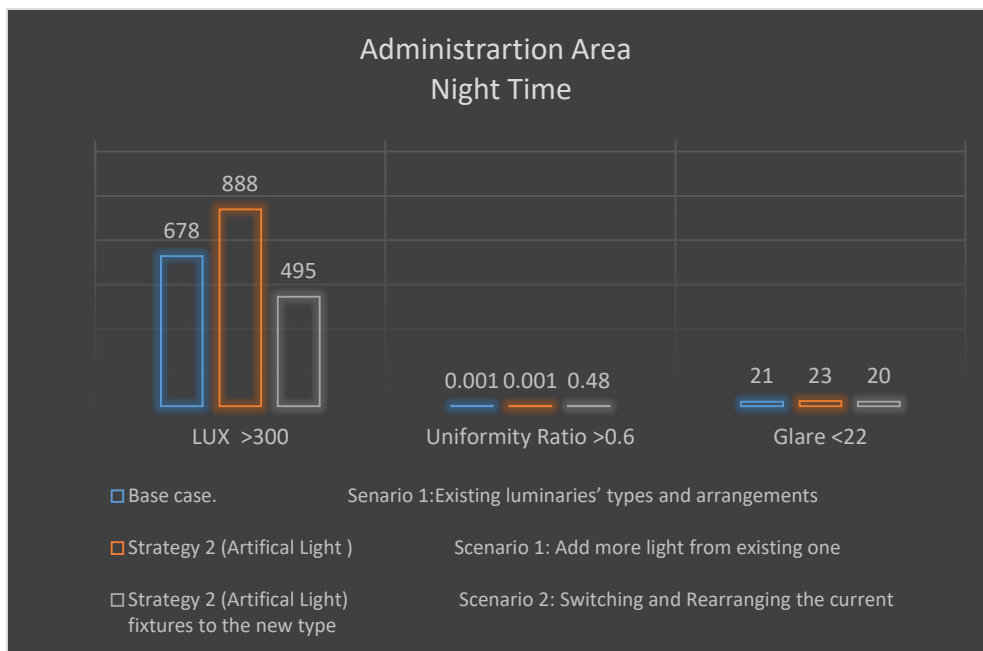


Figure 125: Administration area chart -Night time scenarios

(Source: Author,2023)

Here is a summary and comparison of these strategies with the base case scenario:

- **Illumination Intensity (Lux):** As shown in Figure 125 and Figure 126, the "Add more light from existing luminaires" strategy 2 (Scenario 1) provides the highest illumination intensity at 888 lux. Following this, the base case offers 678 lux, and the "Switching and rearranging current fixtures" strategy 2 (Scenario 2) yields an average of 495 lux. This value is the closest to the target value of >300 lux, as indicated by the isoline map from the previous chapter, which suggests a well-distributed Lux value throughout the space.
- **Uniformity Ratio:** The uniformity ratios are quite low for both the base case and Scenario 1 of Strategy 2, both measuring at 0.001. These low values suggest that the lighting in these scenarios is not distributed uniformly or evenly across the entire space. However, Scenario 2 of Strategy 2 presents a significantly higher uniformity ratio of 0.48, indicating an enhancement in the distribution of light across the space. This improvement in uniformity can contribute to a more evenly lit and visually comfortable open plan office environment.
- **Glare:** The highest glare level observed in the administration area is 23, which exceeds the target level for glare based on the standards EN 12464-1. This measurement was recorded under Strategy 2 (Scenario 1). This higher level of glare is also associated with a lower uniformity ratio in the administration area, as illustrated in the graphical colored maps in Figure 126. In contrast, Strategy 2 (Scenario 2) presents a more favorable scenario in terms of glare control, with the glare level measured at 20, falling within the target level. The glare level is better in Scenario 1 compared to the other scenarios and the base case. These findings underscore the significance of managing glare levels in

different lighting strategies to achieve better overall lighting quality and visual comfort in the office environment.

- **Energy Consumption:** Energy consumption varies across the strategies. Scenario 1 of Strategy 2 consumes the most energy at 3570 kWh per year, followed by the base case at around 2739.56 kWh per year. In contrast, Scenario 2 of Strategy 2 consumes the least energy, totaling 895.86 kWh per year, primarily due to the use of a more energy-efficient lighting type. These differences in energy consumption highlight the potential for energy savings through the implementation of efficient lighting solutions in the administration area.

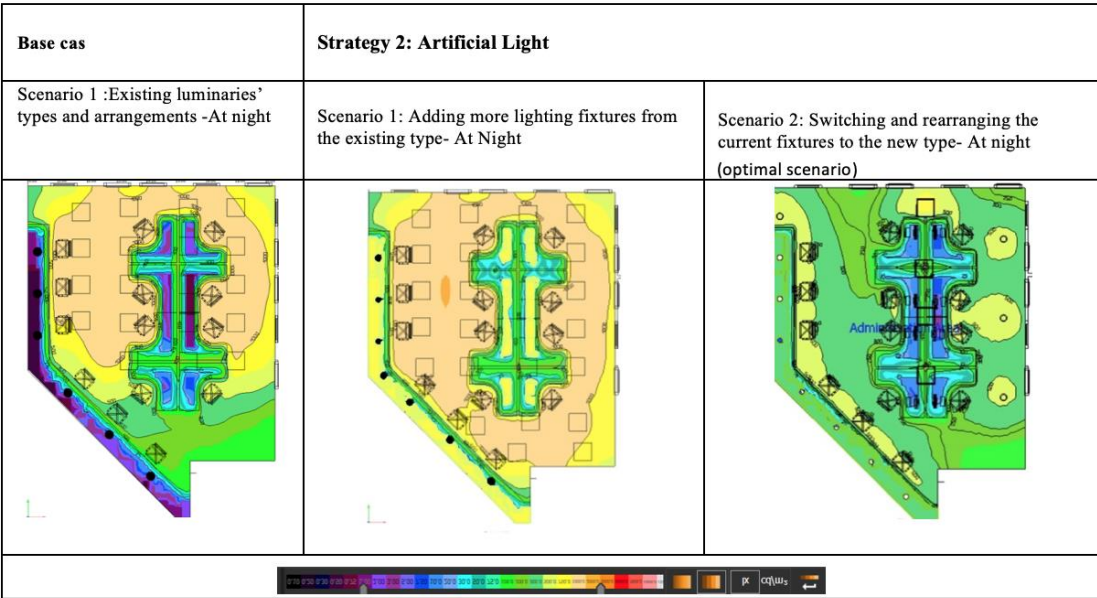


Figure 126: Administration area graphical colored maps-Night time scenarios

(Source: Author,2023)

The strategies for illuminating the open plan office (administration area) at night present trade-offs between illumination intensity, uniformity, glare, and energy consumption. Adding more light from existing luminaires (Scenario 1) results in the highest intensity but also the highest energy consumption. In contrast, switching and rearranging fixtures and enhancing the Lighting Reflectance Value (LRV) of the internal surfaces, as per LEED (ID+C) in Scenario 2, provide a better uniformity ratio and greater energy efficiency, while maintaining satisfactory Lux values and controlling glare. The base case offers higher illumination and energy consumption levels. The choice of strategy should align with specific lighting requirements, energy efficiency goals, and the desired visual comfort and usability of the open plan office.

Figure 127 presents a chart for a group study room, outlining two distinct lighting strategies aimed at achieving optimal illumination during nighttime activities, with a comparison to the base case. These strategies involve different combinations of luminaires, arrangements, and artificial lighting enhancements.

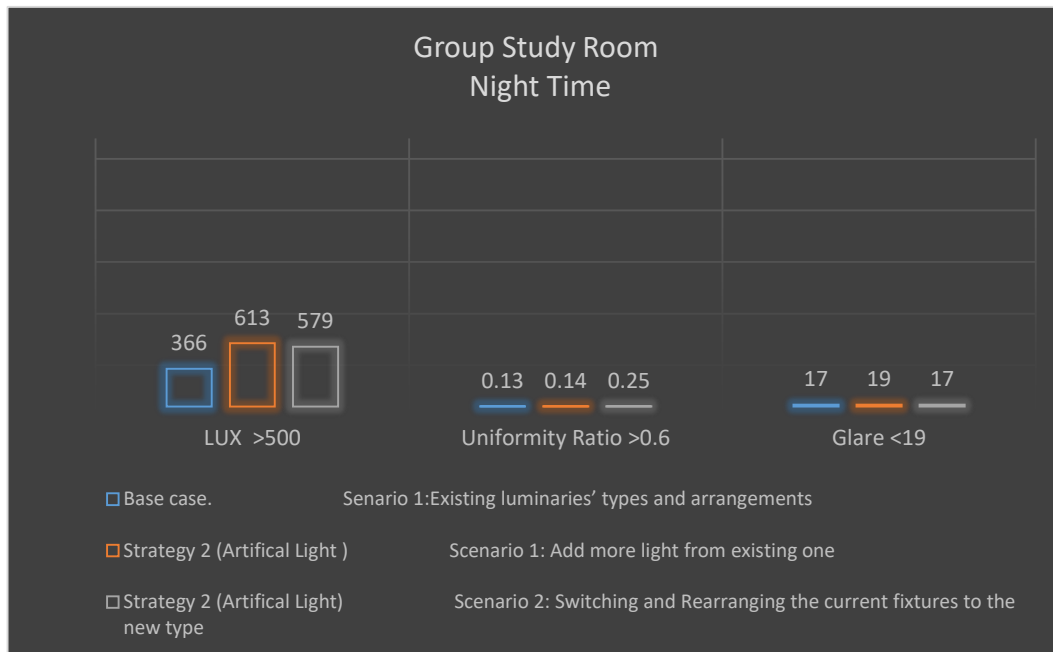


Figure 127: Group study room chart -Night scenarios

(Source: Author,2023)

The following comparison examines various factors that have been measured and investigated using DIALux EVO 11:

- **Illumination Intensity (Lux):** As shown in Figure 127 and Figure 128, the "Add more light from existing luminaires" strategy (Scenario 1) provides the highest illumination intensity at 613 lux. In contrast, the base case offers the lowest Lux level at 366 lux, while the "Switching and rearranging current fixtures" strategy (Scenario 2) provides 579 lux, which is the closest to the target value of >500 lux based on the standards. This enhancement contributes to a more visually comfortable environment, ensuring that users in that space can work efficiently. It also helps to enhance occupant productivity and satisfaction within the group study room.

- **Uniformity Ratio:** The uniformity ratios across the strategies vary. The base case and Scenario 1 of Strategy 2 both have a uniformity ratio of 0.13 and 0.14, respectively, while Scenario 2 of Strategy 2 offers a higher uniformity ratio of 0.25. This indicates that Scenario 2 provides a more even lighting distribution, as evident in the colored graphical map in Figure 128: Group study room graphical colored maps - Nighttime scenarios, obtained from DIALux EVO software. This even lighting distribution can contribute to a more comfortable and visually pleasing environment in the group study room.
- **Glare:** The glare levels are consistent across the base case and Strategy 2 (Scenario 2), with a glare level of 17. This consistency ensures a visually comfortable environment with minimal glare and brightness across the area. However, in Strategy 2 (Scenario 1), a glare level of 19 has been measured, indicating the presence of discomfort glare in this space. Discomfort glare occurs when the lighting settings cause irritation or visual discomfort to users, which can affect their productivity and satisfaction in the group study room.
- **Energy Consumption:** Energy consumption varies significantly across the strategies. Scenario 1 of Strategy 2 consumes the most energy at 2527 kWh per year, which is the highest energy consumption among the scenarios. In comparison, the base case consumes 1404 kWh/year, and Scenario 2 of Strategy 2 consumes the least energy at 866 kWh/year, making it an energy-efficient strategy. This significant difference in energy consumption highlights the potential for energy savings when implementing energy-efficient lighting solutions in the group study room.

The strategies for illuminating the group study room at night offer trade-offs between illumination intensity, uniformity, glare, and energy consumption. Adding more light from existing luminaires (Scenario 1) provides the highest intensity and glare level but consumes more energy. On the other hand, the base case has the lowest energy consumption but provides the lowest lux intensity. Switching and rearranging fixtures and enhancing the Lighting Reflectance Value (LRV) of the interior surfaces (Scenario 2) offer a better lux value, uniformity, lower glare, and energy efficiency. This provides a balanced and optimal choice of strategy for the group study room, offering a comfortable and visually pleasing environment with improved energy efficiency.

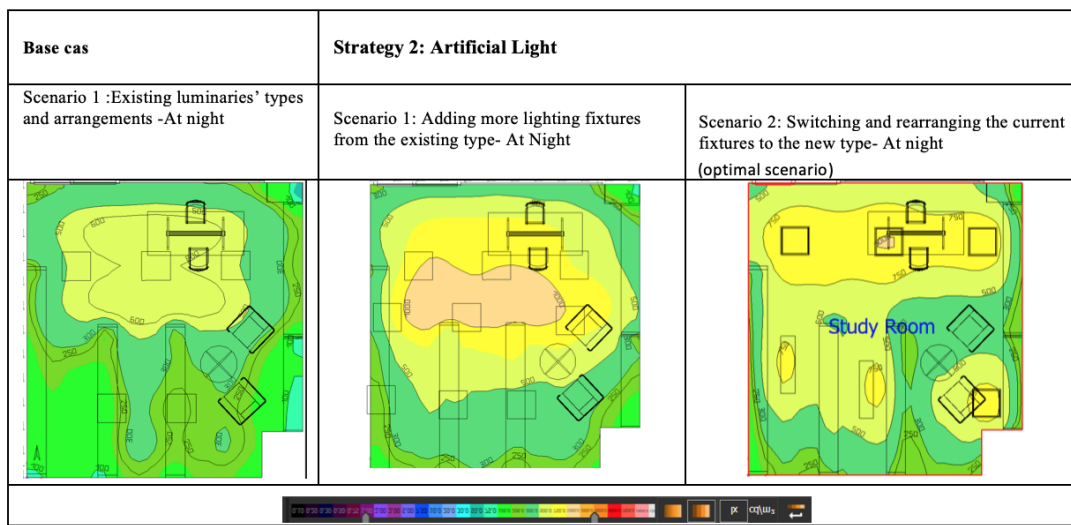


Figure 128: Group study room graphical colored maps-Night time scenarios

(Source: Author,2023)

The student lounge chart in Figure 129 outlines two lighting strategies: Scenario 1 involves adding more lighting fixtures of the existing type, while Scenario 2 focuses on switching and

rearranging the current fixtures to a new type. These strategies aim to achieve optimal illumination during nighttime activities in a student lounge, employing different combinations of luminaires, arrangements, and artificial lighting enhancements. The following summary and comparison will highlight the distinctions between these strategies and the base case scenario.

- Illumination Intensity (Lux): Figure 129 and Figure 130 , displaying the Student Lounge graphical colored maps for nighttime scenarios, highlights the differences among the lighting strategies. Strategy 2 (Scenario 2), involving the switching and rearrangement of current fixtures to a new type, offers the highest illumination intensity, exceeding the target level of 506 lux. Following this, Strategy 2 (Scenario 1) provides 367 lux, the closest to the target value of over 200 lux, while the base case falls short in terms of target lux value. Inadequate lighting can result in various issues, such as poor visibility, making it challenging for occupants to work efficiently and complete tasks, leading to reduced productivity and potential eyestrain, complaints, and decreased satisfaction and well-being among users.

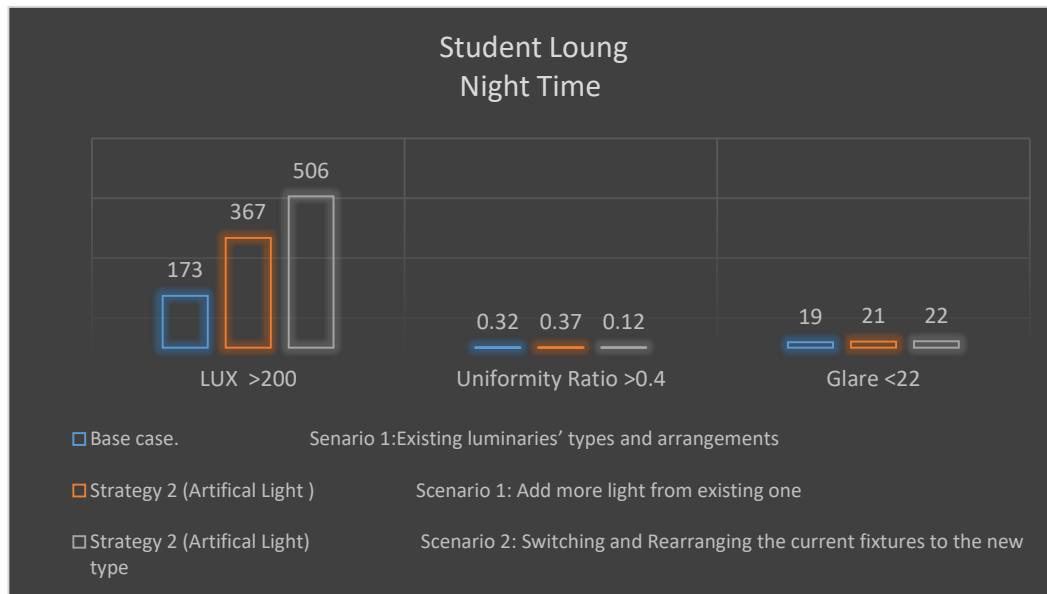


Figure 129: Students lounge chart -Night time scenarios

(Source: Author,2023)

- **Uniformity Ratio:** The uniformity ratios differ across the strategies. The base case exhibits a uniformity ratio of 0.32, while strategy 2 (scenario 1) offers a higher and better ratio of 0.37. This ratio aligns more closely with the target level of uniformity, which is 0.4 based on EN 12464-1 standards for this type of space. In contrast, strategy 2 (scenario 2) provides a lower ratio of 0.12. These findings suggest that strategy 2 (scenario 1) offers a more even and uniform lighting distribution throughout the student lounge, as indicated in the graphical colored map.
- **Glare:** The glare levels in the student lounge vary among the strategies. In the base case, the glare level is 19. Strategy 2 (scenario 2), which involves adding more lighting fixtures from the existing type, results in the highest glare level of 22 in the student lounge area. On the other hand, in strategy 2 (scenario 1), which focuses on switching and rearranging

the current fixtures to the new type, the glare level is 21. This level is within the target range and ensures a visually comfortable environment for the lounge users.

- **Energy Consumption:** Energy consumption across the strategies exhibits minimal variation. The base case and strategy 2 (scenario 1) consume approximately 539.96 kWh per year, while strategy 2 (scenario 2) consumes slightly less energy at 520.36 kWh per year.

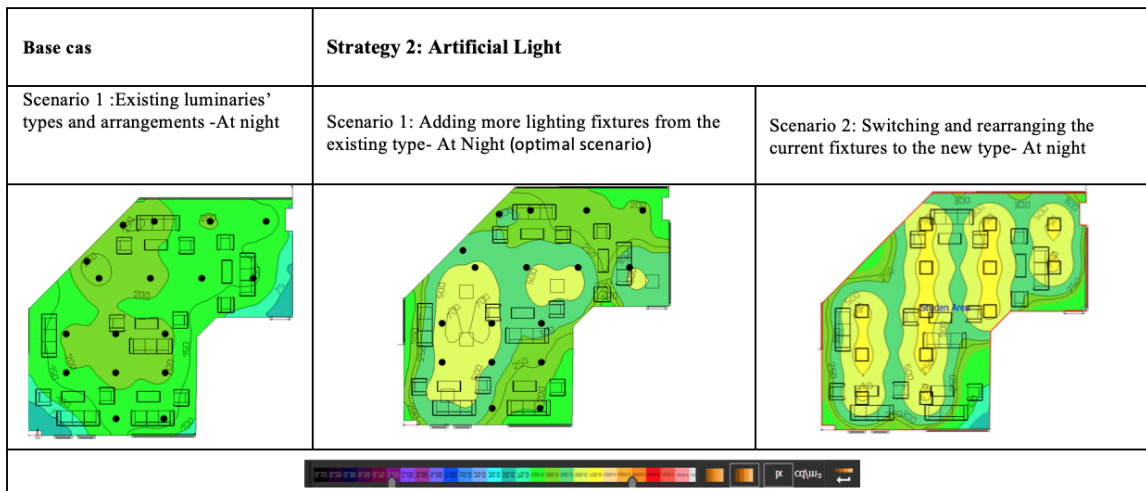


Figure 130: Students lounge graphical colored maps-Night time scenarios

(Source: Author,2023)

The strategies for illuminating the student lounge at night present a trade-off between illumination intensity, uniformity, glare, and energy consumption. Adding more light from existing luminaries (scenario 1) results in higher intensity and moderate energy consumption, along with better uniformity and glare levels. On the other hand, switching and rearranging

fixtures (scenario 2) offer less uniformity and higher glare levels compared to scenario 1 in strategy 2 and the base case, which provides the lowest intensity levels.

The four lighting strategies presented in Figure 131 aim to achieve optimal illumination in a student lounge during daytime activities. These strategies involve a combination of natural daylight, artificial lighting, curtains, and energy consumption.

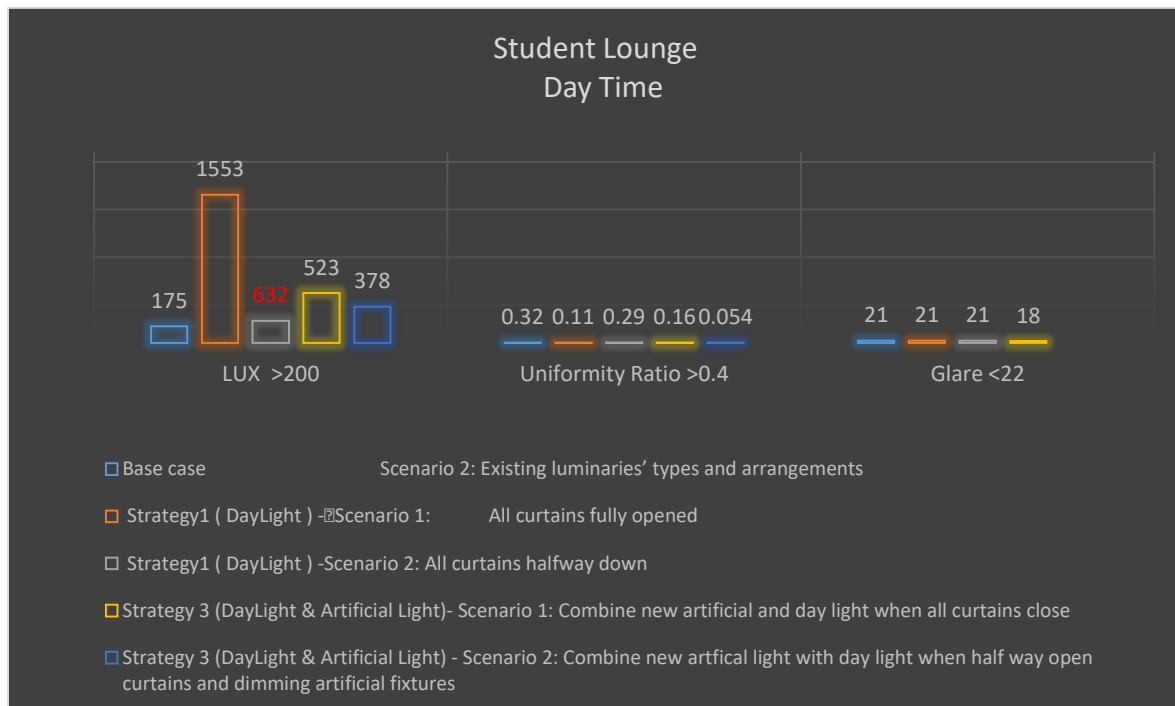


Figure 131: Student lounge chart -Day time scenarios

(Source: Author, 2023)

In the forthcoming summary and comparison, we will analyze the critical aspects and distinctions among these strategies and the base case.

- **Illumination Intensity (Lux):** As shown in Figure 131 and Figure 132, the strategies exhibit differing illumination intensities. Strategy 1 (scenario 1) achieves the highest Lux levels, followed by strategy 3 (scenario 1) at 523lx, strategy 3 (scenario 2) at 378lx, and strategy 1 (scenario 2) at 232lx, which appears to be the most favorable scenario. In contrast, the base case provides 175lx, falling short of the target value set by the software for the required tasks and activities in this space, which is over 200lx.
- **Uniformity Ratio:** The uniformity ratios differ among the strategies. Strategy 1 (scenario 2) has better uniformity ratios, approximately 0.3, which is close to the target level of 0.4 as per EN 12464-1 standards for this type of space, compared to other scenarios. On the other hand, strategy 1 (scenario 1) offers a lower ratio of 0.11. Strategy 3 (scenario 1) provides a ratio of 0.16, and Strategy 3 (scenario 2) offers a very low ratio of 0.054.
- **Glare:** The glare levels are mostly consistent across the strategies, with a glare level of 21. However, in scenario 1, where all curtains are opened, there is a significant increase in glare level, creating an uncomfortable environment for students, as clearly illustrated in Figure 132: Students lounge graphical colored maps - Daytime scenarios. Strategy 3 (scenario 1) offers a lower glare level of 18. Unfortunately, there is no mention of glare levels in strategy 3 (scenario 2) due to software limitations, as mentioned previously.
- **Energy Consumption:** The energy consumption varies across the strategies. The base case and strategy 1 (scenarios 1 and 2) consume around 539.96 kWh per year, while strategy 3 (scenario 1) consumes 520 kWh per year, indicating a slightly lower energy consumption in this particular scenario.

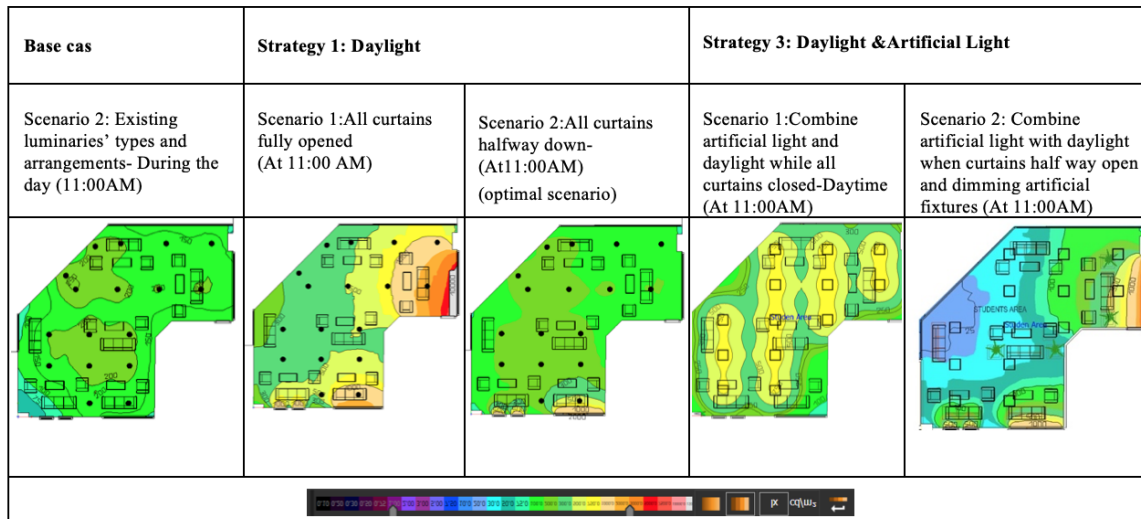


Figure 132: Students lounge graphical colored maps-Day time scenarios

(Source: Author, 2023)

The strategies for illuminating the student lounge during the daytime offer trade-offs between illumination intensity, uniformity, glare, and energy consumption. Utilizing natural daylight (strategy 1) offers high illumination and better uniformity. The optimal strategy in this space is strategy 1 (scenario 2), which depends on specific lounge lighting requirements, desired uniformity, glare tolerance, and energy efficiency goals.

The provided chart in Figure 133 outlines two lighting strategies for achieving optimal illumination in a boardroom during nighttime activities. These strategies include strategy 2 for scenario 1, which involves adding more light from existing luminaries, and scenario 2, which focuses on switching and rearranging current fixtures. Both strategies encompass different combinations of luminaries, arrangements, and artificial lighting enhancements.

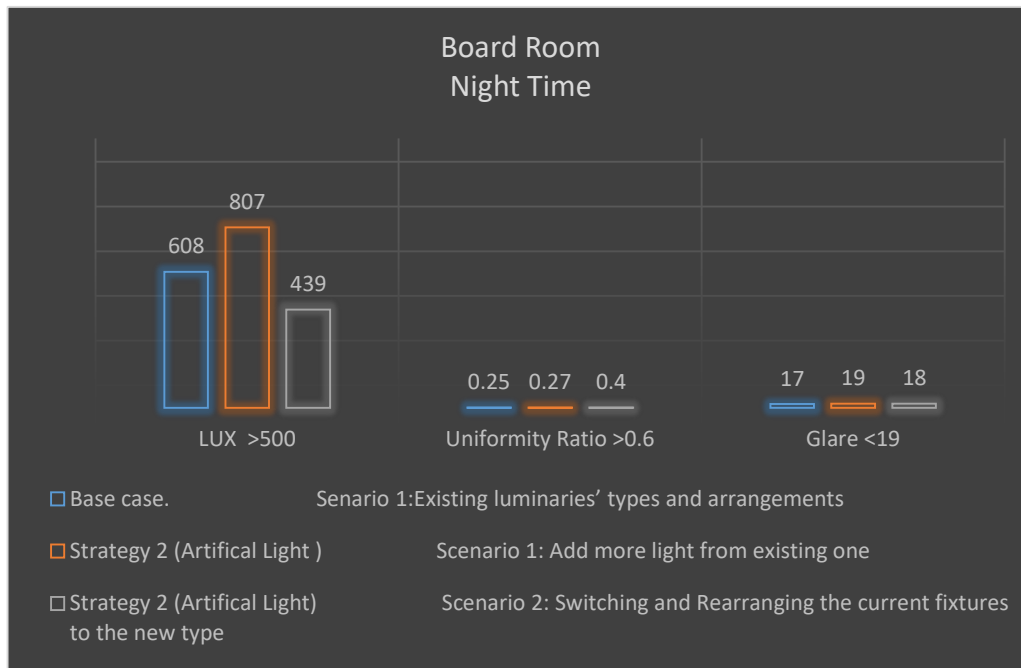


Figure 133: Board room chart at night time scenarios

(Source: Author, 2023)

Here is a summary and comparison of these strategies:

- **Illumination Intensity (Lux):** As shown in Figure 133 and Figure 134, among the strategies, "Add more light from existing luminaries" (Scenario 1) provides the highest illumination intensity at 807 Lux. The base case offers 608 Lux, while the "Switching and rearranging current fixtures" strategy (Scenario 2) has a Lux level of 439, which closely aligns with the Lux level recommended by the EN 12464-1 standards for a boardroom.
- **Uniformity Ratio:** The uniformity ratios vary across the strategies. The base case and scenario 1 of strategy 2 both have a uniformity ratio of around 0.25, while scenario 2 of

strategy 2 offers a higher ratio of 0.4. This indicates a more even distribution of light in scenario 2, providing a more balanced and uniform lighting environment in the boardroom.

- Glare: The glare levels in the base case and strategy 2 (scenario 2) are 17 and 18, respectively, which are within the target level, ensuring a visually comfortable environment. However, strategy 2 (scenario 1), which involves adding more light from existing luminaries, results in the highest glare level of 19 compared to the previous scenario, leading to discomfort in terms of visual comfort.
- Energy Consumption: Energy consumption varies among the strategies. Scenario 1 of strategy 2 consumes the most energy at 1168.27 kWh per year, the base case consumes 1202 kWh/year, and scenario 2 of strategy 2 consumes the least energy at 325.5 kWh/year, indicating a more energy-efficient lighting scenario.

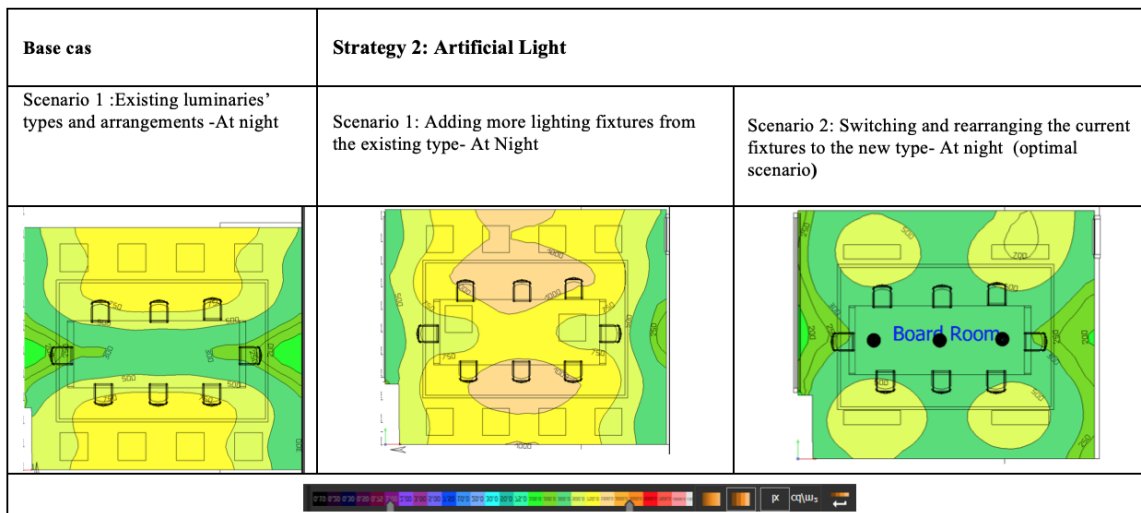


Figure 134: Board room graphical colored maps-Night time scenarios

(Source: Author,2023)

The strategies for illuminating the board room at night offer trade-offs between illumination intensity, uniformity, and glare level. Adding more light from existing luminaries (Scenario 1) provides higher intensity but consumes more energy. Switching and rearranging fixtures (Scenario 2) offer better uniformity, LUX value, glare control, and energy efficiency, making it the optimal strategy. The base case provides moderate intensity with higher energy consumption.

Figure 135 outlines three lighting strategies for achieving optimal illumination in corridors during nighttime activities. These strategies involve various combinations of luminaries, arrangements, and artificial lighting enhancements.

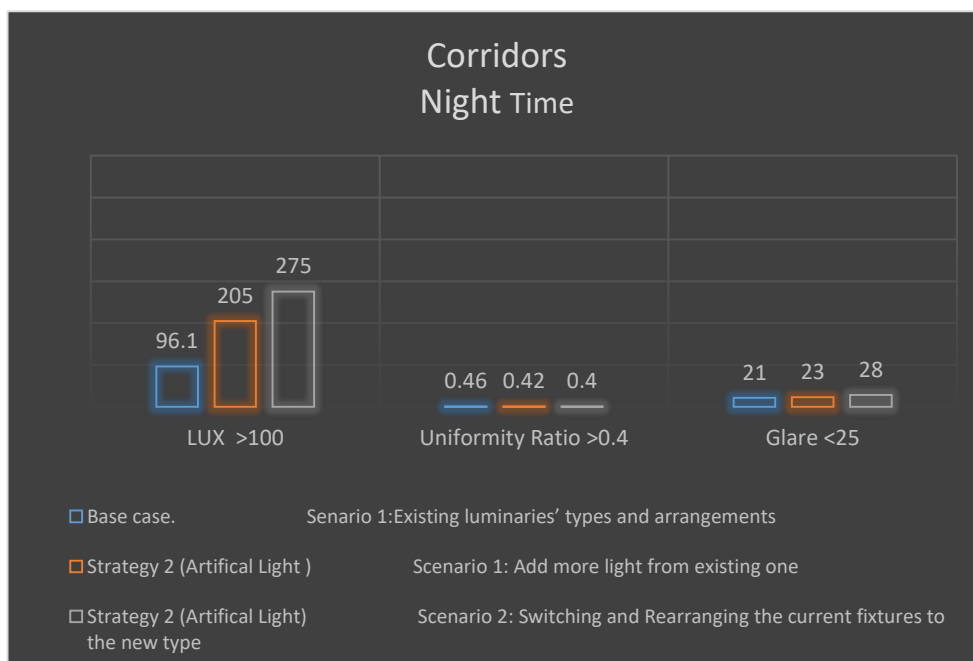


Figure 135: Corridors (General circulation zone) chart -Night time scenarios

(Source: Author,2023)

Below is a summary and comparison of these strategies:

- **Illumination Intensity (Lux):** Among the strategies for corridor lighting in Figure 135 and Figure 136, "Switching and rearranging current fixtures" strategy (Scenario 2) provides the highest illumination intensity at 275 Lux. The "Add more light from existing luminaries" strategy (Scenario 1) offers 205 Lux, while the base case provides 96.1 Lux, which aligns with the Lux level recommended by the EN 12464-1 standards for corridors. Ensuring adequate Lux levels in circulation zones is crucial for security, safety, well-being, and the overall usability of the campus building. It not only improves the general quality of the indoor environment but also enhances the user experience.
- **Uniformity Ratio:** The uniformity ratios in the corridors area vary across the strategies. In strategy 2 (scenario 1), the uniformity ratio is 0.42, while scenario 2 of strategy 2 offers a slightly lower ratio of 0.4, suggesting a more even distribution of light in scenario 2. On the other hand, the base case has the highest and better uniformity ratio of 0.46.
- **Glare:** The glare levels vary across the strategies, with a glare level of 21 for the base case. In strategy 2 (scenario 1), the glare level is 23, while a higher glare level of 28 is observed for scenario 2 of strategy 2. Lower glare levels are generally preferred for comfortable visibility in corridors.
- **Energy Consumption:** Energy consumption varies across the strategies. Scenario 2 of strategy 2 consumes the most energy at 577 kWh per year. In scenario 1 of strategy 2, the annual energy consumption is 290 kWh/year, which closely aligns with the base case's energy consumption of 218 kWh/year.

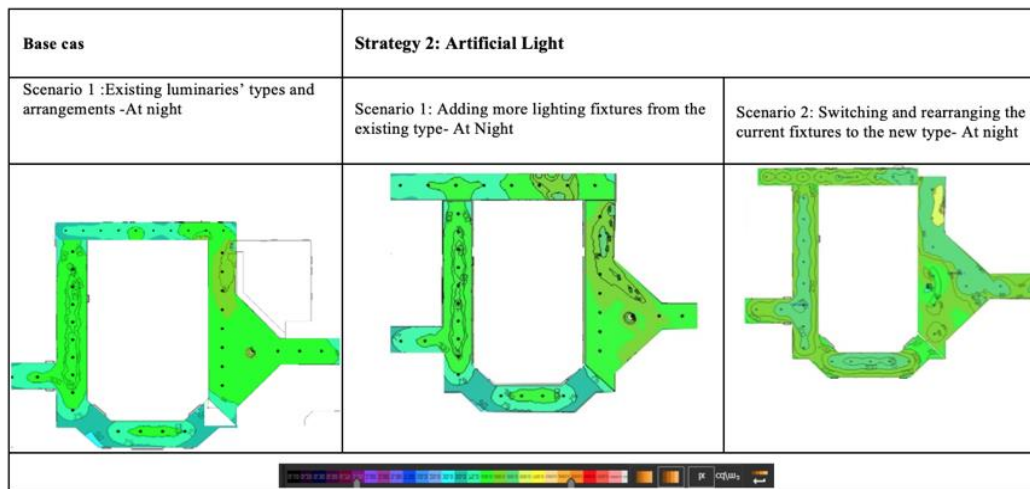


Figure 136: Corridors graphical colored maps-Night time scenarios

(Source: Author,2023)

The strategies for illuminating corridors at night offer trade-offs between illumination intensity, uniformity, glare, and energy consumption. Switching and rearranging fixtures (Scenario 2) provide higher intensity but consume more energy. The base case (Scenario 1) offers a balance between these factors, including glare, lux value, and uniformity. The base case provides a good intensity with lower energy consumption. The optimal choice of strategy depends on specific corridor lighting requirements, desired uniformity, glare tolerance, task and activity requirements in the general circulation zone, as well as energy efficiency goals.

Figure 137 illustrates a chart comparing three distinct lighting strategies for illuminating a registration office during nighttime operations. The assessed performance metrics encompass illuminance (measured in Lux), uniformity ratio, glare level (measured using the Glare Index), and energy consumption (measured in kWh per year). These strategies are evaluated against two

scenarios: strategy 2 (scenario 1) involves the utilization of existing luminary types and arrangements, whereas scenario 2 entails various approaches, including transitioning to new fixtures, rearranging them, and enhancing the Light Reflectance Value (LRV) of internal surfaces to ameliorate lighting conditions. These scenarios exhibit variations in terms of illumination levels and energy efficiency, offering multiple choices for optimizing the lighting environment within the Registration Office. Below is a summary and comparison of these strategies and scenarios:

- **Illumination Intensity (Lux):** In Figure 137 and Figure 138, the "Add more light from existing luminaries" strategy (Scenario 1) yields the highest illumination intensity, measuring 469 lux. This is notably higher than both the base case, which provides 212 lux, and the "Switch and rearrange current fixtures" strategy (Scenario 2), which offers 352 lux, closely aligning with the recommended Lux level of over 300 lux. This indicates that increasing illumination by adding more light from existing sources enhances brightness but also results in higher energy consumption.
- **Uniformity Ratio:** The uniformity ratio indicates the consistency of illumination throughout the space. The base case has a uniformity ratio of 0.45, but as evident in the graphical colored map for the office in Figure 138, the space is not evenly lit. On the other hand, strategy 2 (Scenario 1) offers a uniformity ratio of 0.34. However, scenario 2 of strategy 2 provides a relatively better light distribution with a uniformity level of 0.5 compared to the base case and scenario 1, indicating more even lighting across the space.

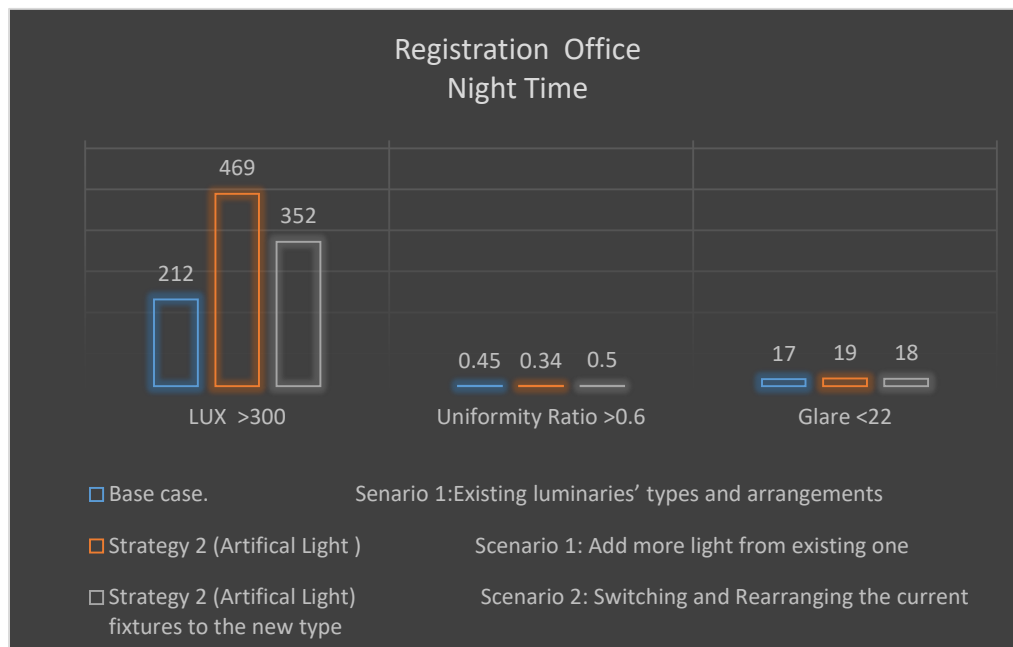


Figure 137: Registration office chart -Night time scenarios

(Source: Author,2023)

- Glare: The glare level in the base case is the lowest at 17, which is desirable for ensuring a comfortable and consistent visual environment. In strategy 2 (scenario 2), the glare level is 18, still within the comfortable glare level range, contributing to a visually pleasing environment. On the other hand, strategy 2 (scenario 1) has the highest glare level compared to the previous scenario and the base case, indicating potential discomfort and reduced visual quality.
- Energy Consumption: The base case consumes the least energy at 171.55 kWh per year. Scenario 1 of strategy 2 has higher energy consumption at 577.02 kWh/year, mainly due to over-illuminated spaces relative to the office's dimensions. On the other hand, scenario 2 of strategy 2 has an energy consumption of around 188.18 kWh/year, which involves a

moderate level of energy consumption while maintaining consistent lighting distribution. Scenario 2 appears to be the most energy-efficient option when considering the overall lighting parameters, indicating that the new luminaire types and rearrangements are relatively conservative in energy use.

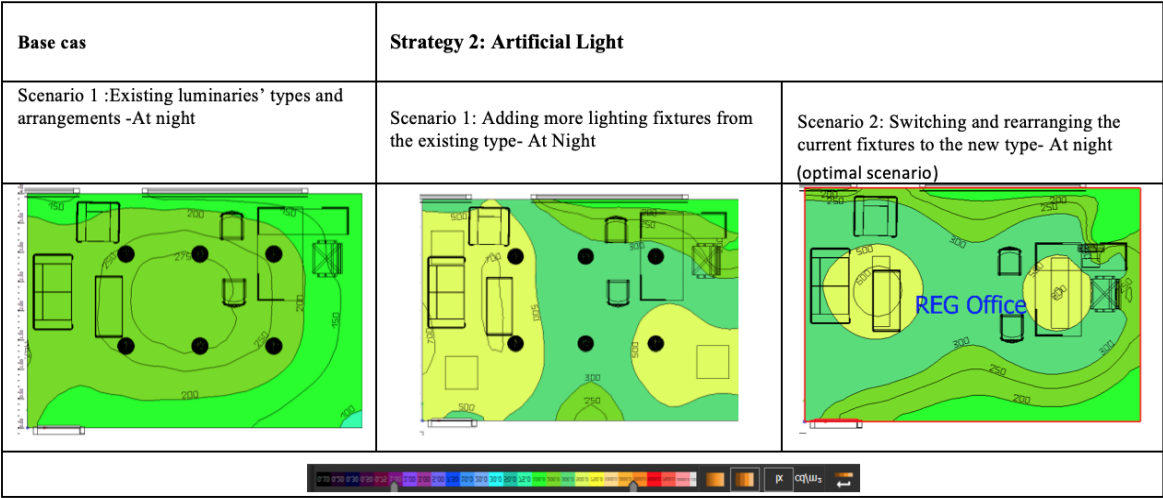


Figure 138: Registration office graphical colored maps-Night time scenarios

(Source: Author,2023)

The strategies for illuminating the registration office at night offer varying compromises between illumination intensity, uniformity, glare, and energy consumption. Adding more light from existing luminaries (scenario 1) provides the highest intensity but sacrifices uniformity and consumes more energy. Strategy 2: Switching and rearranging fixtures (scenario 2) achieves a balance between intensity, glare level, moderate uniformity levels, and energy efficiency.

In Figure 139, the registration office is illuminated using four lighting scenarios from two different strategies: the base case, scenario 2 (involving existing luminaries' types and

arrangements), strategy 1 with two scenarios (scenario 1: all curtains fully opened, and scenario 2: all curtains halfway down), and strategy 3 with two scenarios (scenario 1: combining artificial light and daylight with all curtains closed during the daytime, and scenario 2: combining artificial light with daylight when curtains are halfway open and artificial fixtures are dimmed). These strategies aim to achieve optimal illumination during daytime activities through various combinations of natural daylight and artificial lighting.

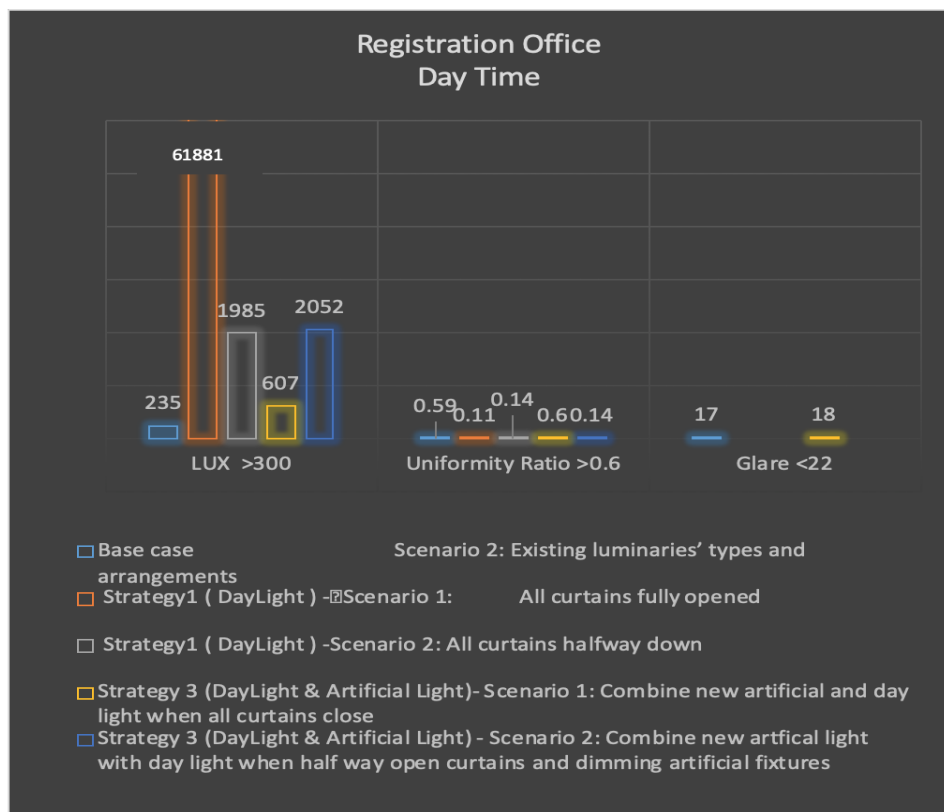


Figure 139: Registration office chart -Day time scenarios

(Source: Author,2023)

The following is a summary and comparison of these strategies:

- **Illumination Intensity (Lux):** In Figure 139 and Figure 140, the Lux values in the registration office scenarios vary significantly. Strategy 1 (scenario 1) provides an exceptionally high Lux value of 6881, while strategy 1 (scenario 2) offers 1985 Lux, which is still an over-lit zone. Strategy 3 (scenario 2) provides 2052 Lux, also in the over-lit range. The base case (scenario 2) offers a Lux value of 235, which is below the target level. Strategy 3 (scenario 1) provides 607 Lux, which is within the recommended Lux range.
- **Uniformity Ratio:** The uniformity ratios across the strategies differ significantly. The base case has a uniformity ratio of 0.59, indicating a relatively even distribution of light. In contrast, Strategy 1 (scenarios 1 and 2) and Strategy 3 (scenario 2) offer lower uniformity ratios of 0.11 and 0.14, suggesting uneven lighting. However, Strategy 3 (Scenario 1) provides a higher uniformity ratio of 0.6, and the graphical colored map confirms that the light is well distributed, aligning with the primary tasks in this space.
- **Glare:** Glare levels are available for the base case (scenario 2) and strategy 3 (scenario 1), both of which have a glare level of 18. However, the other strategies do not provide glare levels or energy consumption data due to software limitations.
- **Energy Consumption:** The base case (Scenario 2) resulted in an estimated energy consumption of around 272.55 kWh/year. It's worth noting that there was less energy consumption observed in strategy 3 (Scenario 1), approximately 188.18 kWh/year when combining artificial light and daylight with all curtains closed. However, it's important to keep in mind that the DIALux EVO software has certain limitations, and it may not generate accurate energy consumption values for strategy 1 and 2, particularly when there

is a significant contrast in Lux values. Additionally, in strategy 3 (Scenario 2), the presence of dimmer options can further complicate the accurate estimation of energy consumption.

The strategies for illuminating the registration office during the daytime offer a wide range of illumination intensities and uniformity ratios. Utilizing natural daylight (strategy 1) results in extremely high Lux values, while combining daylight and artificial lighting in strategy 3 (scenario 1) offers a balance between energy efficiency and illumination quality, making it the optimal scenario in this case. The base case offers lower illumination with moderate energy consumption. The choice of the optimal strategy depends on specific office lighting requirements, desired uniformity, glare tolerance, and energy efficiency goals.

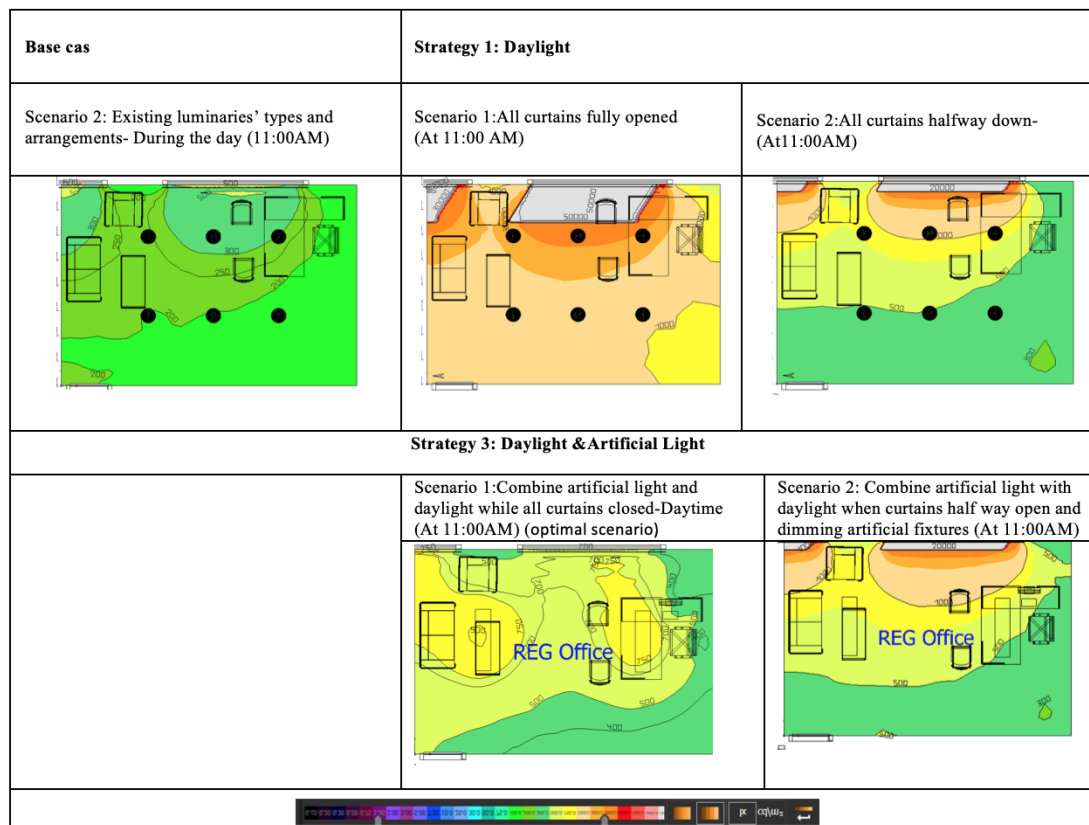


Figure 140: Registration office graphical colored maps-Day time scenarios

(Source: Author,2023)

5.3 Summary of Contributions Findings

To summarize the advantages and disadvantages of the tested strategies through various scenarios, which are based on the previous results obtained from DIALux EVO 11 (computer simulation) and compared with the base case scenarios created using the same software to assess lighting quality in different spaces within the campus building during both daytime and nighttime. In strategy one, which focuses on daylight enhancement by investigating the potential

for improving lighting conditions using the existing window specifications and allowing daylight into the spaces, either fully through fully opened curtains in scenario one or partially with curtains halfway down in scenario two, without any changes to the external elevation design. It's evident that in this strategy, in all examined zones where daylight was introduced, there were very bright areas near the windows, leading to glare in those areas and increased visual discomfort for users during the daytime. On the other hand, opening the curtains either fully or partially improved the quality of views, which is an important factor in enhancing the user experience and well-being.

As mentioned in the study conducted by Dahlan and Eissa (2015), the amount of natural light entering classrooms should generally be maximized, but designers must also be cautious about illuminating too much of the space within students' fields of view. The efficient utilization of daylight in classrooms can lead to substantial energy savings in educational buildings, enhance student attendance, demonstrate environmental responsibility, and create an improved learning and working environment. As previously discussed, considering space orientation during the early design stages, with regard to the sun's direction, is crucial to harness the benefits of natural light and scenic views.

Since the working hours of the selected case study include night shifts, the second strategy of this study focuses on enhancing artificial lighting during nighttime, without considering daylight. In this strategy, two scenarios were examined. The first scenario concentrated on utilizing the existing lighting fixtures and assessing the impact of adding more light to meet the required standards for each zone, considering various tasks and activities without modifying the lighting reflectance value of the interior surfaces. In this scenario, the auditorium area and the

student lounge achieved optimal results by meeting the recommended Lux levels, while other spaces showed a significant increase in Lux values, leading to slightly higher energy consumption.

In the second scenario, the study tested the effects of switching and rearranging the lighting fixtures according to recommendations and manuals included in the software. The rearrangements were performed based on the specific tasks and activities in each zone and aimed to enhance the lighting reflectance value of the interior surfaces, as recommended by LEED V4. This scenario aimed to achieve optimal lighting results based on the literature and standards.

As mentioned, most of the spaces such as classrooms, library, administration area (open plan office), group study room, board room, and the registration office achieved optimal lighting parameters in this scenario. However, the results of adding more light from the existing fixtures increased the Lux values in most spaces. This increase does not necessarily translate to better lighting conditions for each zone and task area; instead, it led to excessive Lux levels and higher energy consumption in some spaces compared to the original case and other scenarios. This, in turn, resulted in uncomfortable lighting levels for users.

On the other hand, replacing the current lighting fixtures with other luminaires can create different lighting moods. However, not all replacements can achieve the desired lighting levels that match the requirements and tasks of each zone. Adding more light can improve the lighting level by achieving a better distribution of Lux values across the area, reducing the stark contrast between dark and light areas, and enhancing the uniformity ratio. This can enhance users' concentration and productivity. However, achieving this result requires additional costs for

adding new lighting fixtures and enhancing the lighting reflectance values of the internal surfaces.

Furthermore, the third strategy involved the integration of daylight and artificial lighting scenarios by combining artificial light with daylight during the daytime in the campus building. This strategy aimed to create a balance between both light sources and included two scenarios. However, it's important to note that the software used had limitations, particularly regarding dimming control, which was restricted to a maximum of fifty percent. In the first scenario, the combination of artificial light with daylight was examined with all curtains closed during the day, and the results varied across the spaces, with some achieving high, moderate, and low Lux values. The registration office came close to the target Lux value in this scenario and consumed less energy than other scenarios. The library zone also achieved optimal results in this scenario. The second scenario similarly combined artificial light with daylight, but with the ability to dim the artificial lighting by around 50%, constrained by the software limitations.

The second scenario, which involved the dimming system, presented challenges in measuring daylight and energy consumption due to software limitations. To address this issue, further research and simulations could be conducted with the integration of sensors. As suggested by Kime and Alibaba (2018), reducing the need for artificial lighting during daytime hours can lead to decreased energy consumption. This, in turn, allows for more natural light and views into spaces like the library, ultimately enhancing user performance and satisfaction. Dimming light scenarios offer flexibility in adjusting lighting levels based on various factors, such as building orientation, window size and shape, shading devices, elevation design, space dimensions, and more. Consequently, strategically integrating daylight in educational buildings can reduce

operational costs, improve students' vision and perception, and enhance their comfort, productivity, and overall well-being.

Chapter 6 : Conclusion

6.1 Summary

The goal of this study was to evaluate the lighting conditions in existing campus buildings in Dubai, which are occupied both during the day and at night. Educational facilities are expected to serve as centers of creativity and intelligence. The study employed a manual assessment method conducted through a field study to measure various lighting parameters on-site, utilizing a specialized lux meter machine (Sekonic-C7000). This assessment was carried out in different spaces within block eleven, first floor of the BUiD campus.

Furthermore, the study included the measurement of user satisfaction levels through an online survey. The obtained information was then correlated with the field measurement results to determine how users perceive the various measured values of lighting parameters in indoor spaces and how these perceptions may impact their productivity and performance. Subsequently, various scenarios and strategies were proposed and tested using DIALux Evo software. These proposals were based on factors such as user needs, feelings, received comments, and the researcher's site experience, as discussed in the previous chapter

Moreover, this integrative design process is a significant strength of this study as it actively involves students and campus users, allowing them to express their opinions about the interior spaces and their level of comfort and satisfaction with the facilities. Additionally, the spaces under analysis varied in terms of tasks, location, spatial configuration, orientation, window-to-wall ratios, and lighting fixtures, among many other parameters that impact the lighting conditions. These variations were carefully considered when devising the suggested strategies

to achieve optimal results for each space, taking into account the specific tasks, activities, and the users' requirements and needs. It's worth noting that previous studies have also emphasized the importance of lighting conditions in indoor spaces. This significance extends beyond artificial lighting fixtures, as highlighted by Irnawaty et al. (2019). Daylight, for instance, offers numerous advantages that positively influence the indoor architecture of campus buildings. One of the most notable advantages is its connection to the well-being of the users, enhancing their moods and reducing stress.

This paper has established its argument by conducting a thorough review of the literature. Numerous pieces of data were uncovered regarding the correlation between lux values and the type of space. As previously mentioned by DiLaura et al. (2011), it is evident that the quality of lighting can significantly impact students' engagement and cognitive performance.

The study aimed to identify diverse strategies to improve the lighting parameters within the indoor campus buildings at BUiD University. These strategies were based on sustainable interior design principles, with a focus on enhancing the occupants' overall quality of experience while minimizing the adverse health and financial impacts associated with conventional design practices. Furthermore, environmental considerations were integrated into the design, recognizing the strong connection between the environment and users' productivity and performance.

An integrative design process for achieving efficient lighting conditions was employed to align with sustainability goals in the interior spaces of existing buildings. This approach involved the careful analysis and selection of materials with appropriate Light Reflectance

Values (LRV), as well as the types and layouts of lighting fixtures within task areas. Additionally, strategies were implemented to enhance natural daylight, fostering a stronger connection between students and staff with the natural world, encouraging a more profound engagement with the outdoors.

The primary objective of the current study was to assess the lighting conditions within existing campus buildings while taking into account the specific use of these spaces. Various zones as defined by LEED (ID+C) criteria were considered, such as individual tenant areas versus shared multi-occupant spaces and frequently occupied areas versus those that are less frequently used. In pursuit of this goal, several spaces underwent testing and analysis through a combination of manual assessment and the use of lighting design software. DIALux EVO was employed for the evaluation of lighting, encompassing both natural and artificial lighting sources. The initial step in this evaluation process involved creating a 3D model of each room that accurately represented its current state. Subsequent calculations were executed using different strategies and scenarios. The analysis began with a base case and proceeded by adding more luminaires to the models. Following that, adjustments were made by switching and rearranging the LED luminaires, and the outcomes were then compared to assess the impact of these changes.

6.2 Main Findings

The study's findings emphasize the significance of ensuring user satisfaction across various areas within a university campus building, particularly highlighting the role of interior lighting elements as a crucial component of indoor environmental quality. Inadequate lighting can lead

to discomfort, while excessive lighting results in unnecessary energy consumption. A well-planned lighting system is designed to provide precisely the right amount of light for its intended purpose. Although this study had a relatively small number of participants, it contributes to our understanding of the importance of involving users in the design decision-making process, taking their needs and requirements into consideration. Furthermore, it underscores that assessing user satisfaction in indoor spaces has a substantial impact on the final design outcomes.

On the other hand, the simulation results, as previously discussed in the preceding chapter, offer further evidence regarding the diverse requirements for lux values in each space, contingent on the specific tasks and activities within each zone. The optimal outcomes for each zone differed in terms of achieving a harmonious balance among the measured lighting parameters, including lux values, uniformity ratio, glare, and energy consumption. These variations were influenced by a multitude of factors, such as the space's location, the presence of natural daylight, windows size, choice of finishing materials, the nature of tasks performed in each zone, the layout of furniture, and the type and arrangement of lighting fixtures.

This study not only reaffirms prior findings but also provides additional evidence that underscores the importance of considering each zone and task area as an individual component in designing and improving its lighting conditions. This approach aligns with the principles of green building, emphasizing the need to start at the smaller scale to achieve optimal designs on a larger scale. As a result, the study's findings indicate that various spaces on the campus rely heavily on artificial lighting and electricity due to their limited access to natural light, primarily because of their locations. For instance, in spaces like the auditorium, artificial lighting use

exceeded that of natural light, leading to increased building energy consumption and higher levels of sleepiness and fatigue among students and staff who utilized these areas. Conversely, the library experienced high energy consumption during both day and night, driven by excessive lux values from daylighting during the day and artificial fixtures during the night.

The present study offers significant contributions on two levels: methodological and practical. From a methodological perspective, it investigates user awareness and reactions, quantifying subjective perceptions of lighting in learning environments. This innovative approach allows designers to align solutions with users' emotional, cognitive, and productivity needs, while considering the specific requirements of each zone and the tasks conducted therein, ultimately enhancing user performance and building efficiency. The theoretical contributions are highlighted as follows:

1. Advancing sustainable design awareness: The analysis in this context contributes to the theoretical understanding of sustainable building design, with a particular focus on the UAE context and the application of LEED (ID+C) standards to enhance indoor lighting.
2. Theoretical frameworks: The research lays the groundwork for developing theoretical frameworks and models for assessing indoor lighting quality in campus buildings, encompassing elements like daylighting, artificial lighting systems, glare control, and visual comfort.
3. Environmental impact evaluation: The study offers methods for evaluating the environmental impact of improved interior lighting, including energy usage in campus buildings in the UAE.

In terms of practical application, the study's results underscore the advantages of using simulation software in the evaluation and design of lighting systems. DIALux Evo, in particular, proves to be a valuable tool for comparing different lighting designs, making enhancements, and identifying potential issues. This software simplifies the processing of outcomes by presenting them in numerical and graphical formats, allowing for clear and easy interpretation. Moreover, it provides a photorealistic representation of the illuminated space model through graphical maps and isolines, enabling designers to visually assess the appearance and suitability of the design. The study aims to emphasize that using automated software calculations is an effective strategy. While there are several lighting design software programs available, DIALux stands out for its versatility, suitable not only for new constructions but also for remodeling existing spaces, as seen in the case study. One of the key benefits of DIALux is its combination of being a powerful design tool and a free plug-in. Furthermore, it accelerates the design process by allowing lighting manufacturers to introduce their products into the software's database, complete with specifications for each fixture type, suggested usage scenarios, and 3D models. This approach has garnered extensive support and has built a large community of users, including designers and manufacturers. The practical contributions of the study can be summarized as follows:

1. **Healthier campus design:** The study offers valuable guidance to architects and designers on how to implement LEED (ID+C) principles and the EN 12464-1 (2021) standard to enhance interior lighting in campus buildings in the UAE. This may involve specific design approaches, materials, and technologies tailored to the region.

2. Energy efficiency: The use of energy-efficient lighting solutions, such as LED fixtures, can lead to reduced energy consumption and lower maintenance costs for campus buildings.
3. Human well-being and health: Improving interior lighting can positively impact the health and well-being of building occupants. Strategies and scenarios for increasing access to natural light, reducing glare, and creating visually appealing indoor environments can provide practical benefits.
4. LEED certification: The study can assist campus buildings in the UAE in meeting the Indoor Environmental Quality (IEQ) requirements for LEED (ID+C) certification. This can benefit developers and project managers by reducing operating costs and enhancing marketability.
5. Government regulations: The findings of the study can inform policymakers and those responsible for developing building codes and regulations in the UAE. Recognizing the advantages of incorporating LEED standards into regional building codes can lead to more livable and sustainable interior spaces with regard to lighting.

Both in theory and in practical terms, the research focus on the application of LEED and IES interior lighting standards criteria to enhance interior lighting in UAE campus buildings holds significant promise. This research deepens our comprehension of sustainable design, offers practical guidance for implementation, and reinforces local construction practices that prioritize both environmental sustainability and the well-being of building occupants. The findings from this study can serve as a valuable reference for architects, designers, policymakers, and project managers seeking to create more sustainable and user-centric interior spaces in campus buildings.

Several important limitations should be taken into account. First, the study faced challenges due to the COVID-19 pandemic, which resulted in remote surveys and limited physical presence on the campus. The majority of students were taking online courses, and both academic and non-academic staff had restricted access to the campus. Additionally, arranging the site visit and obtaining the necessary equipment for field measurements required the researcher to comply with COVID-19 testing and access restrictions.

Moreover, the reduced campus population during the pandemic limited the opportunity for in-person interviews and direct feedback from students and staff regarding their experiences with lighting conditions. This lack of direct interaction with the campus community is a notable limitation. Furthermore, the study is constrained by the limited availability of information on the same topic within campus buildings, especially in the context of the UAE and the Gulf region. While the study successfully demonstrated the applicability of DIALux Evo and its accessibility for interior designers and architects interested in lighting conditions, it has certain limitations in terms of specific variables, as previously mentioned. These limitations are particularly relevant to factors like glare value and energy consumption, especially when dealing with excessive daylight or very high lux values in specific zones, where the software may not provide accurate results and could produce errors.

6.3 Linking the Findings with Literature Review

The study involved conducting simulations of various strategies and scenarios in different spaces within the British University in Dubai. A significant challenge in this research was the selection of multiple spaces with diverse tasks and activities, all of which were investigated and

analyzed according to EN-12464-1 standards. This approach sets this study apart from most literature case study references, which often focus on testing only a single zone. Consequently, this study gains added value by allowing for correlations between the distinct requirements of each task, activity, and zone within an educational campus. Each space in the study had unique orientations and locations within the campus. Some spaces required analysis not only at night but also during the daytime to assess the potential incorporation of natural light and its impact on various lighting conditions and parameters. The following section will delve into the primary findings from each space, with a particular emphasis on the optimal scenarios achieved in the study.

Starting with the Auditorium at nighttime, the simulation results revealed that increasing the light from the existing fluorescent and downlight fixtures improved illumination within the target lux values. The audience area achieved 527 lux, and the lux levels above the podium area ranged from 200 to 250 lux, as indicated in the iso-line diagram from the previous chapter. This led to an optimal distribution of light with a uniformity ratio of 0.5, slightly below the target of 0.6, offering improved illumination for the area. Furthermore, this scenario reduced glare to a level of 19, which is suitable for the required tasks and creates a pleasant environment for users.

In comparison, the base case only reached 318 lux, falling below the EN 12464-1 standards for auditorium spaces, which recommend lux levels of 500 to 700 in the audience zone and 200 to 300 lux on the podium area. The base case also had a low uniformity ratio of 0.32 and a glare value of 21, impacting students' performance and concentration. It's crucial to consider a lighting control system in such a zone due to the variety of activities it hosts, ensuring that lighting can be adjusted to accommodate different tasks. These results align with the findings of Saraswati

et al. (2021), which emphasize that increasing the number of lighting fixtures can improve lux values in a tested zone while enhancing other parameters like uniformity and glare to create a visually comfortable environment. Notably, the base case consumed the least energy at 1404 kWh per year, whereas in scenario 1, it increased to 2597 kWh/year. It's essential to select a strategy based on the specific lighting requirements and energy efficiency goals for the Auditorium, considering the various activities it hosts throughout the year and the recommendations provided by DIALux EVO for this space. In contrast to other zones in the same case study, the optimal scenario for the suggested strategies at nighttime differs in the Auditorium. The choice of strategy depends on the unique lighting requirements and energy efficiency goals of this space, tailored to accommodate the various activities held there. This variability is in line with the recommendations made by DIALux EVO for the Auditorium.

Regarding the use of fluorescent lamps, research conducted by Castilla et al. (2018) indicated that fluorescent lamps (FL) were negatively perceived by students in various aspects. As a result, FL lighting was not considered stimulating, cutting-edge, cozy, comfortable, or attractive technology. LEDs, on the other hand, received positive ratings from students in every aspect. Additionally, a combination of dimming and scheduled light control after several hours is recommended for hallways, as stated by Makaremi et al. (2017).

In the selected classroom for this study (Classroom FF-111), the results of strategy two, scenario two, which involved switching and rearranging lighting fixtures and enhancing the Light Reflectance Value (LRV) for the internal surfaces, yielded a balanced improvement across multiple factors, including lux value, uniformity, and glare. This balanced approach helped create a comfortable and visually pleasing lighting environment. The lux value in scenario two

measured at 602 lux, while in the base case, it was 599 lux, with the target value for this zone set at 500 lux. However, the most intriguing results were related to the light distribution within the area. In scenario two, a uniformity ratio of 0.32 was achieved, compared to the base case, which had a uniformity of 0.18. Although both values are still below the target of 0.6, this improvement enhances visibility and overall learning conditions.

Moreover, the glare value in scenario two reached 18, which is within the target range, and it was the same as the base case where glare was measured at 17. These results are expected to enhance students' learning outcomes in this area, improve their performance, and enhance their communication with both their peers and instructors.

On the energy efficiency front, the base case consumed 560.73 kWh per year, while scenario two significantly reduced energy consumption to 210.87 kWh/year, making it the most energy-efficient option. This highlights the positive impact of switching and rearranging fixtures to LED types in scenario two, resulting in lower energy usage. These results align with previous research findings, as demonstrated in a study conducted by Singh and Arora (2014). Their research emphasized the application of innovative lighting technologies, such as sustainable lighting solutions like LEDs, which contribute to enhancing workplace conditions, increasing energy savings, and improving productivity. According to education regulations, the lighting system in classrooms is typically required to provide a minimum of 500 lux at all times.

Moreover, the importance of well-lit classrooms is further highlighted by Samani and Samani (2012). They emphasized that a well-lit classroom should feature accent lighting, higher reflectance ratings, a glare control system, and balanced brightness. Besides the benefits of

lowering operating expenses, the inclusion of daylight in classrooms has a significant positive impact on the environment.

In contrast, the classroom investigated the combination of daylight and artificial light during daytime, as the existing building had access to daylight in this area. The suggested strategies included allowing direct sunlight into the space by controlling the curtains, which served as internal shading devices to enable light without causing excessive heat gain. The various strategies tested confirmed that direct sunlight near the windows created high brightness, making these areas uncomfortable for reading, writing, or screen-related work. As a result, strategy 1 (scenario 2) emerged as the most effective solution, considering the specific lighting requirements and the desired balance between natural and artificial light for the classroom. In scenario 2, the lux value reached 739 lux, compared to the base case, which measured only 470 lux, making it a better-lit and more comfortable area for the required tasks. The light distribution in scenario 2 reached approximately 0.4, close to the target value of 0.6, while the base case measured 0.24. In contrast, the glare value remained stable for both the base case and scenario 2 since the software, DIALux EVO, primarily measures glare in response to artificial lighting, which was consistent in both cases. The present results align with previous studies, such as the one conducted by Porras (2020), which found that classrooms with windows consistently yielded better exam results for students compared to those in basement classrooms. Additionally, access to daylight in classrooms can improve students' vision and perception, leading to benefits in their well-being, comfort, and productivity, as emphasized by Dahlan and Eissa (2015).

Moreover, the investigation extended to the BUiD library, both during nighttime and daytime, as it is a space where students spend a significant amount of time reading, writing, and working on their screens. In this context, strategy two, scenario two, which involves switching and rearranging fixtures to LED type and enhancing the Light Reflectance Value (LRV) for interior materials as per LEED (ID+C) standards, achieved a well-balanced outcome across various lighting parameters. This scenario optimized the intensity, glare level, and lighting distribution in both the reading zone and the bookshelves area, resulting in a more energy-efficient setting. The lux value measured in scenario two reached 608 lux, which is close to the target value for this area at 500 lux. In comparison, the lux value in the base case was 616 lux. However, the significance of scenario two lies in achieving an overall balance in lighting conditions and parameters across the entire area. The uniformity ratio in scenario two improved to 0.05, whereas the base case had an inadequate uniformity ratio of 0.005. Additionally, the glare level in scenario two was 18, compared to 17 in the base case, with scenario two approaching the target value of 19 for this zone and the required tasks.

Another positive outcome that supports the selection of scenario 2 as the optimal choice for this space is the significant reduction in energy consumption. Scenario 2 decreased energy consumption to 3810 kWh per year, in contrast to the base case, which consumed 8987 kWh per year. This remarkable energy efficiency improvement is encouraging and in line with the findings of Makaremi et al. (2017), where they studied the relationship between two variables: the Light Reflectance Value (LRV) of indoor surfaces and visual comfort indices under artificial lighting environments. Their research emphasized the crucial role of surface reflectance characteristics, particularly of walls, in determining the parameters of visual comfort. They

concluded that wall reflectance significantly affects Unified Glare Rating (UGR) and average illuminance, and that the impact of floor reflection on the selected guides was also substantial. In practical terms, using materials of light color and increasing the reflection factor of indoor surfaces can serve as effective passive solutions or lighting strategies for improving energy efficiency and enhancing indoor environments. This demonstrates the potential for energy savings and improved lighting quality through thoughtful material selection and surface characteristics.

Additionally, the library space involves a combination of natural daylight and artificial lighting strategies. Scenario 3 (scenario 1), which combines daylight and artificial lighting, demonstrates the potential for energy savings, improved lux value, and enhanced uniformity. In this scenario, the lux value was maintained at 650, which is the same as the base case. However, the difference between these two scenarios lies in the results of other lighting parameters. For example, scenario 1 achieved a higher uniformity ratio, measuring at 0.052, in contrast to the base case, where the lighting distribution was only 0.003, falling far short of the target value of 0.6. Furthermore, the glare value in the first scenario improved to 18, while the base case remained at 17. The target value for this room was 19.

Regarding energy consumption, the base case had a high consumption rate of 8987.1 kWh per year, whereas the optimal scenario significantly reduced energy consumption to 380.15 kWh per year. These findings align with research conducted by Omar et al. (2018), which emphasized the importance of integrating shading devices to enhance energy performance and illuminance levels for visually comfortable environments. This integration leads to more suitable lighting conditions for users and the indoor environment, improving visual and interior lighting in

libraries and educational settings while reducing the energy usage of artificial lighting through the integration of daylight and artificial lighting systems.

In the administration area, scenario 2, which involved switching and rearranging fixtures and enhancing the Light Reflectance Value (LRV) of internal surfaces based on LEED (ID+C) standards, resulted in significantly improved lighting conditions. The uniformity ratio in this scenario reached 0.48, indicating a much better distribution of light across the space, approaching the target value of 0.6. The lux value averaged 495 lux, which is close to the target value of 300 lux as specified in the EN 12464-1 (2021) standards. The glare level in scenario 2 measured 20, which falls within the target range. In contrast, the base case provided higher illumination at 678 lux, which is significantly far from the target value. The uniformity ratio for the base case was extremely low at 0.001, indicating poor light distribution in this zone. Additionally, the glare value in the base case was 21, which exceeded the acceptable standards.

In terms of energy consumption, the suggested scenario significantly reduced consumption to 895.86 kWh/year, mainly due to the use of more energy-efficient lighting types, compared to the base case, which consumed around 2739.56 kWh/year. These findings are consistent with research conducted by Ortiz and Bluysen (2022), who noted that Indoor Environmental Quality (IEQ) and psychosocial comfort preferences are influenced by various space specifications, including the space layout, internal surfaces' Light Reflectance Value (LRV), and the type of lighting used.

In the group study room, the optimal scenario 2 during nighttime provides 579 lux, which is closest to the target value of 500 lux specified in the EN 12464-1 (2021) standards. This level

of lighting is adequate for tasks such as writing, reading, and using computer screens. In comparison, the base case provides a lower lux value at 366 lux. Optimal scenario 2 achieves a more balanced set of lighting parameters. The uniformity ratio improves to 0.25, though it is still below the target value of 0.6. In contrast, the base case had a uniformity ratio of 0.13. The glare levels are consistent between the base case and scenario 2, with a glare level of 17. This ensures a visually comfortable environment with minimal glare and consistent brightness throughout the area.

Regarding energy consumption, the base case consumes 1404 kWh per year, while optimal scenario 2 is the most energy-efficient, consuming only 866 kWh per year, making it an energy-saving strategy. The results of this study align with previous research in this field, emphasizing the importance of well-distributed lighting in spaces that serve multiple purposes, such as a group study room with zones for reading and studying, and bookshelves that require adequate lighting for different tasks.

In the student lounge area, which combines both daylight and artificial light due to its campus location, the optimal scenario during nighttime was scenario 1, offering 367 lux. This is the closest to the target value of 200 lux specified in the EN 12464-1 (2021) standards, while the base case provides 173 lux. Scenario 1 also outperforms the base case in terms of uniformity, with a ratio of 0.37, closer to the target level of 0.4 for this type of space based on EN 12464-1 (2021) standards. The base case has a uniformity ratio of 0.32. Regarding glare, the base case had a glare level of 19, while the optimal scenario achieved a glare level of 21, which still falls within the target value recommended by DIALux EVO, using the same standards as a reference.

In terms of energy consumption, both the base case and scenario 1 consumed around 539.96 kWh per year, making them better choices compared to other strategies involving the switching of light types and rearrangement in terms of most of the tested variables. These results are in line with the research of Jago and Tunner (1999), who emphasized the negative physiological consequences of inappropriate illumination levels, which can harm the human eye.

In the student lounge area, which benefits from natural daylight during the day, scenario 2 of strategy 1 is considered the optimal scenario. This scenario involves partially opening the curtains to allow daylight in. It provides 232 lux, which is the closest to the target value of 200 lux specified in the EN 12464-1 (2021) standards. In comparison, the base case offers a lower value of 175 lux. The uniformity ratio in scenario 2 is 0.3, which is near the target value of 0.4. The glare level of 21 is within the target value, which is lower than 22. Students generally prefer to have some natural daylight and views in entertainment areas, as highlighted by the findings of Sulaiman et al. (2013). The study noted that a majority of people prefer bright lighting over dim lighting, with 50 percent indicating a preference for daylight and not closing curtains, while 38 percent decrease artificial lighting. This underscores the importance of increasing students' awareness regarding the benefits of natural light and how it can positively impact their performance and well-being in such areas.

In the boardroom, which is used for meetings and presentations, the results during nighttime for the base case provided 608 lux, while the optimal scenario 2, involving switching and rearranging current fixtures, offered 439 lux. This is close to the lux level specified in the EN 12464-1 (2021) standards. Scenario 2 also achieved a higher uniformity ratio of 0.4, indicating a more even distribution of light across the room. This value is close to the target value of 0.6,

whereas the base case had a uniformity ratio of 0.25. Regarding glare, the base case had a glare level of 17, while scenario 2 measured 18, which falls within the target level of 19. This ensures a visually comfortable environment for meetings and presentations.

In terms of energy consumption, the base case consumed 1202 kWh per year, while scenario 2 was the most energy-efficient, consuming only 325.5 kWh per year. These findings align with the research of Alcaráz et al. (2018), which emphasized that enhancing the lighting conditions of different spaces in educational buildings can have a significant impact on user satisfaction, while also promoting energy savings and suggesting optimal lighting settings for user comfort and vision

In the corridor area, the application of the same lighting enhancement strategies was carried out to investigate their effects on this space. As mentioned earlier, the improvement of lighting conditions should take into consideration the specifications of each space separately, considering its specific function. Surprisingly, the results obtained for the corridor area indicate that the base case was the best scenario. It measured a lux value of 96.1 lux, which is very close to the target value of 100 lux. The uniformity ratio was 0.46, which is also close to the target value of 0.4. This uniform distribution of light in the corridor ensures safety for users, as it is a general circulation zone between blocks.

Moreover, the glare value is typically preferred to be lower, as it generally results in more comfortable visibility. In terms of energy consumption, the base case had the lowest consumption among the scenarios, consuming only 218 kWh per year. These findings suggest

that in certain spaces like corridors, the existing lighting conditions are already suitable, and enhancements may not be necessary.

The registration office, like most other spaces, was tested at night, and the optimal scenario involved switching and rearranging the lighting fixtures, along with enhancing the light reflectance value (LRV) of internal surfaces. This scenario achieved a balance between light intensity, glare level, moderate uniformity, and energy efficiency. In the base case, the lux value was measured at 212 lux, while in scenario 2, it was 352 lux, which is closer to the target value of 300 lux according to the standards. The optimal scenario effectively distributed light across the space with a uniformity ratio of 0.5, compared to 0.45 in the base case, while the target value for this area is around 0.6. Additionally, the glare value in the optimal scenario was around 18, whereas it was 17 in the base case. The target value for this zone is to be below 22. In terms of energy consumption, the base case consumed the least energy at 171.55 kWh per year, while scenario 2 consumed around 188.18 kWh/year, indicating moderate energy consumption with consistent lighting distribution. These results align with the findings of the research by Katabaro & Yan (2019), which emphasized the importance of appropriate uniformity and illuminance levels for improving user's visual perception and reducing signs of exhaustion, including headaches and eye strain. Well-maintained glare levels, uniformity, and illuminance levels contribute to increased alertness and mood among office occupants, factors that are crucial for enhancing their performance.

In this zone, a combination of daylight and artificial light was used. Additional simulations were conducted to test and validate the results of this combination. The results demonstrated a significant increase in lux value, with 607 lux being achieved. The light was evenly distributed

across the area, resulting in a uniformity ratio that met the target value of 0.6 according to the standards. Importantly, this was accomplished without causing any glare, as the glare level measured 18. Comparatively, the base case offered lower illumination at 235 lux with moderate energy consumption of 272.5 kWh per year. It's worth noting that the optimal scenario, which combined daylight and artificial light, had software limitations, and the dimmer function within the scenario wasn't utilized to determine energy consumption as in other strategies. These results underline the importance of combining natural daylight with artificial lighting to achieve optimal lighting conditions while minimizing energy consumption.

In conclusion, this study has demonstrated the improvement of lighting conditions in various spaces within the campus building, catering to different tasks and activities. These enhancements were analyzed using DIALux during both daytime and nighttime, with a focus on meeting the specific requirements of users for each task. The findings of this study align with previous research, such as that conducted by John and Timothy (2005), which highlighted the negative consequences of inadequate light controls on individuals' health and performance, including musculoskeletal injuries, eyestrain, stress, reduced attentiveness, and increased body temperatures. Furthermore, Veitch (2010) identified six human requirements that lighting should meet, including comfort, mood, judgments, aesthetics, safety and health, task performance, visibility, social behavior, and communication. This study contributes to the understanding of how optimized lighting conditions can positively impact indoor environments and the well-being of building occupants.

6.4 Study Importance

This study holds the potential to significantly benefit BUiD (British University in Dubai), its students, staff, and faculty members in several ways. Firstly, it aims to enhance the overall indoor environment by optimizing lighting conditions across various campus spaces. This, in turn, can lead to more comfortable, visually pleasing, and productive areas that cater to the specific needs of each task and activity. Moreover, by promoting sustainable lighting practices and energy-efficient design, the study aligns with BUiD's commitment to environmental responsibility, potentially resulting in cost savings and reduced energy consumption.

Importantly, this research prioritizes user satisfaction and well-being by involving students and faculty in the design decisions and measuring their contentment levels. This approach can lead to higher engagement and enhanced performance, as a well-lit and comfortable environment positively impacts the occupants. By offering tailored lighting solutions for different areas of the campus and considering natural daylight as part of the design, this study can improve the learning and working experience for the university community. Additionally, the potential to earn LEED (ID+C) certification through the implementation of the study's findings can lower operating costs and increase the university's marketability. In sum, this research's comprehensive approach to enhancing lighting quality and user satisfaction can help BUiD create a more sustainable, user-friendly, and energy-efficient campus, fostering a sense of community and engagement among its students and faculty.

Moreover, this study offers valuable insights and practical solutions that extend beyond the confines of the British University in Dubai (BUiD) and have the potential to benefit other

campus buildings nationally in the UAE and internationally. Firstly, the research focuses on improving indoor environmental quality through optimized lighting, which can be universally applied. Campuses worldwide can adapt and implement the lighting strategies and scenarios proposed in this study to create more comfortable, productive, and sustainable learning and working environments. The emphasis on green building practices and alignment with LEED (ID+C) standards can serve as a model for other institutions looking to enhance their environmental sustainability and potentially earn green certifications. By reducing energy consumption and promoting energy-efficient lighting systems, this research can help campus buildings lower their operating costs and reduce their environmental footprint, which aligns with global sustainability goals.

Additionally, the user-centric approach, involving students and staff in the decision-making process, can be a replicable model for other educational institutions, improving user satisfaction and well-being in various spaces. The consideration of individual tasks and activities within different zones on campus can inform targeted lighting solutions that enhance the user experience, a principle that can be applied worldwide.

To sum up, this study's methodology, findings, and recommended strategies provide a blueprint for creating healthier, more energy-efficient, and user-friendly campus buildings not only in the UAE but also internationally. Its focus on sustainability, user satisfaction, and task-specific lighting enhancements can have broad applicability and encourage a global shift towards more comfortable and environmentally responsible educational spaces.

6.5 Recommendations for Further Research Work

These findings provide the following insights for future studies about the indoor environmental quality with focus on lighting either natural light or artificial light through the emphasize the importance of managing natural light usage in learning and working contexts. It implies that a viable solution for insufficient lighting can be found in the installation of artificial lighting fixtures that function in harmony with natural light. In this regards it's interesting to focus on the concept of adding sensors, dimmers and other intelligence control system. However, putting such solutions into practice calls for accurate preparation. To help create the required lighting conditions, a variety of equipment like beamers and shading control systems, either automatic or manual, can be used. Nowadays, there is a lot of innovation ideas to incorporate the natural lighting inside the building either to enhance the quality of light, views, and user experience, which can be applied on existing building or new projects were further experimental investigations are needed to estimate the applicability of these ideas in different situation.

On the other hand, further research regarding the role of LED lighting technology of the new block and the flourcent light in the old class room which considered as the main learning space in educational building of BUiD would be worthwhile and interesting to conduct a comparison between the old block and the new one in terms of many factors and how much the new block taking in consideration the sustainable design principles in interior finishing's and the spaces layout and functions since it's also an existing renovated building for the graduate students. Further study might explore the enhancement where implemented in the administration area and compare it to the old one as a working area with open plan office layout in the old block and the

new one, it would be interesting to compare experiences of individuals within the same space. Moreover, a new space was added to the new block such as the architectural lab where the tasks and activities conducted in this lab required a special consideration of lighting design conditions which make it interesting for further research. This study has thrown up many questions in need of further investigation. A suggested study can be done through applying a concentration test for students and measure their performance in different areas, also it can be done by measuring the students' learning outcomes through their exams for example and create a comparison between LED light classes and the fluorescent light classes and investigate the difference between them and measure the lighting effects on the students' performance and productivity in terms of their results in exams and how this is directly affected by the lighting parameters and the space specifications. Further work could assess the long-term effects of lighting conditions on students' performance.

A natural progression of this work is to understand the sustainable guidelines of educational building with focus on campus are used during the day and night time with different groups of ages in order to create a specific guidelines and strategies to be implemented in the early stages of the design process. Consequently, this will introduce a construction of comprehensive design manual for lighting conditions strategies for campus buildings. A further study could examine the long-term effects of the interior lighting either natural or artificial on the user's health and well-being. So in this regard it is important to educate and increase the community awareness about the sustainable building design in terms of lighting and the importance of day light and how should be connected to the outdoor in the working areas and how this can have big influence on the user health and productivity in indoor areas. Which can be done through a workshop,

seminars, and conferences. Encouraging campus buildings in the UAE to incorporate DIALux EVO software into the course syllabus for interior design students can be beneficial for both students and the institution in terms of emphasize the significance of DIALux EVO software in the field of interior lighting design, and interactive design projects with LEED and other sustainability standards such as EN 12464-1 (2021) standard. Moreover, an implication of these findings is that both natural light and artificial light should be taken into account when renovating an existing building or designing a new one. suggesting several courses of action for important practical implication can be discussed to be done through the campus administration and assist these results on real life. This study will serve as a base for future studies in campus building.

One of the future recommendations also is applying a dynamic double lighting system in educational buildings, to enhance integrate between day light and artificial light to enhance the day light, improve students' performance and the users in the camps as well as improve the energy saving for limited use of artificial light. The DIALux Evo has limitations in its support for sensor and dimming systems. Refer to (Schledermann et al.,2019) the paper presents and investigated numerous features of dynamic double lighting system's impact on the educational environment of Danish elementary school. where the dynamic lighting technology was implemented to enhance and facilitate the learning activities and teaching, as well as, affecting student's behavior, creating a good and specific atmosphere in classroom, supporting the visual comfort and visual tasks. Furthermore, this system helps also, to enhance the energy efficiency be integrated with occupancy timers and sensors to ensure that the lights are only on and used when needed. Considerably more work will need to be done not only in UAE campus building,

but also can be implemented worldwide. At the end, this research work is expected to help multiple stakeholders of a region comprising policy makers, regulators, planners, engineers and several in successfully employing the findings of the research to their environments that share similar profiles. (Singh & Arora 2014), highlighted in their study the importance of students satisfaction in green rated building towards both daylight and artificial light which have a significant impact on the users concentration performance in different task area which mentioned previously to be considered from the early stages of the design process.

References

- Alcaráz, M., Arch F & Carolina Téllez. (2018). Lighting in higher education classrooms, vol. 0263080131, pp. 1–12.
- Alhamad, I.M. & Saraiji, R. (2022). Indoor illuminance selection procedure using fuzzy techniques. *Journal of Building Engineering*, vol. 62, p. 105362.
- Aljunaibi, A. A., Al Zaabi, E. J., Nassif, R. & Mushtaha, E. (2018). Daylighting in educational buildings: Its effects on students and how to maximize its performance in the architectural engineering department of the university of Sharjah. *Lecture Notes in Civil Engineering*, vol. 6, pp. 141–159.
- Aram, R. & Alibaba, H. Z. (2018). Investigation of the effects of daylight in a university library. *Journal of Architectural and Planning Research*, vol. 35(4), pp. 343–356.
- Associate, G. & Easy, M. (n.d.). © 2011-14 Green Building Academy.
- Avcı, A. N. & Akbay, S. (2022). Visual comfort assessment of OLED lighting in an indoor office environment . *GRID - Architecture Planning and Design Journal* , vol 5 (2) , pp. 129-143.
- Bangali, J.A. (2018). Discomfort glare evaluation using DIALux lighting simulation software and using developed Python Program Model. *International Journal of Sustainable Lighting*, vol 20(2), pp. 44–50.
- Bonda, P. & Sosnowchik, K. (2014) *Sustainable commercial interiors*. Hoboken, NJ: Wiley.
- Boyce PR. (2014). Human factors in lighting. 2nd ed. Boca Raton (FL): CRC Press.

- Castilla, N., Llinares, C., Bravo, J. M., & Blanca, V. (2017). Subjective assessment of university classroom environment. *Building and Environment*, vol 122, pp. 72–81.
- Ccc.net. (2019). [online] Available at: <https://www.ccc.net/wp-content/uploads/2019/05/bulletin128.pdf> [Accessed 19 Dec. 2022].
- Cem Catalbas, M. & Bernard Kobav, M. (2022). Measurement of correlated colour temperature from RGB images by deep regression model. *Measurement*, vol 195, p. 111053.
- Choi, S., Guerin, D., Kim, H.-Y., Brigham, J. K. & Bauer, T. (2014). Indoor Environmental Quality of Classrooms and Student Outcomes: A Path Analysis Approach. *Journal of Learning Spaces*, vol. 2(2), p. 14
- Cilento, K. (2012) *Al Bahar Towers responsive facade / aedas*, *ArchDaily*. Available at: <https://www.archdaily.com/270592/al-bahar-towers-responsive-facade-aedas> (Accessed: 03 October 2023).
- Dahlan, A. S. & Eissa, M. A. (2015). The Impact of Day Lighting in Classrooms on Students' Performance. *International Journal of Soft Computing and Engineering (IJSCE)*, vol 6, pp. 2231–2307.
- DIALux. (2016). DIALux evo manual A collection of all wiki articles, p. 100 [online]. Available at: www.dial.de.
- DiLaura, D., Houser, K., Mistrick, R. & Steffy, G. (2011). *IES lighting handbook, 10th edition*. Illuminating Engineering Society of North America (IES).

- El Asmar, M., Chokor, A. & Srou, I. (2014). Are building occupants satisfied with indoor environmental quality of higher education facilities? *Energy Procedia*, vol. 50(480), pp. 751–760.
- Energy Star. (2006). Facility Type : K – 12 Schools. *Energy Star Building Manual*, (November), pp. 1–18.
- Fielding, R. (2006). Learning, Lighting and Colour: Lighting design for schools and universities in the 21st century. 1-7. Retrieved from http://eric.ed.gov/ERICWebPortal/search/detailmini.jsp?_nfpb=true&_&ERICExtSearch_SearchValue_0=ED 497664&ERICExtSearch_SearchType_0=no&accno=ED497664
- Fisk, W. J. (2000). Health and Productivity Gains from Better Indoor Environments and Their Implications for the U . S . Department of Energy. *Building*, (1997).
- Ford, D.Y. (2010) ‘Multicultural issues: Culturally responsive classrooms: Affirming culturally different gifted students’, *Gifted Child Today*, vol 33(1), pp. 50–53.
- Freewan, A. A. Y. & Al Dalala, J. A. (2020). Assessment of daylight performance of Advanced Daylighting Strategies in Large University Classrooms; Case Study Classrooms at JUST. *Alexandria Engineering Journal*. Faculty of Engineering, Alexandria University, vol. 59(2), pp. 791–802.
- Garcia-Fernandez, B. & Omar, O. (2022). Integrated innovative solar lighting system for optimization of daylight utilization for public library in Alexandria, Egypt. *Ain Shams Engineering Journal*. THE AUTHORS, vol. 14(1), p. 101819.

- Gleason, J.D. et al. (2019) ‘Smart lighting clinical testbed pilot study on circadian phase advancement’, *IEEE Journal of Translational Engineering in Health and Medicine*, vol 7, pp. 1–10.
- Greenbuild (2018), USGBC announces new initiatives and updates to LEED U.S. Green Building Council. Available at: <https://www.usgbc.org/articles/greenbuild-2018-comes-close-usgbc-announces-new-initiatives-and-updates-leed> (Accessed: 10 October 2023).
- Gurgun, A. & Arditi, D. (2018). Assessment of Energy Credits in LEED-certified buildings based on certification levels and project ownership. *Buildings*, vol 8(2), p. 29.
- Halonen, L. & E. Tetri (2010). 'Lighting and energy standards and codes', in *CIE 2010-Lighting Quality and Energy Efficiency*. Vienna, Austria :CIE, pp. 188–195.
- Hayles, C.S. (2015) ‘Environmentally sustainable interior design: A snapshot of current supply of and demand for green, sustainable or fair trade products for Interior Design Practice’, *International Journal of Sustainable Built Environment*, vol 4(1), pp. 100–108.
- IES. (2000). *Illuminating Engineering Society of North America*. Ninth. Edited by Judith Block [online]. Available at: www.ies.org.
- Inan, T. (2013). An investigation on daylighting performance in educational institutions. *Structural Survey*, vol 31(2), pp. 121–138.
- International standard organization(ISO). *Lighting of Indoor Work Places*; ISO: Geneva, Switzerland, 2002.

- Jago, E., & Tanner, K. (1999). Influence of the school facility on student achievement. Retrieved March, 3, 2011, from <http://www.coe.uga.edu/sdpl/researchabstracts/visual.html>
- Jensen, C. L. & Jensen, C. L. (2016). What is energy efficient light ? A socio-technical analysis of, (May 2014).
- John, M., & Timothy, E. H. (2005). Illuminating the Classroom Environment. in *School Planning & Management*, 44(2), 34.
- Joshi, N. & Patki, P. (2022). Relationship of shading devices and its effects on daylight in commercial buildings in Pune. *IOP Conference Series: Earth and Environmental Science*, vol 1084(1), p. 012079.
- Kantola, D. (2020). Socially Sustainable Office Buildings - A better business for everyone. dissertation. Uppala University
- Kaplow, S. (2013). Can Green Building Law Save the Planet. *U. Balt. J. Land & Dev.*, vol 3, p.131. Kumar, R. (2019). *Research methodology: A step-by-step guide for beginners*. Sage Publications Limited.
- Katabaro, J.M. & Yan, Y. (2019). Effects of lighting quality on working efficiency of workers in office building in Tanzania. *Journal of Environmental and Public Health*, vol 2019, pp. 1–12.
- Khosravi, S., Mossman, M. A. & Whitehead, L. A. (2014). Core sunlighting system, a new approach to daylighting in buildings. *Energy Procedia*, vol. 57, pp. 1951–1960.

- Kime, B. & Alibaba, H. (2018). Comparative Analysis of Day lighting and Artificial Lighting in Library Building; Analyzing the Energy Usage of the Library. *International Journal of Advanced Research in Science, Engineering and Technology*, vol. 5.
- Králiková, R., Džuňová, L., Lumnitzer, E. & Piňosová, M. (2022). Simulation of Artificial Lighting Using Leading Software to Evaluate Lighting Conditions in the Absence of Daylight in a University Classroom. *Sustainability (Switzerland)*, vol. 14(18).
- Leccese, F., Rocca, M., Salvadori, G., Belloni, E. & Buratti, C. (2021). Towards a holistic approach to indoor environmental quality assessment: Weighting schemes to combine effects of multiple environmental factors. *Energy and Buildings*. Elsevier B.V., vol. 245, p. 111056.
- Makaremi, N., Schiavoni, S., Pisello, A. L., Asdrubali, F. & Cotana, F. (2017). Quantifying the effects of interior surface reflectance on indoor lighting. *Energy Procedia*. , vol. 134(October), pp. 306–316.
- Mazarella, F. (2016) Interior Design , WBDG. Available at: <https://www.wbdg.org/design-disciplines/interior-design> (Accessed: 10 October 2023).
- McKellar, S. & Sparke, P. (2004). Interior Design and Identity, vol. 27, p. 218 [online]. Available at: <http://books.google.com/books?id=xsHsnIUPGw0C&pgis=1>.
- Michael, A. & Heracleous, C. (2017) ‘Assessment of natural lighting performance and visual comfort of educational architecture in Southern Europe: The case of typical educational school premises in cyprus’, *Energy and Buildings*, vol 140, pp. 443–457.

- Mihai, T. and Iordache, V. (2016). Determining the indoor environment quality for an educational building. *Energy Procedia*, vol. 85, pp.566-574.
- Miller, N., Pogue, D., Gough, Q. & Davis, S. (2009). Green Buildings and Productivity. *Journal of Sustainable Real Estate*, vol. 1(1), pp. 65–89.
- Mott, M. S., Robinson, D. H., Walden, A., Burnette, J. & Rutherford, A. S. (2012). Illuminating the effects of dynamic lighting on student learning. *SAGE Open*, vol. 2(2), pp. 1-9.
- Norazman, N., Ani, A. I. C., Ja'afar, N. H. & Khoiry, M. A. (2018). Indoor lighting in classroom environment influences on students' learning performance. *Journal of Social Sciences Research*, vol. 2018(SpecialIssue), pp. 986–990.
- Obralic, A. & Jeghel, S. (2021). The Case Study on Significance of Daylight in Classroom Setting at Sarajevo Campus. *European Scientific Journal ESJ*, vol. 17(1).
- Ocvirk, G. O., Stinson, E. R., Wigg, R. P., Bone, O. R., & Cayton, L. D. (Eds.). (2009). *Art fundamental: theory and practice*. New York: McGraw-Hill.
- Office of Energy Efficiency and Renewable Energy. (2015). Washington, D.C., Washington:United States. Dept. of Energy. Office of Energy Efficiency and Renewable Energy.
- Omar, O., García-Fernández, B., Fernández-Balbuena, A. Á. & Vázquez-Moliní, D. (2018). Optimization of daylight utilization in energy saving application on the library in faculty of architecture, design and built environment, Beirut Arab University. *Alexandria Engineering Journal*, vol. 57(4), pp. 3921–3930.

- Ortiz, M. A. & Bluysen, P. M. (2022). Profiling office workers based on their self-reported preferences of indoor environmental quality and psychosocial comfort at their workplace during COVID-19. *Building and Environment*. Elsevier Ltd, vol. 211(November 2021), p. 108742.
- Penny, J. (2014). How the certification's three biggest changes could affect your project. [Accessed on 17th Dec 2022]. Available at :< <https://www.buildings.com/article-details/articleid/17290/title/can-leed-v4-impact-your-interiors-project/>
- Porras Álvarez, S. (2020). Natural light influence on intellectual performance. A case study on university students. *Sustainability*, vol. 12 (10), p. 4167.
- Pratiwi, N. & Djafar, A. G. (2021). Analysis of Lighting Performance in the Hall of the Faculty of Engineering , State University of Gorontalo by using the DIALux Evo 9 . 0 Simulation Analysis of Lighting Performance in the Hall of the Faculty of Engineering , State University of Gorontalo. *Sustainable, Environment and Architecture*, pp. 0–18.
- Pulay, A. (2010). Awareness of daylighting on student learning in an educational facility. *Built Environment*, pp. 1–62 [online]. Available at: <http://digitalcommons.unl.edu/archthesis/91/>.
- Qutab, S., Faruqui Ali, Z. and Shafi Ullah, F. (2016). Environmentally sustainable library buildings: Opportunities and challenges for Asian countries. IFLA WLIC 2016 – Columbus, OH – Connections. Collaboration Community
- Samani, S. & Samani, S.A. (2012). The Impact of Indoor Lighting on Students' Learning Performance in Learning Environments: A knowledge internalization perspective. *International Journal of Business and Social Science*, vol. 3(24).

Saraswati, R. S., Wibawa, B. A. & Saputra, B. E. (2021). Optimization of Natural and Artificial Lighting System in UPGRIS Lecturer's Workspace using DIALux Evo. *IOP Conference Series: Earth and Environmental Science*, vol. 738(1).

Schledermann, K. et al. (2019). Dynamic lighting in classrooms: A new interactive tool for teaching. *Lecture Notes of the Institute for Computer Sciences, Social Informatics and Telecommunications Engineering*, pp. 374–384. .

Sekonic C-7000 SPECTROMASTER Spectrometer (2023) Sekonic Worldwide. Available at: <https://global.sekonic.com/sekonic-c-7000-spectrometer/> (Accessed: 29 September 2023).

Shams, M. M. E. F., Amr, H. A. E. A. & Moussa, R. R. (2021). Comparative analysis on the effects of natural & artificial indoors lighting on the learning and interactive process. *WSEAS Transactions on Power Systems*, vol. 16(July), pp. 121–127.

Shams, M.M., El-Aziz Amr, H.A. & Moussa, R.R. (2021). Comparative analysis on the effects of natural & artificial indoors lighting on the learning and interactive process. *WSEAS TRANSACTIONS ON POWER SYSTEMS*, vol. 16, pp. 121–127.

'Siemens'. (2023). *AECOM* [online]. [Accessed 3 November 2023]. Available at: <https://aecom.com/projects/siemens/>

Singh, P. & Arora, R. (2014). Classroom Illuminance: Its impact on Students ' Health Exposure & Concentration Performance. *International Ergonomics Conference HWWE 2014 Classroom*, (December 2014), pp. 1–5.

Sokol, N., Martyniuk-Peczek, J., Matusiak, B., Amorim, C. N. D., Waczynska, M., Kurek, J., Vasquez, N. G., Sibilio, S., Kanno, J. R., Scorpio, M., Nazari, M. & Koga, Y. (2023).

- Personas for lighting. Three methods to develop personas for the indoor lighting environment. *Energy and Buildings*, vol. 278(October), p. 112580.
- Sow, S. (2016). Sustainable Development - What is there to know and why should we care?, UNSSC | United Nations System Staff College, Available at: <https://www.unssc.org/news-andinsights/blog/sustainable-development-what-there-know-and-why-should-we-care/>
- Standards, E. (n.d.). Chapter 4 : Lighting and energy standards and codes Topics covered, pp. 57–90.
- Sulaiman, M. A., Yusoff, W. Z. W., Pawi, S. & Kamarudin, W. N. W. (2013). Indoor Environmental Quality (IEQ) of Higher Education Institutions (HEIs): A User Perception Survey. *Journal of Clean Energy Technologies*, vol. 1(4), pp. 318–321.
- Summertown. 2019. *A Quick Guide to LEED Certified Interiors in the UAE* | Summertown. [online] Available at: <https://www.summertown.ae/quick-guide-leed-certified-interiors-uae/> [Accessed 15 Dec. 2022].
- Ticleanu, C. (2021) ‘Impacts of home lighting on human health’, *Lighting Research & Technology*, 53(5), pp. 453–475. doi:10.1177/14771535211021064.
- USGBC. (2021). Interior Design and Decoration. *LEED v4.1 INTERIOR DESIGN AND CONSTRUCTION*, (April), p. 89.
- van den Bogerd, N., Dijkstra, S.C., Koole, S.L., Seidell, J.C. & Maas, J. (2021). Greening the room: A quasi-experimental study on the presence of potted plants in study rooms on mood, cognitive performance, and perceived environmental quality among university students. *Journal of Environmental Psychology*, vol. 73, p. 101557.

Wang, Q., Xu, H., Zhang, F. & Wang, Z. (2017). Influence of color temperature on comfort and preference for led indoor lighting. *Optik*, vol. 129, pp. 21–29.

Woo, J., Rajagopalan, P., Francis, M. & Garnawat, P. (2021). An indoor environmental quality assessment of office spaces at an urban Australian university. *Building Research and Information*, vol. 49(8), pp. 842–858.

Xuan, X. (2012). *Exploring the effectiveness of LEED certification in LEED certified healthcare settings in climate zone 2 and 3*. dissertation. Texas A & M University.