Investigating the Impact of Space Layout on the Energy Performance and Lighting Strategies – A Case Study of a Private School in the UAE

التحقيق في تأثير تخطيط المساحة على أداء الطاقة واستراتيجيات الإضاءة - دراسة حالة لمدرسة خاصة في الإمارات العربية المتحدة

by

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Abstract

Sustainable development of the built environment is one of the major focuses in the modern world. However, the building sectors consume a huge amount of energy globally, as a result, environmental managers are constantly working towards solving this issue. Over the past few years, UAE has been the home for numerous impactful movements towards sustainability and environmental conservation. But being a country with extremely hot summers dominating the climate, UAE's building sectors are facing immense challenges. Schools and educational buildings are a major part of the country's building sector, with a growing number of schools are built every year. Despite several studies being published on schools and their energy performances, a knowledge gap remains on how early design decisions on space layouts can impact the final energy performance. Therefore, this study aims to investigate the impact of space layout on daylight and energy performance of UAE schools. For this purpose, a private school in Al Ain city is selected as a case study. Considering this as the base case, seven alternative layouts of the selected school are generated using the Autodesk Revit space planning tool. Additionally, Revit and DIALux evo are used as simulation tools to simulate the daylighting performances, whereas IES VE is used for energy simulation. The computer simulations are performed in two phases; firstly, the daylight and annual energy performances are simulated. The result of this first phase determined the best layout, which exhibits a 6.9% reduction in total annual energy consumption compared to the base case. Next, this best layout is further improved and an additional reduction of 1.65% on annual energy consumption is recorded. The results of the simulations reveal that the design of a space layout and the allocation of different spaces have direct impacts on the energy performance of school buildings. Finally, the results conclude that it is important to balance the daylight and cooling load performances in order to achieve the maximum reduction in energy consumption. This study provides valuable data on the significance of space layouts and their appropriate analysis in the early stages of design.

ملخص البحث

التنمية المستدامة للبيئة المبنية هي واحدة من مجالات التركيز الرئيسية في العالم الحديث. ومع ذلك، تستهلك قطاعات البناء كمية هائلة من الطاقة على مستوى العالم، ونتيجة لذلك، يعمل مديرو البيئة باستمرار على حل هذه المشكلة. على مدى السنوات القليلة الماضية، كانت الإمارات العربية المتحدة موطنًا للعديد من الحركات المؤثرة نحو الاستدامة والحفاظ على البيئة. ولكن نظرًا لكونها دولة ذات صيف شديد الحرارة يهيمن على المناخ، فإن قطاعات البناء في الإمارات العربية المتحدة تواجه تحديات هائلة. تعد المدارس والمباني التعليمية جزءًا رئيسيًا من قطاع البناء في الدولة، حيث يتم بناء عدد متزايد من المدارس كل عام. على الرغم من نشر العديد من الدراسات حول المدارس وأداءها في مجال استهلاك الطاقة، لا تزال هناك فجوة معرفية حول كيفية تأثير قرارات التصميم المبكرة بشأن تخطيطات المساحة على أداء الطاقة النهائي. لذلك، تهدف هذه الدراسة إلى التحقيق في تأثير تخطيط المساحة على إضاءة النهار واستهلاك الطاقة في مدارس الإمارات العربية المتحدة. لهذا الغرض، تم اختيار مدرسة خاصة في مدينة العين كدراسة حالة. باعتبار هذه كحالة أساسية، يتم إنشاء سبع تخطيطات اضافية للمدرسة المحددة باستخدام أداة تخطيط مساحة .Autodesk Revit بالإضافة إلى ذلك، يتم استخدام Revit وDIALux evo كأدوات محاكاة لمحاكاة اضاءة النهار، بينما يتم استخدام IES VE لمحاكاة الطاقة. يتم تنفيذ عمليات المحاكاة الحاسوبية على مرحلتين؛ أولاً، تتم محاكاة ضوء النهار واستهلاك الطاقة السنوي. وتحدد نتيجة هذه المرحلة أفضل تصميم لتخطيط المساحات، والذي أظهر انخفاضًا بنسبة ٦,٩٪ في إجمالي استهلاك الطاقة السنوي مقارنة بالمدرسة التي تم اختيارها لدراسة الحالة. بعد ذلك، تم تحسين هذا التصميم بشكل أكبر وتسجيل انخفاض إضافي بنسبة ١,٦٥٪ في الاستهلاك السنوي للطاقة. تكشف نتائج عمليات المحاكاة أن تصميم مخطط المساحة وتخصيص المساحات المختلفة لهما تأثيرات مباشرة على أداء الطاقة في المباني المدرسية. أخيرًا، نستنتج أنه من المهم تحقيق التوازن بين ضوء النهار واستهلاك الطاقة لتكييف الهواء من أجل تحقيق الحد الأقصى من تقليل استهلاك الطاقة. توفر هذه الدراسة بيانات قيمة حول أهمية تخطيطات المساحة وتحليلها المناسب في المراحل الأولى من التصميم.

“Working hard is important.

But there is something that matters even more;

Believing in yourself”

~ *Harry Potter*

Dedication

All thanks to Almighty Allah for giving me the opportunity to achieve this amazing milestone in my life

I would like to dedicate my dissertation

To my Father, Mother, and elder Brother

Thank you for being the strongest pillar in my success. You are the reason I am a strong independent person today

To my best friend, soulmate, and an amazing Husband

Thank you for supporting me, motivating me through my post-grad journey, and making me fall in love with research

and lastly,

To myself, the girl that never gives up, who loves to learn and share knowledge.

To all my hard work, dreams, and passions.

Acknowledgment

I would like to acknowledge my deepest gratitude and admiration to my dissertation supervisor Dr. Bassam AbuHijleh. This dissertation wouldn't be complete without the immense support and guidance I received from him. I have learned so much during my postgraduate journey because of his excellent mentorship and continuous encouragement towards new knowledge. I feel honored to be able to study under his supervision.

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Last but not least, I would like to thank my SDBE colleagues who have supported me through my dissertation journey. Their different perspectives and inputs on knowledge widened my understanding and helped me greatly in completing this dissertation.

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Abbreviations

ADEC	Abu Dhabi Education Council
ADEK	Abu Dhabi Department of Education and Knowledge
ANSI	American National Standards Institute
ASE	Annual Sunlight Exposure
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
BEP	Building Energy Performances
BOMA	Building Owners and Managers Association International
CF	Circulation Factor
CFD	Computational Fluid Dynamics
CIBSE	Chartered Institution of Building Services Engineers
CV(RMSE)	Coefficient Value of Root-Mean-Square-Error
DF	Daylight Factor
DIWA	Dubai Electricity & Water Authority
IEA	International Energy Agency
IES	Integrated Environmental Solutions
IESNA	Illuminating Engineering Society of North America
LIS	Liwa International School
LPD	Lighting Power Density
LR	Literature Review
NMBE	Normalized Mean Bias Error
NSF	Net Square Footage
PMV	Predicted Mean Vote
sDA	Spatial Daylight Autonomy
Uo	Uniformity Rate
USF	Usable Square Footage
WWR	Window-to-wall ratio

Chapter One

1 Introduction

1.1 Overview

Urban development and globalization have formed a giant ground for industries and economics to surge. It is not new that with the advancements of technology, the lifestyles of human beings have changed drastically, especially in developed countries. While human behaviors are responsible for natural disasters, pollutions, resource depletion, they are also the ones behind restoring the damage. The vast effects of climate change have led nations worldwide to broaden their awareness, practices, and actions towards sustainability over the past decade. The rapid expansion in infrastructure and services caused by accelerated urbanization calls for an increase in energy demand. The latest report by IEA (International Energy Agency) mentions that due to the pandemic in 2020, the global energy demand dropped by 5% and energy-related CO_2 emissions by 7% (International Energy Agency 2020). However, energy demand is still predicted to increase by the year 2030 based on IEA reports. Almost one-third of global energy consumption is from the buildings sector and is expected to increase as developed countries continue to modernize (World Bank 2015). Therefore, it is essential to make our buildings energy efficient and capable of managing energy usage.

Sustainable development of built environments has become a focused goal as a result of the growing world population and urban advances. As a result, architecture and interior design disciplines thus influence directly in the creation of sustainable cities. They play significant roles during the earliest design phases to ensure building performances. Decisions taken from design phases can determine about 80% of a building’s ecological load and operating costs (Dino & Üçoluk 2017). Various design aspects and strategies, such as passive design, smart interiors, use of proper construction materials, etc. impact the energy performance of a building in multiple ways. A lot of focus is also given to building designs to achieve zero-energy or net-zero energy buildings in recent years. Buildings that are designed sustainably have greater potential in reducing human impact on the environment as well. In short, sustainable design and architecture result in an improved environmentally friendly built environment.

The building sector in the built environment currently covers 150 billion m^2, which is expected to increase to 270 billion m^2 by 2050 (IRENA 2018). Electricity has the largest share in total energy consumed by building sectors globally and is said to increase about 70% by 2050. The latest report from IEA showed commercial and public buildings consume 21.5% of the world's total electricity (IEA 2020). Commercial buildings are also the ones that need complex energy evaluation and are essential to managing efficiency. Schools as commercial buildings, therefore, have significant opportunities for adding to energy-conserving goals. Studies on energy-efficient school buildings go back to as long as the 1900s. A 1996 article published by the IEA discussed energy-efficient schools, energy management, and their design guidelines for different countries. A significant amount of energy was reported to be consumed and wasted by the schools at that time (IEA 1996). Comparing the past scenarios with the present, the crisis of energy consumption and conservation in school buildings remains. Moreover, multiple studies were conducted in recent years discussing the relationship between the architectural and interior design of schools and their energy performance. However, with the progression of time, climate and society, it is critical to identify gaps in knowledge and address them.

1.2 UAE Schools and Current Status

Over the past few years, UAE has been the home for numerous impactful movements towards sustainability and environmental conservation. The country's government and organizations continuously work with international environmental groups to establish a green nation. Currently, UAE mainly aims at energy efficiency in the building sector to meet the growing electricity demand (Asaba 2020). Emirates Green Building Council (Emirates GBC) partnered with the Global Coalition for Green School in 2016 to increase the number of energy-efficient green schools in the UAE. It was stated in their white paper report, a large number of schools did not undergo proper sustainability ratings (Paper 2016). Only 156 schools in Abu Dhabi state were reported to be rating by the Estidama Pearl Rating system among a total of 443 schools. Besides, all new buildings must comply with the Sa'fat regulations since 2018 in the Dubai state. The report also acknowledges that emirates other than Abu Dhabi and Dubai do not necessarily follow any green building regulations, which can also be a big contributor to energy consumption. Therefore, Emirates GBC highlighted the need for UAE-specific research on schools to identify environmental performance and energy efficiency solutions to motivate and promote designers, management, and people of authority (Paper 2016).

In 2009, ADEC (Abu Dhabi Education Council) announced a 10-year strategic plan to build 100 new public schools in the Abu Dhabi emirate, from 2010-2020 with a minimum 2 Pearl Rating (Dakheel, Aoul & Hassan 2018). This plan is called the "Future Schools Programs", and is currently ongoing at Phase 10.and will be further discussed in Chapter 2 of this dissertation. Among the 100 schools, 53 have already been constructed or under construction, depending on the regional population growth and need. Furthermore, according to the latest statistical data, there are currently 220 public and 210 private schools in Abu Dhabi and Al Ain region together (Bayanat.ae 2020).

A study on the green building rating system was done for schools in the Abu Dhabi emirate. The study argued that with the growing number of schools in the state, implementing green rating systems in schools has become a necessity to meet the country's energy goals (Dakheel, Aoul & Hassan 2018). Another literature was recently published with the same context which discussed the need for energy retrofitting of UAE schools (Aldawoud, Hosny & Mdkhana 2020). This research studied a school in Dubai to investigate the situation of existing school buildings, their energy performances, and why it is important to retrofit these buildings. The results presented a substantial reduction in school electricity demand by applying different retrofit measures. Similarly, there has been little research done on the greening of UAE schools and all of them portray high energy demands and the need for further studies on solutions. Though UAE is very keen on implementing sustainable solutions and advanced technologies, the hot climate makes it challenging for greater energy efficiency throughout the year. School designs always tend to compromise between providing natural thermal comfort and natural lighting. According to Emirates GBC, considering the current status, new schools in the UAE must verify the energy performances before they are being constructed (Paper 2016). Retrofitting and re-evaluation of energy performances of existing schools are also advised to ensure the country's schools are on track with its energy conserving goals.

1.3 Research Problems & Questions

UAE is a hot and humid climate where a mild winter season lasts only 2-4 months. Due to this excessive hot temperature, the energy consumption rate for day-to-day life is too high in all sectors. Despite many promising actions taken by the government, this heavy consumption rate is still needed to be resolved. Especially for academic institutions, such as schools, it is a must. Thus, several pieces of research have been done previously on energy efficiency, IEQ (Indoor Environment Quality), thermal comfort, etc. of UAE school buildings. As a result, various solutions have also been offered and applied in some schools, for instance, the use of green walls, improved façade systems, sustainable building materials, smart interior solutions, and so on. However, the available solutions fail to deal with the early stages of architectural design processes. Studies have not been conducted on school architectural/interior space layouts solely to analyze their effects and roles in advance design decisions for improved building performance. Moreover, space layout templates and design guidelines for private schools are minimal compared to public schools. Existing works of literature hence study public schools of UAE mostly. Therefore, the lack of studies and data on the significance of ideal space layouts in accordance with the private schools in the UAE is identified as the research problem. The current research thus will try to answer the following questions:

- To what extent does architectural/interior space layout affect the energy consumption and daylight availability in UAE schools?
- For minimizing the artificial lighting concerning the daylight level, how do the space layouts bring significant impact?
- What are the scopes for an improved space layout to bring significant changes for minimizing the artificial lighting required in classrooms?
- To what extent can space layout design be considered a significant aspect for decision-making in the early project stage?

1.4 Aims and Objectives

The purpose of this study is to explore different solutions based on the basic design principles, which can mitigate the energy consumption problem for the school buildings in UAE. Thus, this research aims to investigate the effect of different architectural and interior space configurations on the energy performance and daylight availability of an existing school in Al Ain, Abu Dhabi. The following are the objectives this research intends to achieve:

- To study the impact of alternative optimized layouts on the energy performance of the case study school building.
- To investigate how different space layouts affect the availability of daylight
- To assess and determine the artificial lighting requirements in classrooms for different layouts
- To provide knowledge on school layout solutions to be used for future retrofitting or new schools in the UAE.

1.5 Research Motivation

Studies show that there is a huge gap between energy-saving methods and data availability to support energy-saving designs in early design phases (Du et al. 2019). There have been works of research that studied the effects of space layout and energy performance earlier (Du et al. 2020a), proving the significance of their relation. However, these studies combined space layout with parameters like the window to wall ratio (WWR) (Dino & Üçoluk 2017), occupancy, function allocation, etc. Therefore, to fully understand the effect of space layout, it is essential to study its impacts alone. On the contrary, the latest review article published in 2020 discussed studies done on the impacts of space layouts on energy consumption. It was reviewed that most of these studies in recent times were conducted mainly for office buildings and residential complexes (Du et al. 2019) (Yi 2016) (Fumagalli 2020) (Alsaadani & Transport 2016). There seems to be a knowledge gap concerning studies done on school space layouts, which motivated the current dissertation topic to investigate a school building.

1.6 Significance of Research

Educational buildings, especially schools are a significant field of energy studies due to various reasons. The most prominent reason for this is that children and teenagers have higher metabolic rates than adults, which results in varied HVAC needs in the internal spaces. Moreover, different spaces have different energy and lighting needs. Previous studies have discussed architectural forms of schools and their effects on energy, which are not sufficient knowledge for multifunctional buildings. Thus, this study aims to focus exclusively on interior space layouts of schools and their different functions to explore possible optimized solutions. This paper will provide data that will be beneficial in the prospective early designing stage of school buildings, or during retrofitting school projects in the UAE. Since the paper proposes a distinctive method of measuring energy performance, the data collected can be very resourceful for future references and studies on this topic. The study will also emphasize the importance of including interior space planning and function allocation during early design decisions and energy predictions. This, in turn, will not only ensure accurate energy consumption readings but will also assist in planning the best layout for a school based on its orientation, lighting, and thermal requirements. Furthermore, due to climatical similarities, the proposed solutions could also be provided in countries that have similar weather conditions as the UAE.

1.7 Research Emphasis and Limitations

The selected case study of this research is a school located in Al Ain, UAE. The study focuses its investigation on the case study building to effectively explore and analyze the targeted goals. Moreover, due to the complexity of space layout generation without using any automation, a limited number of alternative layouts will be generated and analyzed. This could be considered as a limitation of this study due to the smaller sample size. A larger sample size, for example, multiple schools in different locations/emirates, a large number of alternative layouts could provide more elaborative data. However, due to time and automation constraints, focusing the research on one school building with limited layouts of quality can be very effective. Since the primary goal of this research is investigating the influences, this sample approach can act as a base for future scope of development. The research will be focused on the whole building's energy consumption and the daylighting availability in different spaces. Space allocation and daylight availability are the two major variables in this research. While this could be seen as a limitation, the project aims to examine the impact of space layout alone. Parameters such as building orientation, boundary conditions, openings, etc. are kept unchanged from the case study. However, including these parameters in the study as variables after different space layouts are generated could be a prospective broader scope of research.

The current study will be conducted using the IES VE simulation tool, which requires detailed building profiles in order to generate accurate results. Considering the size of the case study school building, properly scheduled profiles are needed. Information required for generating building thermal profiles was collected through online sources, such as ADEK (Abu Dhabi Department of Education and Knowledge) reports on the case study school, school websites, ministry of education, etc. Though, a better alternative could be to collect data from field visits, which was not possible due to the precautionary rules and regulations of COVID-19 circumstances. Data collection and scheduling in this regard could be time-consuming, yet are essential for the study in providing accurate contexts.

1.8 Research Outline

The above section of the current dissertation in Chapter 1, which addressed the overview of the topic, the current context of UAE, research questions, problems, and the research aim, motivation, and significance. The subsequent chapters of the research are as follows:

Chapter 2 is the Literature Review which will explore the different theoretical contexts required to carry out this research. This section will cover the relevant portions in detail, such as space layouts, school space layout, and design requirements, energy and daylighting standards and requirements, etc.

Chapter 3, Methodology, will introduce the selected methods used in this research. the importance of using the selected methodologies will also be highlighted using references from previous pieces of work. This section will also illustrate how the methodologies will be used to conduct the research analysis.

Chapter 4 introduces the Case Study, discussing every aspect like site location, site weather data, building information, etc. This discussion will provide a crucial underpinning to start the simulation process for the study. Furthermore, this chapter will also cover the case study model setup and validations.

Chapter 5 is the research Analysis, Results, and Discussion. The analysis part will cover the generation of alternative space layouts. The chapter will address the simulation strategies, results, and findings and compare the results in the discussion section.

Chapter 6, the final chapter is the Conclusion, which will discuss the conclusions of the research investigation. This chapter will revisit the research question and review to what extent they have been answered in this research. Furthermore, this chapter will also state the importance of the study and recommend opportunities for future research.

Chapter Two

2 Literature Review

2.1 Overview

Knowledge and education are a nation’s backbone. Every year, millions of dollars are invested each year worldwide to constantly improve the educational system. As modernization took place and demand for high-quality education boosted. Children being the future of a country, it is very important to nurture their creative minds in functional, healthy, and superior environments. It is estimated that students spend 30% of their day inside the school, making it one of the most significant topics to be studied more deeply (Al-Khatri, Alwetaishi & Gadi 2020a). There is plenty of research done on making the school IEQ healthier and more sustainable, implementing energy management programs, and introducing various new approaches. However, planning a school from the earliest design stage with the aim of energy conservation is often overlooked. In the upcoming sections, studies related to space layouts, their effects on energy and lighting performances, and school designs will be reviewed. Furthermore, schools of the Abu Dhabi emirate will be given special focus to relate the theoretical knowledge with this paper’s case study. This chapter aims to fully grasp the concept of space layouts, their impacts, and how they are applied and tested in different works of literature. Therefore, space layouts, their influence on energy and daylight performance of a building, and space planning for schools will be covered theoretically in this chapter. Standards and regulations related to UAE codes will also be discussed in the later section.

2.2 Space Layout

Space layout is the most significant task in any building architecture design which occurs during the schematic and design development phase of a project (Fumagalli 2020). Exterior walls and the arrangement of interior partitions usually comprise the space layout, where the partition arrangements depend on function allocation. The space dimension, form, interior openings are some of the variables of designing a space layout (Du et al. 2020a). One of the biggest benefits of space layout is the scope for mapping spaces according to their different comfort, thermal, and lighting requirements. While plenty of studies have discussed the importance of space layouts by studying related aspects, it is not widely studied as the main parameter (Du et al. 2018).

2.3 Space Layout, Thermal Zones and Building Energy Performance (BEP)

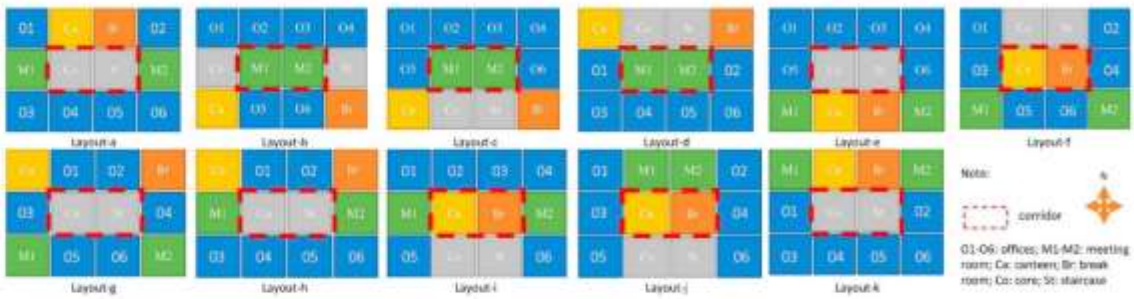


Figure 1: Space layout alterations of an office space (Du et al. 2021)

Architectural and interior space layouts have a direct effect on a building's energy demands. Though the two represent the exterior and interior of a building, they are interdependent in many aspects. It is recognized from the current research problem that it is essential to isolate and study space layouts

alone to understand their impact on different attributes. Very recently, research was done with a similar goal of investigating the effect of the spatial layout of office space for three climates (Du, Jansen, Turrin & van den Dobbelsteen 2021). The research studied 11 variants of an office layout for their energy performances in tropical, temperate, and cold climates (Figure 1). The study also included shading strategies. The resultant energy demands for all 11 layouts had shown significant maximum percentage differences, with 37% being the highest and 3% being the lowest. The research concluded that optimization of space layout in the design process can reduce energy demand substantially, especially lighting demand (Du, Jansen, Turrin & van den Dobbelsteen 2021).

The role of space layout can also be seen during the design phase of HVAC systems where they implement it through "thermal zones". Thermal zoning is done during HVAC design where space is divided into different zones, grouped based on similar thermal requirements (Designing Buildings Wiki 2020). While a single thermal zone will be suitable for simpler spaces, a multifunctional, complex building or space require will require multiple zones due to the significant differences in thermal demand. Thereby, several research papers studied the difference in energy use or energy performance predictions for different thermal zoning strategies. Although thermal zoning mainly focuses on the heating/cooling aspects of energy use, different zoning models essentially represent different space layouts (Du et al. 2020a). Since they have a similar role in the design phase, integrating thermal zoning with space layout is said to provide better improvement in the final BEP (Yi 2016) (cited in Du et al. 2018).

Experimental research conducted by Bleil de Souza and Alsaadani (Souza & Alsaadani 2012) was explored in a review article, which discussed the relation between space layout and internal gain (Du et al. 2020a). Three types of thermal zones were studied for office space in the UK; a simple single zone, a 5-zone model based on orientation, and an office in use model which reflected the actual plan. It was noted that the single layout predicted the annual heating and cooling demand to be 8.47 and 28.04 kWh/m^2 respectively, while the same came out to be 11.69 and 29.72 kWh/m^2 respectively for the actual space layout case (Du et al. 2020a). A similar study was conducted previously by Hwang Yi (cited in Du et al. 2021) where the author argued the necessity of multizone thermal layouts for accurately studying the energy performance of a space (Yi 2016). He created 12 space layouts of office space by moving the position of the core and interior partitions creating various thermal zones. All the layouts showed differences in energy consumption and daylighting availability. The maximum energy demand reduction of the optimized layouts was 30% from the base case, indicating that spatial functions and interior space layouts are crucial for evaluating BEP.

Another study was conducted to explore the role of space design for occupancy and energy predictions. It discussed the significance of dividing space layouts into zones based on similar activities for multifunctional spaces like schools and analyzing the predicted variables (Delzendeh, Wu & Alaaeddine 2018). Here, the zones and occupancy data acted as thermal zones. The study confirms that there is a discrepancy between predicted and post-occupancy energy consumption due to the use of oversimplified layouts during predictive studies. Though the research’s main aspect was occupancy, the significance of optimizing and using space layout at the earlier design stages is highlighted in this literature.

2.3.1 Space Layout and Daylighting

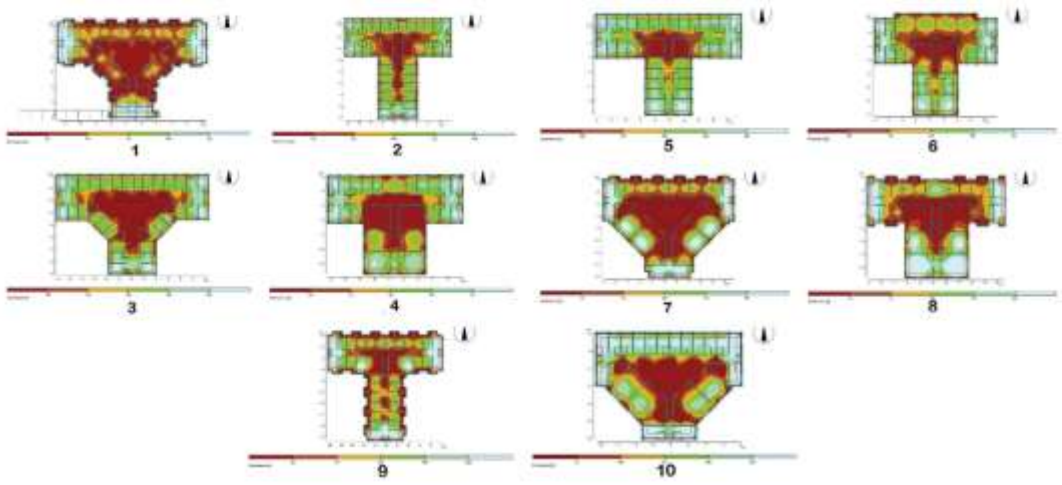


Figure 2: Daylight distribution under different space layout scenarios (Mousavi Asl & Safari 2020)

Space layout is directly proportional to daylight availability for any kind of multifaceted buildings. One of the major criteria prioritized during space planning is to map the interior spaces according to their lighting requirements. This is because the availability of daylight in the interior space determines the amount of artificial lighting needed, the internal gain, and thermal comfort, hence affecting the BEP. The amount of daylight entering into the indoor space of a building based on structural aspects is influenced by the building openings, such as the façade, windows, skylights, courtyard, atriums, etc. Similarly, the natural aspects would be the site location, climatic and weather factors, sun orientation, and more (A.P. 2017). Therefore, careful space planning to optimize daylighting respective to the space requirements is crucial.

A study was done on a multi-story apartment building to find the impact of building typology on the quality and quantity of daylight (Majeed, Mustafa & Husein 2019). The typology studied in this research can be considered as a certain space layout stacked/grouped to form the multistorey building. They analyzed the availability of daylight on 5 residential plan layouts (Figure 2) using three different kinds of simulation analysis, namely Illuminance, LEED v4, and Daylight Autonomy. The results showed that plan types have a noticeable impact on achieving daylight performances and daylight availabilities in the interior spaces. This study also shed some light on the effects of corridors and atriums on daylight distribution. Similarly, an experimental study mentioned in section 2.1.1 above integrated daylighting simulation to their 11 alternative layouts for an office space. Since they were studying a test building, they performed some critical steps for the openings before running the simulations. They also implemented dimming of artificial lights using sensors and divided artificial light levels into 3 zones (Du et al. 2021). This research performed the lighting simulation before the total building energy simulation to integrate the daylighting aspect. Results showed a significant variation in energy reduction in all the layouts and were able to compare and emphasize the best ones.

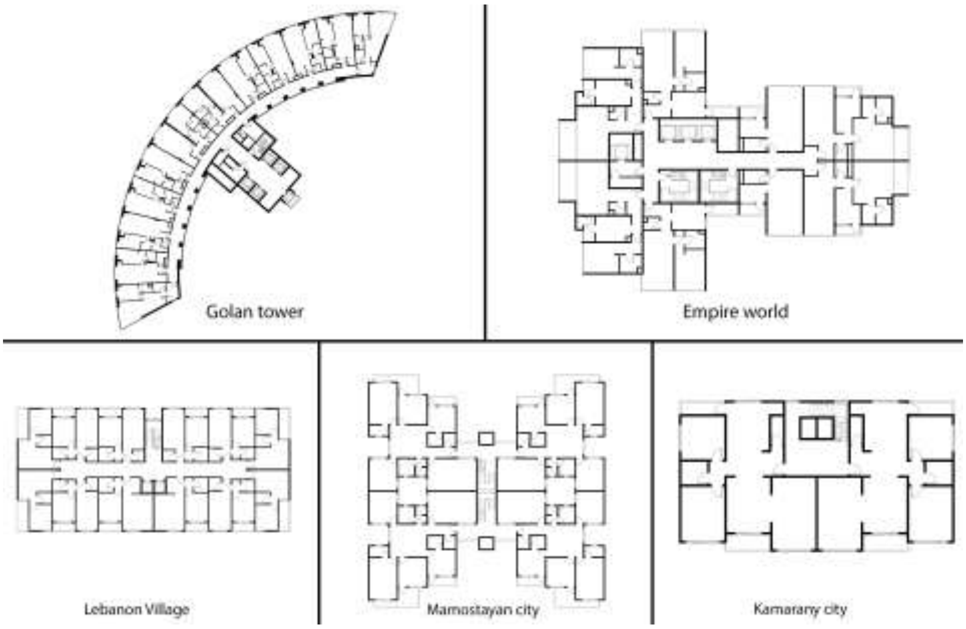


Figure 3: Case studies plan layout (Majeed, Mustafa & Husein 2019)

Ipek Gürsel and Göktürk (2017) conducted similar research for optimizing building space layout but using a genetic algorithm and a design tool named MADE (Multi-objective Architectural Design Explorer) (Dino & Üçoluk 2017). They created 5 layouts for a building with variable openings using a computational algorithm and studied their effects on heating and cooling demand and daylighting. This detailed scientific study concluded that simulation-based evaluation of various space layouts, energy usage, and daylighting is necessary for early design phases. Although it is time-consuming to produce and model alternative space layouts, it can contribute significantly to the prediction and decision-making for BEP (Dino & Üçoluk 2017). A more recent study was published which investigated the impact of interior space layouts on daylight distribution and visual quality and distribution (Mousavi Asl & Safari 2020). The study was done on a medical center where interior space layout was taken as an independent variable. The computational simulation was done on 10 different space layouts for daylighting distribution (Figure 3) and their results were compared based on standards for medical center interiors. The investigation found few scenarios to be better than the rest in terms of uniformity rate and daylight factor and suggested layouts that provided a balanced and optimized solution for the spaces.

2.3.2 Effects of Transitional Spaces on BEP and Daylight

Transitional spaces are described as spaces situated between the exterior and interior which act as a buffer zone and physical links (Pitts & Saleh 2006). Courtyards, atria, corridors, balcony/porch, foyer/lobby are some examples of transitional spaces in architecture and are said to occupy 10%-40% of the total volume in buildings (Tse & Jones 2019). While space planning, transitional spaces play major roles in determining the overall BEP and daylight availability. There have been plenty of studies done on transitional spaces and their effects on various energy-related variables. Therefore, while space planning, careful considerations are required to allocate transitional spaces in the layouts.

2.3.2.1 Courtyards and Atriums

Courtyards and atriums are the most effective and popular ways of passive daylighting, not just in modern sustainable architecture, but for decades. An atrium can be explained as a covered courtyard, mostly using glazing, where the courtyard is simply an internal void (Sharples & Lash 2007). There is no doubt that the implementations of courtyards and atriums help bring diffused or direct daylight into the indoor spaces. However, in recent years, especially for regions with hot and dry climates, the integration of these transitional spaces are done carefully. This is due to the various other effects of courtyards and atriums, such as heat transfer, stack effect, fluctuations in internal gain, etc. Therefore, their effects on the BEP are widely studied to make the space design efficient and environment friendly.

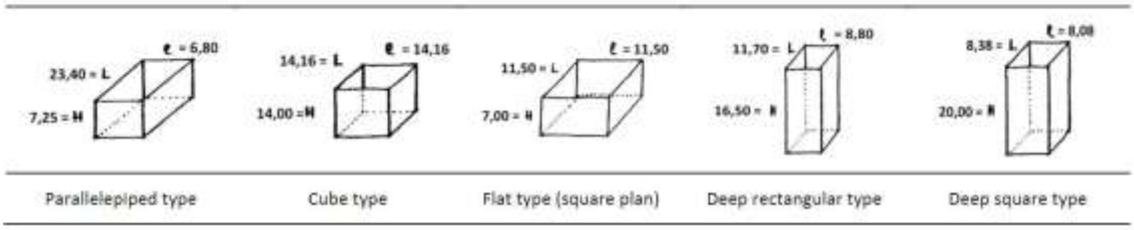


Figure 4: Case study courtyard types based on volume (Guedouh & Zemmouri 2017)

Transitional spaces like courtyards and atriums can greatly alter a building's energy performance, regardless of the climate of the building location. They are implemented in a building or space based on the targeted thermal comfort of that place.
One such study was done in the hot and arid region of Algeria, where the indoor thermal and luminous environments were investigated for 5 existing buildings with courtyards (Guedouh & Zemmouri 2017). The case study courtyards were characterized by their shape and volume (Figure 4) and their opening ratio, aspect ratio, and solar shadow index were calculated. Based on the analysis, it was found that courtyards in all cases work as a temperature regulator, where they reduce heat in summer and keep space warm in winter. The study also proved courtyards regulate illuminance levels in the interior space by reducing higher exterior illuminance in summer and increasing it in winter through vertical surface reflection (Guedouh & Zemmouri 2017). Likewise, another experimental study was done on a hotel building, where 4 alternatives of the atrium were introduced to evaluate the energy performance. This research used numerical simulation using EnergyPlus to simulate monthly final energy demand for cooling and heating. It was evident that the atrium contributes largely to winter heating, and acted as a heat collector due to the presence of a glazed roof (Vujošević & Krstić-Furundžić 2017). However, it was also concluded that buildings without any atrium consumed more energy per volume unit for heating and cooling than a building with it. Summer overheating caused by the atrium can also be avoided to a certain extent by facing it to the north and providing a large skylight area.

Enes Yasa (2017) conducted a study comparing the performances of the courtyard and atrium in different climate zones. The author conducted both experimental and CFD simulation research and provided results on variations in natural ventilation and thermal comfort (Yasa 2017). The research concluded that atriums in hot-dry and hot-humid climates can decrease annual energy use, but increases discomfort hours in the summer season. Courtyards are found to be the exact opposite of this situation; therefore, it is suggested to integrate courtyards where the summer season is prominent. On the contrary, courtyards could be problematic concerning solar absorption, where atriums provide better shading due to compactness and more height. The study also indicates that east-west-oriented courtyards provide a comfortable indoor environment in summer. This research provided some valuable insight on courtyard and atrium choices in buildings that are in hot climates.

2.3.2.2 Corridors

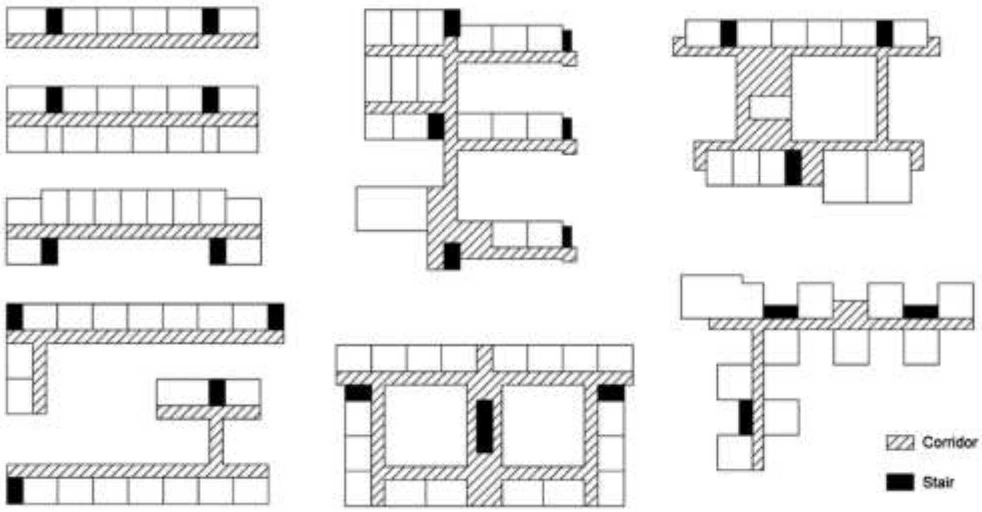


Figure 5: Corridor configurations in school buildings (Zhang et al. 2017)

Corridor design is a vital aspect of building spatial configurations. These are spaces that provide accessibility by connecting different spaces, or places for leisure and entertainment depending on the building type (Zhang, Bokel, et al. 2017a). Depending on the location, whether internal or external, they can contribute to allow daylight into the indoor spaces, as well as affect the BEP. However, the number of studies done on transitional space like corridors is very narrow.

Significant research was done on optimizing a school's thermal and daylight performances in a cold climate of China (Zhang, Bokel, et al. 2017a). This study analyzed different corridor configurations (Figure 5) on classrooms using 3 reference models: a) Corridor open to outdoor, b) Corridor closed to outdoor, and c) Indoor corridor with rooms on both sides. Orientations and WWR (wall-to-window ratio) were also changed using algorithms in Grasshopper and Honeybee software. The analysis results produced the 3 best design solutions that included better thermal comfort in winter, minimum summer discomfort, and maximum daylight utilization. They concluded by comparing the 3 solutions for different scenarios, stating their pros and cons. Another recent study was done on typical building corridors to analyze their effects on daylighting and space design (Yuan et al. 2020). Unlike the previous paper's method, here the authors conducted a questionnaire survey along with computer simulation to understand the overall effect of corridors in a university building in China. Moreover, only internal corridor type was evaluated in this study. It was concluded from the survey and simulation analysis that the width of an internal corridor is not a prominent factor for daylighting availability. Similarly, there is a positive relationship between the corridor length and width of any open room adjacent to it. The length of such corridors is suggested to be 10.1 m or less if it is illuminated by a single end window, and 6.8m or less if there is an open room in the middle as a light source (Yuan et al. 2020).

The effects of corridor design on energy consumption were studied for a school building in China (Zhang, Sun, et al. 2017). The local school buildings were classified into 3 types of corridors: A) double-sided, B) one-sided enclosed, and C) one-sided open. They selected a rectangular basic shape for the simulation with variables such as orientation, temperature controls, corridor width, WWR, glazing types, etc. They found that corridor type C with the rotation 0° south and 180° north consumed the least energy. Furthermore, they concluded that integrating corridors in the design solutions offered savings by around 6% and 17% in type A and B respectively in terms of energy consumption (Zhang, Sun, et al. 2017). Therefore, it is evident that corridor spaces can make noticeable changes in the BEP, and daylight accessibility of a building space based on their design and placements.

2.4 School Design and Space layout

Childhood is a critical phase of a human life where the development of intelligence and personality occurs. Therefore, the educational environment they spend most of their time in needs to be designed carefully to support their physical, psychological, and emotional growth (Kim 2017). As education systems progressed, school architecture has evolved globally since the past century. Today, schools are not only designed for creating learning space but also providing the ideal conditions for sustainability aspects. Energy-efficient systems, optimum daylighting, quality artificial lighting, better IAQ (Indoor Air Quality), acoustics, etc. result in a comfortable and productive environment for a school (Bonnema et al. 2013). Hence, in-depth studies are required for school space layouts in order to optimize them for better performance.

2.4.1 School Building Shape and Layout

School building shape, form, size, etc. have a direct impact on the energy consumed. Several studies and guidelines have been published in the past years discussing school building designs. An advanced energy design guide was published in 2011 developed by a group of standard organizations like the U.S Green Building Council, the U.S. Department of Energy, and more. This guide aimed to provide design guidelines for schools that will consume 50% less energy than conventional schools as per ANSI/ASHRAE/IESNA Standard 90.1-2004 (ASHRAE 2011). This guide mentions that circular, square, and rectangular school plans result in compact building forms and tend to have deep floor plates, thereby gets side lighting for a large occupiable space. Transitional spaces like courtyards and atria can be integrated into such plan types to improve daylighting and ventilation strategies. On the contrary, plans resembling

Figure 6: Design types for School buildings (Rigolon 2010)

alphabet letters such as H, L, or U have shallow floor plates, resulting in a higher percentage of floor area receiving daylight through side lighting. Moreover, less compact forms receive more daylight, but also have greater heat transfer. Therefore, to optimize BEP, it is essential to assess both daylighting and heat transfer characteristics of a building's shape and form. Attention must also be paid in terms of how a building's shape affects the wind movement based on the site aspects. Another important feature related to the form is the size of a school building that determines the possible energy conservation measures. A building's size and depth of the building floorplate can have many impacts on daylighting availability and natural ventilation (ASHRAE 2011).

A notable overview of the European school design types was published a decade ago by Alessandro Rigolon (2010). The author identified four types of school designs (Figure 6) after analyzing several international case studies. These design types are based on morphology and internal layout, aspects that strongly influence the fundamental space planning of a school building(Rigolon 2010). It was found through comparison that the block-type school buildings are mostly used in urban areas due to compactness, whereas the rest are more implemented in rural or suburban settings. Likewise, cluster and city-

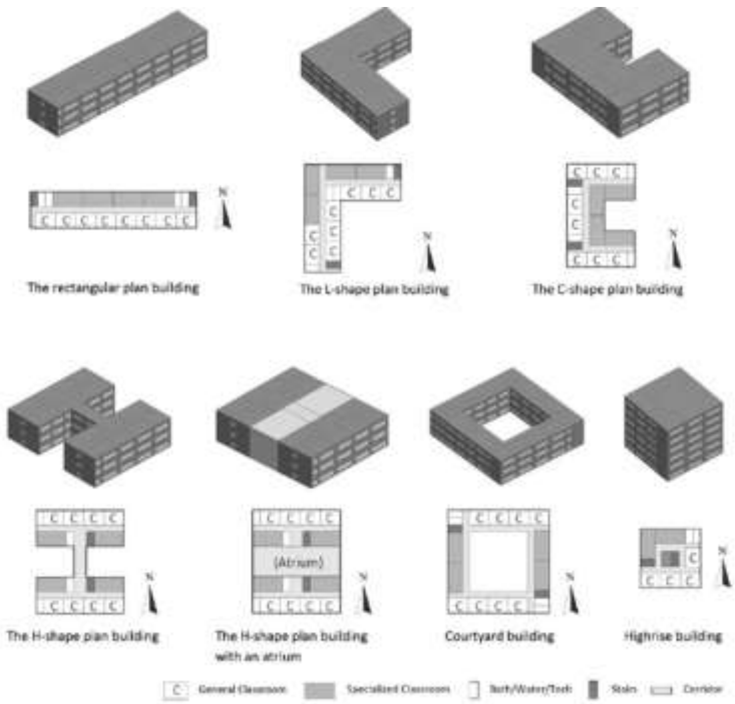


Figure 7: Studied school buildings (Zhang, Bokel, et al. 2017b)

like types are better adapted for elementary schools. However, they run the risk of insufficient daylighting in the internal spaces of the building, and hence require skylight, atria, clerestories, etc. A research project was carried out to assess the environmental comfort in different school building forms in Palestine (Hussein et al. 2016). They studied 6 types of school building typologies and conducted in-situ measurements and occupant questionnaires. The effect of school buildings' geometry was researched in the cold climates of China (Zhang, Bokel, et al. 2017b). Analysis was done on 170 local school building designs to better understand the geometry parameters, summarizing them to 8 typologies: Rectangular, L, C, H, H with atrium, Courtyard, High-rise, and Irregular shape, and 7 of these were studied (Figure 7). After conducting simulation and questionnaire studies, it was observed that H shape building was best in both thermal and energy performances, achieving 13.6% energy savings and 3.8% thermal comfort enhancements (Zhang, Bokel, et al. 2017b).

The courtyard type was also suggested for its high potential for energy savings. Moreover, the study suggested emphasizing summer thermal comfort rather than during building orientation planning. Addressing a recent study done locally in the UAE, the school buildings of Sharjah were explored to promote refurbishment with the purpose of

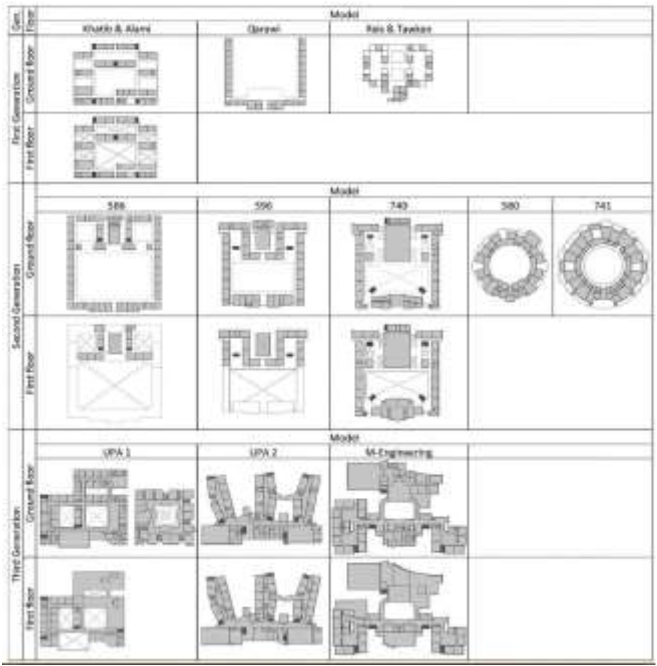


Figure 8: UAE building models for public schools per generation (Belpoliti et al. 2020)

BEP improvement (Belpoliti et al. 2020). The research identified issues with UAE school building architecture and aimed to provide recommendations for refurbishing. They conducted a historical building (1977-2015) typology analysis in the UAE where 3 generations of schools were found, each with 3-4 different models (Figure 8). The research employed a multi-criteria assessment which also included energy performance analyses to provide a comprehensive review of the existing UAE schools. Although this paper does not exactly match with the current dissertation research aim, it provides an interesting understanding of school design and how it can be improved. According to the UAE government, 107 upgraded and 36 new schools are required to reach the goal of accommodating 200,000 students by 2027 (UAE Cabinet 2019) (cited in Belpoliti et al. 2020). However, through the proposed refurbished design, this goal could be achieved with only 80 new schools followed by 16% cost savings. Thus, layout design optimization could be very beneficial in multiple aspects. Similarly, another research was conducted in Al Ain city by Rehmani and Al-Sallal (2020) where they optimize the BEP of Al Ain public schools through proper building design forms (Rahmani & Al-Sallal 2020). This research found linear forms of building mass and the courtyard provided a better shading effect. Moreover, the number of floors tends to have a great impact on BEP. Changing a 1-floor building to 2-floors resulted in significant energy savings, which was also mentioned in other previous literature. It was evident that schools similar to the block types with more than one or two-story have lower construction costs and more energy savings (ASHRAE 2011). Making a two-story school with a more linear building form led to minimized surfaces of the school building to sun exposure. Moreover, this phenomenon also supported the Al Ain climate greatly since the solar radiations are perpendicular to the roof during peak summer months (Rahmani & Al-Sallal 2020).

2.4.1.1 School Courtyards and Atria

In previous sections of this chapter, the effects of transitional spaces like courtyards and atria were discussed. Moreover, the above section also explored building designs with courtyards or atria included. However, several works of literature also studied these spaces in school buildings independently, though not directly intending towards space layouts. Salameh and Taleb (2017)in their research investigated the school courtyard as a passive design solution in the UAE. Three types of courtyards were studied, namely, A) without closed courtyard (L-shaped semi-open), B) closed courtyard with a smaller width, C) closed courtyard with a larger width(Salameh & Taleb 2017).

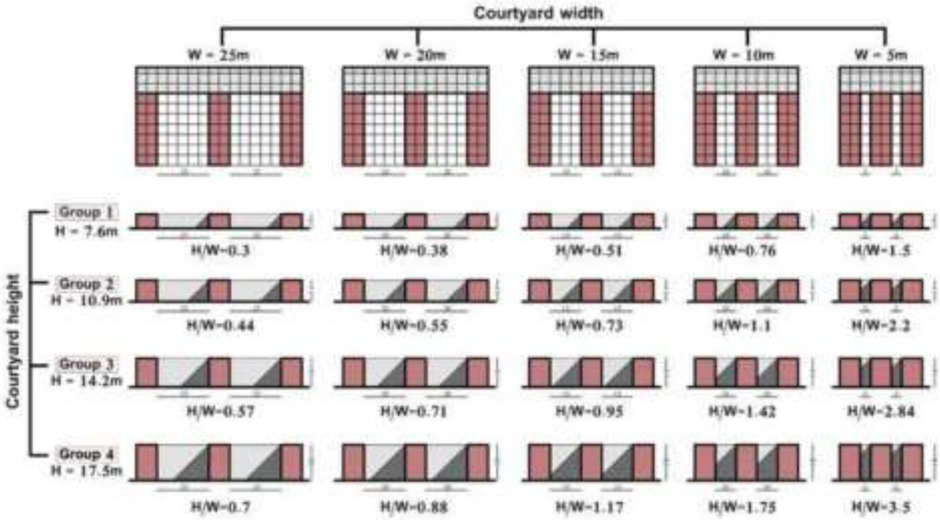


Figure 9: Simulation scenarios for school courtyards with different H/W ratios (El-Samea, Hassan & Abdallah 2020)

After computational simulation analysis, the researchers concluded that type B was better in thermal performances and high ventilation rate. The air temperature in the test room for the type B courtyard was also the minimum on peak summer days. This research mainly focused on the courtyard ratio and its impact on BEP, and its results are similar to another study that was conducted for school buildings in Egypt (El-Samea, Hassan & Abdallah 2020). In this study, a case study building was modeled and simulated for 20 scenarios with different height and width ratios of courtyards and was grouped into 4 based on their floors (Figure 9). Based on their analysis, it was shown that a deep courtyard (<10m width) provides better thermal conditions, which could be achieved by reducing courtyard width and increasing building height. Furthermore, the research concludes that courtyards exceeding 10m width could increase annual energy consumption and excessive exposure to solar radiation. Furthermore, the impact of atria specifically on school buildings is also studied, though limited due to the similar effects on any building. Atrium as a transitional space was studied in research to investigate its performance in a school building located in a hot climate (Odero, Marín & Gómez 2020). Two atriums, northern and southern were investigated at 04.00 PM in January, Spain. It was evident by their analysis results that the atrium temperatures were almost constant over time despite the changes in surrounding classroom temperature. Hence, atriums here acted as tempering spaces during both cold and warm climates. However, from section 2.1.3.1 of this chapter, it is also clear that in the summertime, atriums with the closed glazed roof could have a negative impact on internal temperature and BEP in the summer months.

2.4.1.2 School Corridors

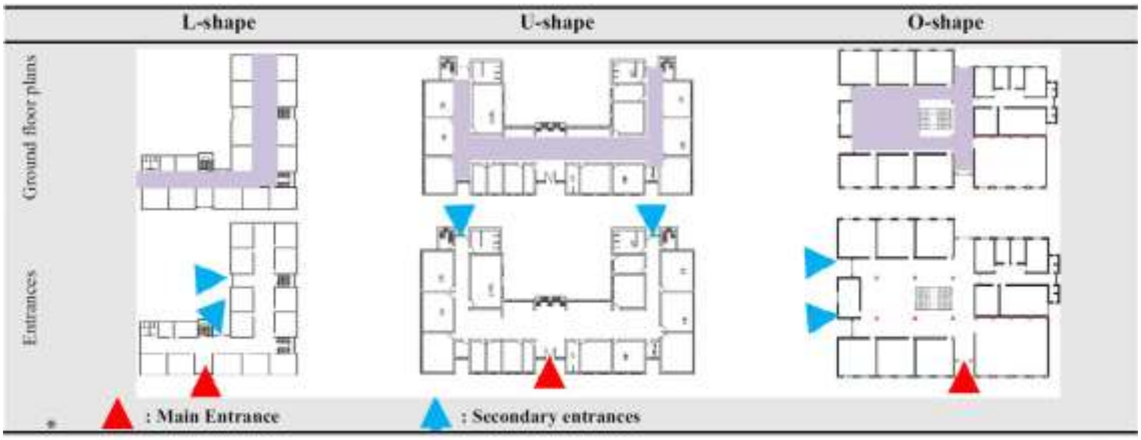


Figure 10: Selected case study plans of elementary schools (Mustafa & Rafeeq 2019)

Exclusive studies on school corridors and their impact on space layouts are currently limited in the research pool. However, a 2018 study mentions corridors in a school building in relationship with spatial layout and space syntax (Sailer 2018). Space syntax is a theoretical and method-based concept where relationships between space, society, and their connectedness with physical spaces are studied. A former research paper (Li et al. 2009) discussed the role of this in building design, where space syntax can provide a configurative description for architectural spaces and other design solutions.

In Kerstin's research, it is used concerning architectural and indoor layouts (Sailer 2018). Corridors are given much importance in this research as they connect classrooms and other spaces of school in a rational spatial layout. Traditional school buildings used predominant corridors with the focal aim of the movement. On the contrary, modern schools have more open space and spatial layouts, making corridors more functional. Five school buildings were studied in this research and their space layout configurations were discussed. The paper concluded that the design of corridors plays a critical role in the circulation of a building’s space. It is more significant for school buildings since transitional spaces like corridors in contemporary schools are more than just connecting spaces. Likewise, a study was conducted on elementary schools in Iraq using a similar concept (Mustafa & Rafeeq 2019). Here, the building types were categorized based on corridor shapes, L, U, and O (Figure 10). The research considered U-shape corridor plan to be more cohesive and perceptible and the most connected shape. The visibility is also best in this type of corridor plan and increases with the added number of entrances. Moreover, the U-shape plan had the highest satisfaction rate in a survey that was conducted. However, survey results for the O-shape were also similar to the U-shape in terms of connectivity and integration. L-shape corridor plan was the least preferable. This paper, although does not directly study the effects of space layout, provides important data on how corridor spaces should also be considered in the school building from a user’s point of view.

2.5 Schools in the UAE

2.5.1 Recent Studies on UAE Schools

Several works of literature mentioned previously in this chapter studied various energy and daylighting aspects of schools in the UAE. One such research mentioned earlier was to promote refurbishing schools in Sharjah with the purpose of BEP improvement (Belpoliti et al. 2020). Similarly, studies were conducted on UAE school buildings for the building architecture, courtyards, and their relation to BEP (Rahmani & Al-Sallal 2020) (Salameh & Taleb 2017).

There have been very limited studies done recently on UAE schools’ energy-related issues. Amoodi and Azar published a research paper on the impact of human actions on the BEP of UAE educational buildings (Al Amoodi & Azar 2018). This research proposed a comprehensive energy analysis framework to quantify human action and its impact on BEP. A G-K school located in Abu Dhabi was studied among the three selected buildings. After conducting the energy modeling on IES VE, the researchers used differential, fractional factorial, and Monte Carlo analyses to achieve the research goal. The results show that human actions have key significance on BEP, as energy consumption can be lowered up to 26% by simply adjusting the AC temperatures by ±2°C. However, it is also highlighted through the results that while adjusting the temperature in this way can reduce energy consumption, it might affect thermal comfort for the occupants. Another observation from this research was the variation in energy intensity based on building types, where the classroom building had the highest intensity. The research concludes that human-related parameters affects differently based on the type and activity of the building.

In a recent study, energy simulation was conducted on existing schools in the UAR to explore the opportunities for retrofitting (Aldawoud, Hosny & Mdkhana 2020). The research studied different retrofitting measure sets, which showed varied energy reduction results. It was found through the simulation results that a 29% reduction in cooling can be reduced by changing existing HVAC equipment. Likewise, 21.5% and 57% reductions in annual electricity consumption can be achieved through adding roof and wall insulations, and thermal resistance in the existing walls, roofs, and windows respectively (Aldawoud, Hosny & Mdkhana 2020). Similarly, in a study of a school building in Dubai, the potentials of energy saving through natural ventilation was investigated (Aldawoud & Salameh 2020). The case study building was modeled and simulated, which showed that natural ventilation is insufficient to prevent internal overheating during summer. However, the cooling load could be reduced minimally, approximately between 7%-10% reduction. Finally, the researchers concluded that if northern windows of a school building in Dubai are opened for cross-ventilation, it could reduce some cooling load but not very much effective for overall internal comfort.

A study on the visual and thermal impact of skylight design for UAE school interiors was conducted by evaluating parameters like daylight factor, glare, and cooling loads (Eiz et al. 2021). This research analyzed 12 case scenarios and the base case with different skylight options. It was found that a skylight with a 90° slope can reduce cooling load without compromising visual comfort. Moreover, an east-west orientation can provide better illumination, but high glare values. The implementation of horizontal shading in the south is suggested to reduce glare and improve thermal comfort.

It can be established from the above discussion that there is a lack of research works done on UAE schools in energy and daylighting-related topics. Although these two parameters are heavily researched in the UAE, most of them are conducted for office or other commercial spaces.

2.5.2 Standards and Regulations

Students spend almost one-third of the day in classrooms, making it essential to provide comfortable thermal and visual learning environments (Jing et al. 2019). Several pieces of literature proved that the thermal and energy performance of a school directly affects students' learning performance. The reason why school design for improved BEP is significant is because of the variable thermal requirements depending on their age, clothing, and metabolic rates. Therefore, an elementary school's thermal requirement will be different from that of a high school. To give an instance, in previous research done on improving thermal performances in tropical climate (Porras-Salazar et al. 2018). One of the aspects of their experimental study was to acquire data for the students. Pupil number, clothing, gender, and thermal insulation of their clothing (unit= clo) were documented. Moreover, children's metabolic rate while performing seated schoolwork is compared to be the same as that of a typical office employ in sedentary activity based on ASHRAE Standard 55-2013. A similar study was done for the Middle East region to explore the thermal comfort experiences of school students (Al-Khatri, Alwetaishi & Gadi 2020b). It was mentioned that the neutral operative temperatures among students in Arabian region schools are between 21°C and 22°C. This paper describes how different parameters lead to varying thermal comfort between students in hot and arid regions. Hence, optimal school building design is clearly essential for not just BEP, but widely for students' thermal comfort and performance. Since people's thermal comfort depends on the climate, site, location, etc. there are international and local standards and guidelines for school design. In UAE, LEED and ASHRAE are extensively used, alongside other international and local codes and regulations. Abu Dhabi school design regulations are set by the Government, ADEC, also known as ADEK (Abu Dhabi Department of Education and Knowledge). The government of Abu Dhabi- Infrastructure and Facilities Management Division published the last design manual in 2013 (ADEC 2013), which is needed to be followed by all public and private ADEC schools.

2.5.3 ADEC's School Design Regulation

Schools in the emirate of Abu Dhabi follow school building guidelines set by the ADEC and are also applicable for Al Ain city. In their 2013 school design manual, different aspects of space programming for schools including examples and formula calculations are provided. These formulas help designers to decide the appropriate size for targeted schools. For example, 50 classrooms for 25 elementary students (Cycle I) will have an area of 3,250 m^2, with the unit area as 65 m^2 (ADEC 2013). The complete space program table included in this manual will be available in the appendix section. Furthermore, the manual strongly suggested providing breakout spaces and outdoor learning spaces adjacent to Cycle I classrooms, especially if it is a standalone elementary school.

School building performance standards should consider the ADEC's design manual, along with computer simulation models and life-cycle cost analysis. Additionally, all school designs should meet or exceed the latest versions of the Estidama requirements as per the project brief, ADEC's sustainability requirements, Abu Dhabi building codes, and other related standards mentioned in Table 1.

Table 1: Building standards approved and followed by the Abu Dhabi government (ADEC 2013)

Standard	Full-Form
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
IESNA	Illuminating Engineering Society of North America
NFPA	National Fire Protection Association
CIBSE	Chartered Institution of Building Services Engineers
ICC	International Code Council
ARI	Air-Conditioning and Refrigeration Institute
UL	Underwriters Laboratories:
BS	British Standards

Integration of natural daylighting is given much priority by ADEC in all school spaces. Moreover, daylight sensors are also suggested in classrooms, breakout spaces, and other common areas (ADEC 2013). Artificial lights in schools should be carefully designed for visual comfort and based on space requirements. ADEC recommends following IESNA standards to comply with the illumination levels, except a few standards mentioned below in Table 2 (Further available in Appendix A).

Table 2: Recommended light levels for schools by ADEC (ADEC 2013)

Spaces	Illumination Levels in Lux
All Educational areas	500 lux in 20% spaces, 400 lux in the balance
Administrative, clinic, auditorium, swimming pool, lunch area and service areas	300 lux
Toilets	200 lux
Kitchen, gymnasium, music, art, design and technology	500 lux
Internal circulations	250 lux
Emergency lighting in common areas and corridors	10 lux

For healthy thermal comfort in an educational environment, ADEC provided thermal standards based on different criteria such as temperature and humidity in Abu Dhabi and Al Ain. The recommended design conditions for space temperature in summer should be 23 +/- 1 C°. For occupied areas, the relative humidity should be between 40% and 60%, +/- 5 (ADEC 2013). ADEC recommends following ASHRAE 62.1 for ventilation standards. This manual also provides other design-related standards and guidelines for designing a sustainable and comfortable environment for children.

2.5.4 ADEC School Designs

Schools in the UAE started to reform from the onset of the twentieth century. The MOE (Ministry of Education sanctions regulations and guidelines for school constructions. However, these regulations did not provide any standards related to the architectural design of schools. A thesis paper published from the UAEU provided direct data received from personal communication with ADEC representatives (Al Dakheel 2017). It was mentioned that before the establishment of ADEC, the MOE constructed 202 public schools in the Abu Dhabi emirate without any energy efficiency code consideration. From 2010 onwards, ADEC established prototype templates for public schools in the emirate in line with the Future Schools Programs and has already been applied to several existing schools. However, pointing out one of the current research problems, there are not energy-efficient templates published for the private schools.

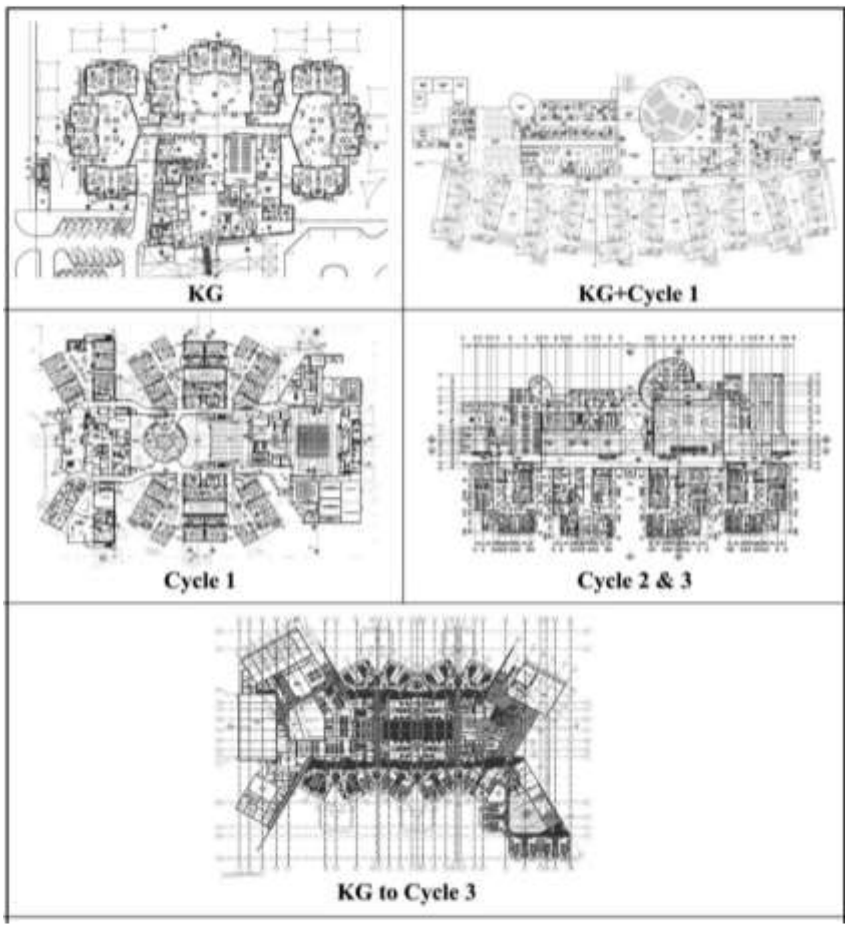


Figure 11: ADEC prototypes for public schools (Al Dakheel 2017)

In the thesis paper of Al Dakheel, 5 prototype design plans (Figure 11) from ADEC were presented and one among them was considered as a case study for further analysis. The research was done as an extension to this thesis where one case study school was chosen from Al Ain which had 2 Pearl ratings (Al Dakheel, Aoul & Hassan 2018). The aim was to find gaps and opportunities for further improving the Estidama performance. The research used qualitative analysis which indicated that the “Resourceful Energy” section was not utilized by 70% (Al Dakheel 2017). Renewable energy strategies were analyzed and proposed to improve energy efficiency and better sustainable solutions. Similarly, a thesis was conducted on public schools in Al Ain designed from the ADEC prototypes (Rahmani 2017). Four schools were selected, and their architectural forms were extracted as outlines to compare the proportion between the learning community and courtyards. Then, the comparisons were represented as simple rectangles, and experimental analysis was conducted in detail. The results of this research demonstrated the effect of compactness of building form in BEP of schools in the Abu Dhabi emirate. Nevertheless, no research paper were found on ADEC private school designs and their potential improvements.

2.6 Chapter Summary

The literature review of this chapter aimed to cover a thorough understanding of the topics related to the current research. The works of literature reviewed in this chapter were no older than 5 years from the development of this dissertation. The chapter is designed in stages, where the broadest themes of this research were covered in the beginning. This included reviewing suitable studies on space layouts in general, and their effects on daylight availability and BEP. Moreover, the role of transitional spaces in space planning was also highlighted, which is linked with other subsections later in this chapter. Next, these topics were narrowed down, and only studies were done on school space layouts, both international and local were reviewed. Aspects like school building shape, size, and layout, along with school transitional spaces were discussed. Finally, the third subsection of this chapter discusses the UAE schools and few attributes that are relevant for this research. Recent studies done on UAE schools were covered in this section, excluding some papers that were already reviewed previously to avoid redundancy.

Furthermore, several findings can be drawn from the above literature review which could support and be used in this research investigation. First of all, studying space layout alone by isolating them as a single parameter can be derived from few latest works of literature. The concept of thermal zoning can also be implemented in the simulation stage. Similarly, the studies reviewed on transitional spaces revealed various useful strategies. Some of the highlighted results from the above-discussed research papers could be:

- Buildings without any atrium might consume more energy per volume unit for heating and cooling than a building with it. However, atriums should always be open to the ceiling in hot countries.
- Atriums in hot-dry and hot-humid climates might decrease annual energy use but can risk causing thermal discomfort in the summer season.
- East-west-oriented courtyards provide a comfortable indoor environment in summer.

- A closed courtyard with a smaller width has better thermal performance and a high ventilation rate.
- U-shape corridor plan to be more cohesive and perceptible and the most connected shape with better visibility.
- An H shape building might be the best in thermal and energy performances

Moreover, standards and regulations found through articles, journals, and other reliable sources were presented at the end of this chapter. Chapter 2 was a theoretical and highly informative chapter that will be supporting this research later during the investigation and discussion process.

Chapter Three

3 Methodology

3.1 Overview

Research methodology is a structured pathway through which research is conducted (Jilcha Sileyew 2020). Structuring a research methodology helps in formulating the research aims and objectives and carry out the proper research design. This chapter aims to discuss such methodologies used in different kinds of literature relevant to the present research. Methods are mainly based on the kind of research questions and the results a researcher is aiming to achieve. Various research methodologies have been used in previous researches on experimenting or investigating building space layout, BEP, and daylighting. Hence, these methodologies will be briefly discussed in the below sections, along with their pros and cons. The discussions on previously used methodologies on similar topics and their pros-cons will support in choosing the methodologies for this current research.

Furthermore, in this chapter, the selected methodology will be discussed in detail including the data sources, tools selection, justification of the chosen methodology, and validation. Finally, a research methodology framework will be provided at the end of this chapter to properly visualize the research plan further.

3.2 Previous Research Methodologies

Studies related to BEP, daylighting, architectural layout and their investigation, energy consumption, etc. are complex for various reasons. One of the factors is the selection of variables or parameters for the evaluation. A variety of parameters are related to BEP, such as the building architecture, construction, building site, location, orientation, functional type, and so on. Therefore, it is important to identify the proper research methodology to carry out efficient evaluation for the variables chosen for particular research. Below are the methodologies discussed which are mostly used in similar topics as the current dissertation research.

3.2.1 Literature Review

LR (literature review) methodology is a qualitative approach that is widely used in the field of research. In almost all studies, this method is used as a background study to gather information on the research topics. LR allows the researcher to review previous works done on relevant and related topics and prospects provided by the authors. This approach can be used as an investigation tool in the case of reviewing previous papers and their data, results, and discussions. On the other hand, a literature review is also helpful in gathering theoretical knowledge on relevant topics. For instance, works of literature related to architectural space layout were reviewed in research to study their effects on energy performance (Du, Jansen, Turrin & Dobbelsteen 2021). It was found through the LR that most of the relevant papers studied the effects of space layouts by simultaneously changing the related parameters. Thus, the isolated effects of space layouts on BEP were never studied or discussed. Moreover, a simplified steady-state calculation method was identified to analyze BEP in some research besides the most common method, which is a computer simulation. Another research was done to evaluate the effect of school building geometry on energy and thermal performance in China (Zhang, Bokel, et al. 2017b). Here, the author used the LR approach to gather data on the same topic in other cold climatic zones, such as Canada, Brazil, Greece, New Zealand, and so on. All of the selected papers studied school plan types, space layouts, and spatial typologies affecting energy and thermal performances. Through this approach, a percentage decrease in energy demand from the original value was identified, which provided crucial data for the author.

Therefore, the LR methodology can be easily described as the most important methodology for conducting any research. However, this method alone is not sufficient to carry out deeper research. LR can be used as a tactic to gather information on relevant topics to be implemented further in other methodologies.

3.2.2 Computer Simulation and Modeling

Computer simulation uses computer programs to run analysis on a mathematical model to predict their behaviors according to the input data and variables (Winsberg 2019). The reliability of computer simulation for predicting and decision-making has escalated in the past few years. Therefore, this methodology is very much compatible with numerous research fields. Moreover, it can be considered both qualitative and quantitative because decisions rely on the simulated data results and the way of interpretation.

The majority of the papers related to BEP, and its sub-topics have computer simulation as their research methodology. An office building was studied in a research where the effects on energy, daylight, and thermal performances were analyzed by changing the space layout (Du et al. 2019). Here, they performed energy and daylight simulation for

11 different layout possibilities using the Grasshopper software, Daysim, and EnergyPlus. Data like building materials, HVAC values, temperature, and space functions were introduced as inputs. The simulation results were then compared and the most balanced space layout design for best BEP and daylight performance were identified. Similarly, a virtual environment software IES VE was used to simulate and investigate the energy and thermal performance of courtyards in UAE schools (Salameh & Taleb 2017). The computer simulation method allowed the analysis of different courtyard types and lead to take best scenario design decision. The courtyard ratio and its effect on school energy consumption were studied in research (El-Samea, Hassan & Abdallah 2020). The school building was located in Egypt, where the hot temperature is a significant attribute affecting thermal comfort. A simulation study was conducted for this research, where the building model was built using Design Builder software. Next, different courtyard design scenarios were simulated for energy consumption and PMV (Predicted Mean Vote). The results from the simulation were then compared, concluding that the height and width ratio of school courtyards plays a major role in thermal comfort and energy consumption.

Studies related to ventilation and thermal performances also widely use simulation as their methodology. Aldawud and Salameh in their research on improving the thermal performance of UAE schools used CFD (Computational Fluid Dynamics), DesignBuilder (EnergyPlus), and ANSYS Fluent software to investigate (Aldawoud & Salameh 2020). The researchers first modeled the selected case study school building and created different ventilation scenarios. These scenarios were then simulated under variable wind speed and wind direction. The simulation results led to some major findings on effective ventilation strategies and combinations that work best in hot climates. In another research, computer simulation was used to assess the performance of passive daylighting techniques and their effect on illuminance, thermal comfort, and energy consumption of a Jordanian school classroom (Al-Khatatbeh & Ma'Bdeh 2017). The study used Radiance, a plug-in of Ecotect and Daysim to simulate the illuminance levels, Evalglare to check glare index, and Ecotect for annual energy loads. Total 9 cases were investigated through the various software simulations and then compared through graphical representations. The use of different software tools provided a variety of results to compare and contrast.

Mohsenin and Hu used DIVA and Rhino simulation tools to assess the relationship between daylight and atrium in buildings (Mohsenin & Hu 2015). They run simulations to the computer model to assess multiple parameters related to daylighting, such as sDA (Spatial Daylight Autonomy), ASE (Annual Sunlight Exposure), UDI (Useful Daylight Illuminance), and DA (Daylight Autonomy). In another research, the software Relux and Depthmap were used to evaluate visual comfort and daylight distribution for different medical center layouts (Mousavi Asl & Safari 2020). Parameters like DF (Daylight Factor), Uo (Uniformity Rate), and visual quality indexes were studied through the simulations, and their results were evaluated in an analytic-descriptive approach. In recent years, researchers use multiple computer software to study different parameters or to combine and connect for result accuracy. One such research was done to optimize thermal and daylight performance in a school building (Zhang, Bokel, et al. 2017a). In this research, the researchers used Rhino and its plug-in Grasshopper for geometric constraints, plug-in Ladybug and Honeybee were used to input the physical properties. This simulation was then connected to EnergyPlus and Radiance programs for the energy and daylight analysis respectively.

Furthermore, computer simulation is frequently used in researches studying the lighting design of a space. Research for analyzing optimal lighting designs for office space, Rhino DIVA plugin, and DIALux evo software tools were used for simulation (Sun et al. 2020). The former tool was used to generate the 3D model and simulate a daylight environment for glare analysis. Then, DIALux was used to create the artificial lighting environment for optimized illuminance distribution. Through the simulations, the researchers were able to predict the glare ratings in different months of the year and optimize the artificial lighting plan of the office space. Another similar study was conducted using DIALux evo to improve a restoration project in Portugal (Amoêda & Carneiro 2020). The researchers proposed 2 scenarios and simulated them for illuminance, Uo, and DF using the DIALux. The results were then assessed, and light energy savings were calculated.

Computer simulation has become the most applied methodology in modern studies. The ability to input a wide range of data to get accurate results encourages researchers to use this methodology to propose predicted solutions. Moreover, this methodology is extremely effective in studies that are related to energy predictions, BEP, daylighting, and similar areas. There are plenty of software tools available currently to be used for research simulations, which allow researchers to effectively carry out their studies.

3.2.3 Questionnaire/Surveys

Questionnaires or surveys are a very effective method for data collection and evaluation. This approach can be both qualitative and quantitative depending on the evaluation approach chosen. The results of a questionnaire or survey can be interpreted descriptively if the goal is to discuss the outcome qualitatively. However, choosing the quantitative side of surveys is more appropriate. Studies related to BEP, and daylighting do not use this type of methodology unless the researcher aims to add thermal comfort as one of the parameters. Daylight characteristics in buildings' internal corridors were analyzed in the research, where a questionnaire survey was used as one of the methodologies (Yuan et al. 2020). The questionnaire was conducted to get subjective feedback on the daylight conditions, importance, and preferences in the interior corridors. User satisfaction and dissatisfaction were recorded, and the results were used to back up the numerical simulation results. Similarly, a subjective survey was conducted in research, but the aim was to assess thermal comfort (Jing et al. 2019). Through this survey, different comfort levels were disclosed by the students and teachers, which was later compared to thermal acceptability standards to quantify the results.

The role of space features on user behavior and satisfaction was studied by Hyun Cha and Kim, where they used a questionnaire as one of the research methodologies (Cha & Kim 2020). They conducted a two-parts, paper-based questionnaire to investigate the space-choice behavior and satisfaction. The results of the questionnaire revealed different attributes like noise level, visual comfort, aesthetics, and amount of space. Another similar research also conducted a survey approach on students' subjective assessment of a building's geometry parameters (Zhang, Bokel, et al. 2017b). The results of the survey were analyzed using a seven-point Likert scale, providing significant data to carry out the study. Therefore, it is evident that a questionnaire survey is an effective methodology for assessing occupant thermal, visual, or acoustic comforts. Furthermore, research conducted in schools in Taiwan implemented a direct survey approach to investigate energy consumption (Wang 2019). Firstly, 231 schools were sampled for this study, and their monthly energy expenses data were collected. Moreover, the schools' class schedules, timings, occupancy, etc. were also recorded. An energy consumption auditing approach was conducted with the survey data and the results were assessed using the multiple regression method.

Surveys and questionnaires are great ways to collect real-time data for research analysis. This methodology is highly effective for studies related to occupant thermal or visual comfort to gather data on occupant experience. Moreover, the results of surveys and questionnaires can be analyzed quantitatively, which helps in deriving the final research outcome. On the contrary, this type of method can be time-consuming, exposed to human errors, and can be expensive if the scale of sample data is large. There are also ethical considerations involved in such a methodology. Furthermore, the survey method is not sufficient to quantify outcomes related to energy or daylighting performances.

Table 3 below illustrates a brief list of reference journal papers mentioned in the above sections. This outlines the research topics, parameters studied, and the approaches used.

Table 3: Summary of research methodologies in reference papers (Author 2021)

Journal/Research title	**Year of publication**	**Parameters studied**	**Methodology**
Assessing daylight performance in atrium buildings by using Climate Based Daylight Modeling.	2015	Daylighting	Computer simulation
Optimization of thermal and daylight performance of school buildings based on a multi-objective genetic algorithm in the cold climate of China	2017	Energy demand, Daylighting, Thermal comfort	Literature review Computer simulation
The Effect of Geometry Parameters on Energy and Thermal Performance of School Buildings in Cold Climates of China	2017	Space layouts, Energy consumption, Thermal comfort	Literature review Computer simulation Questionnaire
Improving visual comfort and energy efficiency in existing classrooms using passive daylighting techniques	2017	Daylighting, Glare Thermal Comfort Energy consumption	Computer simulation
Courtyard as passive design solution for school buildings in hot area	2017	Energy efficiency, Passive design	Literature review Computer simulation
Impact of space layout on energy performance of office buildings coupling daylight with thermal simulation	2019	Space layouts, Energy demand,	Computer simulation

		Daylighting	
Thermal comfort and energy-saving potential in university classrooms during the heating season	2019	Thermal comfort	Survey
Energy consumption in elementary and high schools in Taiwan	2019	Energy consumption	Survey
The Effect of Courtyard Ration on Energy Consumption and Thermal Comfort in a Primary Governmental School in New Assiut City, Egypt	2020	Energy Consumption Thermal Comfort	Computer simulation
Natural Ventilation to Improve the Thermal Performance of Schools in UAE	2020	Natural ventilation Thermal comfort	Computer simulation
Analysis of daylight glare and optimal lighting design for comfortable office lighting	2020	Daylighting, Glare Lighting design	Computer simulation
Daylighting simulation on restoration projects of vernacular architecture: an application of DIALux ® evo 9 . 1	2020	Daylighting analysis	Computer simulation
Analysis of daylighting characteristics and optimization of space design dimensions in typical building corridors	2020	Daylighting, Space planning	Questionnaire survey Numerical simulation
The role of space attributes in space-choice behavior and satisfaction in an academic library	2020	Space planning, Occupant comfort	Questionnaire
Effect of space layouts on the energy performance of office buildings in three climates	2021	Space layouts, Energy demand, Daylighting, WWR	Literature review Computer simulation

3.3 Selected Methodologies and their Justification

Based on the above discussion, it is evident that literature review and computer simulation methodology are the most typical used effective methods to study the current topic. The current dissertation research aims to investigate the effects of space layouts on BEP and daylighting of UAE school buildings. Therefore, this dissertation calls for the need to conduct both qualitative and quantitative research approaches to effectively carry out the study. The literature review method can provide comprehensive insight and data on various relevant topics of this research. Architectural space layout is a broad topic by itself that requires ample knowledge about design principles, regulations, and requirements. On the other hand, the computer simulation method can demonstrate the study hypothesis practically and quantitatively to evaluate energy performance, daylighting, and school BEP. Results of the simulations can also be discussed and interpreted qualitatively by assessing the findings of the literature review. Thus, literature review and computer simulation are the two selected research methodologies for this dissertation.

The literature review approach was identified to be a suitable approach for this study in order to explore the theoretical and conceptual contexts of relevant topics. It is the most effective approach to provide background knowledge on the architectural layout of schools, their design considerations and regulations, and their effects on energy and daylight performances. Moreover, this approach allows investigating different school layouts used in practice or literature and their performance in terms of different parameters. These collected data can help in clarifying theories and hypotheses. A literature review is also a great method to establish the novelty of the current knowledge gap through reviewing the latest research works on the particular topic. It helps in identifying future work scopes mentioned by previous researchers which can support formulating the research framework. Furthermore, this methodology can be used to collect data of UAE school design regulations, existing school design, and data, and such other information. In short, the literature review method will play a crucial step in the current research framework to create a foundation for conducting the study further.

The second methodology for this research will be computer simulation. The data and information from the literature review will be utilized here through computer simulation programs to test and evaluate their results. This methodology is highly essential in studies related to assessing or investigating energy performance and daylight availability. This is due to the ability of simulation programs to provide dynamic results based on different parameters and variable inputs. It is also the most convenient option for conducting multiple simulations with varying simulation settings that allow more substantial results. In the current dissertation, three computer simulations will be used, namely: Revit, IES VE, and DIALux on a case study school building, located in Al Ain, UAE.

Revit by Autodesk is a BIM (Building Information Modeling) software used by architecture and engineering professionals to model, design, and analyze building construction, fabrication, and visualization (Autodesk n.d.). In this research, this software will be used in two phases: 1) in the initial model set up phase where the case study (base case) school building and the other scenario layouts will be modeled, and 2) in the daylight analysis phase where simulations will be performed on various parameters. The reason behind selecting this software as one of the simulation methods is its model accuracy and reliable results. Revit is used very frequently in recent times in both industrial and research fields. For instance, Revit was used in research to analyze the energy performance of a residential building in India (Shivsharan, Vaidya & Shinde 2017). It is said to be a very accessible and useful tool that can link conceptual architecture design with complex sustainable features like daylighting, solar access, etc. Moreover, Revit's BIM features allow it to collaborate with the other simulation software used in this research. The interoperability of the program with other simulation tools like IES VE and EnergyPlus helps in saving time and generate accurate results (Shivsharan, Vaidya & Shinde 2017).

Next, DIALux evo software will be used to conduct the daylight simulation mainly for illuminance and daylight factors. This is a user-friendly software that allows designers and professionals to calculate and visualize natural and artificial lightings, both for indoor and outdoor spaces (DIALux 2021). The daylight calculations done in DIALux provides comprehensive results in both visual and transcribed forms. Therefore, a second perspective of the daylight analysis in detail will support the current study findings. In a recent study, DIALux software was used for daylight simulation in a vernacular building restoration project (Amoêda & Carneiro 2020). The software was found to be very convenient due to its ability to change parameters and recalculate in real-time. Similarly, this tool was used in another research to analyze the daylight glare and optimal lighting design of office space (Sun et al. 2020). DIALux was used to create a light environment to study and compare the optimized plan from the original one. Hence, it is evident from various latest studies that DIALux evo tool is suitable for daylighting study and calculation.

Lastly, IES VE (Integrated Environmental Solutions -Virtual Environment) is a simulation software that is specifically created to do different building and sustainability-related analyses (IESVE 2021). This tool will be used to simulate the school models for annual energy consumption, annual cooling load, comfort index, sun cast analysis, etc.

Therefore, it will evaluate the studied school layouts against the selected case study. Conversely, it is essential to clarify the limitations of IES regarding this research for the readers and future researchers. While the energy simulation can be done effortlessly, daylighting analyses through FlucsDL, RadianceIES, and Dynamic daylighting (sDA, ASE) is not feasible to run on IES. This is due to a computer memory drive constraint in the educational license of the software which allows up to a limited size of building to be analyzed. Since the research building size is bigger than the limit, daylighting analyses are conducted using other software tools. However, for this research, IES is the perfect software to conduct the energy simulation effectively. The literature and software validation for IES will be discussed later in Chapter 4.

3.4 Chapter Summary

This chapter aimed to identify the suitable research methodologies to effectively conduct the current investigation. The best way to achieve this is by exploring what methodologies were used by other researchers on similar topics as this dissertation. Several research papers were examined for the methodologies used. The literature review was found to be the best qualitative research method and most common in any study. Similarly, computer simulation was found to be the most frequently used methodology in studies related to energy consumption, daylight, or BEP. Furthermore, questionnaires and survey methodology were found in studies related to daylighting and energy performances linked with visual or thermal comforts. However, did not meet the current investigation requirement. Therefore, the literature review and computer simulation methods were selected as the research methodologies which were also justified. Finally, IES VE software was chosen to conduct the energy simulation, whereas Revit and DIALux evo software tools were selected to do the daylighting simulations. Based on the discussions held in this chapter, a framework is developed (Figure 12) which visualizes how the current research investigation will take place step-by-step.

3.5 Research Methodology Framework

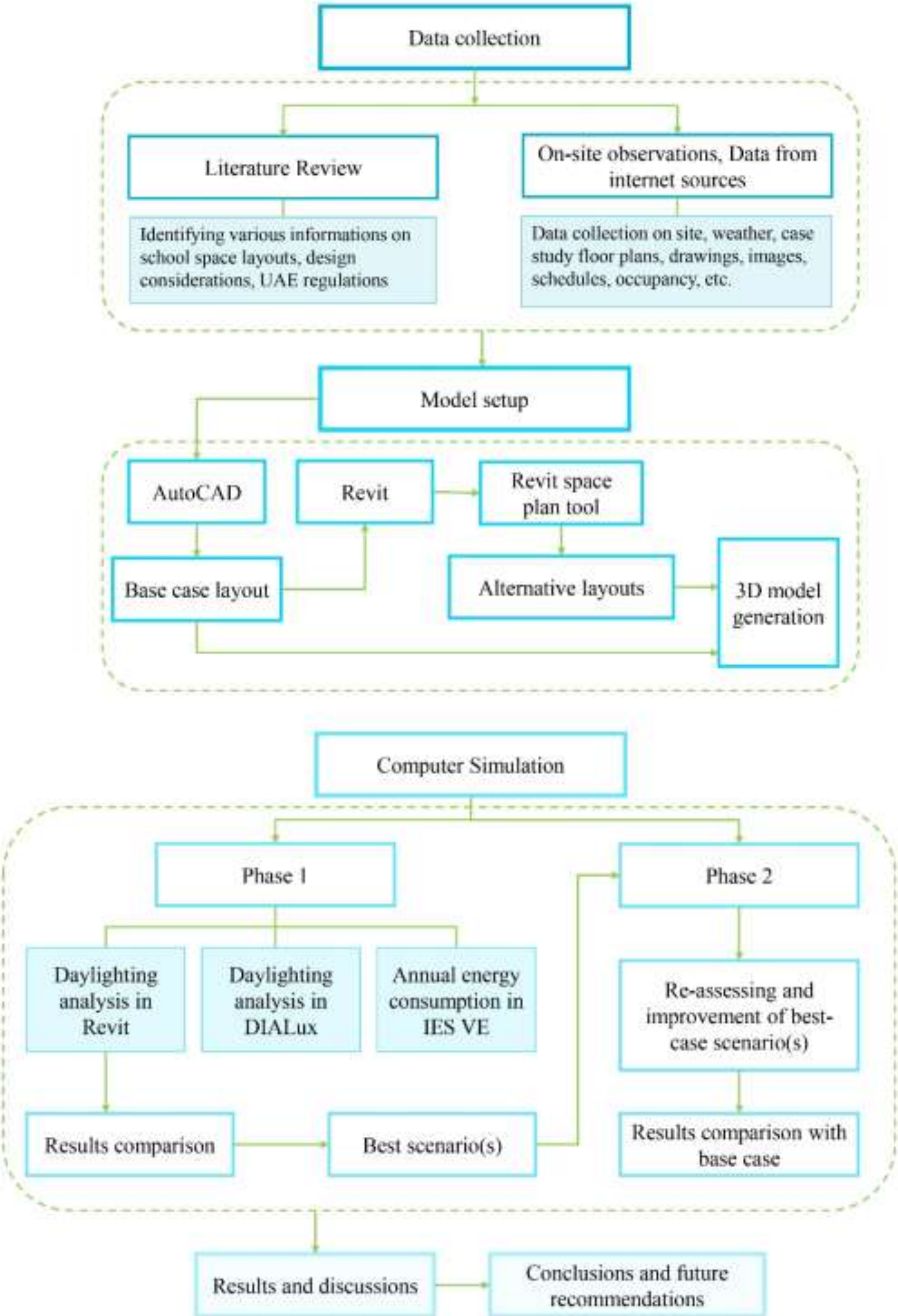


Figure 12: Research Methodology Framework (Author 2021)

Chapter Four

4 Case Study and Research set-up

4.1 Overview

This chapter of the current dissertation will talk about the selected case study school which will be considered as the Base Case. The case study school location, site, climate of the city, and other details related to the building will be discussed in detail. Next, validation and calibration of the simulation software IES VE will be conducted. This procedure will form a base for the upcoming scenario analyses. Furthermore, in this chapter, the alternative school scenarios will be generated using the Revit Space planning tool and their features will be elaborated. Lastly, strategies for simulation procedure will be established based on the above-mentioned sections' discussion. These strategies will be followed by the energy and daylighting simulation analyses to further carry out the current study.

4.2 Case Study

4.2.1 Liwa International School Al Ain

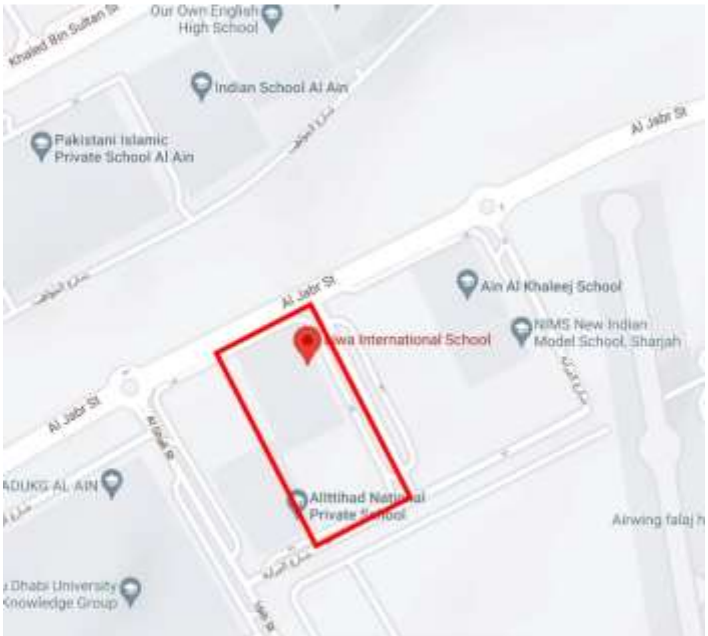


Figure 13: Liwa International School location (Google Maps 2021)

The selected case study for this research is the Liwa International School (LIS), which is a private establishment situated in Al Ain City, United Arab Emirates. As seen in (Figure 13), the school is in a school cluster area in Falaj Hazza, Al Ain with very reduced traffic. It is a K-12 school constructed in 1992 and has separate buildings for elementary and high school. A private school was selected for the case study to address the current research problem of inadequate studies and data on UAE private schools. However, it is wise to state the fact that the selected case study does not represent all types of private schools in the UAE. Rather, it can be an indicator for further research and practical applications of the gathered results.

Figure 14: Old Liwa International School Al Ain (The National News 2011)

Figure 15: Current Liwa International School Al Ain, Elementary Building (Author 2021)

The motivation behind choosing LIS is the availability of reliable data and the school's previous involvement with sustainability. LIS was a part of a case study in a research conducted in 2011 (Elmasry & Haggag 2011), in which its sustainability approaches against the Estidama rating criteria were reviewed. This school converted from a conventional to a green building in 2010 and participated in the World Future Energy Summit 2010 through the integration of green wall systems (Figure 14), photovoltaics on the roof, and a greywater recycling system. It was concluded in the research that LIS contributed to few Estidama criteria such as resourceful energy (RE), natural systems (NS), and precious water (PW). However, since this study, the school was re-designed and as a result, the green wall system was removed, leading to the inspiration to select this school as a case study to investigate. This research will be studying the elementary building (Figure 15) of the LIS.

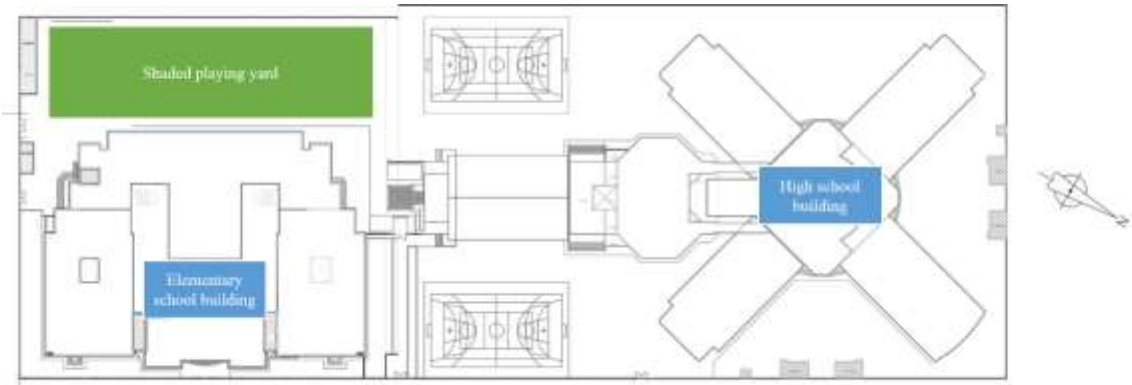
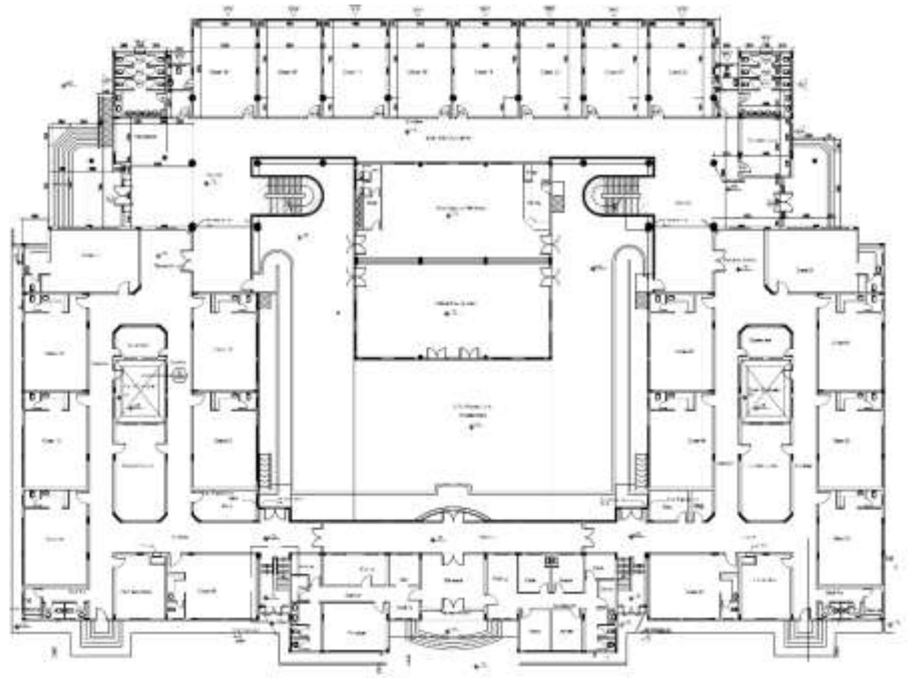


Figure 16: LIS Site Plan (Author 2021)

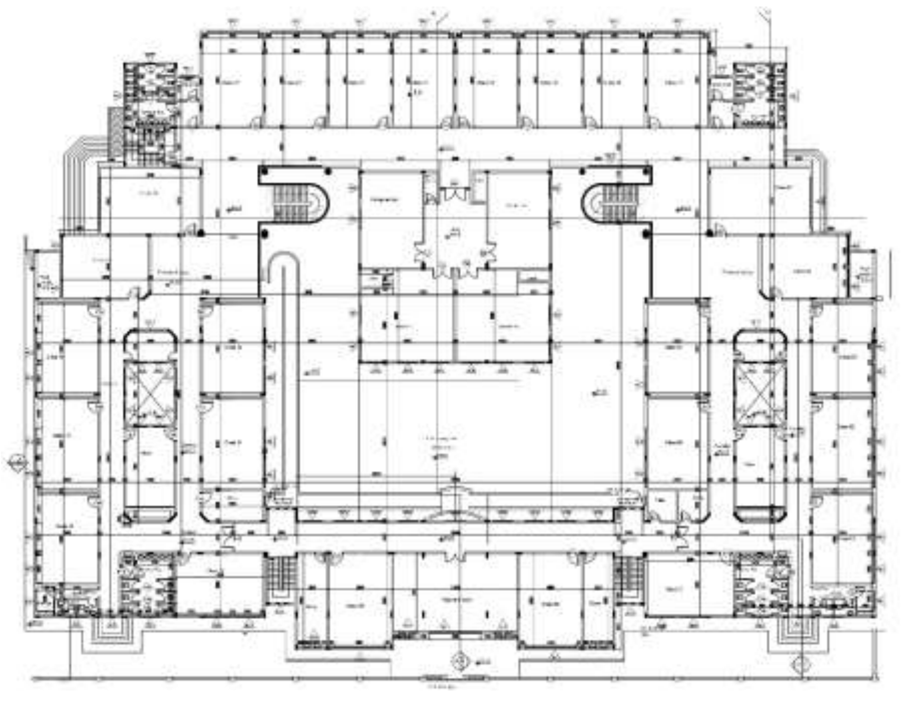
The case study building is the elementary division of LIS which is a two-storied building (Figure 16). The plot area for the building is 4,476 square meters. The facility is for students from KG- Grade 5.

4.2.2 LIS Building Documents

The original architectural floor plans and elevations are presented in this section, which will be used in a later section for the Base case model set-up (Further available in Appendix B).



Ground Floor



First Floor

Figure 17: LIS Existing Floor Plans (Collected from Granada Archi. & Consulting Engineers L.L.C, 2020)

4.2.3 The Climate of Al Ain

Al Ain is located 150 km inland from the capital Abu Dhabi and is known as the "Garden City of the Gulf" (UAEU 2021). The city has a desert climate with long summers and short winters. Due to the absence of ocean bodies, there is a lower humidity level in the summer season compared to Abu Dhabi city.

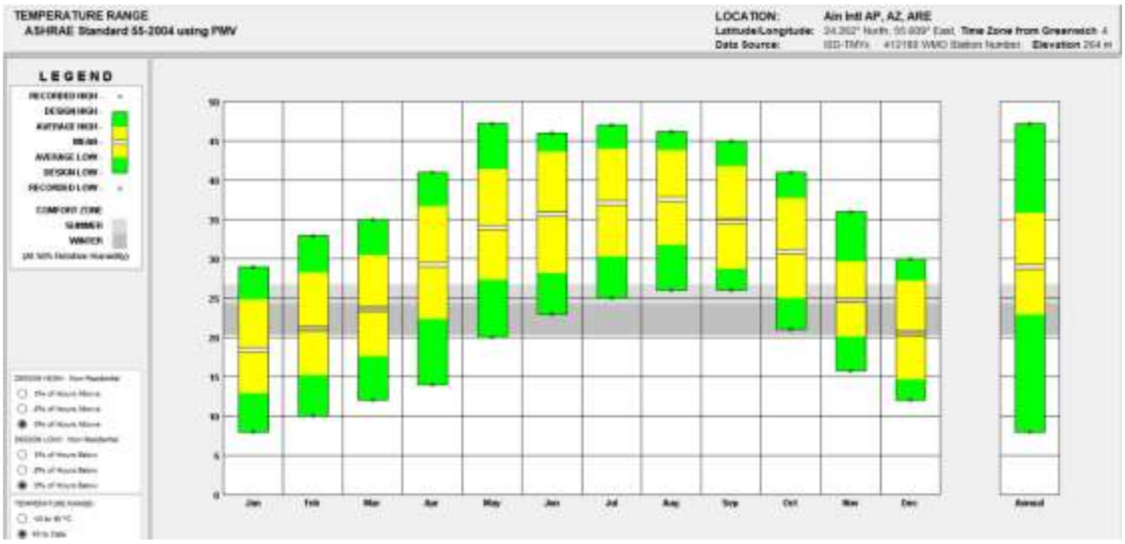


Figure 18: Annual temperature range of Al Ain (Climate Consultant 6.0, 2021)

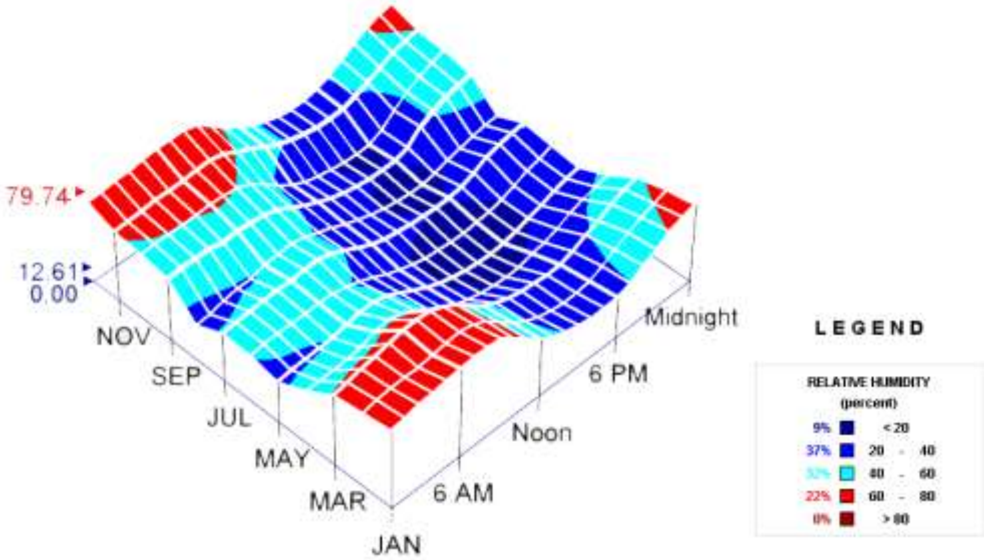


Figure 19: Annual relative humidity of Al Ain (Climate Consultant 6.0, 2021)

The annual temperature range of Al Ain city was obtained from the Climate Consultant software (Figure 18). The months of May to August show the highest temperature in Al Ain, which is usually above 45°C. On average, the temperature of Al Ain is mostly high. On the contrary, the temperature can go as low as 10°C or sometimes 8°C between January and February. Furthermore, the relative humidity ranges from 40-60% in the morning but reduces to 20-40% in the evening (Figure 19).

4.2.4 Sun Path

Figure 20: Sun path diagram for LIS site (https://drajmarsh.bitbucket.io/sunpath-on-map.html)

The sun path diagram (Figure 20) of the school site was retrieved, which shows the summer solstice is the orange line on the top and the winter solstice on the bottom. The middle red line shows the autumn/fall equinox. This will further support the simulation and discussion of results in future chapters.

4.3 Software & Model Validation

Simulation modeling is a method where real-world scenarios are re-created using computer-based software, algorithms, and equations. Simulation models are progressively being used in various research and work fields to help in decision-making and problem-solving (Liao et al. 2011). Since the results and information obtained from these have a direct effect on individuals, there are always some concerns related to whether the results of the simulations are correct. Therefore, this concern is addressed in model validation. Model validation is the process of ensuring the degree to which a simulation model and its data are a correct representation of the real world, from the intended users' point of view (MITRE 2021). The validation process for energy modeling simulations is done in iterations. That is, tests and evaluations are conducted and adjusted repeatedly until it is assured that the energy consumption results of the model are the same or very close to the real-life case.

4.3.1 Literature Validation

IES VE is a simulation software that performs integrated analysis for the design and retrofitting of buildings. The software is accepted and used worldwide and follows various building compliance rating systems like LEED, BREEAM, Estidama, etc. (IESVE 2021). Multiple works of literature have been published that used IES VE software for energy consumption studies. IES VE shows a high rating for its accuracy and usability compared to other simulation tools. Research on energy simulation tools for architectural research compared several simulation tools and found IES VE to be more professional and detailed performance in simulation results (Baamer, Bruton & O'Sullivan 2020).

Several other researchers have used IES VE as their simulation tool for studying and analyzing energy consumption in buildings and had substantial outcomes. Salameh and Taleb used IES to study the effect of the school courtyard as a passive design solution (Salameh & Taleb 2017). Similarly, the software was used in literature to compare the electricity cost and energy consumption of a university in Malaysia (Hussin et al. 2018). Through their simulation, they showed how changing the set point of the HVAC system can reduce energy consumption. A research paper conducted in UAE assessed the potential of converting an existing federal office building to a net-zero electricity building through retrofitting (Alkhateeb & Abu-Hijleh 2019).

4.3.2 Simulation Validation and Calibration

Apart from literature validation, an accurate simulation model validation is required to validate the setup of the correct model and input parameters. Such model validation is done by collected real-time energy bills, field measurements, and other data to establish a simulation profile. However, such data was not possible to be collected from the case study's school management due to the reason of ongoing pandemic precautionary rules and regulations. Therefore, to check the accuracy and capability of the model setup and simulation, a validation process from reference literature was taken. Albedwawi performed IES VE model validation in her dissertation research for a two-story villa (Albedwawi 2020). Her literature provided the architectural layouts of the villa, electricity bills from DEWA, construction details, and information about occupant numbers and activities. An architectural model was built in Autodesk Revit using the provided layouts and was exported to IES VE (Figure 21). The existing villa construction materials and U-value details were provided in the reference literature and were assigned to the construction template of IES VE.

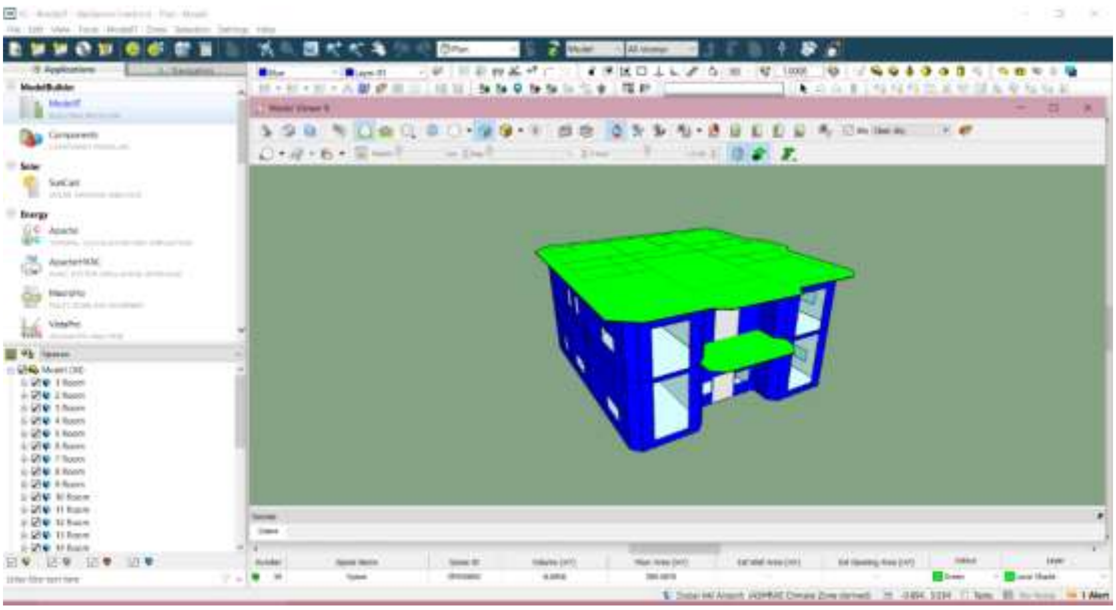


Figure 21: Validation model set up in IES VE 2019 (Author 2021)

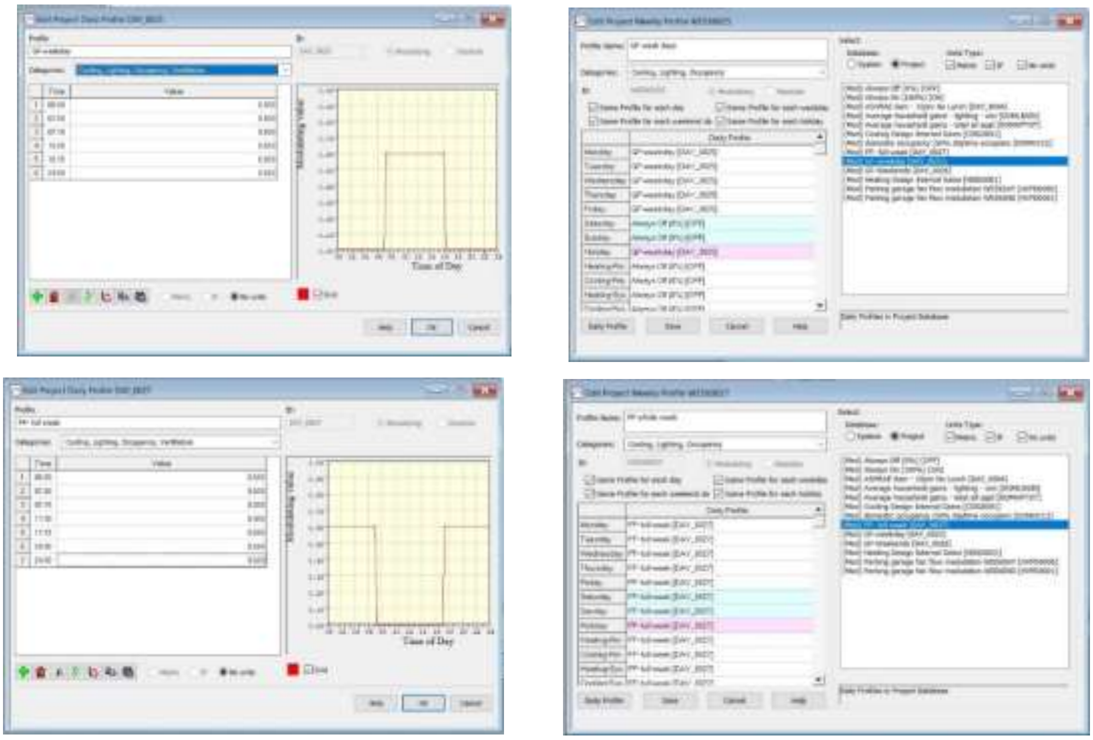


Figure 22: Daily and weekly thermal profiles for Apache simulation (Author 2021)

The reference literature also briefly provided the occupancy and their activities. Albedwawi created several thermal profiles based on her case study to match the occupancy behaviors (Albedwawi 2020). However, the profiles were not available in the literature appendix, therefore, new profiles were made for the current validation (Figure 22). Based on the weekly profiles, several thermal profiles were created, and the energy simulations were done using ApacheSim.

According to the reference case literature, the actual energy consumption was an average of two months of energy since the DEWA bill dates were irregular. As for the validation model case, multiple simulations were done with different thermal profiles until the results matched that of the original case. However, IES thermal profile allows only one amount of occupants per project. Therefore, the final validation results

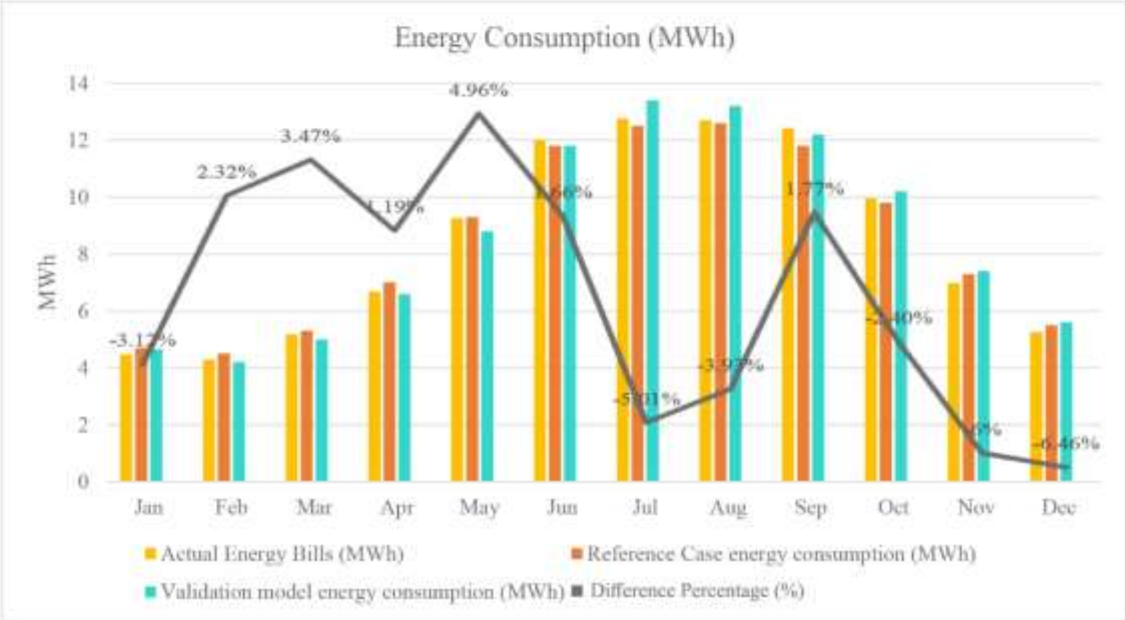


Figure 23: Annual energy consumption comparison (Author 2021)

are taken as the average of two simulation results with accurate occupancy of both floors of the villa. The final energy consumption is demonstrated through a bar chart, including the percentile discrepancy (Figure 23).

Table 4: Annual energy consumption data comparison (Author 2021)

Months	Actual Energy Bills(MWh)	Validation model energy consumption (MWh)	Difference percentage (%)
Jan	4.48	4.4	1.78
Feb	4.3	4.1	4.65
Mar	5.18	5.3	-2.31
Apr	6.68	6.6	1.19
May	9.26	8.8	4.96
Jun	12	11.8	1.66
Jul	12.76	13.4	-5.01
Aug	12.7	13.2	-3.93
Sep	12.42	13	-4.66
Oct	9.96	9.5	4.6
Nov	6.98	7	-0.28
Dec	5.26	5.6	-6.46

The difference percentages between the actual energy bills and validation model energy consumption range between 0.28-6.46% for the months January to December (Table 4).

While model validation includes comparing a simulation model behavior to the real system behavior, model calibration is the process of reducing the uncertainty of a model by comparing the predicted output (simulated result) to the actual measured data (ASHRAE 2014 n.d.). IES VE software is compiled with all the requirements mentioned for a simulation tool in section 4.3.2.4 of ASHRAE 14-2014 standards. They also specify that the computer model data should have an NMBE (Normalized Mean Bias Error) of $\pm\mathbf{5}$ % and a CV(RMSE) (Root-Mean-Square-Error) of $\pm\mathbf{15}\%$ for monthly values (ASHRAE 2014 n.d.).

Firstly, the NMBE was calculated using the formula:

$\boldsymbol{NMBE} = \frac{\mathbf{1}}{\bar{\boldsymbol{m}}} \cdot \frac{\Sigma_i^n = \mathbf{1}(\boldsymbol{mi} - \boldsymbol{si})}{\boldsymbol{n}-\boldsymbol{p}} \boldsymbol{x}\ \mathbf{100}\%$ (Ruiz & Bandera 2017), where,

$\bar{m}$= mean of measure values
n= number of total data
i=n^{th} value
mi= measure value
si= simulated value
p= number of adjustable model parameters, which is suggested to be zero.

Secondly, the CV(RMSE) was calculated using the formula:

$\boldsymbol{CV}(\boldsymbol{RMSE}) = \frac{\mathbf{1}}{\bar{\boldsymbol{m}}} \sqrt{\frac{\Sigma_i^n = \mathbf{1}(\boldsymbol{mi} - \boldsymbol{si})^{\mathbf{2}}}{\boldsymbol{n}-\boldsymbol{p}}}\ \boldsymbol{x}\ \mathbf{100}\%$ (Ruiz & Bandera 2017), where the letter notations were the same. The values of the equations are the same as the NMBE formula, except, the value of p is suggested to be one (ASHRAE 2014 n.d.).

The calculated NMBE for the validation data is **-0.7%** and CV(RMSE) is **-4.54%,** hence they are well under the acceptable range of ASHRAE, and the validation model is calibrated.

4.4 Base Case and Scenario Set-ups

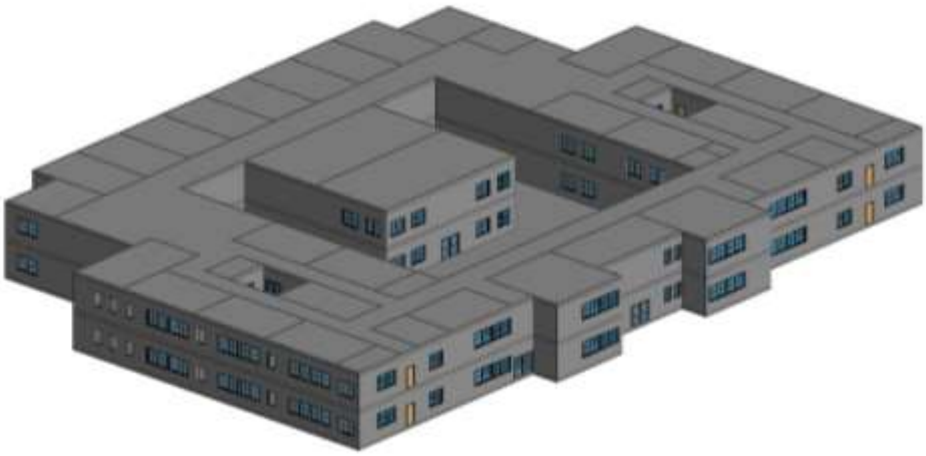


Figure 24: Base case model in Revit (Author 2021)

After effective completion of the validation procedure, the main research set-up was conducted. First, Autodesk Revit was used to create the 3D model (Figure 24) of the base case using the original AutoCAD floor plans (Figure 17). According to IES VE's tutorial program, it is suggested to model any building in a simplified manner. Therefore, the base case building's architectural outline was slightly simplified. The original height of the ground level, floors, slab, windowsill height, window heights, wall thickness, etc. were translated accurately to the Revit model. It is essential to note in this stage that primarily, the base case model is created with reference to the original architectural layout. Currently, the LIS building's courtyard is shaded with temporary shades, which will be considered later in the investigations.

4.4.1 Space Planning

The aim of this research was to investigate how energy and daylighting are influenced by different space layouts. Therefore, to conduct these investigations, several alterations of the base case architectural layout will be designed. To examine the effects of space layouts effectively, it is important to keep certain factors constant. Thus, the concept of space planning will be utilized to create multiple alterations of the base case layout. Space planning is a fundamental step in any architectural design process and is done either through manual sketching or using various software tools. In manual processes, architects and designers use "bubble" and "zoning" sketches to conduct space planning. In this

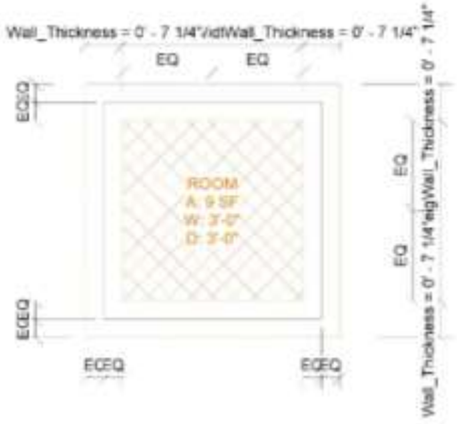


Figure 25: Revit Space Planning Tool- Rectangular (Sam 2015)

Figure 26: Base case layout with Space Planning Tool (Author 2021)

research, a Revit tool called "Space Planning Tool" will be used, which was developed by an architect (Figure 25)(Sam 2015) based on the same idea of bubble or zoning sketches. This tool allows zoning each space of a layout or floor plan and allocates color coding, name, and area in square feet. Moreover, if the space boundary is changed, the area is automatically changed. The spaces can also be scheduled into an Excel sheet. The reason why this tool is so effective in this particular research is the ability to alter the

No. of Spaces	Ground Floor	First Floor
Classrooms A (KG)	14	
Classrooms B (Grade 1 And 2)	8	
Classrooms C (Grade 3 And 4)		28
Teacher's Room	3	1
Supervisor Room	2	
Administration Area(with W/C)	1	
Canteen (KG)	1	
Indoor Playground (KG)	1	
Labs		2
Art Room		1
Library		1
Courtyard	1	
Atriums	2	2
Stores	4	4
Janitor Room		2
General W/C	4	6

Classrooms	Administrative	Activities	Courtyard/atrium	General services

Figure 27: Color coded Space schedule for base case (Author 2021)

space layout while keeping the same area, number, and function of spaces. This allows the base case layout's space areas, number, and function of spaces to be kept constant.

4.4.2 Space Layout Scenarios

After creating the space planning layout for the base case (Figure 26), a color-coded space schedule was created (Figure 27). The base case is a two-floored building with identical layouts for both floors. Therefore, only the ground floor space plan is displayed for simplification. In order to produce alternative layouts, multiple parameters of the base case's architectural layout were considered constant or non-variable:

- The building plot boundary
- Number of respective spaces
- Area sq. ft for each space
- Adjacencies of spaces based on function
- External windowsill height, window width, and heights

Considering the various design, flexibility, and function knowledge gained from the literature review and present experience, 7 different layouts were generated for further investigations. The layouts were designed manually, that is, without the use of algorithmic AI tools to replicate the early space planning process from the designer's perspective. Multiple entrances and emergency exit points are provided, as well as staff and general services adjacencies are carefully spaced. The classroom clusters were also placed based on the grades. The design and transitional spaces of all 7 layouts are discussed in the below subsections.

4.4.2.1 Scenario 1

This space layout was designed with the courtyard being in the South-East and East side of the building (Figure 28). Previous research done on the relation between courtyards and thermal comfort suggested that east or west-oriented courtyards provide a comfortable environment in the summer. However, courtyard shading might be required, which will be discussed in the next chapter. The courtyard is directly adjacent to the KG indoor play area. Two atriums are placed in the center of the layout.

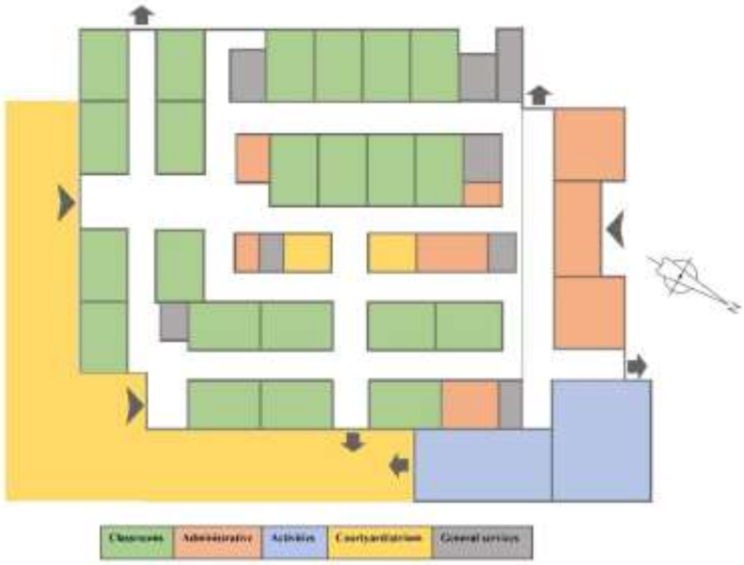


Figure 28: Scenario 1 zoning plan (Author 2021)

4.4.2.2 Scenario 2

A research paper reviewed earlier in the literature review studied the effects of school building geometry. This research concluded that an H-shaped building with wither open or closed courtyards in the gaps was best in thermal and energy performance (Zhang, Bokel, et al. 2017b). Therefore, H shaped layout is utilized in scenario 2 (Figure 29) to investigate this theory. One of the courtyards is connected with the KG indoor play area,

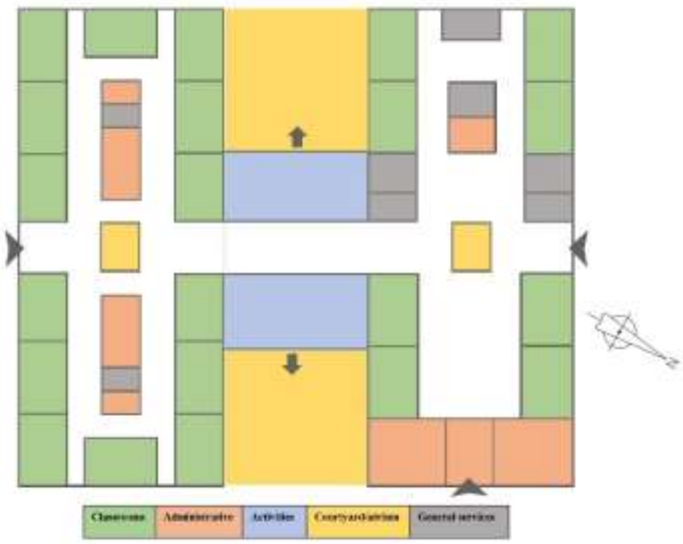


Figure 29: Scenario 2 zoning plan (Author 2021)

while the other is connected with the existing outdoor playing yard. The atriums are placed on both sides of the layout and the corridors are kept spacious.

4.4.2.3 Scenario 3

This layout has a rectilinear courtyard facing the South-East direction (Figure 30). Classrooms are distributed mostly in the East. North and North-West sides. The two atriums are placed carefully in the internal locations of the layout. Administration offices are kept secluded from the classrooms.

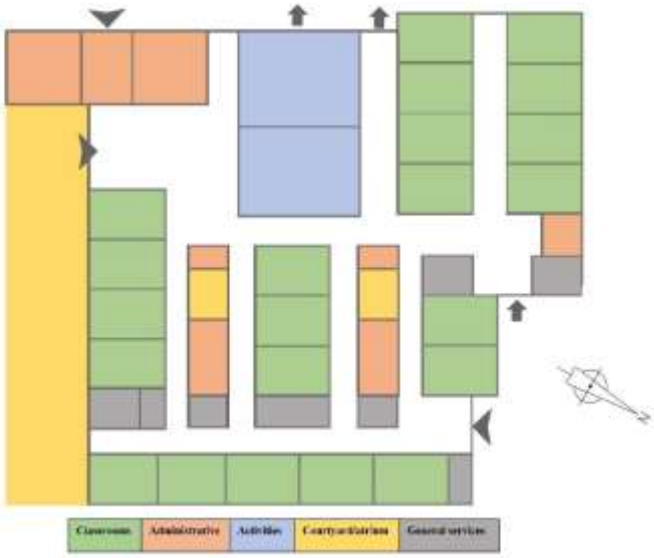


Figure 30: Scenario 3 zoning plan (Author 2021)

4.4.2.4 Scenario 4

Scenario 4 layout is almost identical to the base case, except the courtyard is moved from the center to the Eastside (Figure 31). Four internal atriums are provided in this layout with increased length. This layout intends to investigate the findings from research reviewed in the literature review on the atrium as a transitional space. The results of the research showed that open roof atriums can act as tempering spaces in hot climates, despite the surrounding spaces' internal temperatures (Odero, Marín & Gómez 2020).

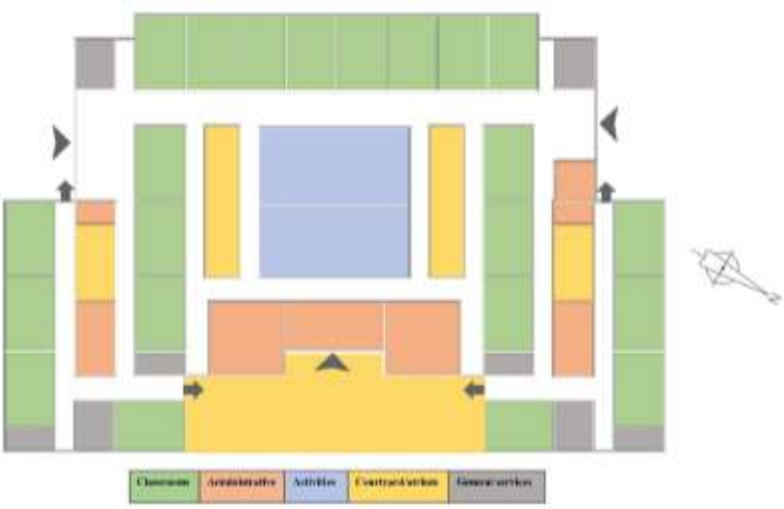


Figure 31: Scenario 4 zoning plan (Author 2021)

4.4.2.5 Scenario 5

The C-shape layout was studied in research to explore the effects of building geometry (Zhang, Bokel, et al. 2017b). Additionally, this type of layout was also studied by Salameh and Taleb in their research about courtyards in school buildings, as it creates a semi-closed courtyard (Salameh & Taleb 2017). Therefore, scenario 5 utilizes a C-shaped layout (Figure 32), with a semi-closed courtyard on the South-West side of the building. Furthermore, the layout has a U-shaped corridor plan, which is suggested to be cohesive, perceptible, and well-accepted for school interiors (Mustafa & Rafeeq 2019).

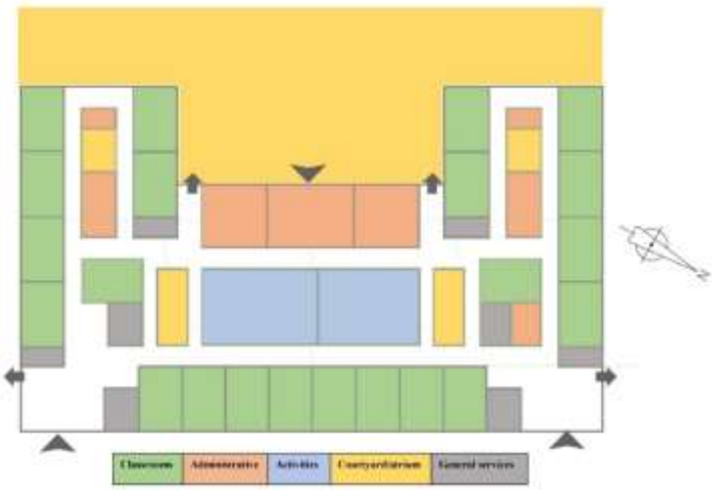


Figure 32: Scenario 5 zoning plan (Author 2021)

4.4.2.6 Scenario 6

Scenario 6 is an L-shaped layout motivated by previously mentioned literature (Zhang, Bokel, et al. 2017b). A unique aspect of this layout is it can be implemented in the case study building plot in 4 different mirrored directions. For the purpose of this research, only 1 of the options is investigated (Figure 33), with a Semi-opened (Salameh & Taleb 2017) courtyard facing the South and South-West side. The classrooms are arranged in small clusters and a larger atrium is placed in the center.

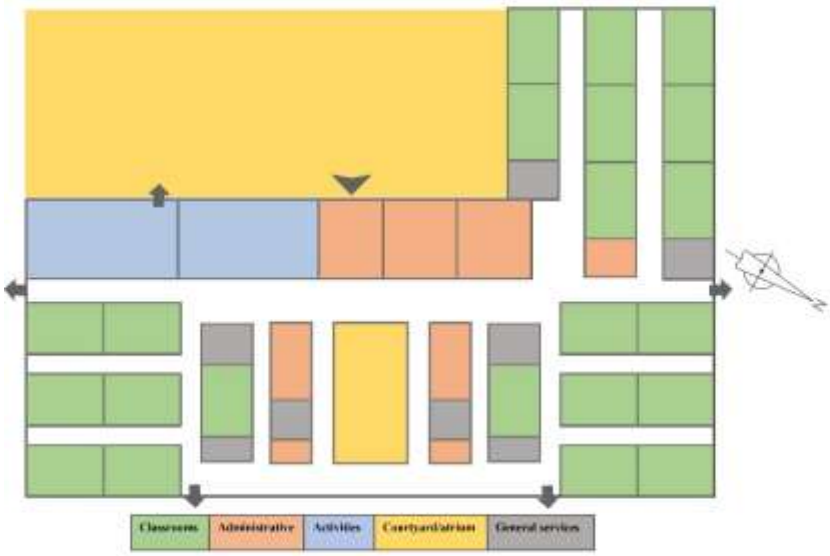


Figure 33: Scenario 6 zoning plan (Author 2021)

4.4.2.7 Scenario 7

This is the final layout of this research and is designed with a slightly different approach than the previous layouts. The interior spaces of this layout are arranged by mimicking ADEC's KG+Cycle 1 school's layout template mentioned in Section 2.5.2 (Al Dakheel 2017). In the template, classrooms were arranged in small clusters with large corridor spaces for breakout sessions for children. This concept is developed in this layout, considering the size and constraints of the building plot. A smaller internal courtyard is added with two atriums (Figure 34).

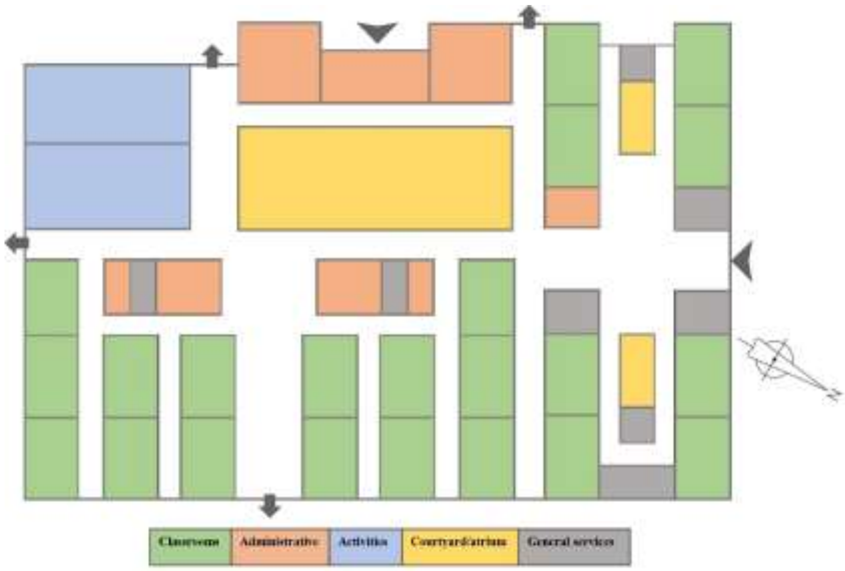


Figure 34: Scenario 6 zoning plan (Author 2021)

4.4.3 Circulation Area Evaluation for Scenarios

Circulation area is a crucial aspect to consider during architectural space programming for non-residential buildings. This is often calculated by first determining the space requirements, area, and quantity of that particular project, also known as the Net Square Footage (NSF) and the Usable Square Footage (USF) (Gensler 2012). BOMA (Building Owners and Managers Association International) publishes standards for measuring building spaces, which are ANSI approved. These standards are usually used for rentable spaces such as offices (ANSI/BOMA Z65.1), retail shops, industries, and mixed-use commercial buildings (ANSI/BOMA Z65.6). However, since this research is working on an existing project, the given formula for CF (Circulation Factor) will be used to compare the scenarios against the base case. Here, the CF is the percentage of USF that consists of the circulation area (Gensler 2012) and is calculated as Circulation factor = Circulation Area ÷ USF x 100%.

Table 5: Circulation Factor (Author 2021)

Scenarios	Circulation Factor
Base case	34%
Scenario 1	37%
Scenario 2	40%
Scenario 3	37%

Scenario 4	31.5%
Scenario 5	33%
Scenario 6	34%
Scenario 7	36.6%

The recommended percentage for CF according to BOMA standards is between 25%-40% (Gensler 2012). As observed from Table 5, CF for the base case is 34%, and range between 31%-40% for the scenario 1 to 7, hence being in the percentile range. Scenario 1 and 2 have the highest CF of 37% and 40% respectively due to the layout shape calling for spacious circulation. Moreover, scenario 2 provides adequate spaces for small breakout activities in the corridors which is highly encouraged by ADEC's school design manual (ADEC 2013). Scenario 7 has a CF of 36.6% which is due to the breakout spaces created for the children. Scenario 4 has the least CF of 31.5% and therefore is a compact layout.

4.5 Simulation Set-up and Procedures

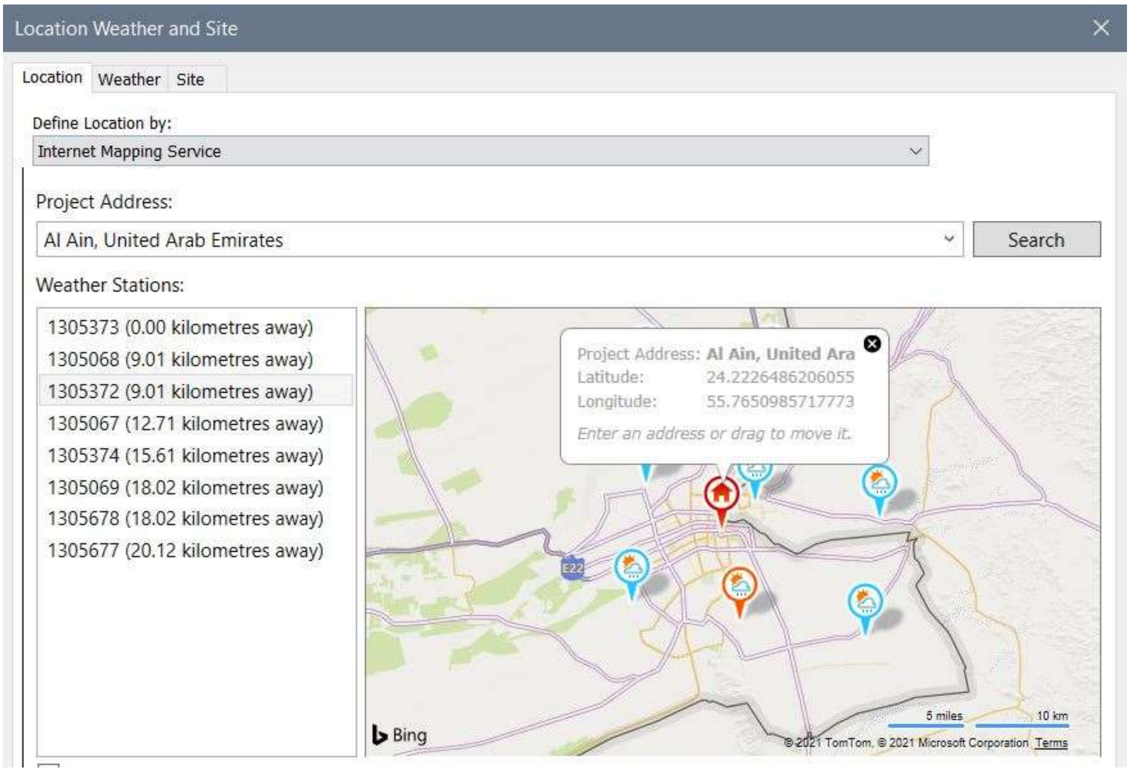
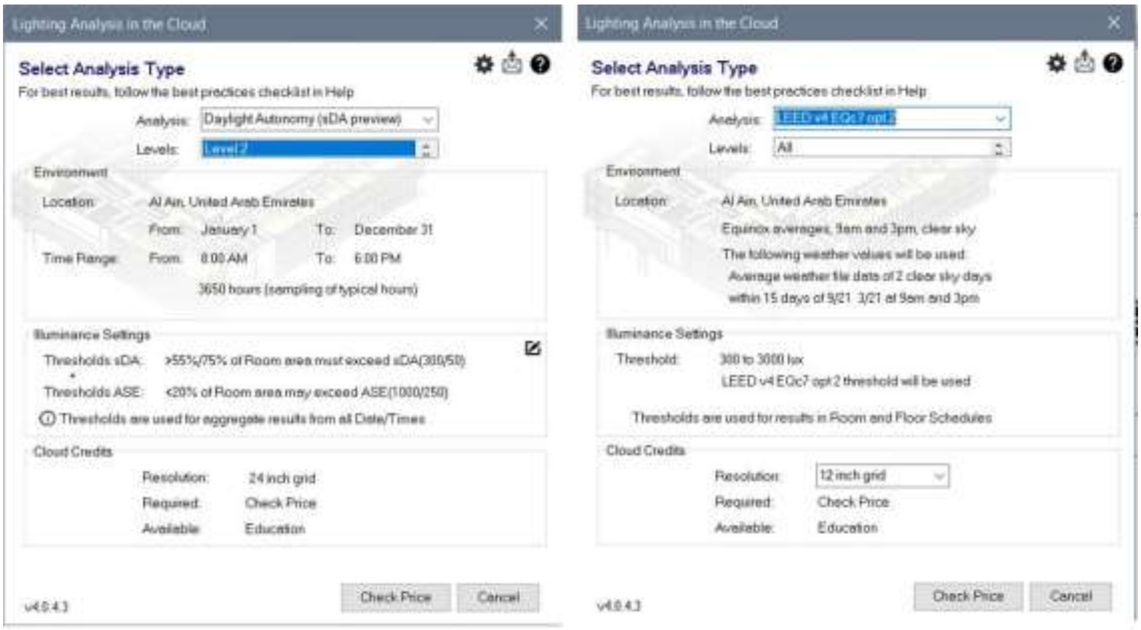


Figure 35: Internet mapping service in Revit (Author 2021)

This last section of Chapter 4 will discuss the simulation setup for energy and daylighting simulations and their procedures. As mentioned in Chapter 3, three different software will be used independently to conduct the simulations, namely IES VE, Revit, and DIALux. After the simulation procedures, the results will be examined in detail in the next chapter.

4.5.1 Daylight Analysis in Revit



sDA Analysis LEED v4 EQc7 Analysis

Figure 36: Lighting analysis window for Revit cloud (Author 2021)

Revit has a cloud-based feature to run daylight simulations within the software. The feature is a plugin developed by Autodesk Insight and is free to install. Moreover, the simulation procedure is pretty straightforward and can be conducted right after the modeling is done. First, the location and weather data were specified in Revit and the closest weather station to the case study site was chosen using the internet mapping service (Figure 35). Next, lighting analysis was run in the cloud by choosing the parameter type. In this research, analysis for the sDA (Spatial Daylight Autonomy) was performed. Additionally, a supporting simulation of LEED v4 EQc7 was conducted (Figure 36). The sDA analysis will show the annual daylight autonomy of the scenarios and how much of the space percentage has passed the standard values. On the contrary, the LEED v4 EQc7 analysis will provide analysis from a different point of view for comparison purposes.

Both of these standards will be defined in the next chapter. The simulations run on Revit cloud and can be viewed inside the file as floor plans of the building once completed. The daylight analyses on Revit are done for both the floors of each scenario and are on annual basis and the results are obtained.

4.5.2 Daylight Analysis on DIALux

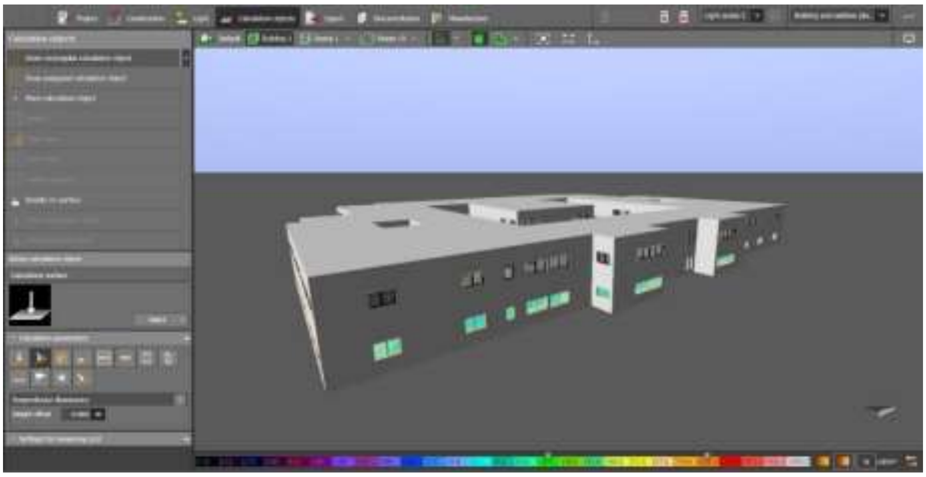


Figure 37: DIALux analysis (Author 2021)

DIALux software was used to conduct the DF (Daylight factor) and Illuminance simulation. Since Revit simulations conduct whole building analyses, an orientation-based analysis was done on DIALux. Both the AutoCAD plan and Revit model were initially imported into the software (Figure 37) and several data were entered, such as the location of the project, weather, site type, date, time, and sky conditions. Then, four classrooms from each floor were selected facing North, East, West, and South façade. For the illuminance analysis, three days were chosen based on the seasons in the UAE: March 21, June 10, and December 2 indicating Spring, Summer, and Winter seasons respectively. Furthermore, three timings for each day were decided to investigate the morning, mid-day, and afternoon results.

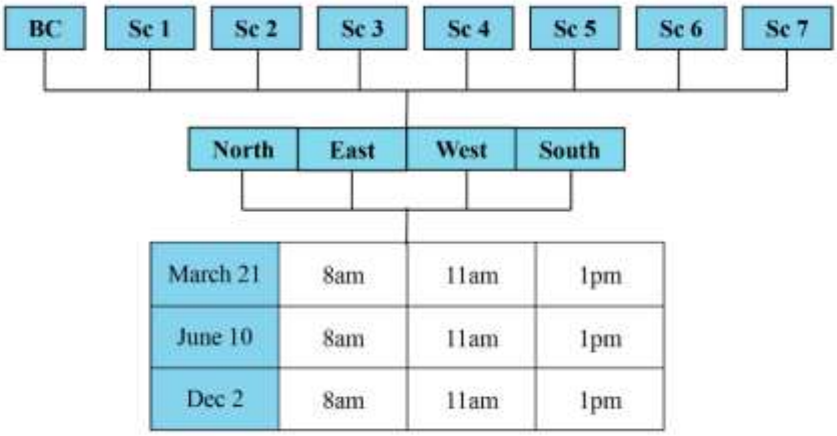


Figure 38: Daylight analysis schedule for DIALux (Author 2021)

The analysis schedule is clearly shown in (Figure 38). DF however is calculated on an annual basis and therefore will be taken from the classrooms in four directions independent of the selected times. After DIALux performs the simulation, the results are available in floor plan form with false-color contours as well as written documentation.

4.5.3 Energy Simulation in IES VE

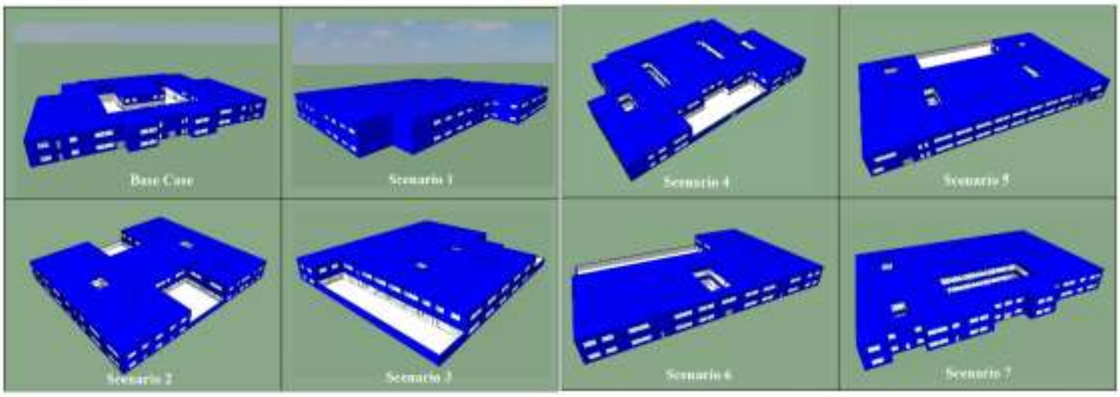


Figure 39: Scenario models in IES (Author 2021)

After the layouts were created using the space planning tool, they were modeled in Revit and exported to IES for the energy simulation (Figure 39). The construction features are directly imported from the Revit file to create a Construction Profile in IES that will input data about the building walls, floor, ceiling, windows, doors, material properties, U-values, etc. However, the most crucial feature for energy simulation is the Thermal Profile. Thermal profiles are used in IES by entering various data sets such as HVAC conditions, occupancy, operating hours, lighting gains, etc., and creating schedules based on day, week, or year for the simulation to run. Thermal profiles allow the building energy simulation results to be accurate and resemble real-life scenarios. However, creating a thermal profile for a school is slightly complicated than that of commercial space. This is due to the various class timing, occupancies, and light schedules. Therefore, an effective, space-by-space approach is developed for this research. First, some primary data related to the case study are recorded.

Table 6: Case study data for thermal profiles (Author 2021)

School hours	7 am – 2 pm
Lunch breaks	10am-10.30am and 12.10-12.30pm
School holidays	Summer holidays: July 11- August 22 Spring holidays: March 28-April 10 Winter holidays: December 14-31
No. of students (KG to Grade 5)	1480
No. of teachers and teaching assistants	92
HVAC system temperature in occupied hours	23°C
HVAC system temperature in unoccupied hours	26°C
HVAC system temperature in holidays	32°C

Table 6 shows the initial information needed to create the thermal profiles for IES energy simulations. The school hours and holidays are recorded from the updated LIS academic timetable (Liwa International School 2021) (Further available in Appendix C). The no. of students and teaching staff is acquired from the latest ADEC report of the school (ADEC 2020). The air conditioning temperature is kept constant at 23°C during occupied hours as per the ADEC regulations (ADEC 2013). Similarly, two values of set-back temperatures are fixed for the profiles. According to ASHRAE 90.1 energy standards, 1b climate zones (such as the UAE) shall have an adjustable cooling setpoint of 90°F or 32°C as setback temperature to prevent high humidity levels (ASHRAE 2010). However, the latest research is done on building retrofit in Abu Dhabi state suggests 26°C be an optimal temperature for setback hours. Therefore, the setback temperature for unoccupied hours on weekends is kept at 26°C, and for weekends and holidays, it is kept 32°C.

Figure 40: Modulating daily profiles (Author 2021)

With the help of the above schedule information, 3 modulating daily profiles (Figure 40) were created based on space, schedule, and occupancy. These profiles include class hours, lunch breaks, and spaces that need constant control. Keeping these profiles as the base, 3 weekly profiles, and finally, 4 annual profiles were created. The holidays are well accounted for in these 4 profiles, created for 4 categories of spaces:

1. Classrooms/labs/admin offices
2. Canteen and indoor play area
3. Teachers/ staff rooms
4. Corridors/WC/storerooms

This space-by-space method is ideal for buildings/spaces with a systematic pattern of schedule. Next, other details of internal gains are added to the profiles.

Table 7: Occupancy and lighting gain data (Author 2021)

Occupancy	
Maximum sensible gain (W/person)	56.25
Maximum latent gain (W/person)	41.25
Fluorescent lighting	
Maximum illuminance (lux)	1000
Lighting power density (W/m^2) : Classrooms	13.4
Corridors	7.1
Cafeteria	7.0
Office	12.0
Restrooms	10.6
Storage rooms	6.8

Table 7 shows data regarding the occupancy and light gain are taken into consideration for the thermal profiles. Firstly, the maximum sensible and latent gain are taken 56.25

and 41.25 W/person respectively. These values are the gains of children, as they dominate the majority of the occupants of the building, and are calculated based on the 2017 ASHRAE handbook. The values are 75% of an average adult male's gain for light seated work or standing in a 23-24°C conditioned room, which is 75 sensible and 55 latent gain (ASHRAE 2017). Moreover, the number of staff is adjusted according to the used metabolic gain. Secondly, the LPD (Lighting Power Density) data for lighting heat gain is applied using the space-by-space method. The values for different spaces are in accordance with the ASHRAE Standard 90.1-2013 and were used in the respective thermal profiles (ASHRAE 2017).

The last step before running the simulation is to place daylight sensors using the RadianceIES tool. Sensors are placed in the interior spaces that are exposed to the exterior windows in all four directions. The sensors were then simulated, which will be read later by Apache during the simulation. Additionally, a separate dimming profile is created to support the sensors using the fuzzy logic formula given by the IES manual and linked to the main thermal profiles (IESVE 2020). Apache dynamic simulation was then conducted, considering the sun cast and RadianceIES link, and the energy simulation parameters were recorded. For the rest of the scenarios, IES allows importing thermal profiles from previous files to keep consistency. The thermal profiles templates were allocated respectively for each scenario and results were obtained.

4.5.4 Sun-cast Study for Courtyards

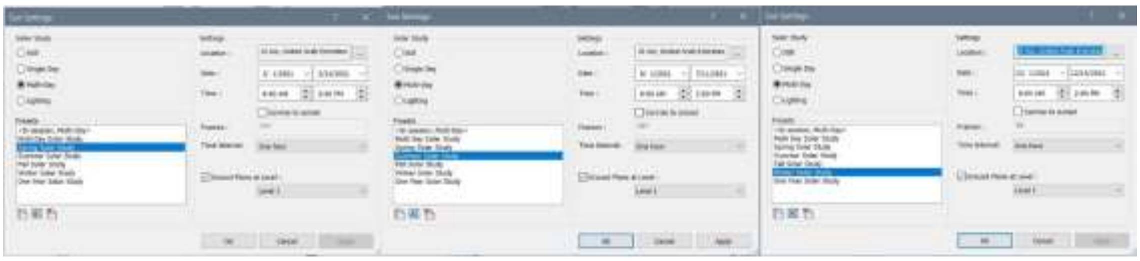


Figure 41: Sun-path settings for analysis in Revit (Author 2021)

A brief sun-cast study is conducted specifically to examine the sun exposer on the courtyards of each scenario. This study was conducted for Spring, Summer, and Winter seasons, for 8 am, 11 am, and 1 pm (Figure 41). The aim of this study is to support the best-case scenario(s) in the results discussion and conclusion. As the scenarios are simulated without any courtyard shading, this brief study can support different hypotheses, as well as provide guidelines for further addition of strategies and investigations.

4.6 Chapter Summary

Chapter 4 of the current dissertation has discussed the research's case study building, which is a private school situated in Al Ain city, UAE. Different aspects of the school have been presented, such as the building site, floor plans, and elevation drawings. The climate and sun path of the location were also presented. Next, software validation and calibration were performed for model and energy simulation on IES, and the results were found well in the standard range. After these initial procedures, this chapter discussed a base for the main simulation procedure through the base case model setup, space planning, and scenarios generation. Seven different layouts were created and explained briefly for different aspects. Additionally, all of the scenarios were compared against their circulation areas. Finally, this chapter discussed the energy and daylighting simulation setup and procedures using the software tools selected earlier in the previous chapter. The current chapter provides an elaborate perspective of the research's investigation from scratch. The step-by-step progression from initial data to final simulation setup offers a good understanding of how the investigation developed and led to the results which will be discussed in the coming chapter.

Chapter Five

5 Results and Discussions

5.1 Overview

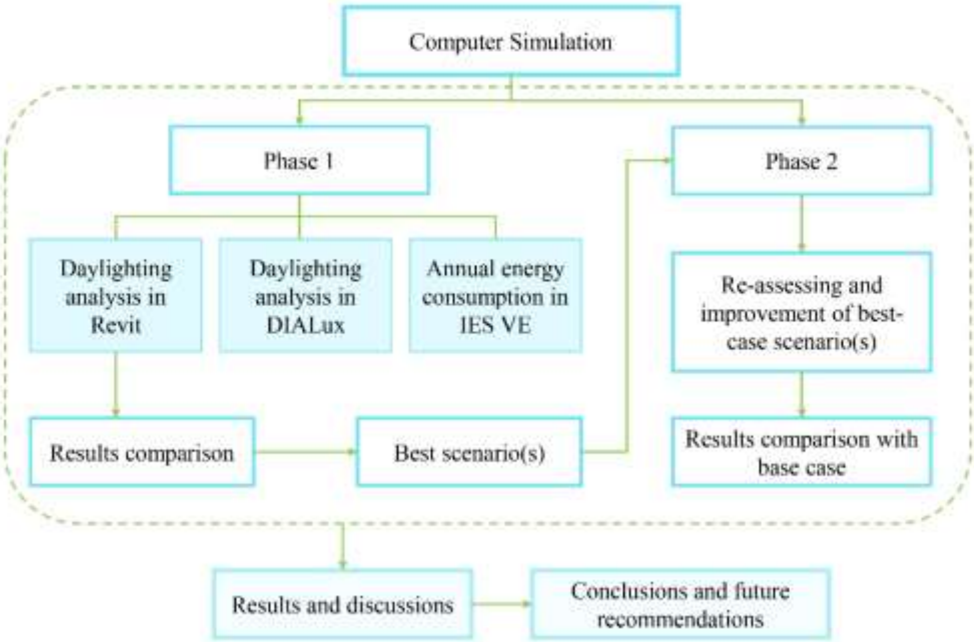


Figure 42: Results and Discussions sequence (Author 2021)

In this chapter, the simulations discussed in the previous chapter will be presented and examined in detail. Phase 1 (Figure 42) is the main research investigation and will be presented first and their results will be discussed. Moreover, the results of the sun-path study conducted in Revit will be presented. Next, based on this discussion, Phase 2 will be presented with discussion. The obtained results from both phases will be critically analyzed in this chapter considering the goal of this dissertation.

5.1.1 Parameters and Definitions

Before proceeding to the results, it is important to define the terms of the parameters analyzed in this research. This will support a better understanding of the results.

1. **Spatial Daylight Autonomy and Annual Sunlight Exposure (sDA and ASE):** These thresholds are used by LEED to analyze the quality of daylighting in interior spaces. The sDA ($sDA_{300,50\%}$) threshold says that a minimum of 50% of the total building floor area must receive more than 300 lux for 3650 annual hours (Autodesk 2021). LEED points can be earned if 55%, 75%, or 90% floor area of the total floor area receives the threshold (USGBC 2021). On the other hand, The ASE ($ASE_{1000, 250}$) threshold says

that the percentage of the floor area that gets over 1000 lux for more than 250 of 3650 annual hours should not exceed 20% of the total floor area. LEED points can be earned if rooms have ASE less than 20% and 20% in different space options (USGBC 2021).

In the research simulation, the percentage of the total building area passing the sDA and ASE threshold will be determined, that is, both sDA and ASE thresholds must be met by rooms (Autodesk 2021).

2. **Illuminance (E):** It is the ratio of the luminous flux that strikes a certain surface to the size of this surface and can be as lm/m² = lx (DIALux evo 2016). It will be crucial to highlight that illuminance is mostly calculated "including" artificial lights in the interior spaces. However, for daylight-only cases, this can be a vital parameter to determine required light levels for artificial light sources.

   The unit of E is Lux (short form lx). The required illuminance level depends based on different tasks involved in space and is defined by various international standards. In this research, the standards were approved by ADEC (Table 2- Chapter 2), which states that an average E of 400-500 lux is the ideal range for teaching areas. Moreover, below 300 lux is considered insufficient, and lux exceeding 500-600 lux could cause glare and internal gain.

3. **Daylight factor (DF):** This indicates the percentage of daylight penetrated an interior space of a building as the ratio of illuminance at any point in the indoor to the outdoor illuminance (Amoêda & Carneiro 2020). A standard CIE overcast sky condition is needed for DF calculation. According to CIBSE Lighting standards, the DF of interior space should range between 2%-5% (CIBSE 2010).
4. **Chiller energy (CE):** The energy consumed by the chiller unit to cool the building interior. This is related to the cooling load of the building. The more the load, the more energy is required for the chiller.
5. **Lights energy (LE):** The electrical energy consumed by artificial lights.

5.2 Phase 1- Daylight Analysis

This chapter will first present the analyses related to daylighting which were done using Revit and DIALux evo. For the purpose of clarity, results of all the scenarios including the base case will be presented first, and then followed by their discussions individually.

5.2.1 Daylight Autonomy (sDA and ASE)

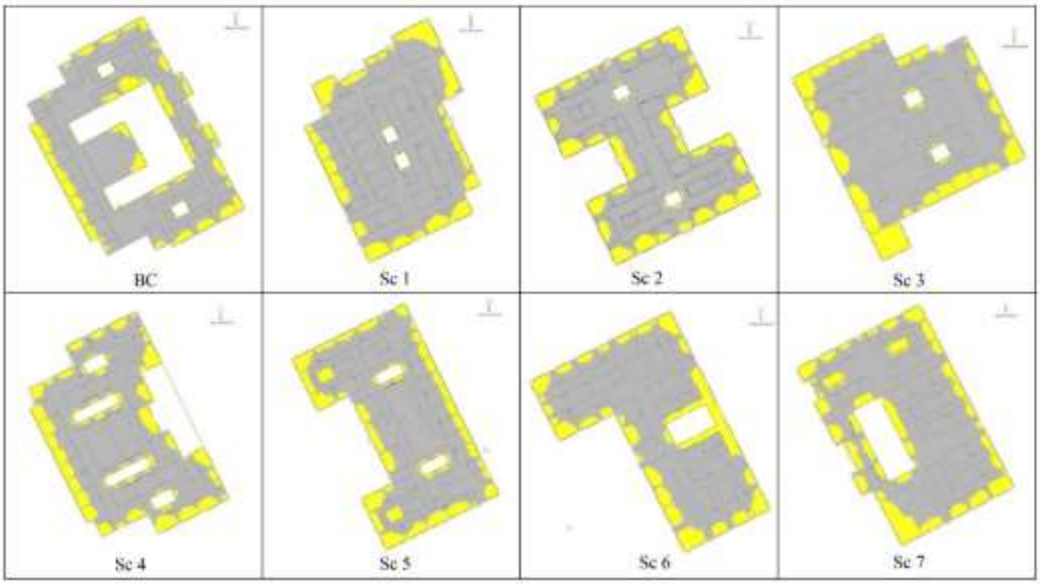


Figure 43: sDA Analysis in Revit (Author 2021)

The sDA and ASE simulation was conducted using Revit and is done on an annual basis, from Jan 1 to Dec 31, 8.00 am to 6.00 pm (Figure 43). The results are obtained in different considerations to investigate all aspects.

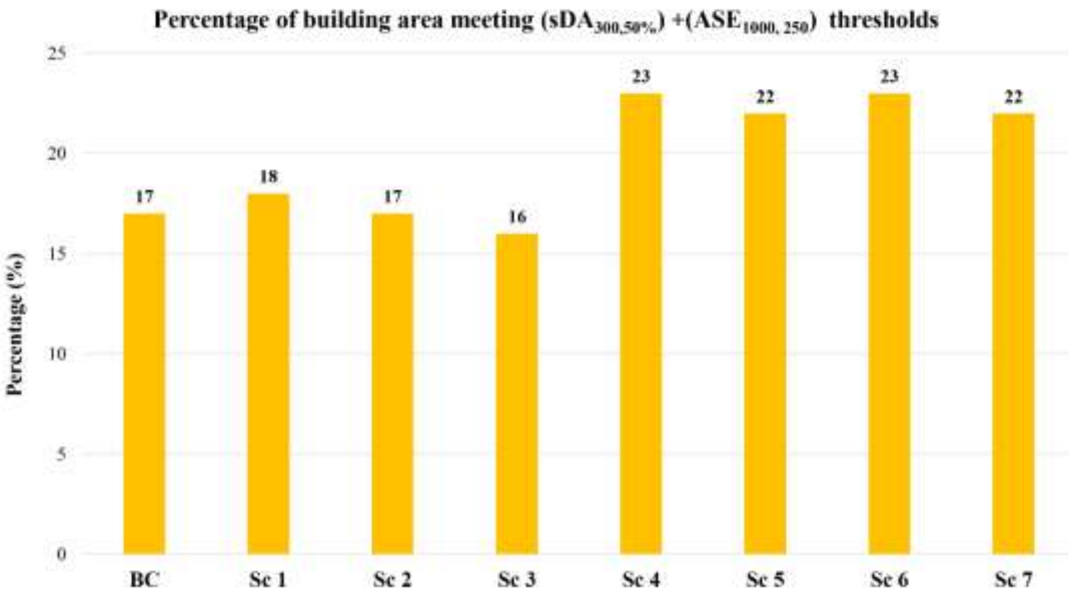


Figure 44: Result of (sDA300,50%) +(ASE1000, 250) for all scenarios (Author 2021)

Figure 44 illustrates the percentage of total building floor area that meets both the $sDA_{300,50\%}$ and $ASE_{1000,\ 250}$ thresholds together. The BC (base case) shows 17% total building floor area meeting both the thresholds. Sc (scenario) 3 shows the lowest, 16% while Sc 4 and 6 indicate the highest 23%. Moreover, Sc 5 and 7 show 22% which is closer to the highest values. Therefore, in the case of meeting both the thresholds together, Sc 4 and 6 are the best layout options.

Table 8: Detailed breakdown of sDA analysis (Author 2021)

Layouts	Building area that meets sDA>50% hours threshold (%)	Rooms that meet sDA >55% room area (%)	Rooms that meet sDA 75% room area (%)	Building area that meets >ASE hours threshold (%)
		(LEED point options)		
Base case	**24**	**17**	**15**	**6**
Scenario 1	**22**	**10**	**7**	**7**
Scenario 2	**26**	**19**	**12**	**7**
Scenario 3	**23**	**9**	**8**	**5**
Scenario 4	**34**	**21**	**16**	**16**
Scenario 5	**27**	**13**	**9**	**10**
Scenario 6	**28**	**14**	**6**	**10**
Scenario 7	**30**	**19**	**13**	**13**

Furthermore, in the investigation, the Revit simulation also provides a detailed breakdown of the analysis on a different aspect basis which is presented in (Table 8). Firstly, the sDA threshold alone is calculated, in which we can see the base case has 24% of the total area meeting the sDA threshold for more than 50% annually. The lowest is Sc 1 with 22% of the area meeting the threshold, while Sc 4 is the highest being 34% area. Furthermore, other options for LEED points are analyzed. Sc 4 has the highest percentages of rooms that achieve sDA >55% and 75% of the total room area, which are 21% and 16% respectively. The lowest value is shown for sDA >55% is Sc 3, whereas for sDA 75% it is Sc 6. On the contrary, the highest building area that meets >ASE hours is Sc 4 with 16% and the lowest is Sc 3 with 5%.

5.2.2 Illuminance (E) Analysis

The average illuminance (E) analysis was conducted in DIALux following the scenario strategy mentioned in the previous chapter (Figure 38). This analysis will be done for three selected days of this year: March 21, June 10, and December 2, for three timings of each selected day. This is because illuminance is not calculated as a combination of a single day, month, or year due to the continuous changing of the sun's position.

5.2.2.1 March 21

Table 9: Average illuminance (lux) analysis- March 21 (Author 2021)

	8 am				11 am				1 pm			
	North	**East**	**West**	**South**	**North**	**East**	**West**	**South**	**North**	**East**	**West**	**South**
BC	144	141	113	143	282	276	500	522	494	503	486	494
Sc 1	160	218	209	207	359	490	470	465	380	518	497	492
Sc 2	248	419	422	290	554	936	940	647	586	989	993	684
Sc 3	215	235	233	216	483	527	524	484	511	557	554	512
Sc 4	231	216	227	239	519	485	509	536	495	502	486	500
Sc 5	203	300	220	205	456	674	493	459	482	713	522	486
Sc 6	220	336	227	214	493	755	509	481	521	798	539	509
Sc 7	230	217	219	242	516	488	492	544	545	516	520	575

Table 9 shows the illuminance analysis for March 21. Average E values below 300 lux are marked in red since they are below minimum lux requirements. Similarly, values above 600 lux are shaded in yellow to depict the possibilities of glare due to higher lux values than recommended. Considering the E values at 8 am, almost all scenarios show below 300 lux except the east classrooms of Sc 2, Sc 5, and Sc 6, and west classroom of Sc 2. At 11 am and 1 pm, all scenarios reveal E within the recommended lux range, except for north and east classrooms of the base case being below 300 lux. These results imply that the classrooms facing towards the façade can turn off or dim light intensity after 8-9 am in the spring. However, it is noticed that Sc 2 is exposed to high E values for east, west and south classrooms in both 11 am and 1 pm. Likewise, Sc 5 and Sc 6 face the same glare for east classrooms at the same time.

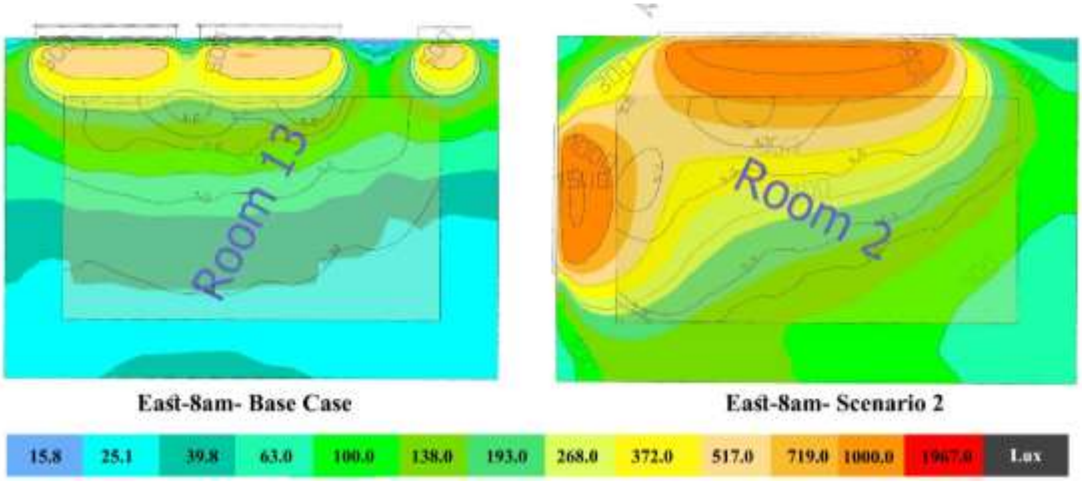


Figure 45: Comparison between below and recommended E values (Author 2021)

To demonstrate classrooms with E below and within recommended values, east classrooms of BC and Sc 2 are presented at 8 am (Figure 45). It can be seen that as the room gets deeper, lux levels reduce in the BC, resulting in an average E of 141 lux. In Sc 2 however, daylight is distributed deeper into the plan and the E is 419 lux, although north and south classrooms have lower E values for the same layout.

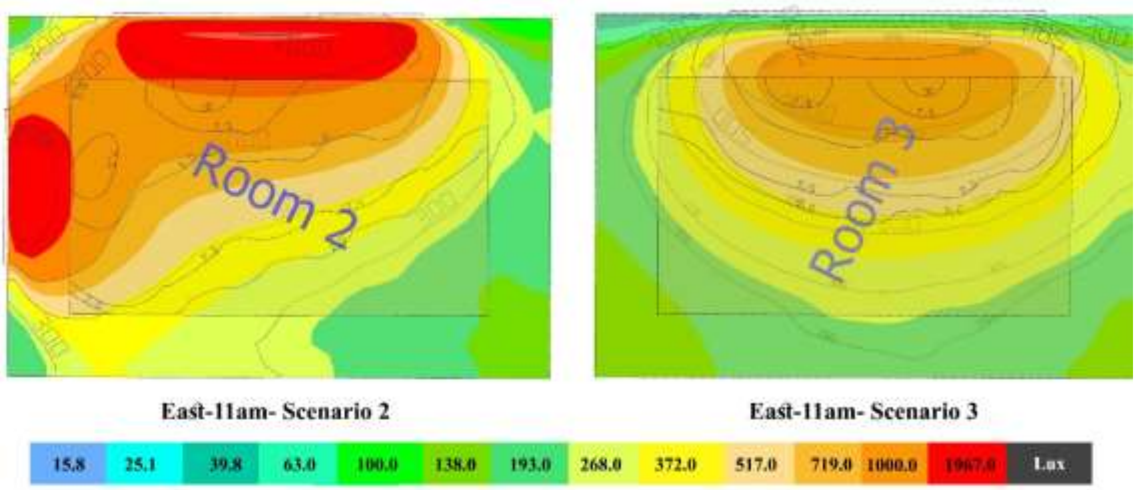


Figure 46: Comparison to assess high average E value vs recommended range (Author 2021)

Furthermore, the east classroom is taken from Sc 2 and Sc 3 at 11 am is presented to evaluate the high E for comparison (Figure 46). As it can be seen, Sc 2 classroom generated high lux spots near the windows, which could be caused by the shape and orientation of the classroom in the layout. While the daylight distribution reaches deeper into the Sc 2 classroom, excessive illuminance could cause the internal temperature to rise.

5.2.2.2 June 10

Table 10: Average illuminance (lux) analysis- June 10 (Author 2021)

	8 am				11 am				1 pm			
	North	**East**	**West**	**South**	**North**	**East**	**West**	**South**	**North**	**East**	**West**	**South**
BC	202	197	158	200	574	541	550	594	586	564	592	600
Sc 1	224	306	294	291	401	548	525	520	414	566	542	537
Sc 2	346	584	586	404	618	1044	1048	722	638	1077	1082	745
Sc 3	302	330	328	303	540	589	586	541	557	608	605	559
Sc 4	206	200	156	210	580	542	569	600	599	560	588	619
Sc 5	285	421	308	287	510	753	552	514	526	778	570	530
Sc 6	308	472	318	301	551	844	569	538	569	871	588	556
Sc 7	322	305	307	340	576	546	550	608	595	563	568	628

The average E values for June 10 are shown in Table 10. The BC and Sc 4 tend to show lux values below 300 for all four classrooms at 8 am. Similarly, Sc 1 displays a lower average E for north, west, and south classrooms, as well as Sc 5 for north and south classrooms. Furthermore, Sc 2 shows very high average E values, sometimes exceeding 1000 lux for all classrooms at 1 am and 1 pm. This could result in glare and increased internal gain. Likewise, Sc 5 and Sc 6 show similar E values as March for the same classrooms. East and west classrooms of Sc 3 also have high E value at 1 pm, south classroom of Sc 4 at 1 pm, and Sc 5 at 11 am and 1 pm.

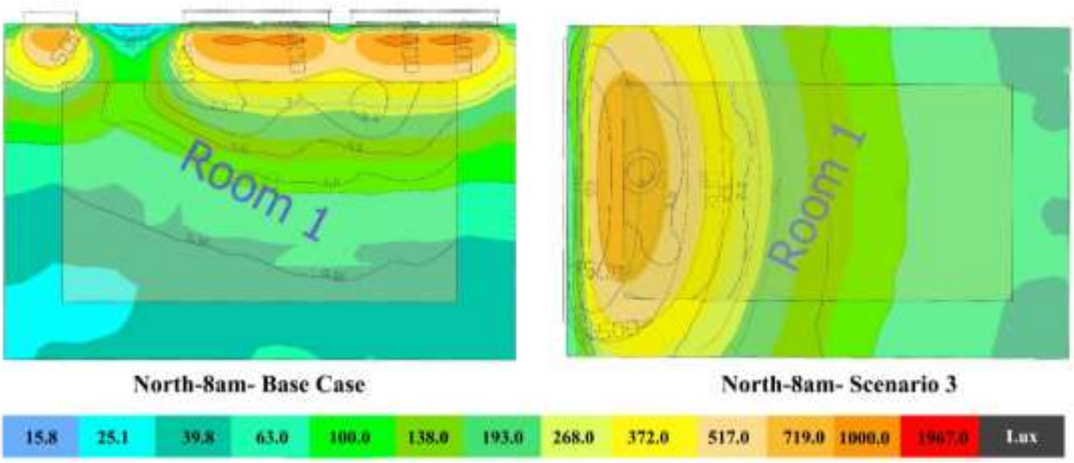


Figure 47: Comparison between base case and scenario 3 (Author 2021)

To demonstrate the low average E value at 8 am, the north classroom of the BC is compared with Sc 3 (Figure 47), where their values were 202 lux and 302 lux respectively. It can be seen that daylight does not reach much deeper into the plan of BC and is very low towards the other side of the window compared to Sc 3.

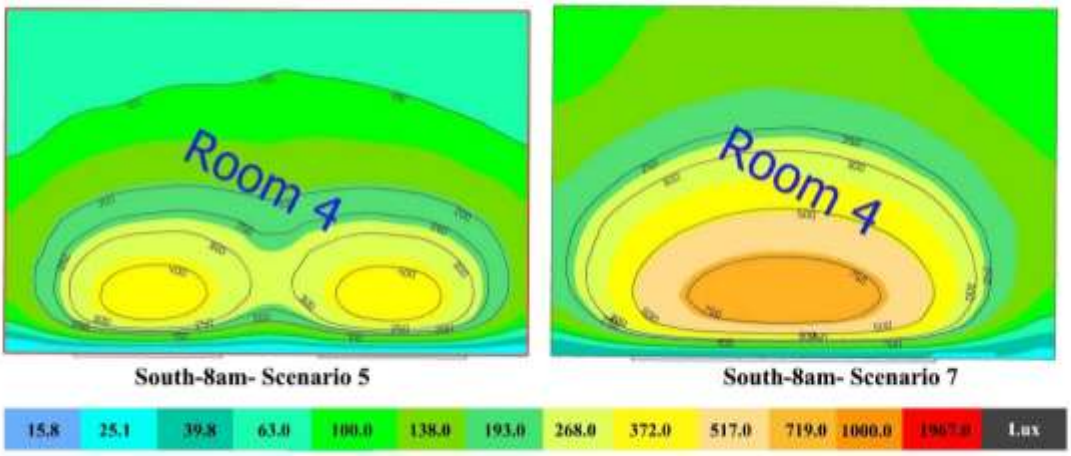


Figure 48: Comparison for a different perspective (Author 2021)

The illuminance results can be viewed from another perspective, for which the south classrooms of Sc 5 and Sc 7 are compared at 8 am (Figure 48). Their E values were 287 lux and 340 lux respectively and it can be seen how a minimal difference in average E value can change to daylight availability inside a classroom. The opposite side of the window inside the Sc 5 classroom receives below 100 lux at 8 am, whereas Sc 7 receives >100 lux.

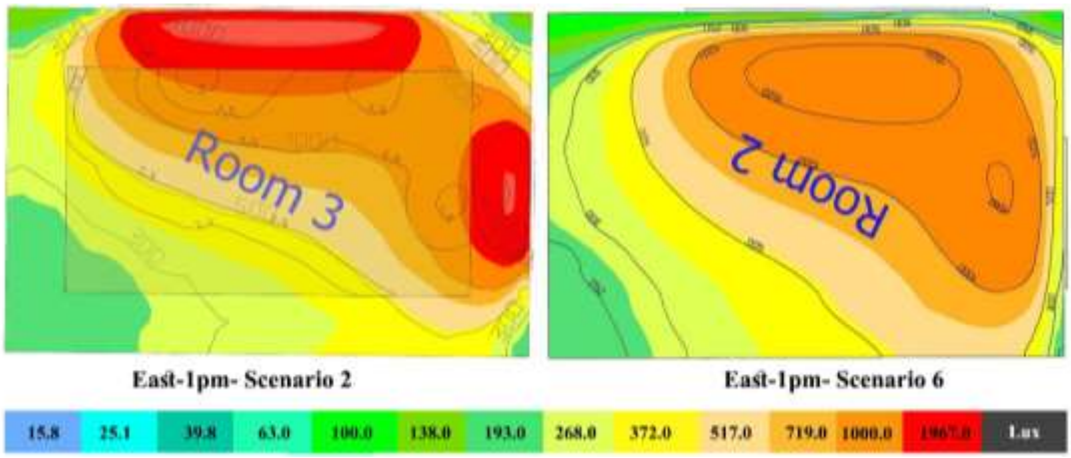


Figure 49: Examples of two high E classrooms (Author 2021)

Furthermore, classrooms with high average E values can be different from one layout to another and can have different impacts. To demonstrate this, the east classrooms of Sc 2 and Sc 6 were compared at 1 pm (Figure 49). The Sc 2 classroom showed 1077 lux as the average E, whereas Sc 6 had 871 lux, therefore, both of the classrooms have higher average E than the recommended values. In both the layouts, windows are placed on two sides of the exterior façade. However, Sc 2 results in a concentrated illuminance situation near the windows which is above 1000lux. On the other hand, Sc 6 results in 1000 lux to be very smoothly distributed inside the classroom. While both of these classrooms can result in heat gain and potential glare, the daylight also reaches deeper into the plan which can reduce the need for artificial lighting.

5.2.2.3 December 02

Table 11: Average illuminance (lux) analysis- December 02 (Author 2021)

	8 am				11 am				1 pm			
	North	**East**	**West**	**South**	**North**	**East**	**West**	**South**	**North**	**East**	**West**	**South**
BC	150	132	145	163	251	245	196	248	400	350	400	420
Sc 1	108	147	141	140	277	379	363	359	283	386	370	366
Sc 2	168	284	285	197	430	725	728	501	437	739	742	511
Sc 3	145	158	158	146	373	407	405	374	380	415	413	381
Sc 4	156	146	153	161	256	310	199	239	409	382	401	422
Sc 5	137	203	148	138	352	521	381	355	359	531	389	362
Sc 6	148	227	153	145	381	583	394	372	388	594	401	379
Sc 7	155	147	148	168	398	377	380	420	406	384	387	428

The sun path presented in the previous chapter (Figure 21) indicates the sun positions in the winter with respect to the case study building site. Due to this phenomenon, all four classrooms for all the scenarios show average E values below 300 lux at 8 am (Table 11). At 11 am and 1 pm, almost all scenarios can be seen with E values within the recommended range. However, the BC and Sc 4 shows classrooms below 300 lux. On contrary, Sc 2 shows E values higher than recommended for east and west classrooms at 11 am and 1 pm.

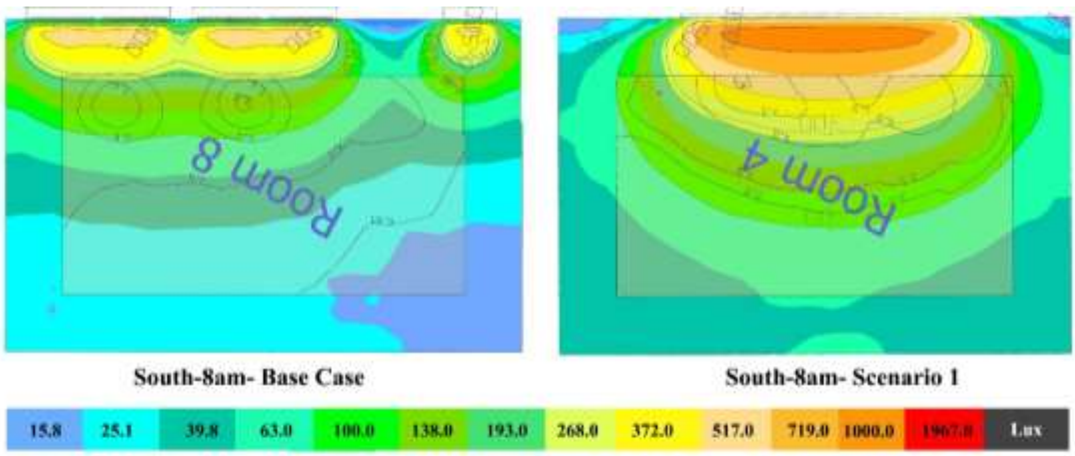


Figure 50: Examples of low average E classrooms (Author 2021)

Since all the layouts displayed average E values below 300 lux at 8 am, the BC and Sc 1 are compared as an example (Figure 50). The south classroom of BC has high illuminance near to the window; however, the values decrease in the rest of the room, resulting in the average E being 163 lux. Similarly, Sc 1 spreads the daylight, but the lux levels are low, resulting in an average E of 140 lux. Therefore, artificial lights are required in December when the classes begin in the morning.

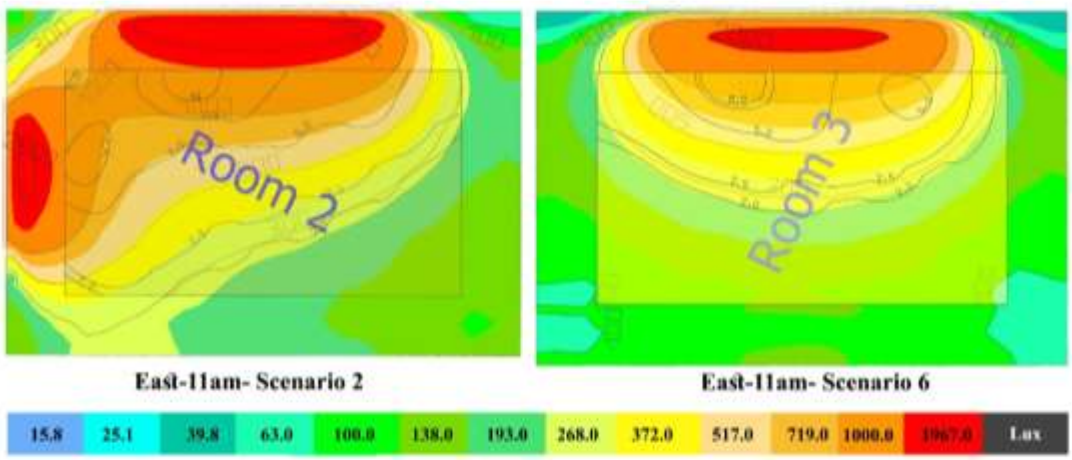


Figure 51: Comparison between Sc 2 and Sc 6 (Author 2021)

Likewise, the high E values of Sc 2 east classroom were compared with Sc 6 at 11 am (Figure 51). The east classrooms for Sc 2 and Sc 6 had average E 725 lux and 583 lux respectively. Noticeably, Sc 2 having a high average E could be due to the presence of two windows. Other than this, both classrooms have a similar pattern of higher lux being near the windows. This could result in dimming strategies for the artificial lights near that area while illuminating only the deeper plan areas for light energy savings.

5.2.3 Daylight Factor (DF) Analysis

Table 12: Daylight Factor analysis (Author 2021)

Layout	Daylight factor of Assessed Classroom (%)							
	North		East		West		South	
	GF	FF	GF	FF	GF	FF	GF	FF
Base case	1.80	1.80	1.58	1.57	1.68	1.68	2.00	2.00
Scenario 1	1.64	1.64	1.88	1.89	2.18	2.18	2.28	2.27
Scenario 2	2.24	2.22	3.65	3.62	3.67	3.66	2.61	2.59
Scenario 3	1.87	1.88	2.76	2.76	2.89	2.89	1.82	1.83
Scenario 4	2.65	2.65	1.88	1.88	2.60	2.60	2.81	2.81
Scenario 5	2.26	2.26	2.80	2.81	1.91	1.91	2.15	2.15
Scenario 6	1.90	1.90	3.67	3.67	2.64	2.64	1.85	1.85
Scenario 7	2.65	2.65	1.90	1.90	1.90	1.90	3.00	3.00

The average illuminance analysis conducted above demonstrates how different layouts result in different illuminance levels in the classrooms, despite their orientations. Another effective way to investigate the daylight availability provided by different layouts is to compare the daylight factors (DF) of the classrooms from the previous analysis. DFs that are below 2% are marked in red, while the values which are within the range are shaded green (Table 12). It can be observed that Sc 2 has DF within the recommended range for all four classrooms annually. This result corroborates with the illuminance analyses, where Sc 2 was always found to have higher E values. The next best scenarios are Sc 4 and 5, where DFs are 1.88% for east and 1.91% for west classrooms respectively. Furthermore, Sc 1, Sc 3, Sc 6, and Sc 7 show a low DF percentage for two classrooms, while above 2% for the other two. Finally, the BC has a DF of 2% only in the south classroom while the others are lower than the recommended range. The three analyses conducted above will be further discussed and concluded in the next subsections.

5.3 Phase 1- Energy Analysis

The final part of the Phase 1 investigation is the energy analysis done in IES as discussed in the previous chapter. For this particular investigation, the monthly or annual energy outcome will be heavily based on the cooling load (HVAC) and the energy from artificial lights. However, it is important to highlight that the light energy for the vacation months was subtracted from the energy consumption of that duration. This is because IES allows a single modulating profile to be added to the annual profile. Therefore, the energy simulation was first conducted with lights present during the vacation days, and another simulation with lights absent. The total energy was then adjusted based on the simulations and the final results were plotted.

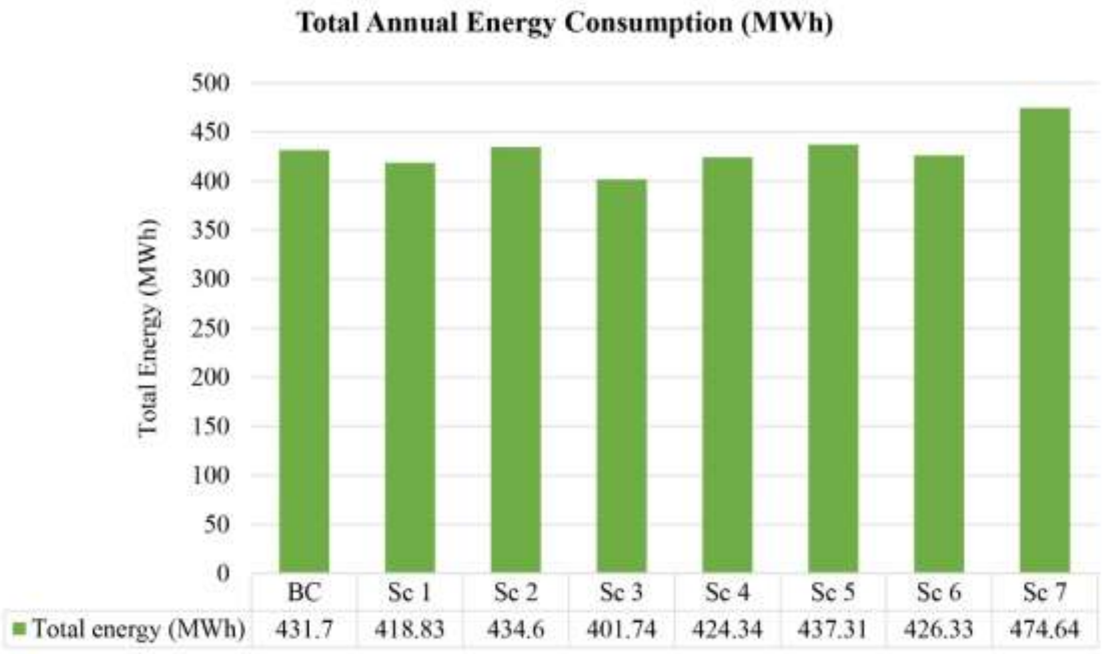
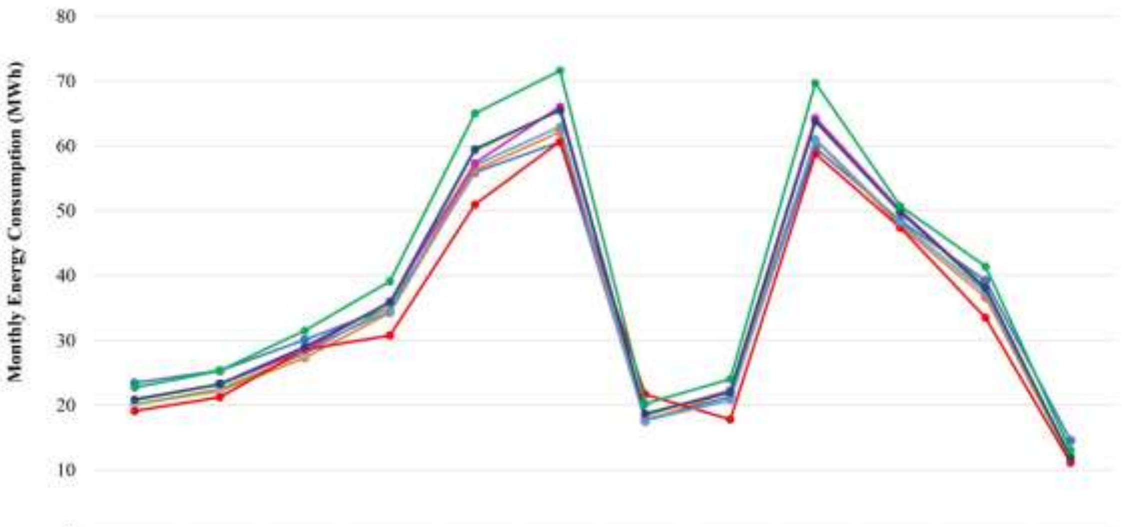


Figure 52: Total annual energy consumption analysis (Author 2021)

In this section, the total annual energy for all the layouts is displayed first. Next, the breakdown of the total energy will be discussed, which is comprised of lights energy, chiller energy, and other HVAC-related loads. Later, each scenario case will be discussed separately if required. The results of the IES simulation reveals that Sc 3 has the lowest annual consumption from all the scenarios (Figure 52). The BC annual energy came out to be 431.7 MWh, where Sc 3 is 401.74 MWh. After Sc 3, the second-lowest annual energy consumption is of Sc 2 being 418.83 MWh. The highest energy consumption is shown by Sc 7 as 474.64 MWh.



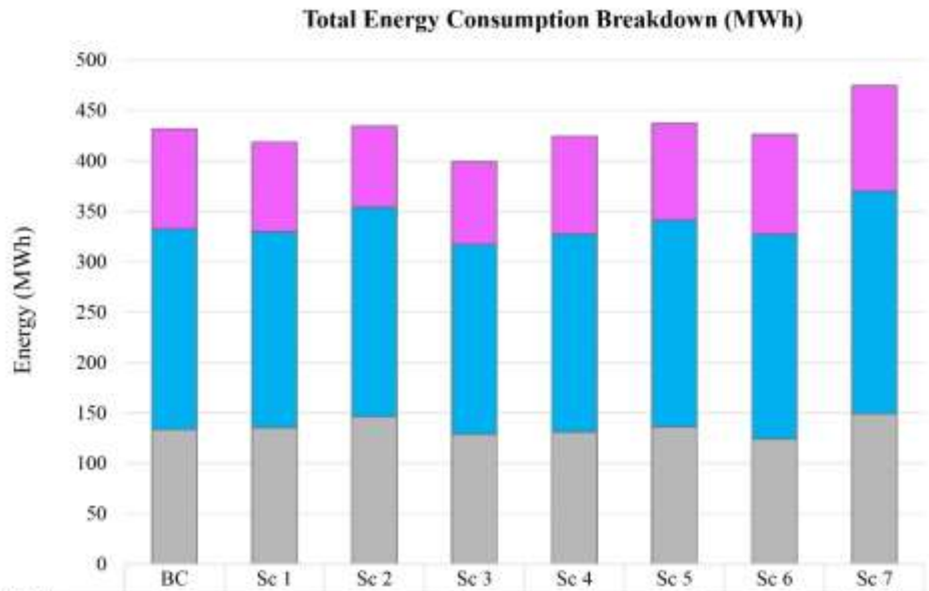
	Jan	Feb	Mar	April	May	Jun	July	Aug	Sept	Oct	Nov	Dec
BC	23.44	25.34	30.1	35.13	55.95	60.6	17.8	21.3	59.71	48.48	39.23	14.56
Sc 1	20.12	22.21	27.34	34.28	56.29	62.17	17.54	22.09	60.9	47.63	36.65	11.56
Sc 2	20.14	22.49	27.96	35.26	59.33	65.48	18.39	22.32	64.14	49.88	37.71	11.51
Sc 3	19.1	21.23	28.6	30.76	50.98	60.7	21.68	17.79	58.8	47.37	33.5	11.13
Sc 4	20.93	23.26	28.55	34.54	57.02	63	17.65	20.77	61.08	48.16	37.42	11.98
Sc 5	20.8	23.19	28.5	36.04	57.36	66.09	18.67	22.14	64.34	50.07	38.18	11.97
Sc 6	20.84	23.26	29	35.86	59.52	65.51	18.69	22	63.76	49.76	38.13	11.95
Sc 7	22.73	25.3	31.53	39.12	65.05	71.64	20.23	24.03	69.73	50.7	41.41	13.04

BC, Sc 1, Sc 2, Sc 3, Sc 4, Sc 5, Sc 6, Sc 7

Figure 53: Monthly energy consumption (Author 2021)

The monthly energy consumption values are plotted on a line chart (Figure 53). Here we can notice Sc 3 values, which are indicated with red. The graph shows the lowest energy consumed by Sc 3 in the months of January, April, May, June, August, and November compared to the other scenarios, including the BC. Interestingly, this scenario has the highest energy consumption in June, and the other months are almost similar to some of the other scenarios.

Furthermore, the Sc 7 indicated by green can be seen on the graph showing the highest consumption in March, April, May, June, August, September, and November. Similarly, in the months of January, February, and December, the BC shows the highest energy consumption. Therefore, it can be derived from this analysis that although the total annual consumption favors one particular layout to be the lowest, different layouts respond differently based on months, and other related factors such as lights, sun exposer, orientation, etc.



	BC	Sc 1	Sc 2	Sc 3	Sc 4	Sc 5	Sc 6	Sc 7
Total lights energy (MWh)	99.01	88.81	80.48	81.85	96.97	96.14	98.98	104.74
Chiller energy (MWh)	199.2	194.49	207.68	188.24	196.33	205.03	203.16	220.97
Other HVAC related loads (MWh)	133.56	135.6	146.5	129	131.1	136.2	124.2	149

Figure 54: Annual energy breakdown (Author 2021)

As mentioned earlier, the total annual energy consumption simulated for this dissertation is based on the electrical lights and HVAC operations. To further investigate the scenarios, these parameters are displayed in Figure 54. First of all, it can be observed that Sc 2 has the lowest lighting energy being 80.48 MWh annually. This result corresponds with the daylight analyses results where Sc 2 showed high illuminance values, which were then detected by the sensors in IES. Sc 3 has the next lowest light energy as 81.85 MWh. Sc 7 is the highest consumer of light energy, which is 104.74 MWh, and BC is the second-highest being 99.01 MWh.

Furthermore, Sc 3 shows the lowest and Sc 7 the highest values for chiller energy, which are 188.24 MWh and 220.97 MWh respectively. However, Sc 2 has the second-highest consumption for chillers energy- 207.68 MWh, which could be resulted from the heat gain caused by high daylight illuminance. This can be explored further by comparing the lights energy for the same months in which the illuminance analysis was conducted.

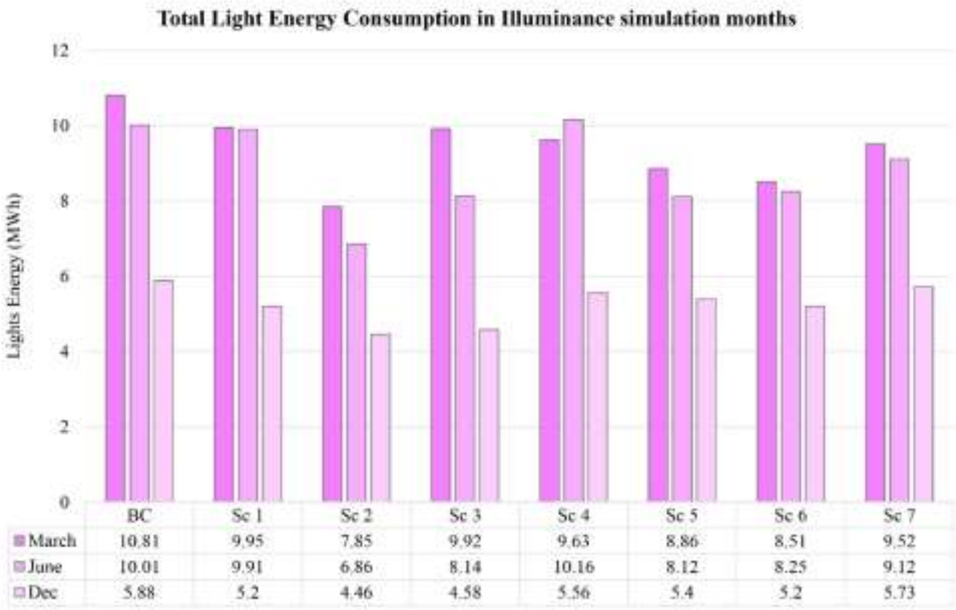


Figure 55: Light energy consumption in illuminance simulation months (Author 2021)

As discussed previously, the illuminance E simulation was conducted on March 21, June 10, and December 02 (Figure 55). Therefore, to explore the light energy from a different angle, its consumption can be compared for these three months. It can be noticed from Figure 56 that the light energy for Sc 2 is the lowest in all three months. Moreover, the month of December has very low light energy due to the winter vacation. Furthermore, BC has the highest light energy consumption in March and December, which as 10.81 MWh and 5.88 MWh respectively. According to the bar chart, Sc 5 and Sc 6 also show comparatively low light energy right after Sc 2. Therefore, it can be established that E values are inversely proportional to light energy. That is, when the illuminance level is high in space, artificial lights can be turned off or dimmed in order to save energy, hence lower light energy.

5.4 The Sun-cast Study

In the process of generating alternative layouts, the courtyards were affected the most, since their orientations, shapes, and sizes were changed. Moreover, all the scenarios in this research, including the base case were simulated without any shading system for the purpose of investigation. Therefore, the sun-path study will allow exploring the need for shading for courtyards in different scenarios. The study was done for peak Spring, Summer, and Winter durations and the results will be displayed as Full Shaded (fully shaded by the school building's shadow), Half-shaded (partially shaded by the building's shadow), and Full exposed (fully exposed by sunlight).

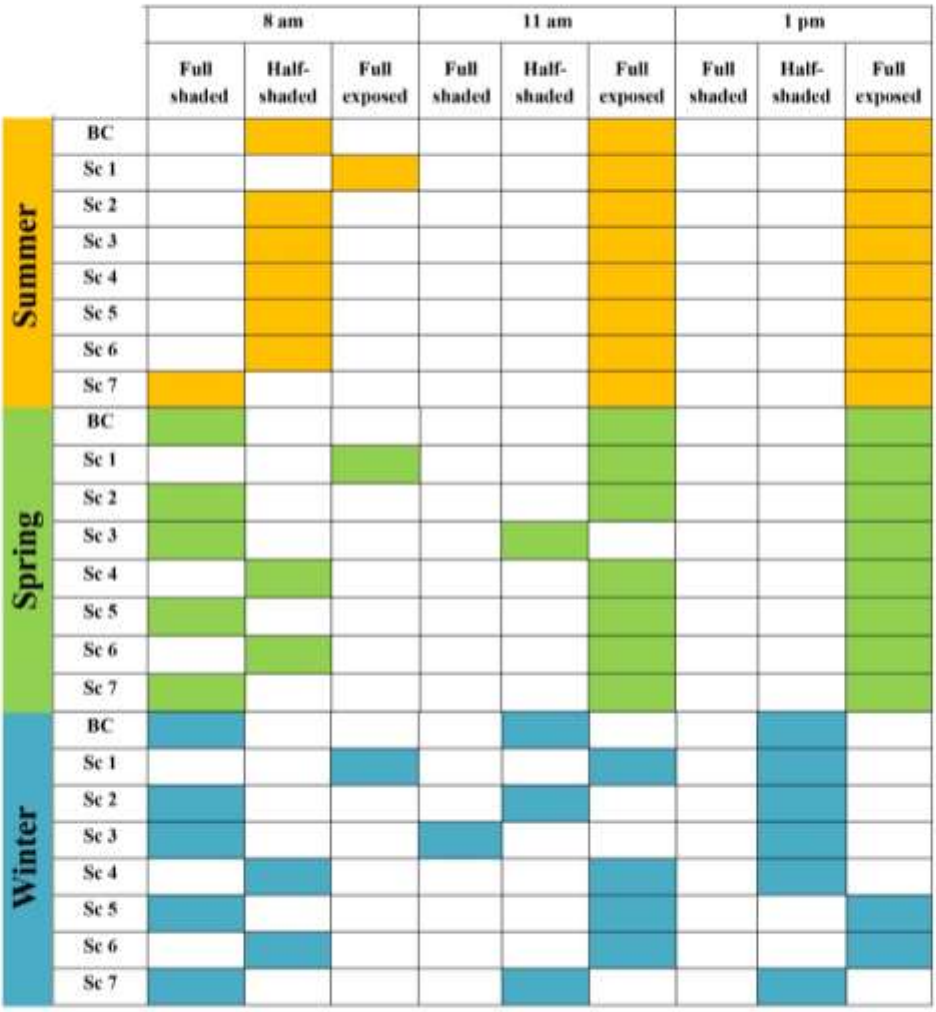


Figure 56: Sun-cast results for courtyards (Author 2021)

The above illustration displays how sun-cast affects the courtyards of different layouts at three timings of three seasons, without using any external shading system (Figure 56). It is noticeable that in the summer season and 8 am, Sc 7 gets full shading by the sun cast, whereas Sc 1 is fully exposed. All other layouts, including the BC, are half-shaded. At 11 am and 1 pm, all the layouts are fully exposed to the sunlight, indicating the necessity of implementing shading systems for the summer season. Next in the spring season at 8 am, Sc 1 alone is fully exposed, where Sc 4 and Sc 6 are half- shades. All the other layouts are fully shaded at this time. Furthermore, at 11 am and 1 pm, all layouts are fully exposed to the sunlight, except Sc 3, which is half-shaded at 11 am. Finally, the winter season at

8 shows the same sun cast results as the spring at 8 am. However, at 11 am, only Sc 3 is fully shaded, while BC, Sc 2, and Sc 7 are half-shaded. The rest of the layouts are fully exposed to the sunlight at 11 am. At 1 pm, all the layouts are half-shaded, except Sc 5 and Sc 6 which are fully exposed. Thus, this brief study indicates the possible impacts of different layouts on energy and sunlight to some extent.

5.5 Phase 1 Discussion & Conclusion

Several conclusions can be derived from the results and discussions conducted so far in this chapter. To find the best layout, it is important to examine and evaluate the results from each parameter, re-evaluate them by cross-checking facts, and comparing them with previously reviewed literature.

Firstly, the results of the sDA and ASE analyses indicate that Sc 4 is the best scenario showing the highest floor area percentages that achieve the thresholds. This layout has 4 atriums, and the courtyard is situated on the east side of the building.

However, according to the results for average illuminance analysis, Sc 2 shows exceptionally higher values of E in all three simulation months. While some of its E values tend to exceed the recommended value of classrooms, this layout was able to achieve the lowest light energy in the IES simulation. This is due to the presence of sensors in the RadianceIES that used fuzzy logic to implement dimming strategies, where daylight is present as 500 lux or more. On the contrary, this scenario stood at a mean position in sDA analysis among all the other scenarios. Furthermore, Sc 2 was found to be best performing in terms of DF, showing the percentages well within the recommended range for all the classrooms. A prominent factor for these results could be the H-shaped layout of Sc 2 that allowed the classrooms to be mostly placed near the building façade. This shape also enabled spaced to have windows on two sides of the wall. However, if we consider the energy simulation results, Sc 2 has 434.6 MWh total energy, where BC had 431.7 MWh. While Sc 2 had the lowest light energy, it caused heat gain from the daylight, resulting in the second-highest value for the chiller energy (207.68 MWh). Therefore, Sc 2 is best in terms of daylighting, did not perform well in the total annual energy consumption.

If the best layout is considered in terms of the total energy consumption, it is Sc 3 according to the simulations results. Sc 3 has the lowest annual energy consumption based on the HVAC load and lights energy, which is 7% less than the base case layout. It also achieved the lowest consumption for the chiller's energy, which was 188.24 MWh, and the second-lowest for the light's energy being 81.85 MWh. However, Sc 3 performed averagely in the illuminance analysis and achieved recommended DF in two classrooms out of four. Another cause for Sc 3 achieving the lowest energy consumption from a layout design perspective is the smallest building surface area exposed to the sun. There is plenty of evidence through various studies stating that reduced surface area of a building that is exposed to the sun can reduce energy consumption. This is due to the reduction in heat loss and heat gain with reduced surface area exposed towards the sun (Yüksek & Karadayi 2017). Sc 3 has a surface area of 1441.09 m^2 that is exposed to the sun all year round, whereas the BC surface area is 1666 m^2. On the contrary, the surface area exposed to the sun for Sc 7 is 1724.31 m^2 which led this layout to have the highest energy consumption.

Additionally, in the courtyard sun cast study, Sc 3 courtyard was found to be fully shaded at 8 am spring, winter, 11 and winter, and half-shaded at 8 am summer, 11 am spring, and 1 pm winter. This allowed the southeast courtyard to be shaded and contribute to reduced cooling load, mostly in summer. Several studies confirm that east or south-east-oriented courtyards support passive design strategies. In research studying courtyard design for hot-summer climate region of China, south-east courtyard orientation was suggested to guide summer wind-pressure-driven ventilation (Xu et al. 2018). Likewise, a study comparing the performances of the courtyard and atrium in different climate zones found that east-oriented courtyards provide a comfortable indoor environment in summer (Yasa 2017). Among the scenarios generated, Sc 1 also has its courtyard oriented towards the south-east and east and achieved the second-lowest annual energy consumption (418.83 MWh). Its chiller energy was 194.49 MWh and lights energy was 88.81 MWh. Therefore, it can be validated that different courtyard orientations play a significant role in energy consumption.

Apart from the best-case scenario, it is also important to discuss two layouts Sc 4 and Sc 5 where two more atriums were included in the space planning. As previously stated, Sc 4 performed the best in sDA analysis. On the contrary, Sc 5 also performed well and was above the average results. Their performances for average E were also satisfactory, along with DF within the recommended range for three classrooms out of four. However, looking at the annual energy consumption, Sc 4 and Sc 5 revealed 424.34 MWh and

437.31 MWh, hence, Sc 4 reduced energy from BC by 5 MWh, and Sc 5 increased by 6 MWh. Therefore, these two layouts did not improve the annual energy consumption significantly, even though their performances for daylight were satisfactory. Moreover, this shows a different result from the literature that motivated the addition of atriums, where it said to act as tempering spaces during summer (Odero, Marín & Gómez 2020). The C-shape layout of Sc 5 was also supported by multiple studies. However, this layout can be re-evaluated in Phase 2 by moving the current courtyard to the east direction.

The current dissertation research aimed to investigate the further improvement in the above-mentioned parameters that were analyzed. Hence, Phase 2 will conduct few simulations to test some enhancing possibilities.

5.6 Phase 2 - Re-developing Best Scenarios

In Phase 1, the base case and the 7 scenarios were simulated by modeling the original structure of the case study building. Moreover, the courtyards were kept unshaded for consistency and investigation purposes. From the conclusion of Phase 1, Sc 3 was found to be the best-case scenario, as this layout was a balance between daylighting and energy performances. On the other hand, Sc 2 was the best layout in terms of daylighting but resulted in high chiller energy due to high solar gain. Therefore, Phase 2 will conduct few daylight and energy simulations for these layouts by changing some parameters from the original building, with the aim of further improvements.

5.6.1 Reducing Excessive Daylight in Scenario 2

The issue with Sc 2 was the high amount of daylight entering into the building due to the layout and orientation. Even though the layout achieved the lowest light energy consumption, excessive daylight led to high chiller energy. To handle this, few window openings were reduced, and the daylighting was re-investigated.

Table 13: Phase 2 investigation of Sc 2 (Author 2021)

Phase 1	Phase 2	Remarks
sDA300,50% + ASE1000, 250 (Percentage %)		
17%	19%	✓
Average Illuminance (Lux) in June 10, 11 am – North, East, West, South		
618, 1044, 1048, 722	485, 568, 575, 567	✓
Daylight Factor (Percentage %)) in June 10, 11 am – North, East, West, South		
2.24, 3.65, 3.67, 2.61	2.22, 2.60, 2.65, 2.59	✓
Annual Light Energy (MWh)		
80.48	81.63	✗
Annual Chiller Energy (MWh)		
207.68	201.75	✓
Total Annual Energy Consumption (MWh)		
434.6	428.5	✓

In addition to reducing some windows from spaces with excessive illuminance, a shading system was implemented for the two courtyards of Sc 2. The height of the shade was kept 4 meters from the ground, similar to the existing play-yard shade of the case study site. Then, daylighting and energy simulations were conducted similar to the Phase 1 simulations. Improvement was observed for the sDA+ ASE analysis since the percentage area passing ASE thresholds is now increased (Table 13). The average E values are also stabilized, and DF stayed within the range. However, the windows reduction and the shading system caused a very mild increase in annual light energy. However, this was compensated by the chiller energy, which had reduced from 207.68 to 201.75 MWh. Finally, there was a 1.4% decrease in the annual energy consumption compared to Phase 1. The reason why there was no drastic change in the energy outcomes is that the surface area of Sc 2 exposed to the sun has not reduced. The shading of the courtyard will change the microclimate of the courtyard; however, the heat gain remains. But it is evident that daylighting strategies are heavily connected to BEP.

5.6.2 Improving the Best-case Scenario

This section of Phase 2 will investigate how other strategies can further improve the overall performance of Sc 3. Initially, the target of improvement for Sc 3 was to try reducing the artificial light energy consumption. Thus, the external windows are selected as a variable here, which was kept unchanged in Phase 1. There are numerous studies conducted on building WWR (window-to-wall ratio) and their relationship with daylighting. One such study was done where the impact of WWR on energy loads was studied in a building located in Saudi Arabia (Alwetaishi & Benjeddou 2021). The research concluded that a variable WWR percentage is most favorable in countries with hot and dry climates. It was recommended to provide 30%, 25%, and 25% of WWR in the north, east, and south façade of buildings in this climate. Similarly, in another research, north façade of a building in hot and dry climate was recommended a WWR between 20-40%, south façade 20-30%, east façade 30-40%, and west façade 20-30% (Shaeri et al. 2019).

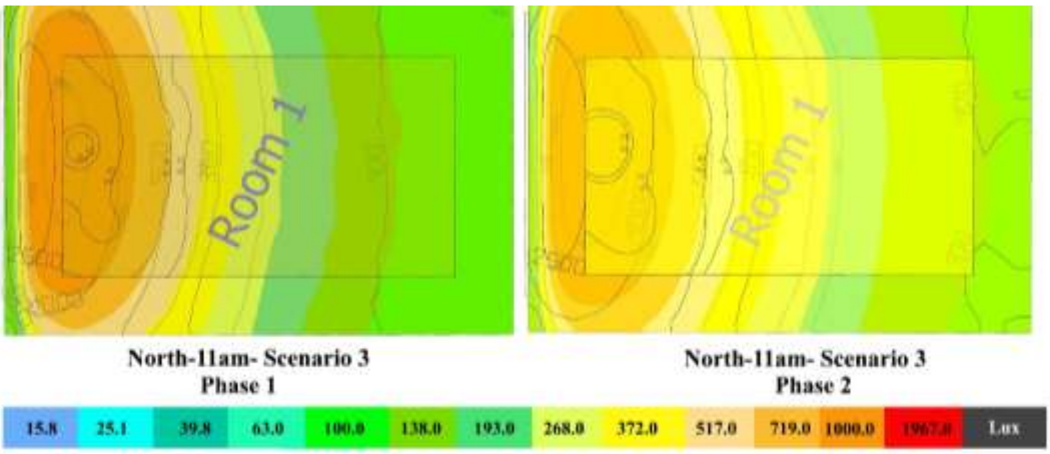


Figure 57: Comparison between illuminance of Phase 1 and Phase 2 (Author 2021)

In the present case study, the WWR of the BC was 28%, whereas Sc 3 was 26%, although Sc 3 had better daylighting results than BC due to the layout design. Therefore, in Phase 2, the recommended percentage of WWR from the reviewed literature was applied on Sc 3 by increasing the height of the windows. Furthermore, Phase 2 will also implement courtyard shading similar to Sc 2.

After integrating the reviewed strategies for recommended WWR, the total WWR of Sc 3 came out to be 35% in Phase 2. In Figure 57, it can be observed that E values more than 300 lux reach more than half of the north classroom in Phase 2 compared to Phase 1. Therefore, it can be expected that the sensors present in IES shall detect sufficient lux values and hence reduce light energy.

Table 14: Result comparison of Phase 1 and 2 for Sc 3 (Author 2021)

Phase 1	Phase 2	Remarks
sDA300,50% + ASE1000, 250 (Percentage %)		
16%	14%	✗
Average Illuminance (Lux) in June 10, 11 am – North, East, West, South		
540, 589, 586, 541	590, 621, 615, 574	✓
Daylight Factor (Percentage %)) in June 10, 11 am – North, East, West, South		
1.87, 2.76, 2.89, 1.82	2.25, 3.28, 3.13, 2.20	✓
Annual Light Energy (MWh)		
81.85	77.91	✓
Annual Chiller Energy (MWh)		
188.24	185.06	✓
Total Annual Energy Consumption (MWh)		
401.74	395.1	✓

Table 14 displays the results of Phase 2 simulations. Firstly, the sDA+ ASE result came out to be 14%, which was 16% in Phase 1. This is because, with the increase in WWR, the percent area passing ASE has reduced, therefore reducing the cumulative result. However, there were clear improvements in average E and DF values. The improved Sc 3 with higher WWR and southeast courtyard shading showed a 4.81% reduction in light energy. Moreover, the chiller energy went from 188.24 to 185.06 MWh. Finally, the annual energy consumption showed a reduction of 1.65% in Phase 2.

Furthermore in this investigation, the same strategies of Sc 3 were applied for the BC to assess the effect. Firstly, the light energy was reduced from 99.01 to 91.32 MWh, resulting in a 7.7% reduction. However, the chiller energy slightly increased, from 199.2 to 202.72 MWh. Finally, the annual energy consumption was reduced from 431.7 to 420.01 MWh, resulting in a 2.7% reduction. Although BC observed a higher percentage improvement in energy reduction than Sc 3, the annual energy consumption of Sc 3 remains the lowest. Therefore, it is evident that space layout has a significant impact on BEP.

5.7 Chapter Conclusion & Further Improvement Strategies

Chapter 5 have discussed the results of the investigations conducted in this dissertation to explore the impacts of space layout on daylighting and energy performances on UAE private school. A major goal of the investigation was to study the space layout as an independent variable while keeping other parameters constant throughout the scenarios. Furthermore, the discussions of Phases 1 and 2 demonstrates that space layout has a significant impact on how a building performs in terms of daylight and BEP.

5.7.1 Final Discussion

"To what extent does architectural/interior space layout affect the energy consumption and daylight availability in UAE schools?"

The above was the main research question raised at the beginning of this dissertation and acted as the foundation for the entire investigative study. The results of the investigations confirm that space layouts have a significant impact on the overall building performance. This statement has been proven through several important research reviews and experimental investigations previously. Researchers have been studying the domains of architectural space layout design and energy-efficient building for decades. However, the overlapping area of these two, which is an energy-efficient space layout design is rarely researched (Du et al. 2020b). While space layouts are given much attention by many researchers recently, the studies are confined to the office or residential spaces on a small scale. Therefore, this dissertation investigated the impact of space layout design alone in a large school building to fill the identified knowledge gap.

Efficient space layout design needs to be the most important design decision in the early stages of any building project. Therefore, it is crucial to evaluate the space layouts against different possibilities for daylighting, thermal, energy performances, etc. In a recent paper studying the impact of space layout on energy performance coupled with daylight and thermal simulation, significant changes in energy results were observed by only changing the core spaces of an office building. This research concluded that the space layout of office buildings can affect 65% of the lighting and 10% of the cooling and heating demands (Du et al. 2019). Likewise, similar results on BEP can be observed by another research when the same space layout investigation was conducted for a residential space (Fumagalli 2020). These results support the current dissertation's findings, where BEP was optimized for the school building by changing the space layout design.

Few factors impacted the building energy performances differently in different space layouts. Firstly, as observed in the Phase 1 discussion, Sc 3 had the lowest chiller energy because of the lowest surface area of the building exposed to direct sunlight. This resulted in reduced heat gain in the summer and heat loss in winter, therefore lower HVAC demands, especially the cooling load. This is an important aspect that needs to be addressed while studying architectural space layouts. Another important aspect that is closer to the HVAC demands of different layouts is the thermal zoning mentioned in Chapter 2. In multifunctional spaces, layout design plays a major role in BEP due to different thermal needs based on zone activities (Alsaadani & Transport 2016). This is another way how the current study of school spaces is different from the previous studies done on office buildings. Secondly, transitional spaces were also found to be a vital part of space layout design. The placement and orientation of transitional spaces like courtyards and atriums need to be well planned. Several research papers reviewed in this dissertation studied courtyards and atriums as the main variable and found their effects on energy, thermal, and lighting performances. The current investigation results do not differ from the previous findings. Both literature and Phase 1 simulation results established that school buildings with southeast and east-facing courtyard are best for hot and dry climates.

Furthermore, the finding of this research investigation results in an interesting regarding the architectural space layout. It was noticed that the best-case layout was not designed by following any conventional shape unlike the existing private schools in the UAE. Instead, this layout was designed based on strategies and solutions provided by previous studies. Therefore, it confirmed the need for focusing on energy-efficient space layouts in the early design stages and for experimenting with new building layouts that are designed solely for better BEP and comforts.

5.7.2 Improvement of Additional Aspects

Although the investigations aimed to keep other parameters constant, Phase 1 results revealed that the supporting building parameters need to be altered to explore further improvements. One such study was the implementation of a shading system for courtyards. UAE is an extremely hot climate; school courtyard shades are a must to be implemented. A majority of schools here use fix shading systems that provide thermal comfort in summer, but also block daylight during cooler months, resulting in increased light energy. From the sun cast study in Phase 1, it is evident that courtyards are naturally shaded in some layouts during Spring and Winter. Therefore, a dynamic shading system can be proposed to operate courtyard shading according to climate and necessities to provide optimum thermal comfort.

Sufficient integration of daylight without causing excessive heat gain is an important strategy for schools in the UAE. Addressing the case of Sc 2, the layout was effectively designed to allow an abundance of daylight but additionally caused heat gain and glare. Two strategies can be observed from Phase 2; minimizing exterior windows with added shading system if the layout allows extra daylight, or increasing the overall WWR along with shading to balance the light energy if the layout has average daylight availability. The need for adjusting WWR also relies on the layout design. Thus, planning effective WWR for the school building based on façade orientations and regulations based on local literature can be proposed. Additionally, other construction-based parameters need to be considered, such as glazing materials, and U-values. This way, the light and chiller's energy can be balanced, and annual energy consumption can be reduced. Furthermore, daylight sensors can be proposed in spaces near the exterior façade, especially the classrooms. In the IES simulation conducted in Phase 1 and 2, daylight sensors were used by RadianceIES, which allowed the software to detect the space illuminance levels and determine the artificial light energy. Therefore, this smart interior strategy will be very much effective in dimming and controlling light levels whenever necessary.

5.7.3 Further Recommendations

In light of the above discussion, some additional recommendations can be provided to further optimizing energy-efficient space layout design for designers and architects:

- **Internal partitions and space functions should be given more focus during the space layout design.** This is because, in practice, designers or building managers tend to keep interior partition decisions to a late design stage, which results in less liberty to change space functions after energy simulation and auditing. Therefore, it is highly recommended to designers and architects consider interior spaces during early design phases.

- **Geometry design needs to be combined with space layout design in the early design stage to attain high energy conservation.** This recommendation is in accordance with the previous point. Generally, building geometry and the boundary are decided before space layout and function allocation, the effects of energy requirements in different spaces are overlooked. A perfect example can be the best-case layout, where the building geometry was not pre-determined, unlike typical school building templates.
- **Space layout optimization can be done together with varied design variables of the building envelope.** It was apparent from this dissertation's results that daylighting, WWR, solar gain, etc. play significant roles in final energy consumption. therefore, it is recommended to focus on space layout and the building envelope variables parallelly in the early design phase.

Chapter 5 of this dissertation held several important discussions examining the whole investigation that was carried out. Moreover, several research questions were raised in Chapter 1 based on the research problems (Section 1.3) which were elaborately examined and presented in this chapter. Therefore, in the next chapter, a comprehensive summary of the previous chapters will be provided, along with recommendations for future researchers.

Chapter Six

6 Conclusion

The current dissertation carried out a detailed investigation on how space layouts can impact daylight and energy performance of school buildings in the UAE. The investigation was conducted on a case study of a private school in Al Ain. Moreover, all the research questions have been effectively addressed in Chapter 5. This chapter hence will further summarize the whole research for a thorough understanding of this dissertation.

Several objectives were set at the beginning of this dissertation in Chapter 1.4, and they were successfully completed:

- To study the impact of alternative optimized layouts on the energy performance of the case study school building: Chapters 4 and 5 explain the generation, simulation, and impacts of alternative optimized layouts.
- To investigate how different space layouts affect the availability of daylight: Similar to the previous objective, this was also solved in Chapters 4 and 5 through daylight simulations.
- To assess and determine the artificial lighting conditions in classrooms for different layouts: Through the daylight analyses and IES simulations with sensors, the need for artificial lightings was determined and their energy consumptions were examined for different layouts.
- To provide knowledge on school layout design solutions to be used for future retrofitting or new schools in the UAE: The discussions performed in Chapter 5 provide significant suggestions and solutions for future development for UAE schools.

6.1 Research Summary

Sustainable development of the built environment is the most important focus in today's world. Sustainable cities are built rapidly in developing countries, where urban, architecture, and interior design disciplines and their decisions play direct roles. UAE is not different from this focus, where the government and other organizations are continuously working towards a sustainable, green nation. Nevertheless, being in the hot and dry climate zone, the country faces multiple challenges while implementing sustainable strategies and reducing building sector energy consumption. The current dissertation, therefore, targeted a portion from the challenging fields of UAE, that is the school building sector. The goal was to highlight a research knowledge gap, where there is a lack of studies and data on how early design decisions on school space layouts have a significant impact on the overall BEP. The research was then narrowed down to a case study of a private school in Al Ain city, because of the lack of local research done on private schools. This investigation aimed to understand how different space layouts solely affect the daylighting and energy performances of a school building.

Through a comprehensive literature review of the most recent works of literature, a theoretical understanding was first developed. Several studies were done in the past that studied the impact of space layouts but in office and residential buildings only. It was revealed that the best way to understand how architectural and interior space layouts impact the overall performance of a building is to study them as a single, independent variable. Moreover, this practice is highly effective while studying multifunctional spaces. Furthermore, several international and local papers on school buildings, their design aspects, and their relationship with energy and daylighting were reviewed. The literature review provided theoretical knowledge, standards, and ideas for further carrying out the investigation and supported with facts and solutions. Next, a methodological framework was needed to conduct the investigation. Research has been done previously on similar topics, such as school building layout, daylighting, energy performances, etc. Based on paper reviews, computer simulation was chosen as the main methodology to investigate in this research.

Using the case study as a base case, seven different layouts were generated by implementing the lessons learned from the literature review. Then, computer simulation methods were used on the case study elementary school building in Al Ain city using IES VE, Autodesk Revit, and DIALux evo. The simulation frameworks were designed to analyze various parameters of daylighting and energy consumption. There were mainly two phases of investigation: first, all the scenarios were simulated keeping the originality of the base case in terms of construction parameters, and their results were discussed. After determining the best layouts among the seven, a second phase simulation was conducted to attempt to improve their performances further. Through detailed discussions, the research questions established at the beginning of this dissertation were answered successfully.

The results of the simulations reveal that the design of a space layout and the allocation of different spaces have direct impacts on the BEP. It was also found that for better energy performance, it is important to balance the daylight availability and cooling load performances. Scenario 3 was found to be the best layout, where both light energy and final annual energy consumption were reduced compared to the base case. Several factors related to the space layout contributed to the best reductions, such as the reduced surface area of the building exposed to direct sunlight, a well-oriented courtyard with shading, a compact building structure, etc. The best scenario resulted in a 6.9% reduction in annual energy consumption compared to the base case in Phase 1, and an additional 1.65% reduction after improving it in Phase 2.

Schools in the UAE follow government-sanctioned layout templates, particularly public schools. Private schools also follow a conventional pattern of internationally used school buildings. However, with all the changes going on around the world such as climate change, population expansion, high energy and power demand, and technological advancements, it is fairly important to start implementing new solutions. This research investigation confirmed that layouts designed not based on typical forms, but by implementing multiple sustainable and functional strategies can lead to a significant reduction in energy consumption. Therefore, detailed analysis and examining space layouts for specific school projects are suggested in the early design stages.

6.1.1 Research Constraints

It is evident from the previous chapters and concluding discussions that the investigative goal set by this research was successfully achieved. However, it must be acknowledged that the study possesses some limitations. Although the selected case study for this dissertation is a conventional space layout of a private school, the layouts generated and simulations conducted were highly specific to the case study building, location, plot size, and function. For instance, a different public school in Al Ain city can have either a bigger plot boundary, allowing the layouts to be different, or a smaller plot where layout generation possibilities would be limited. Furthermore, strategies for improvements might also vary. Strategies like multiple courtyards and integrated skylights could be used and simulated in a bigger public school, resulting in entirely different BEP and reduction strategies. Therefore, the current case study and the investigative results can be highly valuable to understand the concept, the impacts, and guidance towards further research, but cannot be a generalized standard for other public schools.

6.1.2 Research Contribution

This dissertation research has proved the significance of space layouts on energy and daylighting performances of school buildings in the UAE. It aimed from the beginning to strengthen the role of designers and architects on existing knowledge of this topic. The findings of this investigation force designers to look back to the fundamental concepts of design and enforce to optimize these concepts through energy simulations. Therefore, this research will enlighten designers and architects, as well as school building owners to consider energy-efficient strategies from a different perspective. The results debated in this research may also motivate new school building typologies in the UAE, especially for private schools. Furthermore, this research contributes to the UAE's future goal for green schools and energy conservation in the building sectors. In the end, early design decisions will result in a ripple effect, as energy-efficient space layout designs will act as the foundation and create a broader building sector with optimized building energy performances.

6.1.3 Recommendations for Future Research

The current dissertation conducted investigative research on a private school located in Al Ain and filled a knowledge gap through the research results and data. Also, the layouts were generated with the help of architectural design knowledge along with theoretical supports. Moreover, the main studied parameters were daylight availability and energy consumption. Therefore, by narrowing down the above specific aspects, this dissertation provides a base for further studies on the impact of space layouts by exploring other factors.

Few recommendations for further research by the author or any future researchers interested in this topic are:

- Working with a different set of school buildings with variable sizes, locations, or climatic backgrounds.

- The further sample size for the generated layouts. While this research generated layouts from a designer's perspective, the process of generation could be simplified by using automated or AI-based software.
- Extended parameters could be studied in the future, such as variable space layouts coupled with variable building orientations.
- The same strategies found in the current research results could be used as a template for similar public schools to analyze their performances.

In conclusion, research knowledge has no limitations. There will always be more opportunities to research a single topic, depending on the research focus. This dissertation thus concludes by encouraging designers, architects, as well as school managers to gain knowledge from studies like these and further improve the school building industries in design energy-efficient space layouts.

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Appendices

Appendix A

ADEC Design Manual standards

Spaces	Illumination Levels in Lux
All Educational areas	500 lux in 20% spaces, 400 lux in the balance
Administrative, clinic, auditorium, swimming pool, lunch area and service areas	300 lux
Toilets	200 lux
Kitchen, gymnasium, music, art, design and technology	500 lux
Internal circulations	250 lux
Emergency lighting in common areas and corridors	10 lux

- Light should be adequately distributed throughout walls, teaching surfaces and desk levels. Accent light may be for some walls and teaching surfaces.
- Design all instructional spaces to provide a combination of diffused, indirect and direct illumination depending on educational needs.
- Supplement natural light as necessary with electric lighting to satisfy minimum comfort level requirements.
- Fluorescent fixtures tube shall be T-5 lamps with high frequency electronic ballasts, and Color Rendering Index (CRI) not less than 85.
- All fixtures should be low maintenance and with suitable protection grade for dust and water.
- Light fixtures shall not be located over stairwells or hard to reach places. Use wall mounted light fixtures to light stairwells.
- Warm white light with color temperature of 3500 K to be used in gyms, multi-purpose rooms, high corridors and high library ceilings.
- When fixtures are used which require a warm-up, switches need to be located to assure against accidental or malicious switching. If the switches cannot be located in a secure location, then locking switches are required.
- Exterior lighting shall be provided for building entrances, outdoor storage areas, loading docks, bus drop off, covered walkways to the entrances, exterior mechanical room doors, and other outdoor areas where lighting is required for night functions, security or safety lights.
- Exterior facade and /or boundary wall lighting shall be provided at certain locations only, review on site by site basis with ADEC.
- Provide provision only (power load and conduits with pull-wire to locations only) for sports field lighting for future installation.
- Vandal-resistant and impact resistant materials or metal guards shall be used to protect fixtures and equipment within reach of floors and all outdoor locations and in gymnasiums.
- The central battery system and associated slave luminaries will cover the

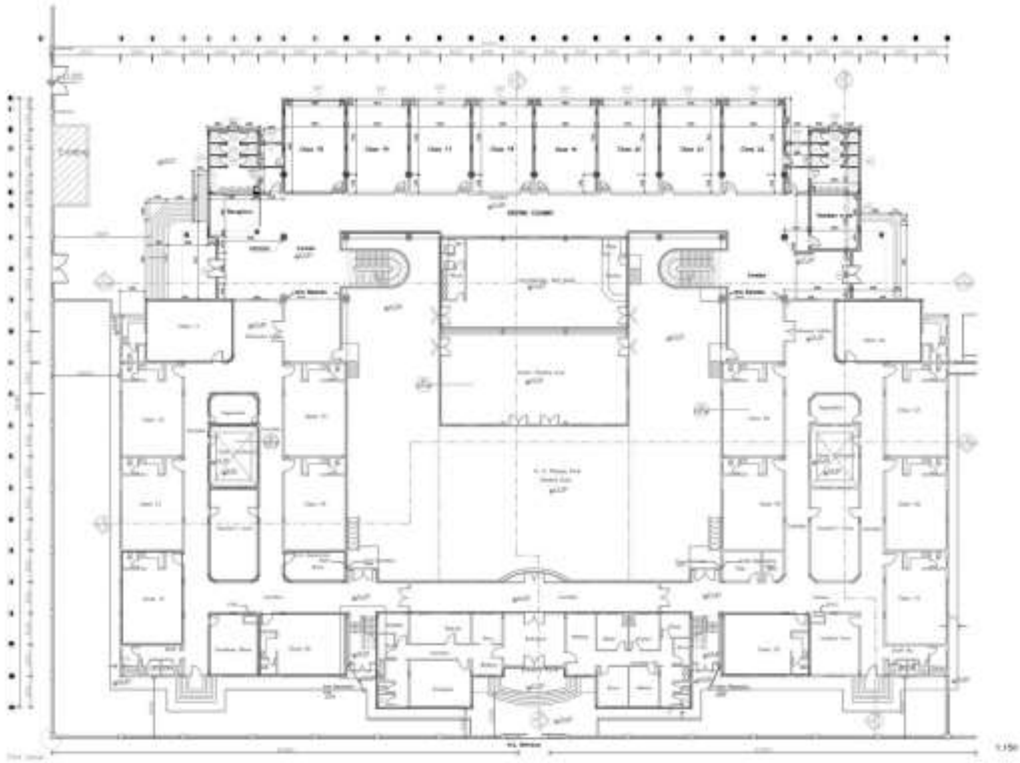
D.6 Thermal Comfort and Ventilation

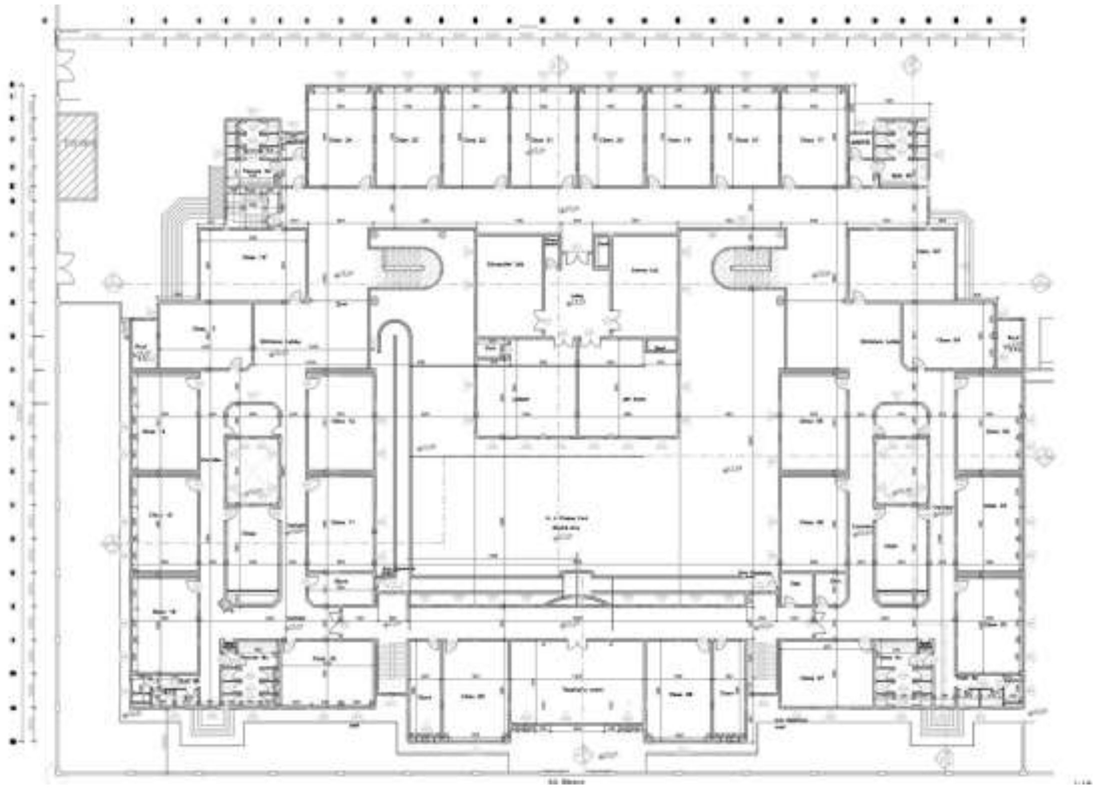
The building's HVAC system must be designed, installed, and operated to enhance the learning and the teaching by eliminating "thermal distractions". The effective design for thermal comfort must control three vital indicators of a healthy educational environment: temperature, humidity, and ventilation.

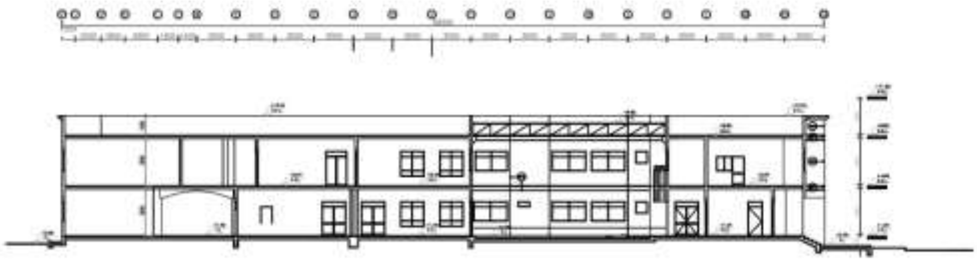
- The ambient temperature to be
  - 46 C DB and 29.5 C WB – Abu Dhabi;
  - 48 C DB and 31.5 WB Al Ain and Western region.
- • Temperature: Design conditions for space temperatures shall be: Summer: 23 +/- 1 degrees C; Winter: no artificial heating required.
- Humidity: Design conditions for the range of temperatures listed above shall be between 40% and 60% 50% +/- 5 relative humidity for occupied areas.
- Ventilation: Design conditions shall be considered as per ASHRAE 62.1 recommendations, the latest edition.
- All mechanical equipment shall work up to 52 C ambient temperature.
- Swimming Pools require a speciality design for the HVAC system to provide humidity control and to minimize evaporation. Air temperatures in pool area should be maintained 1 to 2 degrees C above the water temperatures year round. Relative humidity in the pool area should be maintained at 50 to 60%. Suggested water temperature for recreational pools is 24 to 29 degrees C.
- The base building cooling system shall be a chilled water system. The system shall have full load and part load.
- Provisions shall be made for connection to city chilled water grid if service is available.
- Computer hub rooms may be served by individual DX systems for supplemental needs if necessary.
- The cooling systems shall be sized and zoned to allow after hour operation of designated areas. The associated air distribution systems for designated after hour and community use, shall be designed separately from other building systems such that the operation of these designated areas will not result in or require the operation of non designated areas and so that the services may be billed be separately.
- Recover air conditioning system condensate and store in localized cisterns with gravity-fed drip irrigation for adjacent planting.
- Ventilation air shall be supplied to each separate air distribution system. Demand control ventilation schemes shall be implemented in each system and ventilation air volume shall be modulated to maintain a maximum carbon dioxide level of 700 PPM above ambient for each zone.
- All exhaust vents shall be located a minimum of 5 meters from all ventilation intakes and building openings.
- All HVAC systems within a facility shall be controlled through a direct digital

Appendix B

Liwa International School architectural documents

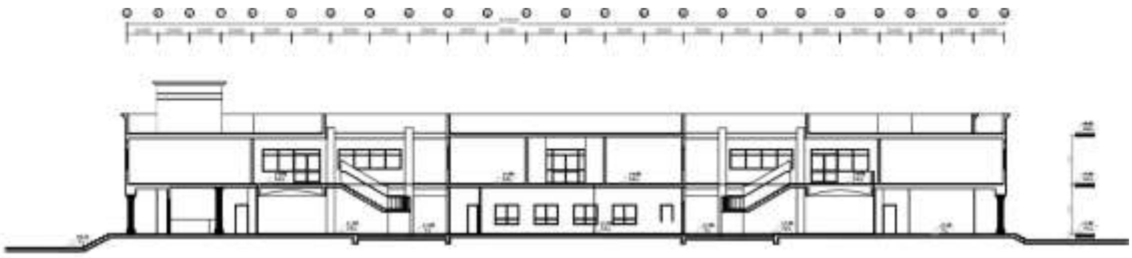




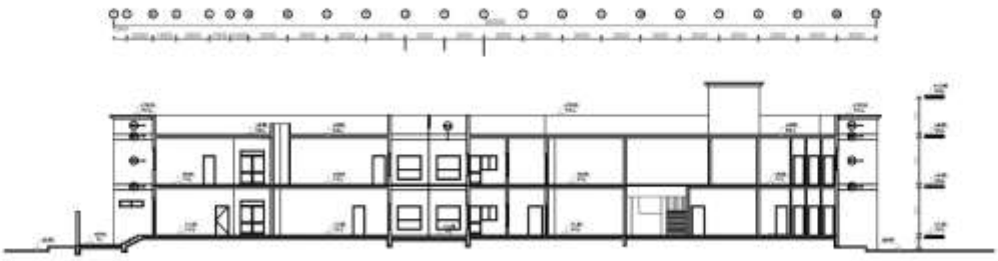


SECTION A-A

SECTION B-B



SECTION C-C



SECTION D-D

Appendix C

Liwa International School Details

دائرة التعليم والمعرفة
DEPARTMENT OF EDUCATION
AND KNOWLEDGE

School Information

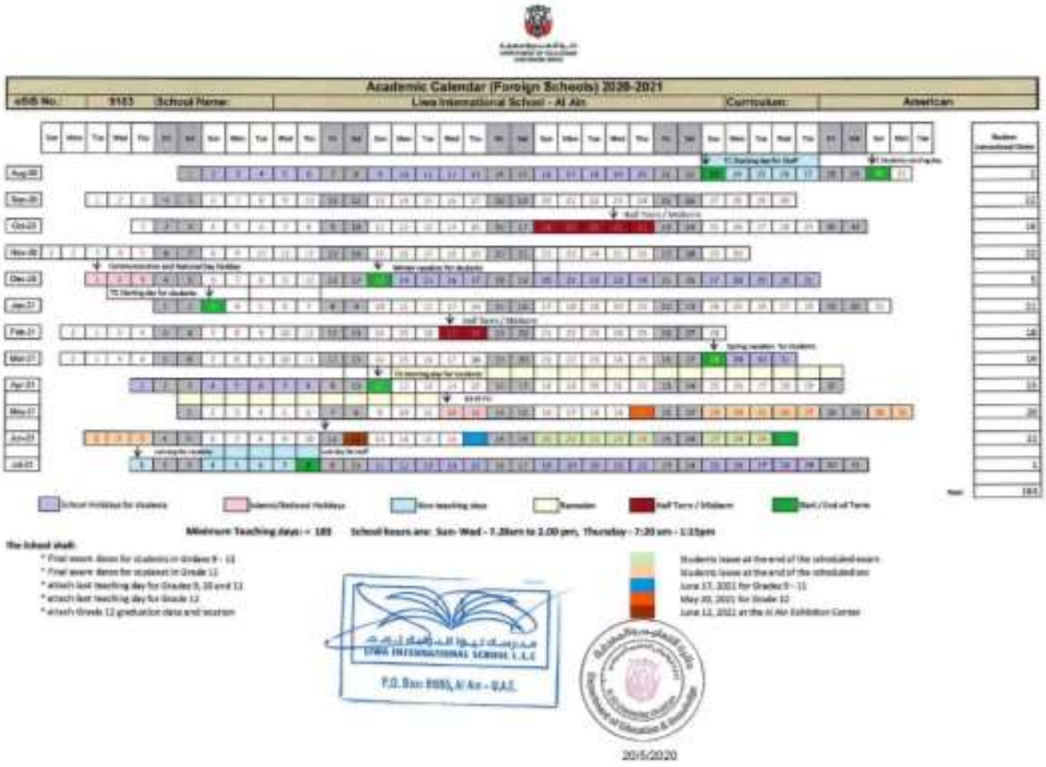
School Profile			
School Name:	Liwa International School		
School ID:	9163	School phases:	KG1 to Grade 12
School Council:**			
School curriculum:*	American	Fee range and category*	AED 16,870 to AED 30,460 (medium to high)
Address:	Falaj Hazaa Al Ain	Email:	9163@adek.gov.ae
Telephone:	+971 (0) 37810444	Website:	www.liwaschool.ae

*Relevant for Private schools only ** Relevant for Government schools only

Staff Information			
Total number of teachers	162	Turnover rate	21%
Number of teaching assistants	67	Teacher- student ratio	1:16

Students' Information				
Total number of students	2597		Gender	Boys and girls
% of Emirati students	90%		% of SEN students	4%
% of largest nationality groups	Egypt 2%, Jordan 2%, Oman 2%			
% of students per phase	**KG**	**Primary**	**Middle**	**Secondary**
	16%	41%	28%	15%

Inspection Details			
Inspection Hijri dates from:	25/05/1441	to	28/05/1441
Inspection Gregorian dates from:	20/01/2020	to	23/01/2020
Number of lessons observed:	140	Number of joint lessons observed:	34


Academic Calendar (Foreign Schools) 2020-2021
School Name:
Liwa International School - Al Ain
Curriculum:
American
School Holidays for students
Islamic/National Holidays
Non teaching days
Ramadan
Half Term / Midterm
Start / End of Term
School hours are: Sun-Wed - 7.20am to 2.00 pm, Thursday - 7:20 am - 1:15pm
The School shall:
June 17, 2021 for Grades 9 - 11
June 12, 2021 at the Al Ain Exhibition Center
LIWA INTERNATIONAL SCHOOL L.L.C
2015/2020