QATAR UNIVERSITY

COLLEGE OF ENGINEERING

A METHODOLOGY TO ASSES ENVIRONMENTAL SUSTAINABILITY OF EDUCATIONAL BUILDINGS IN QATAR WITH A CASE STUDY

BY

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ABSTRACT

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Title: A methodology to assess environmental sustainability of educational buildings in Qatar with a case study

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Addressing the urgent global call for sustainable solutions in the building sector, this study embarked on suggesting an approach to investigate the life cycle sustainability analysis of the school buildings in Qatar in order to determine the provisions to improve the sustainability performance, and investigating the feasibility of achieving a net-zero carbon operational status for the school buildings in Qatar. This study contributes to knowledge by developing and using a comprehensive life cycle analysis methodology for a school building. It considers scope 2 emissions, which includes the embodied carbon and operational use carbon of the buildings. One of the main suggestions was installation of the photovoltaic solar panels (PV) to produce zero carbon electricity. Before installation of PVs, embodied carbon was 23% of the total life cycle carbon emissions while the operational carbon dominated with the77%. To evaluate different coverage areas of PV installations on the school's rooftop, the proportion essential for neutralizing operational carbon emissions during the operational phase was identified. Findings reveal that a 48% coverage of the school's rooftop with PV panels is pivotal in achieving the operational carbon balance, turning the establishment into a carbon-neutral entity. Moreover, surpassing this coverage threshold can potentially position the school as an energy surplus generator, indicating the school's prospective role as a local energy contributor. A basic cost benefit analysis suggests that the PV system is not economically viable, however, in future work, a detailed economic assessment has been suggested to conclude this with greater confidence. In summary, this project contributes to knowledge by (i) presenting a LCA methodology for a non-domestic building in Qatar (ii) Presenting improvement suggestions to make the building carbon neutral. In view of the United Nation's Sustainable Development Goals, this project contributes to SDG 7 (Affordable and clean energy), SDG 9 (Industry innovation and infrastructure), SDG 11 (Sustainable Cities and Communities) and SDG 13 (Climate Action). Finally, this project is also in line with the Qatar 2030 vision, as it promotes sustainable development and environmental preservation. Such results should help decision makers in the future to consider solutions and assessments to develop low or zero carbon buildings in Qatar.

DEDICATION

This research paper is dedicated to my wonderful work colleagues and mentors and family. Your unwavering support and dedication were pivotal to the completion of this work. Your belief in my abilities is deeply appreciated.

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I would like to thank my friends and family for their support during this long journey. Also, I would especially like to thank my supervision team as this success would not be possible without their support.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1: INTRODUCTION

The building sector contributes significantly to global carbon emissions. According to the Intergovernmental Panel on Climate Change (IPCC), buildings are responsible for about 39% of global energy-related carbon dioxide (CO_2) emissions (Rock et. al., 2020). This includes emissions from the construction, operation, and demolition of buildings, as well as the production of building materials and equipment.

The main sources of carbon emissions in the building sector include:

1. **Energy use for heating, cooling, lighting, and powering appliances in buildings**: In modern societies, buildings demand a significant portion of total energy use. Heating and cooling often account for the bulk of a building's energy consumption, given the need to maintain comfortable indoor temperatures regardless of external climatic conditions (Dakwale et. al., 2012). Lighting, although more energy-efficient in recent years due to advances like LED technology, still constitutes a noticeable segment of energy usage, especially in commercial and industrial spaces. Additionally, appliances, ranging from everyday household items like refrigerators and ovens to specialized equipment in offices or factories, continuously draw power. The combined energy needs of these elements result in substantial carbon emissions, particularly if the energy sources are non-renewable.
2. **Manufacturing and transportation of building materials and products**: The creation of building materials involves a plethora of processes, many of which are energy intensive. For example, cement production, a key ingredient for concrete, is notorious for its high CO_2 emissions (Nejat et. al., 2015). Similarly, the extraction and processing of raw materials, whether it's mining metals or harvesting timber, have environmental implications. Beyond manufacturing,

transporting these materials to construction sites—often across vast distances—exacerbates their carbon footprint. Efficient logistics and sustainable manufacturing practices can help mitigate these impacts, but they remain a significant concern in the building sector.

3. **Construction and demolition activities**: Construction activities, from site preparation and foundation laying to the actual assembly of structures, require vast amounts of energy and resources. Heavy machinery, often running on diesel, excavate, lift, and transport materials on-site. The longer a construction project takes, the greater its environmental toll. On the other end of a building's life cycle, demolition not only uses energy but also generates vast amounts of waste. Properly dismantling structures, recycling usable materials, and responsibly disposing of non-recyclables is paramount to ensuring minimal environmental harm.
4. **Waste management and disposal of building materials and products:** As buildings undergo repairs, renovations, or eventual demolition, they generate waste in the form of discarded materials. How this waste is managed has far-reaching environmental implications. Landfilling, the most common disposal method, has long-term repercussions, including land degradation and methane emissions. On the other hand, recycling and reusing building materials can significantly reduce the environmental impact. Practices such as deconstruction, where buildings are carefully taken apart to salvage and reuse components, can help divert waste from landfills and reduce the need for new raw materials.

The urgency of mitigating emissions in the building sector becomes even more pronounced when considering rapid urbanization trends. In regions like Qatar, the intersection of an increasing demand for infrastructure and a hot desert climate brings forth unique challenges and opportunities. Given the prevalent construction activity in Qatar and its unique environmental and operational demands on buildings, it serves as a fitting context for a focused investigation.

This research aims to delve deeper into the materials aspect of embodied carbon. While operational carbon emissions are significant, understanding the complete lifecycle emissions, starting from the material phase, provides a holistic view. For the purpose of this study, a school building in Qatar has been chosen. The selection of a school building is grounded in its standardized design across the country, making it a suitable candidate for understanding the material-related emissions without considerable variances in architectural nuances.

Our primary objective is to design a comprehensive approach to evaluate the embodied carbon of building materials and subsequently implement this methodology on the selected school building. This not only contributes to the academic discourse on sustainable construction practices but also provides actionable insights for the stakeholders in the Qatar construction sector. The research aim and objectives are summarised below:

Aim:

To investigate the life cycle carbon emissions of a case study school building in Qatar and suggest improvements.

Objectives:

1. To review life cycle analysis in buildings
2. Re review green building standards and policies in Qatar
3. To collect data for a case study building and implement the life cycle analysis based on the ISO14040 standard.
4. To analyse the results and suggest improvements to achieve a net zero carbon emissions building.

CHAPTER 2: LITERATURE REVIEW

In this section, a global review of journal articles is carried out that provide overview information about the contribution of buildings to the global carbon emissions. This will provide a theoretical foundation for the project and help identify future steps.

Contribution of buildings to global carbon emissions:

Buildings significantly impact the environment and contribute to climate change, so it's crucial to consider their entire lifecycle, beyond just operational energy usage. Research by Rock et al., (2020), which examined over 650 building projects, revealed that while buildings are becoming more energy-efficient, they still generate considerable pollution throughout their lifecycle. This is largely due to the manufacturing and transportation of building materials. Surprisingly, even buildings that are highly energy-efficient in operation can be major polluters. In buildings adhering to current energy performance standards, embodied GHG emissions account for about 20-25% of their total lifecycle emissions. However, this figure jumps to 45-50% for highly energy-efficient buildings and can even surpass 90% in some extreme cases. The study emphasizes the urgent need to reduce the embodied GHG emissions in buildings by focusing on both energy consumption and the materials used in their construction.

In a different approach, Khanna et al., (2021) explored the impact of building occupants' behavior on CO2 emissions in residential buildings. They employed machine learning to assist a systematic review and meta-analysis, aiming to evaluate the effectiveness of various interventions in reducing energy demand in residential settings. This study highlights the significant role that occupant behavior plays in the environmental footprint of residential buildings. The study summarized in Figure 1 analyzed 360 specific effects from 122 studies across 25 countries. The researchers discovered that both financial and non-financial methods work in lowering household energy use, but financial rewards usually have a bigger impact. They also found that using the right mix of different methods can make these interventions more effective. According to their research, these methods could reduce global carbon emissions by 0.35 gigatonnes (Gt) of CO2 per year. However, using the most effective combinations of these methods could lead to even larger reductions in emissions.

Intervention type	Intervention	Description
Monetary incentives	Critical peak pricing, seasonal pricing, time-of-use pricing, real-time pricing, rewards and rebates	Time-of-use pricing aligns the prices faced by households with the underlying cost of supply, which is higher during peak demand periods[43]. Other interventions reward consumers for reducing peak-period consumption. Households are expected to reduce consumption as long as the financial savings from reduced consumption outweigh the costs of shifting or reducing consumption[21].
Information	Home audits, tips, reminders	These policies focus on promoting energy-saving behaviour by reducing the information deficit faced by households with activities and actions that can help reduce energy consumption[17]. The information provided may be general advice like energy-saving tips and practices through workshops[44] and mass media campaigns[45] or tailored advice in the form of home audits[46].
Feedback	Historical, in-home displays	Feedback interventions are rooted in psychological research that posits that directing an individuals' attention to a feedback-standard gap that is relevant to the individuals can engender behavioural change[16]. Most experiments provide individuals information about their energy use, drawing comparison with their historical consumption. The effect of feedback seems to depend on its frequency, medium and duration[16,47].
Social comparison	Home energy reports, norms-based comparison	Households are benchmarked against the performance of their social group[20,48]. Norm-based communication has been widely adopted by utilities in the form of home energy reports[49], which seem to be effective in some cases even years after households received their initial reports[50].
Motivation	Commitment devices, goal setting, gamification	Social pressure has also been employed in the form of public pledges or commitments by households to practice energy-conserving behaviours[17]. Goal-setting interventions in which households commit to reducing energy consumption by a certain percentage over the course of the experiment are other commitment devices[18]. Some recent experiments have used web-based gamified platforms or mobile apps to induce behavioural change.

Figure 1: Interventions aimed at the building occupant to change their behaviour and reduce carbon emissions of residential buildings (Khanna et. al., 2021).

In a study conducted close to Qatar, Radhi (2009) looked at how global warming might affect houses in the UAE, especially in terms of reducing CO2 emissions. The research focused on how much energy air conditioners might need in the United Arab Emirates, particularly in the city of Al-Ain, due to global warming. The study used simulations and energy analysis to find good ways to deal with these issues under different weather conditions. The results showed that if the temperature in Al-Ain goes up by 5.9°C, the energy needed to cool buildings could increase by 23.5%, which might lead to a 5.4% increase in CO_2 emissions over the next few decades. The study points out the importance of designing buildings to save energy, like using thermal insulation, to help fight the effects of global warming. It also found that the size and type of windows are very important for adapting to climate change, and that shading devices help a bit in reducing CO_2 emissions from buildings but are less affected by global warming. The study also notes that electricity is the main source of energy in Al-Ain and other cities in the UAE. Apart from electricity generation, energy use is split between homes, businesses, industry, and farming. Residential buildings, in particular, use a lot of electricity, making up 45.9% of Al-Ain's total electricity use. The increase in people, desire for more comfort, and more devices that use electricity in buildings have all led to more electricity being used. In the UAE, especially in Al-Ain, the use of air conditioning in the summer has grown tenfold in the last 20 years. This information is helpful because the UAE is ahead of Qatar in terms of development. So, if there's no data for Qatar, it's likely that Qatar's buildings will follow a similar trend to those in Al-Ain, UAE.

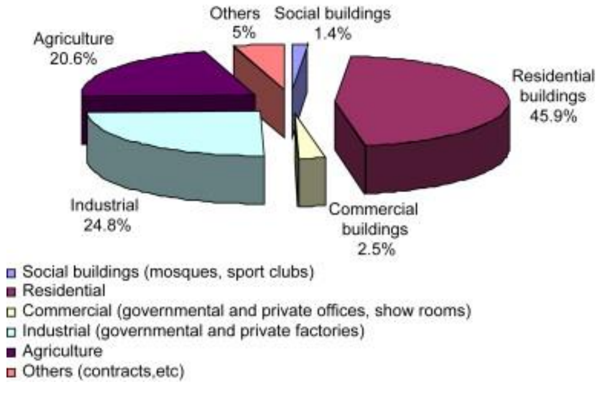

Figure 2: Composition of buildings in Al-Ain in terms of buildings energy use (Radhi, H., 2009).

Onat et al., in their 2014 study, looked at the carbon emissions from both commercial and residential buildings in the United States. They used a detailed method called hybrid economic input-output life cycle analysis to figure out the emissions from the construction, use, and disposal of buildings for the year 2002. Their approach classified carbon emissions into three categories: Scope 1, 2, and 3.

Scope 1 emissions are the direct greenhouse gases (GHG) that come from sources owned or controlled by the company, like burning fossil fuels in their boilers or vehicles. Scope 2 emissions are indirect GHGs from electricity, steam, heat, or cooling that the company buys and uses, but the emissions are produced somewhere else. Scope 3 emissions are all other indirect GHGs that happen in the company's supply chain. This includes things like emissions from goods and services they buy, their employees commuting, and how they dispose of waste. These emissions are harder to measure because they happen outside the company's direct control. The study explains these categories with a diagram in Figure 3.

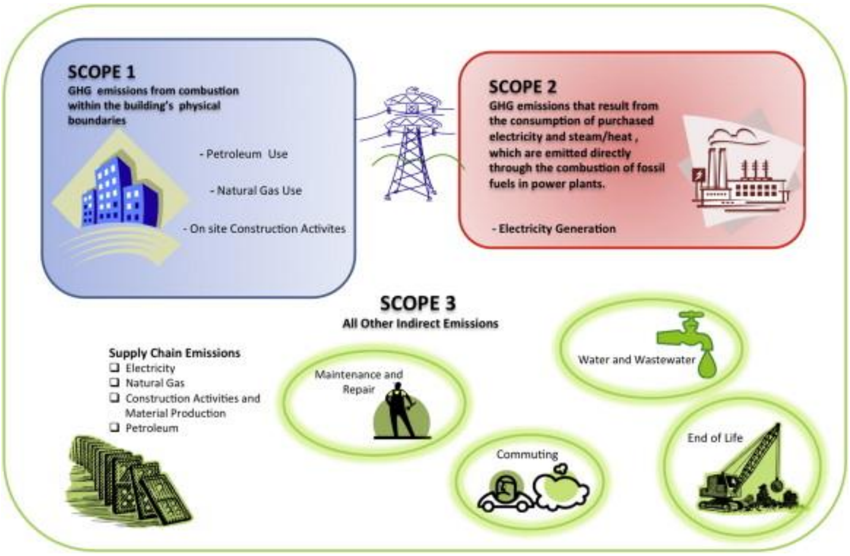

Figure 3: Emissions Scopes (Onat et. al., 2014)

The study discovered that the biggest source of carbon emissions in U.S. buildings is the electricity they buy directly, which makes up 48% of their total carbon footprint. Indirect emissions (from things like services they use) are more than the direct emissions (from their own sources) at 32% and 20.4% respectively. The biggest part of these indirect emissions, over 10%, comes from people commuting. The construction supply chain also adds a significant 6%. The phase when buildings are being used has the highest emissions, with 91% of the total emissions over their lifetime.

In 2015, Nejat and colleagues did a big study on how much energy homes use, their CO2 emissions, and the related policies all over the world. They looked closely at the top ten countries that emit the most CO2, which include the US, China, and India. This study found that homes are a big part of the world's energy use and CO2 emissions, responsible for 27% and 17% of these respectively. The study showed that from 2000 to 2011, the energy used by homes around the world went up by 14%, mostly because of developing countries. Although CO2 emissions went down in most developed countries, they went up by 4% in the US and Japan. The main sources of energy in homes were biomass, electricity, and natural gas, and there was less use of fossil fuels over the last ten years. Energy policies like building codes and incentives helped reduce energy use. But in developing countries like China, India, and Iran, the lack of strong policies led to a big increase in greenhouse gas emissions and energy use. The study included a figure that shows the biggest global greenhouse gas emitters from buildings.

Also, in 2012, Urge-Vorsatz and others looked at carbon emissions from buildings all over the world. They talked about how important buildings are in fighting climate change, noting that it's possible to reduce CO2 emissions in ways that also save money over the building's life. The study estimated the potential for reducing CO2 emissions in buildings worldwide, based on 80 studies from different countries and regions. The researchers emphasized the need for policies that are specific to local conditions and have strong rules and enforcement to really cut down emissions in both homes and commercial buildings. They also pointed out that there are many other benefits to these measures.

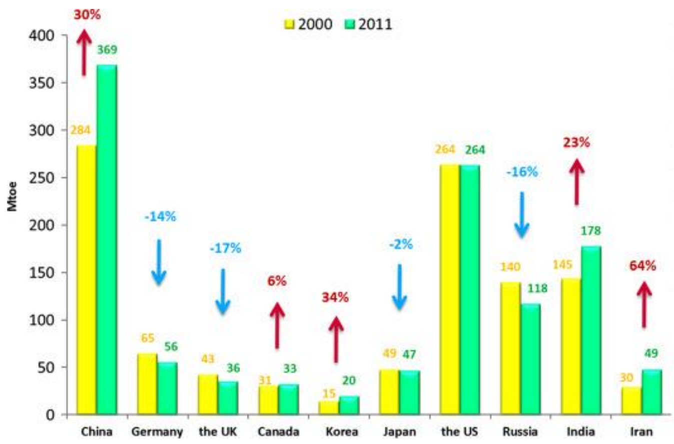

Figure 4: Major global carbon emittors (Nejat et. al., 2015)

In 2015, Hong and colleagues conducted a study focusing on China's building construction phase. Their goal was to deepen the understanding of greenhouse gas (GHG) emissions during this phase, utilizing detailed onsite process data and a broader system boundary. Previous research in this area was hindered by insufficient data. The study revealed that 97% of GHG emissions during construction were indirect, primarily stemming from onsite electricity use and the production of building materials. It also highlighted that human activities related to construction significantly contribute to GHG emissions, a factor often overlooked in past studies. Additionally, certain materials like polyamide safety nets and aluminium, though lightweight, were found to have a notable impact on GHG emissions.

In a separate 2016 study by Peng, C., the use of building information modelling (BIM) was emphasized through a Nanjing, China case study. This research underscored BIM's utility in simplifying carbon emission estimates throughout a building's lifecycle. BIM provides essential data and tools for life cycle assessment (LCA), addressing the challenge of insufficient information in LCA processes. The study's sensitivity analysis showed that a building’s operational phase is the primary source of carbon emissions, contributing approximately 85.4%, with the construction and demolition phases contributing 12.6% and 2% respectively. Carbon sequestration by vegetation was found to have minimal impact on overall emissions. These findings suggest that while targeting the operational phase of buildings is crucial for reducing carbon emissions, the construction phase should not be ignored.

Wu et al., in their 2019 study, evaluated the factors influencing carbon emissions in China's building and construction industry from 2000 to 2015. This comprehensive analysis, from a life cycle perspective, identified raw material extraction and manufacturing, as well as building operation, as the largest emission sources. The research advocates for improved energy efficiency and lower emission factors during construction, and for increasing development density, enhancing emission factors, and modifying energy and industry structures during building operation to reduce emissions. This study offers valuable scientific evidence to aid policymakers in setting and implementing emission reduction goals for China's building and construction sector.

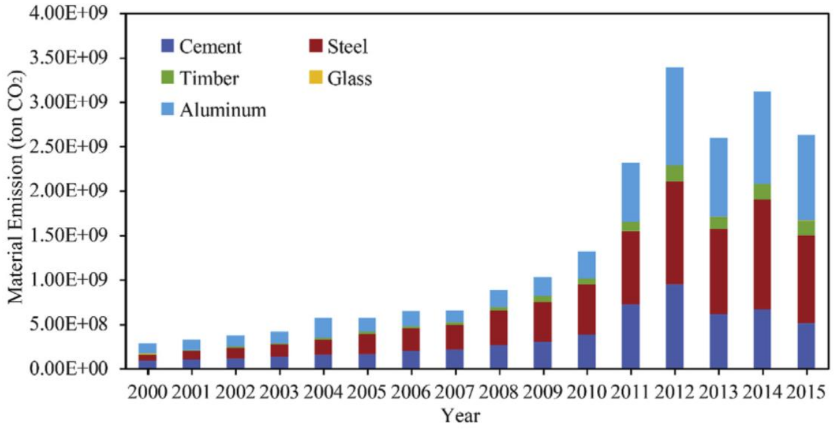

Figure 5: Annual carbon emissions from China building sector, material extraction and manufacturing (Wu, et. al., 2019)

Lu et al. (2020) reviewed 101 journal articles on carbon emissions from commercial buildings. Their extensive research, which included official data, government statistics, authoritative websites, and these articles, found that global carbon emissions are still rising, despite various incentives and subsidies aimed at reducing them.

When it comes to well-known building environmental rating methods, carbon emissions are a key factor in BREEAM and Green Star. However, in LEED and BEAM Plus, carbon emissions are only considered under the category of energy analysis. The authors concluded that despite many efforts, the increase in carbon emissions continues to be a problem, and future research should focus on finding solutions.

BREEAM, created by the UK's Building Research Establishment, evaluates the sustainability of buildings, considering energy, water use, pollution, waste, and materials. It uses a scoring system to rate a building's sustainability. LEED, developed by the US Green Building Council, also uses a scoring system and assesses buildings based on energy efficiency, water use, indoor environment, materials, and resources. LEED for Schools specifically addresses the needs of K-12 and higher education facilities.

Green Star, from the Green Building Council of Australia, evaluates buildings across nine categories, including energy, water, and materials, also using a scoring system for sustainability performance. GSAS, developed in the Middle East, particularly Qatar, has criteria tailored to the region's conditions, with special focus on schools to ensure a conducive learning environment.

All these systems aim to promote sustainable design, construction, and operation, advocating for environmentally friendly and socially responsible buildings.

Dakwale et al. (2012) took a more solution-oriented approach in their review. They found that carbon emissions are increasing due to technological advances and lifestyle changes. They emphasized the need for stakeholder awareness and the adoption of safe environmental methods. The review suggests that emission mitigation policies, fuel switching, and power generation shifts to cogeneration or hybrid technology can significantly reduce emissions. Improving the thermal performance of building envelopes and using recycled materials can save up to 31-36% of emissions. Simulation methods are recommended for predicting heating and cooling needs and selecting shading devices to reduce emissions. The review advises focusing on the primary sources of emissions and including carbon emissions in the assessment of energy-efficient buildings.

The following section will provide further details on modelling carbon emissions in buildings, from which the gap that this thesis aims to fill will be clear. Based on the current review, it was found that there is a lack of studies on life cycle energy use and carbon emissions modelling in public buildings in Qatar. This project aims to fill this gap by carrying out a life cycle analysis with a case study involving a school building., We consider a very typical building so that our results may be mapped to many other buildings with a similar design in Qatar.

CHAPTER 3: BUILDINGS CARBON EMISSIONS MODELLING METHODOLOGY

In their comprehensive review, Mostafavi et al. (2021) examined 48 previous studies spanning from 2005 to 2020, focusing on energy and carbon efficiency in skyscrapers across various climates. Their analysis revealed that enhancements in a building's exterior can lead to up to 78.9% energy savings, layout optimization can yield up to 17% savings, and incorporating natural ventilation can reduce energy use by as much as 45%. The review also pointed out strategies to decrease operational carbon emissions by about 25% and embodied carbon emissions by roughly 60%, mainly through better heat transfer design and the use of recycled materials. The study also explored and calculated a method to diminish carbon emissions throughout a building's life cycle, including the implementation of solar rooftop PV systems.

Considering the significant amount of construction materials used in high-rise buildings, it's crucial to identify methods to curb their greenhouse gas emissions. Carbon emissions in buildings arise from two main sources: embodied carbon from the production of construction materials and operational carbon from the building's use over time. Research, such as that by Gan et al. (2019), has delved into reducing embodied carbon in skyscrapers, examining how design elements influence carbon emissions. For example, employing 80% recycled steel can slash embodied carbon in steel structures by around 60%. The total embodied carbon in a skyscraper is particularly sensitive to its structural design, especially in buildings over 100 stories tall. Other research, like Choi et al. (2017), has suggested design innovations to lower costs and CO_2 emissions during the material production, transportation, and construction stages of tall buildings. Implementing these innovations could lead to a 29.2% cost reduction and a 13.5% decrease in CO_2 emissions. Optimizing a building's structure using a hybrid optimality criteria genetic algorithm can also cut carbon emissions and material costs by 18–24%.

Studies have also investigated the balance between operational and embodied carbon in skyscrapers. Key structural materials, such as concrete and rebar, constitute over 90% of a building's embodied carbon. Utilizing recycled fly ash or slag in concrete can lessen embodied carbon by up to 28% and operational carbon by up to 4% (Gan et al. 2018). Additionally, implementing thermal insulation in external walls or high-performance glazing can significantly reduce operational carbon emissions. Hence, construction materials substantially influence both embodied and operational carbon emissions in tall buildings, with a notable trade-off between their weight and carbon emissions, often quantified using mathematical models.

However, calculating embodied carbon poses challenges. As shown in Pan et al.'s (2021) study, the methodology for assessing embodied carbon can significantly alter the carbon footprint of a building. This research aimed to explore how various factors impact embodied carbon evaluations and to measure their precise effects. The team developed a framework examining variables across four dimensions: temporal differences, spatial disparities, procedural inconsistencies, and physical diversities. Analyzing 244 case studies from 2000 to 2020, they normalized the data for better comparison. They pinpointed eleven variables significantly affecting the results. After normalization, the average embodied carbon in the manufacturing, transportation, and construction phases showed a substantial reduction from initial estimates, with significant assessment variations attributable to differences in modeling techniques, emission factor databases, and building structures.

These are **three very important considerations** in embodied carbon emissions calculations of buildings;.

First issue is the **emission factor databases**. The emission factor databases for lifecycle analysis are a data intensive requirement for calculating carbon emissions (Schlanbusch et. al. 2016). The problem with these is that the collection of this data requires a lot of time and resources, and as a researcher, one must rely on what data is available, as collection of new data, specific for the project is costly and requires long times, which often renders the collection of new data impractical.

The **second issue** is that of building structures, but they will change depending on the building considered. Therefore, this variation must be there, which means that the carbon emissions from only similar building structure type can be reasonably compared. This means that residential homes should not be compared with office buildings or factories. In this project, the focus is on an education building, so it will be compared against other educational buildings.

The **third factor** is that of the modelling approach which can be considered here in detail. Following review of articles, the following was found. There are several modelling approaches to calculating embodied carbon in buildings, each with its advantages and disadvantages. We cover them in the following section.

The main modelling approaches include the following;

Cradle-to-Gate (Process-Based) Approach: This method focuses on calculating the embodied carbon of building materials by examining the environmental impacts at each stage, from raw material extraction to their transportation and processing. It primarily looks at direct emissions from producing these materials but might overlook indirect emissions, like those from the broader supply chain (Zhang et al., 2019).

Input-Output (IO) Approach: This technique utilizes economic data to approximate the embodied carbon emissions linked to the lifecycle of building materials – their production, usage, and disposal. It leverages industry-wide data to assess emissions from the entire supply chain of a material or product. The IO approach captures both direct and indirect emissions but may lack the precision of process-based models in detailing the specific emissions of individual products or materials (Nässén et al., 2007).

Hybrid Approach: This method merges aspects of both the process-based and input-output approaches for a more thorough and accurate estimation of embodied carbon emissions. It applies the process-based model for direct emissions from material production and the IO approach for indirect emissions from supply chains. Generally considered the most effective, the hybrid approach is adept at handling a variety of emission sources and the complexities of supply chains (Onat et al., 2014).

Life Cycle Assessment (LCA): LCA is an all-encompassing method that assesses the environmental impacts of a product, material, or building throughout its entire life cycle, from extraction to disposal or recycling. It encompasses both embodied and operational carbon emissions, along with other environmental impacts like water usage and waste production. The approach for LCA can be based on process-based, input-output, or hybrid models, depending on the desired level of detail and precision (Nwodo et al., 2019). Subsequently**, a decision is made regarding the preferred life cycle assessment approach.**

Available analysis tools:

The choice of modelling approach is also dependant on the tools that can be used to employ them. Two tools that were discovered during the review are PHPP (Passive house planning package) and the ZEBRA (Zero emission buildings reduced algorithm) (Kylili et. al., 2017; Fosas et. al., 2022).

The Passive House Planning Package (PHPP):

PHPP, created by the Passive House Institute (PHI), is a tool for modeling building energy. It's mainly used to design energy-efficient buildings, especially those that meet the Passive House standard. This standard is a stringent, optional guideline for energy efficiency, leading to buildings with extremely low energy requirements, significantly reducing the need for heating and cooling. PHPP calculates the building's energy balance by accounting for various factors such as insulation, windows, ventilation, and heat recovery. The tool follows the Passive House standard methodology, which emphasizes building envelope optimization, airtightness, and minimal thermal bridging (Norouzi et. al., 2022).

ZEBRA (Zero Emission Buildings reduced algorithm):

The ZEBRA tool, developed by the University of Bath, is a software tool for estimating embodied carbon in building materials. ZEBRA is designed to assist designers, architects, and engineers in evaluating and minimizing the embodied carbon emissions in their building projects. This tool employs a life cycle assessment (LCA) strategy, encompassing emissions from every stage - raw material extraction, transportation, manufacturing, construction, and the final stages of disposal or recycling. It adheres to international LCA standards and guidelines, specifically ISO 14040 and ISO 14044, which offer the foundational principles and structure for performing and documenting life cycle assessments. The main advantage of this tool, as evident from its name, is that it is a simpler approach to modelling. This is a great advantage for practical reasons and is therefore selected as the tool of choice.

Selected modelling tool:

In this project, the recently developed ZEBRA tool proves to be an ideal fit for the objectives, offering a valuable resource for low carbon building design (Fosas et al., 2022). As a novel tool from 2022, the results generated from this analysis are expected to be intriguing and insightful.

During the early stages of building design, comprehensive information about construction materials, window layouts, and the building's intended use might not be available. Additionally, the engineering team might not have been assigned yet. ZEBRA aims to tackle two common challenges that may lead buildings to stray from low-carbon targets: limited understanding of the relative significance of elements impacting a building's energy consumption during the early stages, and the lack of general knowledge about zero-carbon design among some team members.

Developed as a user-friendly tool for architects, engineers, and users with no prior modelling experience, ZEBRA requires minimal input and is free to use, promoting skill development for future projects. The Excel-based tool comes with no cost or maintenance, featuring graphical outputs to analyse energy consumption and offering a low-energy design primer. It accommodates users with different levels of knowledge and project involvement by providing three complexity levels, depending on the available information.

The ZEBRA tool allows users to easily adjust complexity levels and modify default values without recreating the model. By starting with a basic model and increasing complexity as needed, users can quickly obtain essential information and learn from the model, leading to more energy-efficient building designs. Moreover, ZEBRA offers around 30 advanced optional inputs, accessible by setting the appropriate complexity level. A very useful functionality is the availability of weather data which is a crucial input for modelling the energy and carbon emissions of the building when it is operation. The following figure shows the interface where the ZEBRA tool has downloaded data for London. In this project, the suitable Qatari location will be acquired and used appropriately.

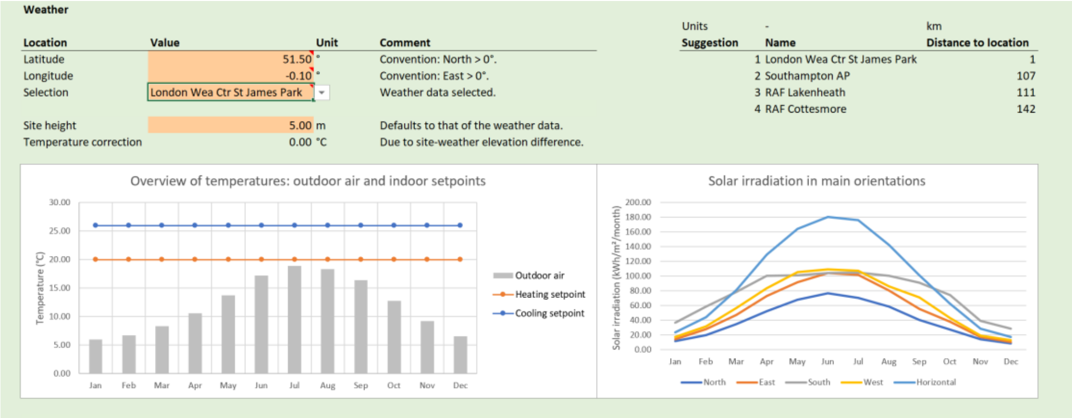

Figure 6: Weather data availability based on inputting the latitude and longitude.

This example is that of London, but in this project, the school location data will be used ZEBRA encourages experimentation with different building design parameters, allowing users to instantly observe the impact of changes like U-values or window orientation on the building's energy use. This contrasts with other building software tools that may prompt users to alter multiple parameters simultaneously, making it difficult to distinguish the effects of each parameter.

The results from ZEBRA are typically reported in terms of treated floor area (TFA), facilitating meaningful comparisons of energy use between buildings of varying sizes and enabling direct comparison to headline figures such as the Passivhaus standard.

In summary, the ZEBRA tool offers an interactive and user-friendly approach to building design, focusing on annual energy, carbon, and monetary running costs of individual building elements. By using ZEBRA, designers can achieve a better understanding of their designs and develop generic knowledge for future projects. This tool is particularly useful for this project as it allows for comparison between typical concrete-based construction and alternative building materials, such as date palm fibers, at different mass percentages.

Key inputs to accurately calculate carbon emissions with ZEBRA, or an energy and carbon assessment of a building in generate include:

Building form and materials:

Building form and materials play a crucial role in shaping the energy consumption and overall performance of buildings. Architects and designers recognize the significance of building shape and design, particularly when considering passive environmental design strategies. Research shows that thoughtful consideration of building form is essential to achieve low-energy architecture and minimize energy consumption.

The relationship between building form and energy use is complex and can vary depending on factors such as climate, location, and building size. Hemsath et al. (2015) acknowledge that while the influence of building form on energy performance is recognized, quantifying its exact magnitude is challenging due to the vast solution space. Nevertheless, understanding the energy performance specifically associated with building form is crucial for informed decision-making during the early design phase. Several studies, including the work of Konis et al. (2016), have focused on evaluating building form's impact on energy consumption. Through sensitivity analyses, researchers assess the energy performance of geometric variations and material considerations. The findings emphasize that both geometric proportions and material choices are critical factors influencing a building's energy performance.

To facilitate energy-efficient design, various software tools and technologies have been integrated into the early stages of the design process. These tools include Excel forms, BIM software, visual programming languages (VPL), and decision support tools, among others. These integrated tools enable designers to conduct parametric analyses, daylight and energy consumption simulations, and multidisciplinary design optimizations, thereby empowering them to explore alternatives and optimize building parameters for enhanced energy performance.

Expanding on the key debates regarding the relationship between urban form and building energy use, as discussed by Quan and Li et al. (2021), several significant issues arise, such as how much does Urban form matter? Which kind of urban form is more efficient? These are now discussed.

The extent of urban form's influence on building energy use remains a subject of debate. While early studies questioned its significance, later works generally agreed on its importance, but with varying opinions on its magnitude. Simulation studies reported a wide variation in the influence of building form on energy use, ranging from 100% to more than 400%. Empirical studies also show that specific urban form metrics, such as density, land cover, and geometric measures, have relatively large magnitudes and are worthy of consideration in energy efficiency policies.

The debate on the energy efficiency of different urban form typologies and patterns remains unsettled. While some studies suggest that multi-family housing is more energy-efficient than single-family housing, comparisons of various typologies or real urban patterns have produced contradictory and less comparable results. The lack of a clear consensus makes it challenging to determine a definitive preference for a specific urban form typology in terms of energy efficiency. Fortunately, the chosen methodology of this project uses ZEBRA, that accounts for form factor of the building (See table 10).

The analysis of the relationship between urban form and building energy use requires considering differences in definitions, measures, and representations in various studies.

The use of diverse approaches and methodologies can lead to varying conclusions, highlighting the need for a systematic and comprehensive framework in this analysis.

In conclusion, building form and materials are integral to a building's energy consumption and performance. Thoughtful consideration of shape, orientation, and materials can significantly improve energy efficiency and contribute to sustainable building design. Integration of simulation-based workflows and advanced software tools empowers designers to make informed decisions and achieve high-performance buildings with reduced energy consumption.

Occupancy:

The impact of building occupancy on energy consumption is a significant factor, as pointed out by Azar and Menassa (2012), Santin et al. (2009), and Kim and Srebric (2017). Recognizing this influence is key to sustainable development and energy-saving measures in the commercial sector. The initial step towards enhancing energy efficiency in buildings involves design optimization, where energy modeling and simulation tools play a vital role in the design stage. These tools help forecast energy usage and guide decisions regarding building systems, a concept explored by Azar and Menassa (2012). Yet, there's a notable gap between anticipated and actual energy use, suggesting that models are highly responsive to various inputs, particularly those concerning occupant behavior in energy consumption.

Research by Santin et al. (2009) and Kim and Srebric (2017) through observational studies underscore the profound effect of occupant behavior on energy usage. For instance, a significant portion of energy in buildings is consumed outside working hours due to behaviors like leaving lights and equipment on. Modifying these behaviors can lead to substantial energy reductions in commercial settings, as observed by Santin et al. (2009). Although the role of occupants in energy use is well-established, most sensitivity analyses have traditionally concentrated on technical and physical aspects, often overlooking occupancy-related factors. Azar and Menassa (2012) stress the importance of recognizing how changes in occupancy-related parameters affect energy models to ensure accurate building representations and make well-informed design decisions for optimal energy efficiency.

Enhancing the precision of energy modeling software necessitates an examination of its sensitivity to various input parameters, including those related to occupancy, as Azar and Menassa (2012) have indicated. Analyzing the sensitivity to occupancy factors, such as out-of-hours usage of equipment and lighting, heating and cooling settings, and hot water use, can illuminate their individual effects on energy estimates, leading to more accurate forecasts and design strategies.

Applying these insights to a school building illustrates the critical nature of occupant behavior, especially during non-operational hours, in energy use. Implementing energy-conserving solutions like smart occupancy sensors, as demonstrated by Kim and Srebric (2017), can be highly effective in schools. By adjusting heating, lighting, and ventilation systems based on actual occupancy, schools can minimize energy wastage during idle periods, thereby contributing to a more sustainable and energy-efficient educational environment.

In conclusion, occupants' energy consumption behavior significantly affects a building's energy use. Sensitivity analyses that include occupancy-related parameters can lead to more accurate energy modelling and informed decision-making for optimal building energy performance. For school buildings, understanding and quantifying the impact of occupant behavior during non-operating hours are particularly relevant to implementing effective energy-saving measures. By considering the interplay between building design and occupants' actions, schools can create more sustainable and energy-efficient learning environments.

Energy use data:

Accurate and comprehensive energy use data is essential for analyzing a building's operational energy performance and carbon emissions (Karlsson et. al., 2007). Energy use data typically includes electricity consumption, gas usage, and other forms of energy utilized for heating, cooling, lighting, appliances, and equipment.

Accurate energy use data is essential for modelling building energy and carbon emissions. It helps us make trustworthy predictions during the design process. When we design buildings, we want to know how different materials, designs, and operations affect energy use and indoor comfort. Good energy use data allows us to choose the best options for energy efficiency and lower costs. Having precise data is crucial for validating our simulation models. We can compare the predicted energy use from these models with actual measurements to see if they match. If there are differences, we can improve the models to make them more reliable (Karlsson et. al., 2007). Understanding how people use energy in buildings is also vital. The behaviour of tenants, like how they use lighting and equipment or control temperatures, has a big impact on energy consumption. Good data that considers these factors helps us develop accurate models that reflect real-world situations.

For existing buildings, energy use data helps us evaluate how much energy we can save through upgrades. By analysing past energy use, we can identify areas where improvements can be made to make buildings more energy efficient. This was the case for this school building case study in the next chapter (Chapter 4), and an attempt was made collect actual energy use of the building.

Location and weather data:

The geographical location and climate conditions surrounding the building significantly impact its energy demands and carbon emissions. Buildings in different climates have varying heating and cooling requirements based on temperature, humidity, solar radiation, and wind patterns.

Weather significantly influences the energy use of buildings, making it a critical factor in building energy performance (Hong et. al., 2013). Traditional energy simulations often rely on Typical Meteorological Year (TMY) data, which represents the building's performance for a typical year. Such information is crucial for building energy management and for assessing the risk associated with energy efficiency investments. Additionally, the size of the building also plays a role, with medium-sized office buildings being the most affected, followed by large and small offices. Thus, energy conservation measures evaluated using TMY data can be used for energy savings and peak demand reductions.

Furthermore, uncertainties in weather datasets can introduce performance gaps in building energy simulations (Erba et. al., 2017). Factors such as incorrect modelling of building components, inadequate characterization of operational schedules, and limitations in simulation algorithms can influence the accuracy of simulation results. While the first three limiting factors may be somewhat under the control of the simulation operator, weather data is entirely out of their control. Different weather databases can vary in data accuracy, and some may refer to climates that have substantially changed over the last decades. The choice of weather dataset can have a substantial impact on building energy simulation results, leading to performance differences depending on the dataset used (Erba et. al., 2017). In the face of climate change, new buildings need to be designed to cope with its effects (Roberts S., 2008).

This includes adapting to warmer weather, extreme and wet weather, and increased subsidence risk. The summary figure for the selected methodology is as follows.

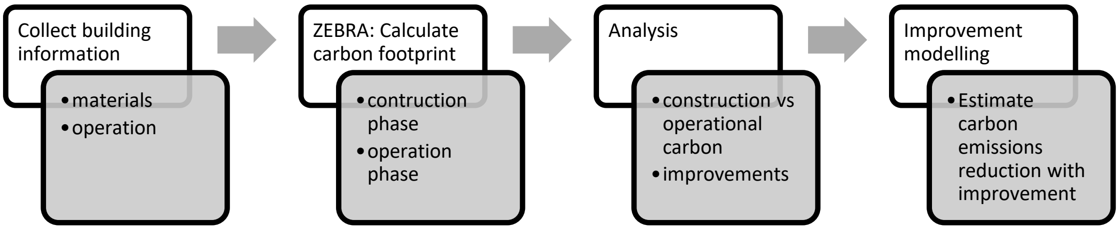

Figure 6a: Overall project methodology

In summary, understanding weather data and its impact on building energy use is of utmost importance for informed design decisions, effective energy management, and meeting energy efficiency goals in the face of climate change.

In conclusion, these important inputs (building form and materials, occupancy patterns, energy use data, and location/weather data) are integral to accurately assessing a building's energy consumption and carbon emissions during its operational phase. Therefore, this thesis will analyse both the construction and the operational phase of the building. A thorough analysis of these factors allows building owners and stakeholders to identify opportunities for energy efficiency improvements and implement sustainable practices that contribute to a reduced carbon footprint. For this reason, the case study in the following chapter use all this information to arrive at accurate results.

CHAPTER 4: CASE STUDY RESULTS AND ANALYSIS

The Renad academy is a school that helps children with autism (Figure 7 shows the outside view). It provides education and specialized services to students, and training and support to parents. The school presently serves students aged 3 to 10, but each successive year, it will add a grade level until students of all ages can be served. At the moment, the occupancy for grade is 15 students, adding up to approximately 120 students, and a total of about 25 staff working in different capacities. The facility has an internal occupied area of 3959 m^2.

Figure 7: Renad academy

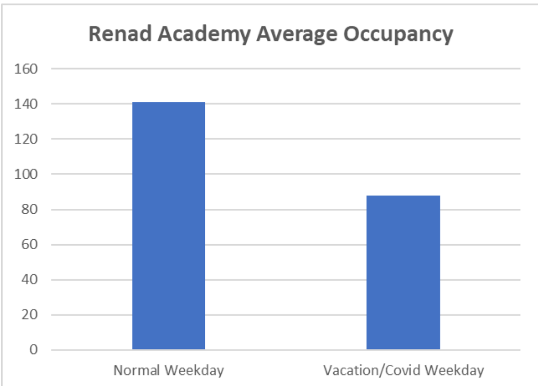

Figure 8: Occupancy pattern on working and non-working days (Data acquired from facility manager of Renad Academy)

Note that the occupancy includes Staff, teachers, and children. To effectively mitigate the challenge of carbon emissions from buildings, it is essential to understand the factors driving these emissions and identify opportunities for improvement. A critical step in achieving this is collecting comprehensive energy use data from buildings. Fortunately, this data was collected for the Renad academy as shown in the following figure. The electricity load is mainly driven by cooling in the hot desert climate. The facility is cooled with 14 packaged air conditioning units, all mounted on the roof tops. Moreover, the energy use in the summer increases significantly as expected, and this can also be seen in Figure 9. Also, the profiles for the years 2019 and 2020 have significant differences to the years before, which was the effect of the covid pandemic. As the building was not occupied to the normal levels during those times, the energy consumption was significantly different from that of typical consumption. For this reason, in this project, the energy use for the average of the five years is taken in the analysis, as shown in Figure 9.

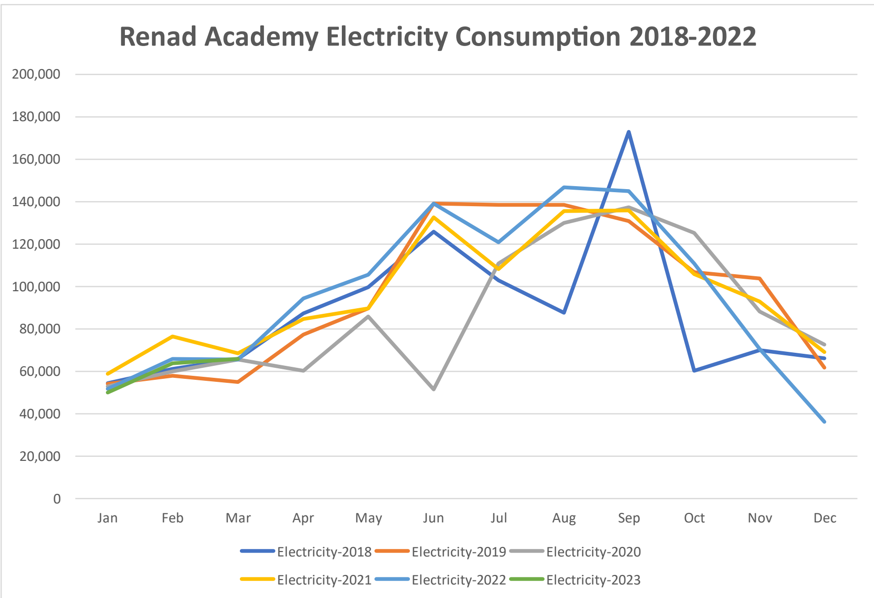

Figure 9: Energy consumption data of Renad academy for four years. The units are in kWh (Data acquired from facility management of Renad Academy).

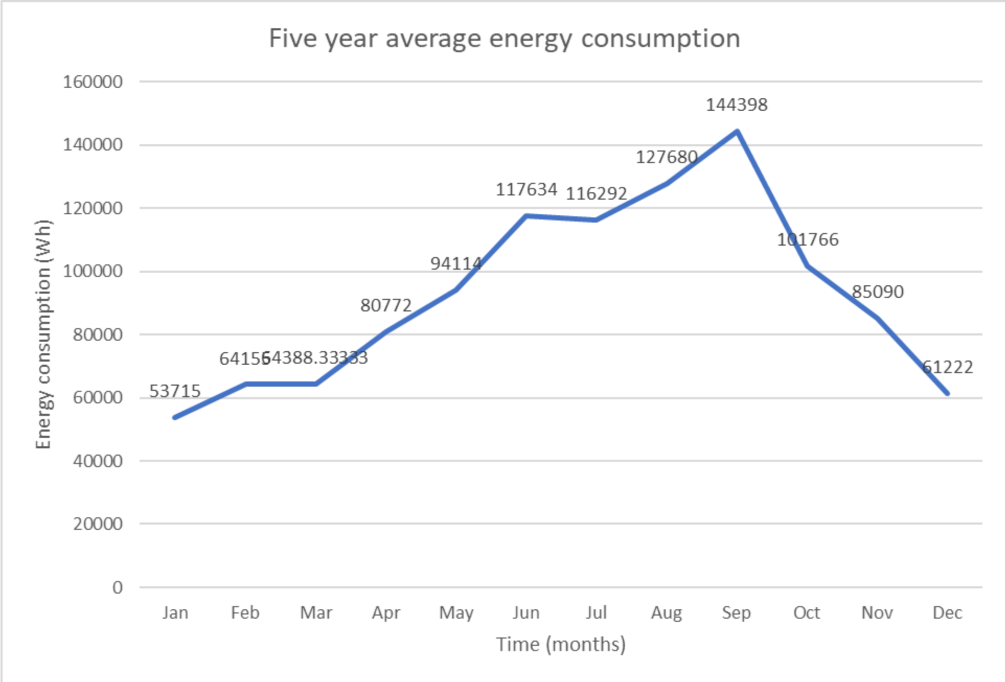

Figure 10: Average five year energy consumption profile (Data acquired from facility management of Renad Academy).

The following paragraphs provide the importance of gathering energy use data in investigating carbon emissions from buildings, highlighting three key reasons: enabling accurate calculations, identifying inefficiencies, and monitoring progress.

Firstly, collecting energy use data is crucial for accurately calculating the carbon emissions generated by a building. Energy use data provides a detailed insight into how much energy is consumed, the types of energy sources used, and the associated greenhouse gas emissions (IPCC, 2014). By obtaining this information, researchers can determine the carbon footprint of a building with a high level of precision. In turn, this enables decision-makers to design and implement targeted strategies for reducing emissions based on accurate and reliable information.

Secondly, collecting energy use data helps identify inefficiencies in a building's energy performance. Energy consumption patterns can reveal areas where energy use is higher than necessary, such as poorly insulated spaces, outdated HVAC systems, or inefficient lighting (Menezes et al., 2012). These inefficiencies not only increase the carbon emissions of a building but also result in higher energy costs for occupants. By analyzing energy use data, researchers can pinpoint the specific areas and systems contributing to increased emissions. This information is invaluable in designing targeted interventions to improve energy efficiency, reduce emissions, and lower operational costs.

Lastly, energy use data is essential for monitoring progress in reducing carbon emissions from buildings. Establishing a baseline of energy consumption and associated emissions allows researchers to track changes over time (Menezes et al., 2012). This enables them to assess the effectiveness of implemented interventions and identify areas where further improvements may be necessary. Monitoring progress is crucial for informing policy development, allocating resources effectively, and ensuring that targets for reducing emissions are met.

Therefore, collecting energy use data plays a vital role in investigating carbon emissions from buildings. It allows for accurate calculations of emissions, helps identify inefficiencies in a building's energy performance, and enables monitoring progress in reducing emissions. By leveraging this data from the Renad academy, researchers and decision-makers can design and implement targeted strategies to mitigate the impacts of climate change and contribute to global efforts in reducing greenhouse gas emissions.

Carbon emissions during the construction of Ranad Academy

This section details the steps for calculating the carbon emissions in the construction of Ranad Academy. Note that carbon emission factors for Qatar have been used in this study to make sure that the results are accurate. These have been taken from the IPCC

(Intergovernmental panel on climate change) database (IPCC, 2023). The table below details the relevant data that can be used in this project:

Table 1: IPCC data for Qatar (IPCC, 2023)

IPCC 2006 Source/Sink Category	Gas	Fuel 2006	Description	Region / Regional Conditions	Value	Unit
1.A - Fuel Combustion Activities	CARBON DIOXIDE	Crude Oil	1990 Country-Specific Net Calorific Values for Selected Countries	Qatar	42.87	TJ/kt
1.A - Fuel Combustion Activities	CARBON DIOXIDE	Natural Gas Liquids (NGLs)	1990 Country-Specific Net Calorific Values for Selected Countries	Qatar	43	TJ/kt
1.A.1.b - Petroleum Refining	CARBON DIOXIDE	Refinery Gas	Carbon dioxide emission factor from combustion of refinery fuel gas.Carbon oxidation factor=95%	The State of Qatar	12.5+/-0.7	tC/TJ

Steps of the applied methodology

The flow chart (in Figure 10a) below summarizes the methodology employed, that is detailed afterwards.

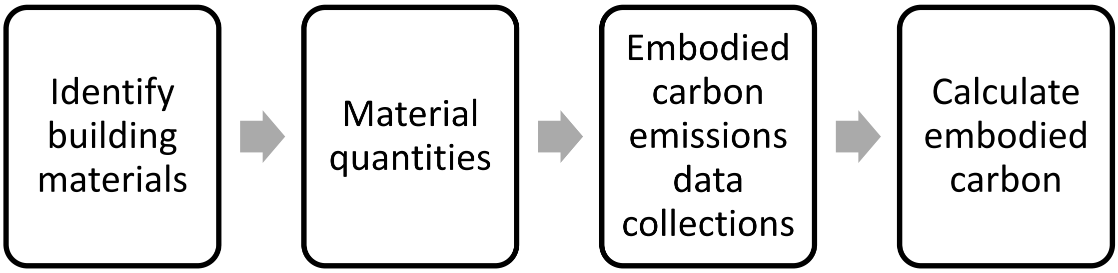

Figure 10a – flow chart for embodied carbon methodology.

Step 1: Identify Building Materials: Based on common construction standards in Qatar, we can assume the following building materials:

- Concrete: Used for the foundation, columns, and slabs.
- Steel: Used for structural beams and reinforcement.
- Glass: Used for double-glazed windows and doors.
- Insulation Materials: Use foam board insulation.

Fortunately, relevant data was collected from Renad Building's facility management team, which helped identify the exact material types used in the construction.

Step 2: Material Quantities (Assumed quantify be collected material information): From the Building's facility management team, the following information was collected, on a per square meter basis.

- Concrete – Aggregate concrete and fine concrete mix, Gabbro aggregate. Cement used for all works. Ordinary Portland cement for substructure and SRC cement for super structure: 0.1 m3 (Based on a floor thickness of 0.15 meters)

- Steel – Reinforced steel bars conforming to BS4449, minimum yield strength 460 N/mm^2 : 2 kg (Assuming a steel percentage of 0.5% of the concrete volume)
- Glass: 1.5 m2 (Assuming 50% window-to-wall ratio)
- Insulation Materials: 0.01 m3 (Assuming 0.25% of the concrete volume)

Step 3: Embodied carbon emissions Data Collection (From Jang et. al., 2022): For this simplified assessment, we'll use standard carbon emission factors for different building materials based on global averages.

- Concrete: 414 kg CO2/m3
- Steel: 409 kg CO2/kg
- Glass: 22.4 kg CO2/m2
- Insulation Materials: 0.1 kg CO2/kg

Step 4: Calculate Embodied Carbon (Estimation): Using the assumed material quantities and emission factors, we can estimate the embodied carbon for each material and then sum them up to get the total embodied carbon for the building.

Embodied Carbon Calculation (per square meter):

- Concrete: 0.1 m3 x 2,400 kg/m3 (average density) x 0.3 kg CO2/kg
- Steel: 2 kg x 1.6 kg CO2/kg
- Glass: 1.5 m2 x 0.8 kg CO2/kg
- Insulation Materials: 0.01 m3 x 200 kg/m3 (average density) x 0.1 kg CO2/kg

Total Embodied Carbon Estimate: As most of the carbon is a result of concrete and steel, the glass and insulation have been ignored. The following table summarizes the Embodied Carbon Assessment results for the school building:

Table 2: Carbon emissions from the construction phase of the building

Construction Materials	Quantity (kg/m^2)	Total Quantity (kg)	Carbon Emissions (kg CO2e/kg)	Total Carbon Emissions (kg CO2e)
Concrete	100,000 (based on 0.1 m^3/m^2)	940,800	414 (per m^3)	389,451.2
Steel	2	18,816	409	7,698,144

The embodied carbon assessment estimates the carbon emissions associated with the construction materials used in the school building, which is approximately 8,404 metric tonnes of CO2e. This will be combined with the results of the use phase which is described as follows.

Carbon emissions during the use phase of Ranad Academy

During the use phase, the building needs to be cooled and maintained to satisfy the requirements of the building occupants. Additionally, there are water requirements and electrical equipment such as computers and lighting. All these are now modelled using the ZEBRA software with the details of all these inputs provided below.

The “energy and carbon philosophy input section” in the software allows to set the targets that need to be achieved in the target design. For example, zero operational carbon means that the building operates without generating any carbon, which is a low carbon building. The following table provides a clear picture of the energy and carbon targets set for Ranad Academy. The standards for space cooling demand and primary energy are emphasized, where the latter is doubled compared to the Passivhaus default, a renowned energy standard. The building's expected lifetime is set at 60 years, which is a crucial parameter when considering the building's operational carbon emissions. The embodied carbon, representing the carbon footprint from the initial stages of building construction to its completion, is noted as 500 kgCO2e/m2TFAkgCO2 e/m2TFA, which is currently considered best practice. Interestingly, the operational carbon target is set to zero, highlighting a strong aspiration towards sustainability and environmental conservation.

Table 3: The Energy and carbon targets of the building if low or zero carbon is to be achieved. The comments for defaults are from the ZEBRA software based on relevant scientific literature (Fosas et. al., (2022)). Some additional context is added based on relevance to Qatar.

Energy and carbon target	Value	Unit	Comment
Space cooling demand standard	30	kWh/m²(TFA)/a	The Passivhaus default is 15 but that is for heating buildings. 30 is a reasonable value for the Qatari climate as cooling is far fore electricity intensive than heating (Saffouri et.a l., 2017).
Primary energy standard	240	kWh/m²(TFA)/a	The Passivhaus default is 120. This does not account for offsets (for example, those due to renewable energy production or the context of the climate). Therefore, 240 is chosen as this can be found in literature (Al-Otaibi et. al., 2015;)
Assumed lifetime of the building	60	a	Sets a frame of reference to study operational energy use. 60 years is another commonly used value.
Embodied carbon [A1-A5]	500	$kgCO_2e/m^2(TFA)$	500 is best-practice at the moment. 0 is the aspiration for new zero carbon buildings by 2030.
Operational carbon	0	$kgCO_2e/m^2(TFA)/a$	0 is the aspiration at the moment.

Table 4 provides a clear picture of the energy and carbon targets set for Ranad Academy. The standards for space cooling demand and primary energy are emphasized, where the latter is doubled compared to the Passivhaus default, a renowned energy standard. The building's expected lifetime is set at 60 years, which is a crucial parameter when considering the building's operational carbon emissions. The embodied carbon, representing the carbon footprint from the initial stages of building construction to its completion, is noted as 500 kgCO2e/m2TFAkgCO2e/m2TFA, which is currently considered best practice. Interestingly, the operational carbon target is set to zero, highlighting a strong aspiration towards sustainability and environmental conservation.

Table 4: Basic key inputs that effect the operational energy and carbon emissions of the building

Key characteristics	Value	Unit	Comment
Treated floor area (TFA)	3,563	m^2	TFA is about 90% of gross internal floor area, or 97% for a bungalow (as no stairs). Here, 90% is taken.
Thermal mass level	60	Wh/K/m^2(TFA)	This is the specific heat capacity per TFA. Typical value is 60. Typical values are between 20 (lightweight) and 100 (heavyweight).
Key characteristics	Value	Unit	Comment
Heating setpoint	18	°C	Typical heating setpoint in this climate
Cooling setpoint	23	°C	Typical cooling setpoint in this climate

Figure 11 provide a summary of the weather data used in this analysis. The software allowed to import weather data with solar radiation, wind speed etc., for a location that was quite close to Renad academy and was considered acceptable.

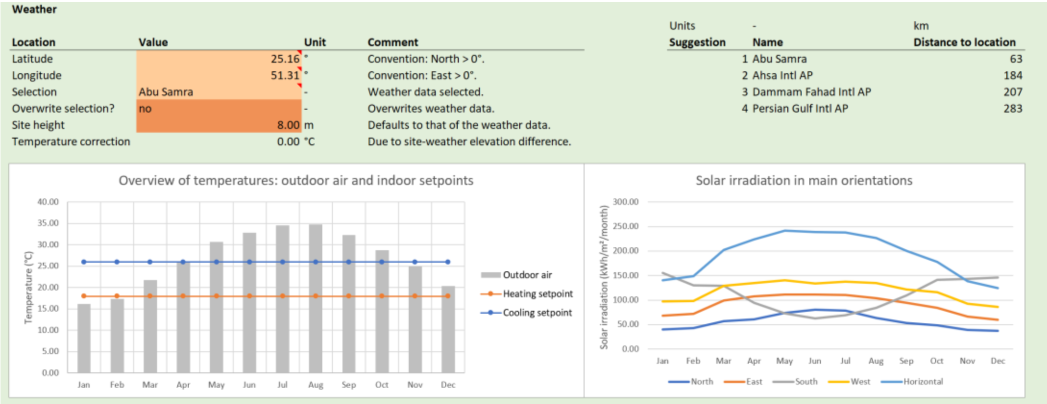

Figure 11: The weather data for the location that was closest to Doha has been acquired here. The average monthly temperature, heating and cooling setpoints are mentioned. The location was 63 km from Renad academy, but this is okay because there is not much geographic variation by the 63km.

The following table provides a clear picture of the energy and carbon targets set for Ranad Academy. The standards for space cooling demand and primary energy are emphasized, where the latter is doubled compared to the Passivhaus default, a renowned energy standard. The building's expected lifetime is set at 60 years, which is a crucial parameter when considering the building's operational carbon emissions. The embodied carbon, representing the carbon footprint from the initial stages of building construction to its completion, is noted as 500 kgCO2e/m2TFAkgCO2e/m2TFA, which is currently considered as the best practice.

Table 5:The thermal characteristics of the walls and doors in the building. This is acquired from literature (Ibrahim et. al., 2022; Kharseh et. al., 2016; GBPN, 2014)

Units:	m	W/m²/K	W/m²/K	m²
Wall - door	Insulation thickness	U-value	U-value	Area
external walls	0.20	0.36		1,006.00
lobby doors	0.10	2.00		105.80
lobby walls	0.10	0.36		106.00

The roof (Table 6), much like the walls and doors, plays a vital role in a building's thermal performance. While this table's content hasn't been deeply examined yet, it's expected to detail similar thermal characteristics, ensuring that the roof doesn't become a significant source of energy loss.

Taken together, these tables provide a comprehensive overview of the energy and carbon targets, as well as the design elements and characteristics, that contribute to Ranad Academy's operational phase emissions. The emphasis on reducing operational carbon to zero and the detailed attention to building characteristics like insulation and thermal mass demonstrate a robust commitment to sustainability and energy efficiency.

Table 6: Thermal characteristics of the roof (values used form literature (Ibrahim et. al., 2022; Kharseh et. al., 2016; GBPN, 2014)

Roof		
Units:	m²	W/m²/K
Roof name (optional)	Area	U-value
a	3,959.00	0.29
b	0	0
c	0	0
Summary	3,959.00	0.29

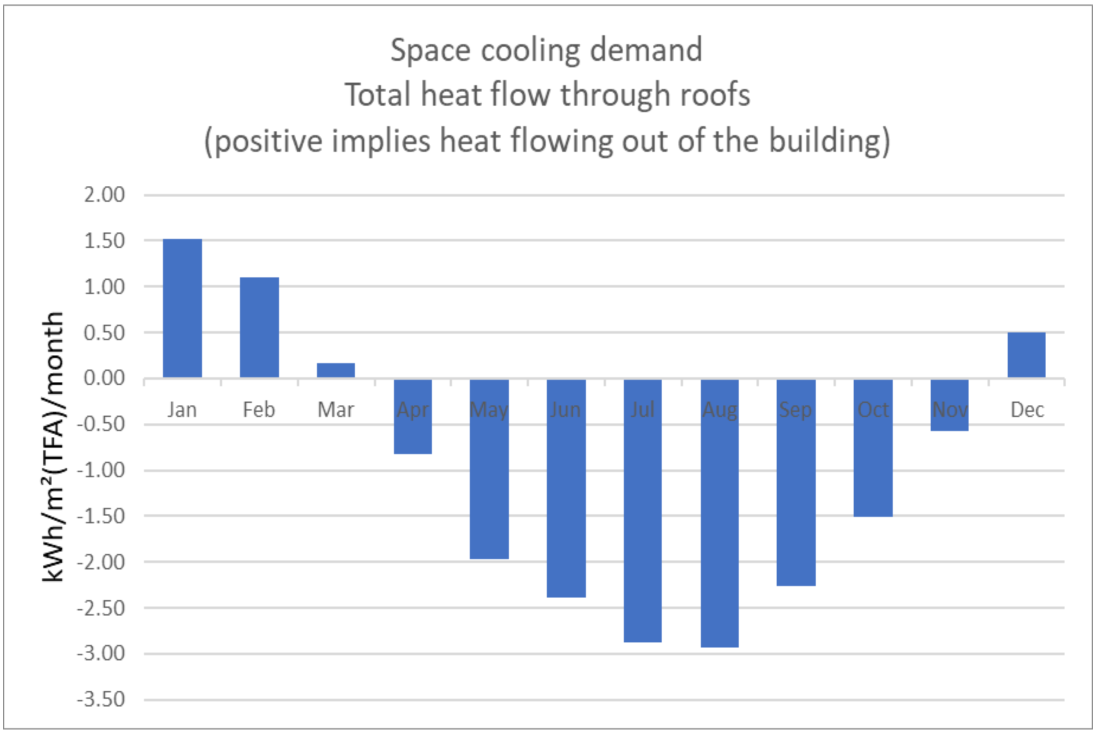

Figure 12: Space cooling demand where the negative -2.12 peak in the summer represents 2.12 kWh/m2/month for the treated floor area (TFA).

The glazing of a building, essentially its windows, significantly influences its thermal performance (Table 7). The table touches upon the mid pane U-value of the glazing, which is set at 3.16 W/m2K. The U-value gauges the rate at which heat is transferred through the glazing. Interestingly, the table offers a comparison, mentioning that a typical triple glazing would have a U-value of 0.85. The value of 3.16 suggests that the glazing at Ranad Academy is not as insulative as the triple-glazed benchmark, potentially allowing for more heat transfer. Solar gains refer to the amount of heat a building gains from the sun, primarily through its windows. This table shows the solar gains experienced by the building from different orientations (North, East, South, West) throughout the year. Solar gains can significantly influence a building's cooling needs, especially in a sunny locale like Qatar. Properly understanding and managing these gains can lead to more efficient cooling strategies, ultimately conserving energy and reducing carbon emissions (Table 8).

Table 7: Glazing thermal properties

Glazing			
Parameter	Value	Unit	Comment
Mid pane U-value	2	W/m²/K	Reasonable defaults are: 0.85 (triple glazing); 2 (double glazing); 5 (single glazing).
Frame U-value	2.00	W/m²/K	2 would be a reasonable default.

Table 8: Solar heat gains from the windows through the year

Solar gains	26,266 (kWh/month)	7.4 (kWh/m2TFA/month)

The glazing is 15% of the external wall surface area, which was considered a reasonable assumption based on the observation of the RENAD academy building. Air conditioning is often a major energy consumer in buildings, especially in hot climates. The table highlights the ventilation rate, set at 10 m3/h/p, and contrasts it against the Passivhaus standard of 30. A lower ventilation rate indicates lesser fresh air intake, which can reduce the energy required to condition this air. However, it's crucial to strike a balance to ensure indoor air quality isn't compromised. From the tables examined so far, it's evident that Ranad Academy's design and operational strategies prioritize energy efficiency and sustainability. The data underscores the significance of every design element, be it the walls, roof, glazing, or ventilation systems, in achieving the building's energy and carbon targets. The resulting cooling energy demand requirements are displayed in Figure 13. Moreover, the contributions of the different elements of the building the eventually result in this energy demand are also shown in Figure 14, from which it can be seen that the incidental gains are the largest energy contributor to heat addition. This is from the heat emission from human occupants and electrical equipment.

Table 9: Cooling energy requirements

Parameter	**Value**	**Unit**	**Comment**
Ventilation rate	10.00	$m^3/h/p$	Passivhaus demands 30.
Assumed infiltration rate	1.00	ACH	0.6 or better to be a Passivhaus, the average value in the UK is probably 6 for a small building. (1 ACH reasonable estimate).
Treated floor area (TFA)	3,563.10	m^2	TFA is about 90% of gross internal floor area, or 97% for a bungalow (as no stairs).
Internal volume of building	10,689	m^3	Floor height of 3m
Likely infiltration rate at normal pressures	0.07	ach	Tight envelop in this country because of hot summers
Time taken for infiltration to replace all the air in the building	14.29	h	Standard assumption from ZEBRA
Average number of occupants (see end of commentary)	101.50	p	Suggestions: 0.014 * TFA for homes; 0.01 * TFA for offices; 0.072 * TFA for schools (fraction of an occupant is fine). In this case, 0.7, or 70% has been used.
Ventilation rate	1,015.00	m^3/h	Calculated by multiplying with occupants
Ventilation rate	0.09	ach	Calculated by multiplying with occupants but expressed as air changes per hour

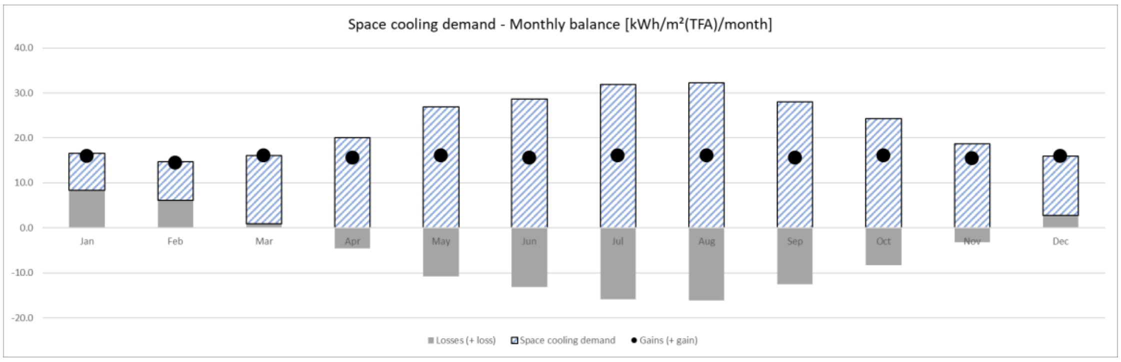

Figure 13: The space cooling demand closely matches the one recorded form the building (Also see figure 15 for the close match between calculations and actual cooling electricity use)

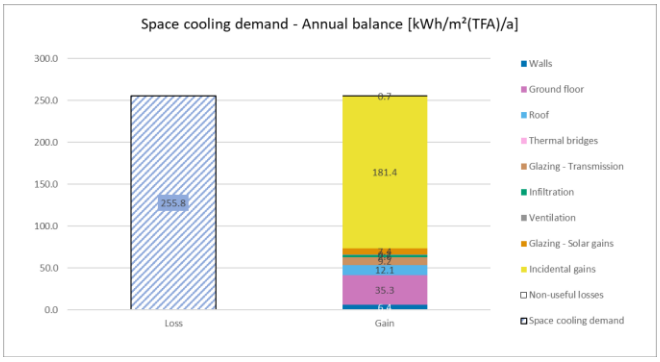

Figure 14: Reasons for cooling electricity

Table 10 revisits and consolidates the crucial thermal design parameters of the Ranad Academy. The treated floor area (TFA) is reiterated, emphasizing its importance as a base metric for various energy calculations. The TFA is often used to normalize energy consumption, allowing for comparisons and benchmarks with other buildings. The inclusion of this summary table underscores the significance of the various thermal characteristics in influencing the building's energy performance.

Table 10: Summary of the thermal characteristics of the building

Key design parameters		
Parameter	Value	Unit
Treated floor area (TFA)	3,563.10	m²
Internal volume of building	10,689.30	m³
Thermal envelope area	9,408.10	m²
Compactness (envelope area / volume)	0.88	-
Form factor (envelope area / tfa)	2.64	-
Average U-Value	0.70	W/m²/K

This table revisits and consolidates the crucial thermal design parameters of the Ranad Academy. The treated floor area (TFA) is reiterated, emphasizing its importance as a base metric for various energy calculations. The TFA is often used to normalize energy consumption, allowing for comparisons and benchmarks with other buildings.

Table 11: Summary of the heating, cooling and water system energy requirements

Space heating system	Value	Unit
Energy demand	0.16	kWh/m²(TFA)/a
Space cooling system	Value	Unit
Energy demand	255.8	kWh/m²(TFA)/a
Domestic hot water (DHW)	Value	Unit
Total daily hot water requirement of building	220.00	litres/day
		Based on Al-Maadid et. al., (2022)

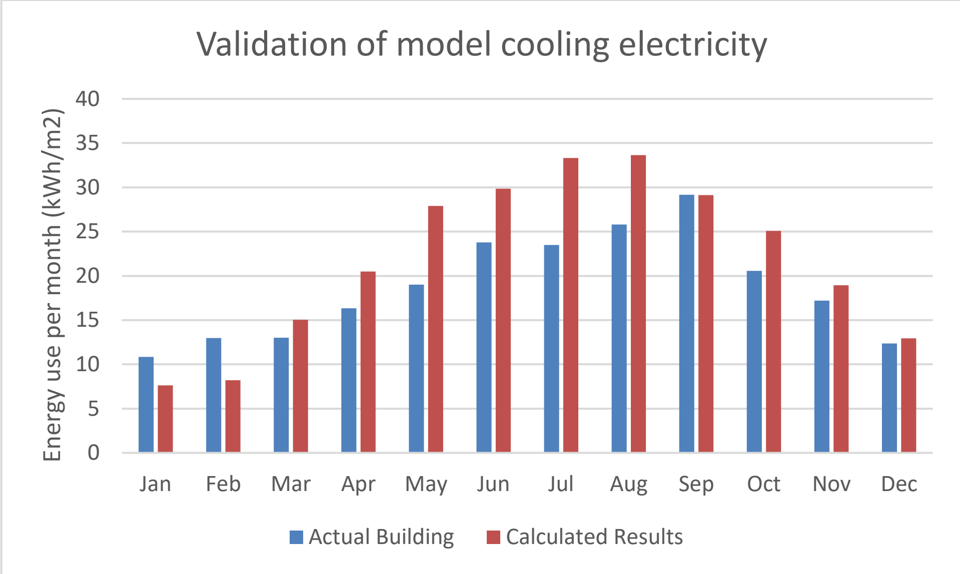

Figure 15: There is a very close matching between the calculated and collected data.

The figure above and the following table focus on validating the energy model against actual collected data. The importance of such validation can't be overstated. By comparing modelled energy use with actual measurements, one can gauge the accuracy of the predictions and make necessary adjustments in future projections. The table appears to present values for total energy use per annum and deduces the total cooling energy based on the assumption that 80% of the energy is used for cooling. Such a validation process is vital in ensuring that the building's design and operational strategies are on track to achieve the set energy and carbon targets. The results are a close match as the error is only 6.6% between the calculated and the actual building cooling electricity requirements. This difference can be attributed to several reasons. This can be due to inaccuracy in the weather data which is based on the nearest weather file, which is 60km away from the site location. Furthermore, the software has limited capability in terms of detail which means additional aspects of the buildings, such as detailed HVAC design my have been ignored. Nonetheless, the energy consumption profiles match to a good degree and an error of 6.6% is considered acceptable for this case study.

From the tables examined so far, there is a clear emphasis on understanding every aspect of the building's energy profile, from its thermal characteristics to its heating and cooling needs. By setting clear targets, detailing design parameters, and validating predictions with actual data, Ranad Academy's approach to achieving energy efficiency and sustainability is both comprehensive and methodical.

Table 12: Summary of the close matching between the calculated and collected data.

Energy results validation of model against collected data		
280	Total energy use per annum	kWh/m2/a
262	Total cooling energy (calculated)	kWh/m2/a

Table 13 provides carbon emissions factors specific to Qatar, which are essential for calculating the carbon footprint of any energy-intensive activity in the region. These factors, sourced from the IPCC database and Statista, enable a more localized and accurate assessment of carbon emissions. The table lists various fuels and their associated carbon emissions factors measured in kgCO2e/kWhkgCO2e/kWh. By utilizing region-specific factors, the analysis ensures that the carbon emissions calculations are tailored to Qatar's energy mix and consumption patterns.

Table 13: Carbon emissions factors for Qatar (IPCC, 2023; Statista, 2023)

Fuel database (Qatar specific)	Source: IPCC database
Units:	$kgCO_2e/kWh$
Name	Carbon
Electricity	0.489
Mains gas	0.500

The following figure emphasizes the contribution of space cooling in the total energy consumption. This is also seen in Figure 19, because carbon emission naturally follows the large energy use because of space cooling in the building.

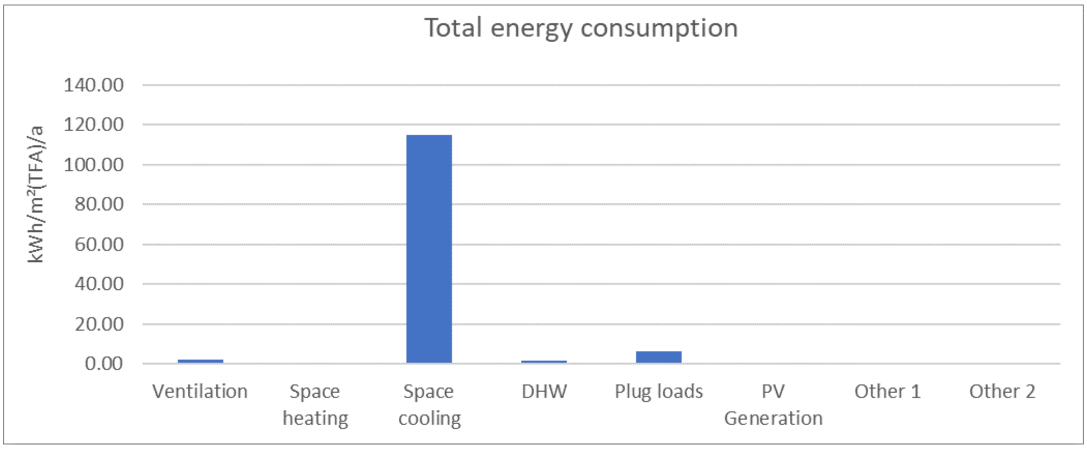

Figure 16: This figure shows that the energy requirements during the operational phase are completely dominated by the space cooling needs of Renad academy.

Tables 14 and 15 and Figure 17 offers a breakdown of the embodied carbon emissions based on different building components, from the substructure to other elements. Clearly, the façade and the structure are the main contributors to embodied carbon emissions. Such a detailed breakdown helps in pinpointing areas that contribute most to the building's embodied carbon, guiding efforts to reduce the carbon footprint in future projects. For instance, the table highlights that the substructure contributes to

0.21% of the total embodied carbon. Such insights can be invaluable for designers and architects aiming for sustainable and low-carbon buildings.

Taken together, these tables emphasize the meticulous approach taken in understanding and calculating both the operational and embodied carbon emissions of Ranad Academy. From using region-specific carbon emissions factors to detailing the embodied carbon breakdown, the analysis showcases a deep commitment to understanding every facet of the building's carbon footprint.

Table 14: Embodied carbon as calculated manually in the earlier section, entered into the software

Embodied carbon	
Building information	Value
Building Type	Educational
Construction Type	Standard
Manual calculation of embodied carbon	2358 (kgCO_2e/m^2(TFA))

Table 15: Summary of the embodied carbon emissions breakdown by the structure

Cradle-to-Gate Building Component Breakdown [Life Cycle Stages A1-A3]	
Building Element	% of Total Embodied Carbon
Substructure	28%
Superstructure	29%
Façade	19%
Interiors	14%
Buildings Services / MEP	10%

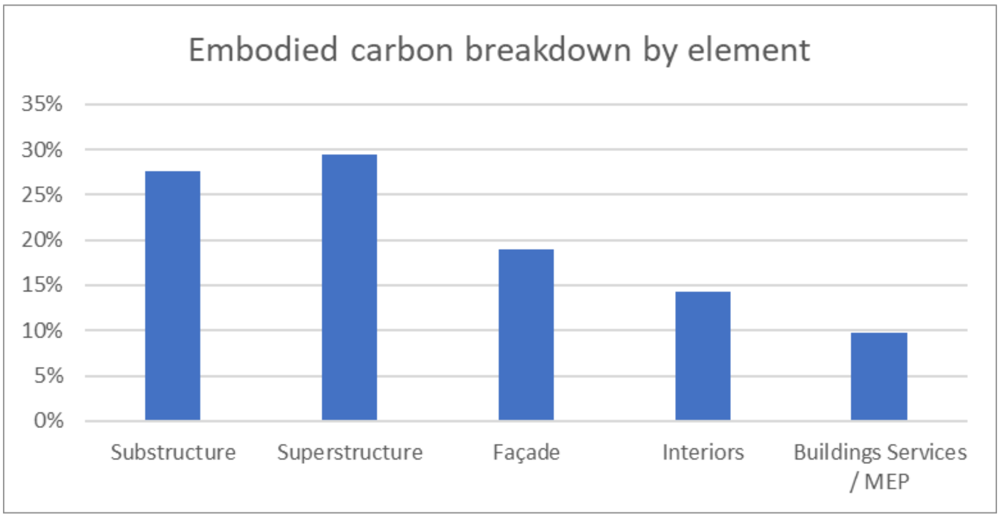

Figure 17: Break of the carbon emissions by the building structure.

Operational energy use intensity (EUI) is a key metric in evaluating a building's energy performance and is presented in Table 16. It represents the amount of energy a building consumes relative to its size, often expressed in terms of energy per unit area per year. The table offers insights into Ranad Academy's energy consumption patterns. A lower EUI indicates a more energy-efficient building, and understanding this value can help benchmark the building against similar structures and guide future energy-saving initiatives.

Table 16: Operational energy use intensity (energy use per meter squared per year)

Operational intensity				
Units:	kWh/m²(TFA)/a	kWh/m²(TFA)/a	kWh(primary)/m²(TFA)/a	$kgCO_2e$/m²(TFA)/a
System	Energy Demand	Energy Consumption	Primary Energy	Operational carbon
Ventilation	2.2	2.2	3.4	1.1
Space heating	0.0	0.0	0.0	0.0

Space cooling	255.8	127.9	192.0	62.6
DHW	1.8	1.8	2.6	0.9
Plug loads	6.2	6.2	9.3	3.0

Based on the energy use results, the carbon emission during the operational phase, as seen in figure 18, are dominated by the space cooling requirements

Finally, table 17 summarizes the overall carbon footprint of Ranad Academy, consolidating both embodied and operational carbon emissions. An understanding of the total carbon footprint is invaluable for any sustainability initiative, allowing stakeholders to gauge the environmental impact of the building throughout its lifecycle. Figure 20 then compares the embodied and operational carbon, where it can be seen that both phases of the life cycle are very important. Although operational carbon emissions dominate, the embodied emissions cannot be neglected.

To conclude, the tables provided in the document offer a comprehensive view of the energy and carbon profile of Ranad Academy. From setting ambitious energy and carbon targets to detailing the thermal characteristics of the building and validating energy predictions with actual data, the analysis showcases a meticulous and committed approach to sustainability. The emphasis on both operational and embodied carbon emissions ensures a holistic understanding of the building's environmental impact, setting the stage for effective carbon reduction strategies. The use of region-specific carbon emission factors and the detailed breakdown of embodied carbon further enhance the accuracy and relevance of the analysis for Ranad Academy in its Qatar locale.

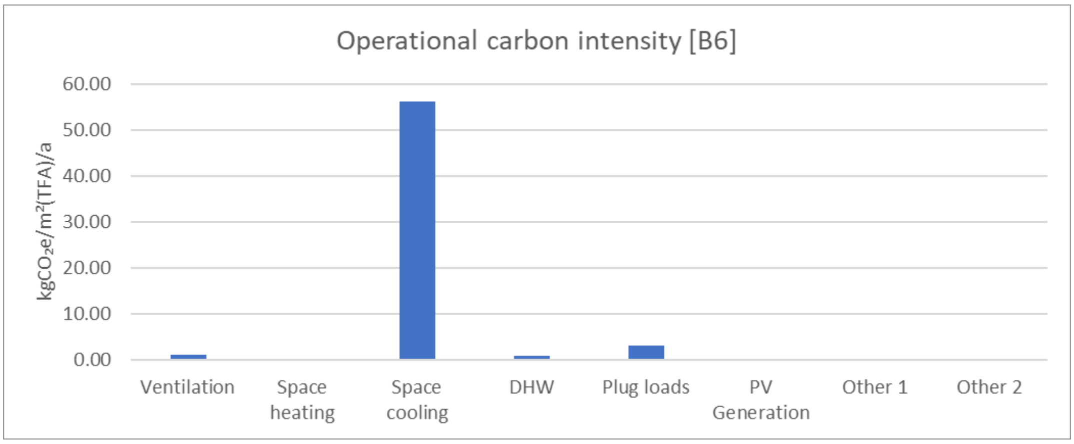

Figure 18: Carbon emissions during the operational phase

Table 17: Overall carbon footprint of Renad academy

Carbon footprint		
Parameter	Value	Unit
Assumed lifetime of the building	60	a
Embodied carbon [A1-A5]	1150	$kgCO_2e/m^2(TFA)$
Operational carbon [B6]	4,053	$kgCO_2e/m^2(TFA)$
Years it takes operational carbon to match upfront embodied carbon	17	years
Absolute carbon footprint estimated [A1-A5 + B6]	18,538,864	$kgCO_2e$

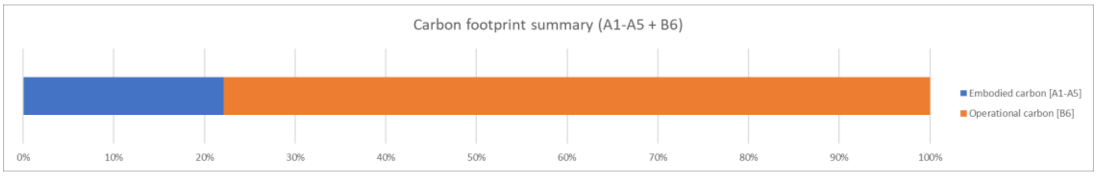

Figure 19: Comparison between embodied and operational carbon emissions over a 60 year assumed life period of the building.

Proposal of rooftop PV installation

To reduce the carbon emissions and achieve the net zero carbon target, it is proposed to install rooftop PV. As the objective is to achieve zero carbon during operation phase, various percentages of roof top PV coverage area where explored to find out the proportion of the roof needed to result in a zero carbon building during operation phase. The PV rooftop area was varied between 10% and 80%, resulting in the following annual operational carbon.

Table 18: Fraction of roof area needed for PV to achieve net zero carbon operation

PV rooftop covered area (%)	Annual Operational carbon $kgCO_2e/m^2$(TFA)
10	3209
20	2364
30	1520
40	675
48	0
50	-169
60	-1013
70	-1858
80	-2702

The same data is visualised below to emphasize the 48% rooftop area is needed. Following the figure, detail about the energy generation and carbon reduction with the 48% covered area is provided.

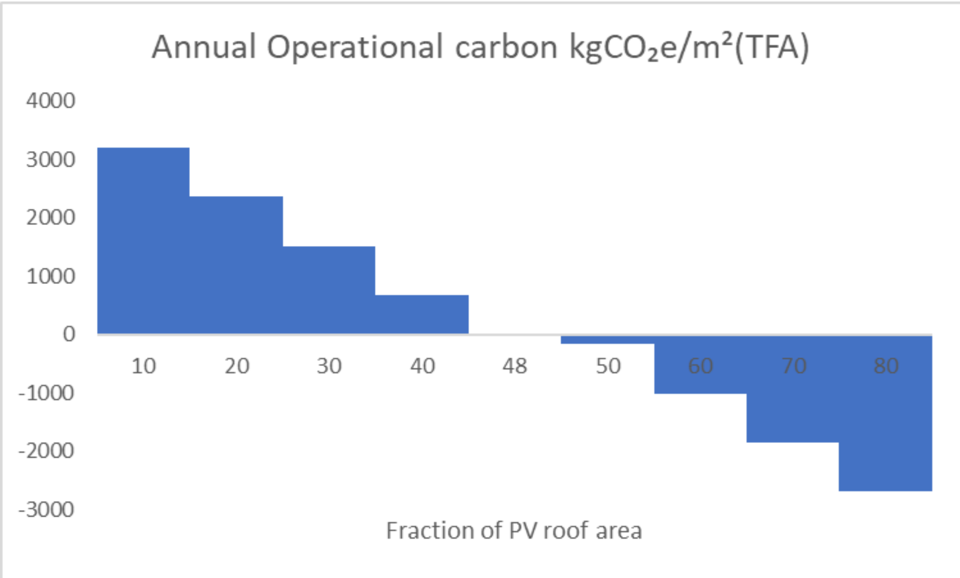

Figure 20: Net zero PV fraction

From Table 18, it is clear that covering 48% of the rooftop with PV panels can negate the operational carbon of the building, making it net-zero in terms of operational carbon emissions. It's notable that further increase in PV coverage not only negates the operational carbon but even overcompensates, potentially allowing the building to become carbon negative during operation or to act as an energy source for surrounding facilities.

The figure emphasizes this point visually, showing the drop in operational carbon emissions with increasing PV coverage. This showcases how renewable energy can significantly reduce a building's carbon footprint and help in achieving sustainability goals.

From Table 19, the total area suitable for PV installation is approximately 1,900.32 m². With a PV panel efficiency of 15%, and after accounting for all losses (including inverter losses and shading) as represented by the performance ratio, the solar irradiation available for conversion to electricity is approximately 2,302.38 kWh/m²(panel)/a.

Given these parameters, the total annual energy generation from the PV system is around 492,215.76 kWh. This impressive generation is based on the solar irradiation data specific to the location, and it showcases the potential of rooftop PV systems for large buildings like the school.

When analyzing on a per square meter basis:

- The generation per m² of the panel is approximately 259.02 kWh. This represents the effectiveness of the PV system itself in converting available solar radiation into electricity.
- The generation per m² of the Total Floor Area (TFA) stands at 138.14 kWh. This metric helps to understand how much energy is generated concerning the entire floor area of the building, giving stakeholders an idea about the self-sufficiency of the building in energy terms.

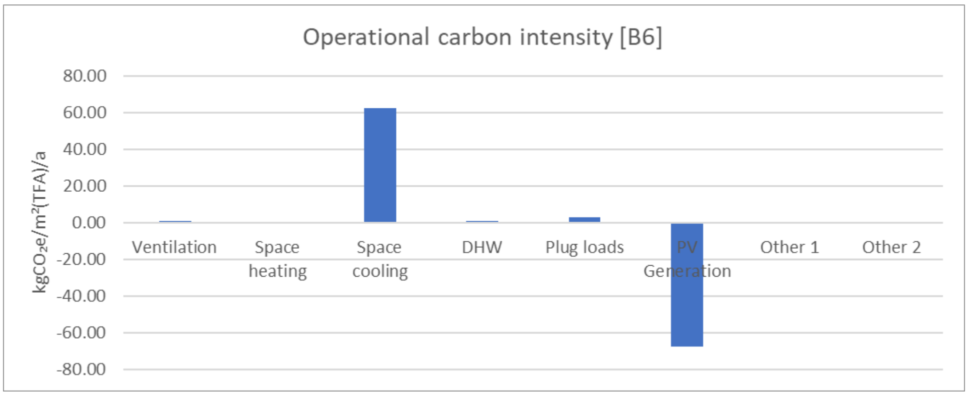

Figure 21: The operational carbon intensity of cooling and other loads balanced by PV

Table 19: PV rooftop input data

PV	Value	Unit	Comment
Total roof area	3,959.00	m²	This is the physical roof area, which may not be necessarily the same as the total area in the "Roof" sheet.
Fraction of roof area suitable for PV	0.48	-	Assumes horizontal unshaded panels.
Final area for PV	1,900.32	m²	
PV panel efficiency	0.15	-	Default = 0.15, i.e. 15% (This is minimum achievable according to Vaishak et. al., 2019)
Performance ratio	0.75	-	Represents all losses, including inverter losses and shading (default = 0.75, i.e. a 25% loss (Vaishak et. al., 2019)).
Input of available solar irradiation	2,302.38	kWh/m²(panel)/a	Based on the weather data, roof orientation, area and PV module specs
Available solar irradiation	2,302.38	kWh/m²(panel)/a	
Generation	492,215.76	kWh/a	
PV	Value	Unit	Comment
Equivalent efficiency	0.11	-	Represents the fraction of available solar radiation that the whole PV system is able to use.
Generation per m² of panel	259.02	kWh/m²(panel)/a	Describes the performance of the PV system itself.

Generation per m² of TFA	138.14	kWh/m²(TFA)/a	Describes the influence of the PV system considering the characteristics of the building.

Based on the analysis, a 48% coverage of the school's rooftop with PV panels is recommended to achieve net-zero operational carbon emissions. It is also worth noting that increasing the efficiency of PV panels or optimizing other factors could potentially reduce the required coverage, but the 48% is based on the given efficiency of 15%.

Additionally, if the school or surrounding facilities can utilize the surplus energy from a coverage greater than 48%, it could serve as an incentive for increased investment in PV.

Given the potential for significant energy savings and carbon emissions reduction, stakeholders and decision-makers should prioritize the integration of this PV system into the school's infrastructure. Beyond the environmental benefits, there are potential economic advantages in terms of reduced energy bills and possibly selling the surplus energy back to the grid. However, as the electricity to public buildings has a very low economic cost based on the current policies, it is advisable to install the minimum covered area required to achieve net zero carbon emissions, with the objective to keep the costs of installation to a minimum. A basic cost payback analysis is finally conducted to get an idea of this.

The analysis of the rooftop PV installation project combines two scenarios. The first, based on the actual cost of electricity from the Kahramaa bill for October 2023 at 0.11 Qatari Riyal (QR) per kWh (approximately $0.030 USD), reveals a prolonged payback period. The key parameters are:

- Annual Electricity Usage: 20,508 kWh

- Electricity Cost per kWh: $0.030 USD
- Annual Savings: $615.24 USD
- Total PV System Cost: $427,572 USD
- Payback Period: Approximately 694.97 years

This extended payback period is largely due to the region's low electricity cost. However, if the government offers financial incentives for reduction of carbon emissions, then it could contribute to a better financial outlook. This required an analysis of Qatar's environmental policy, a review of any policies towards this and possible policy recommendations. This is recommended in a future project and is considered out of scope of this current project.

In contrast, the second scenario is to determine the electricity cost needed for a feasible 20-year payback period, considering this is a typical lifespan of a PV system. This analysis found that an electricity cost of approximately $1.04 per kWh is required to achieve annual savings of $21,378.60, necessary for a 20-year payback on the same PV system investment. This is calculated by dividing the total cost ($427,572 USD) by 20 years. This cost is significantly higher than the current rate, highlighting that for economic viability within a 20-year span, either a substantial increase in electricity costs or a decrease in the initial investment of the PV system is necessary.

Next, a net present value (NPV) is calculated. The Net Present Value (NPV) of the rooftop PV installation project, calculated with an initial investment of $427,572 USD, annual savings of $615.24 USD, a discount rate of 5%, and over a 20-year project lifetime, is approximately $419,904.75−$419,904.75. This negative NPV suggests that under the given assumptions (particularly the low annual savings), the project is not financially viable as the present value of the cash flows does not cover the initial investment. It's important to note that this negative projection is due to (i) the very low electricity cost in Qatar for public buildings (ii) the absent of any carbon tax by the government (iii) the absence of any carbon rebate/cost benefit of reducing carbon emissions.

Therefore, we can conclude that adding such carbon tax/rebate measure could make such de carbonisation projects viable and contribute to the national vision 2030 positively.

Additional recommendations for a more energy efficient building envelope:

The performance of building envelopes in Qatar can be effectively estimated by referencing studies conducted in Saudi Arabia due to the similarity in climate between the two regions. In particular, the extensive research by Ghabra, N. (2018) on energy-efficient building envelope solutions for residential tall buildings in Saudi Arabia provides valuable insights that are applicable to Qatar as well. This study delves into various strategies aimed at reducing energy consumption and cooling loads, which are crucial considerations in the hot climates of both countries.

Ghabra's study emphasizes the importance of certain design elements such as the orientation of glazed façades, the use of external shading, and the provision of openable windows to enhance energy efficiency. The orientation of at least 60% of glazed surfaces predominantly northwards helps mitigate solar gains and reduce cooling loads. External shading devices, preferred over tinted glass and internal blinds, can significantly reduce building cooling demand, with reductions up to 7% in certain scenarios. Additionally, openable windows facilitate mixed-mode ventilation, combining mechanical and natural ventilation, which further reduces energy consumption and improves indoor environmental quality.

The thesis also highlights the role of both opaque and transparent elements of the building envelope in affecting a building's energy balance. The study draws attention to the high percentage of solar gains through glazing, which can account for up to 85% of incident radiation.

Here are the specific U-values and related guidelines as detailed in Saudi Arabia's SBC 601, which are applicable for building envelopes in areas with similar climatic conditions:

Table 20: suggestions for an improved envelope

Building Element	Glazing Percentage	U-Value (W/m²K)	Cost Estimation
Windows	≤ 10%	3.975 - 2.271	Medium
Windows	10 – 25%	3.975 - 2.271	Medium
Windows	25 – 40%	3.975 - 2.271	Medium
Windows	40 – 50%	3.975 - 2.271	High
External Walls	Metal Framing	0.43 - 1.89	Medium
External Walls	Wood Framing	0.51 - 1.40	Low
CMU Walls	Metal Framing	0.51 - 0.43	Medium
CMU Walls	Wood Framing	0.51 - 0.51	Low
Other Masonry	Metal Framing	0.51 - 1.89	Medium
Other Masonry	Wood Framing	0.51 - 0.51	Low

The cost estimations for these solutions range from low to high, reflecting the variance in material quality, complexity of installation, and regional economic conditions. Renowned for their durability, fire resistance, and insulation qualities, CMU walls are a staple in both residential and commercial construction. They can be finished with various treatments like paint or plaster, adapting to diverse architectural styles.

External walls with metal framing are another option, offering a blend of structural integrity and flexibility in design. These walls typically involve a metal framework covered with panels or other materials, and are known for their durability and resistance to environmental factors. Wood framing, an alternative, is widely used due to its natural insulation properties, ease of installation, and versatility. Wood-framed walls provide a classic aesthetic and can be easily modified or repaired. Other masonry walls, such as those made from bricks or stones, offer excellent thermal mass, contributing to energy efficiency by moderating indoor temperatures. They are valued for their aesthetic appeal, strength, and longevity. Each of these wall types has distinct characteristics in terms of U-values, which measure their insulation effectiveness, and are chosen based on factors like climate, architectural requirements, and energy efficiency goals.

. These guidelines and cost estimations offer a foundation for enhancing the effectiveness of local building codes and energy efficiency regulations in similar hot climates. For more precise and region-specific cost information, consultation with local construction and energy efficiency experts or suppliers is recommended.

CHAPTER 5: RECOMMENDATIONS AND CONCLUSIONS

Renad Academy, a commendable educational institution catering to children with autism, is situated in the heart of Qatar's desert climate. With an increasing number of students each year, it currently educates approximately 120 students with the aid of 25 staff members, all within a sprawling area of 3959 m^2. The structure is not only architecturally significant, but also pivotal in the broader context of building carbon emissions.

The aim of validating the energy model for Ranad Academy has been satisfactorily met. The model has been contrasted with actual energy consumption data, showcasing a strong correlation. The deviation of just 6.6% in cooling energy requirements indicates a successful validation process.

The objective of understanding the energy consumption pattern, particularly with a focus on space cooling, has been addressed. The analysis highlights space cooling as a major component of the building's energy consumption. Another objective was to use region-specific carbon emission factors for Qatar. This was achieved by sourcing data from the IPCC and Statista, ensuring the research was locally contextualized.

As for the exploration of net-zero carbon operation, the introduction of the concept of integrating a rooftop PV system has been proposed. The research suggests that covering around 48% of the building's rooftop with PV panels could notably offset the academy's operational carbon emissions. However, this is not economically beneficial with the current cost of electricity.

In conclusion, it can be said that all of the project's aim and objectives have been met. The energy model for Ranad Academy was validated successfully, the major energy consumption patterns (specifically space cooling) were identified, and a viable strategy for achieving a net-zero carbon operation was proposed and explored.

The energy model validation process undertaken for Ranad Academy is both detailed and rigorous. Specifically, the discrepancy in predicted energy consumption, especially regarding cooling energy requirements, exhibits a deviation of a mere 6.6%. This margin, while minimal, signifies the effectiveness and accuracy of the employed modelling process. Furthermore, a thorough examination of the energy consumption patterns of the building reveals a predominant emphasis on space cooling. This observation is vital, as it underscores the significance of space cooling in the building's overall energy consumption.

In terms of carbon emissions, the research employs region-specific carbon emissions factors for Qatar. These have been sourced from established and reputable databases, such as the IPCC and Statista. By leveraging these region-specific factors, the research provides a detailed understanding of both operational and embodied carbon emissions. The incorporation of this localized data ensures the findings are tailored and specific to the regional context of Qatar.

In a bid to realize a net-zero carbon operation for the academy, the research introduces the concept of integrating a rooftop PV system. By covering approximately 48% of the building's rooftop with PV panels, the study suggests that it's feasible to offset the academy's operational carbon emissions significantly. However, in the absence of any kind of tax or rebate on carbon emissions by the government, the net present value (NPV) suggested that the project has a negative NPV value, and therefor note feasible.

Limitations and recommendations:

The research, while comprehensive, does present a few potential sources of error. One prominent source stems from the reliance on weather data situated 60 km away from the actual site. Such a distance could introduce discrepancies, as it might not capture the microclimatic variations specific to the academy's location. The software used in energy modelling, though proficient, might have its inherent constraints. These limitations could lead to potential oversights in capturing intricate building aspects, especially the detail of HVAC design. Another pivotal assumption that the research hinges on is the building's lifetime. Projecting a 60-year life for the building might introduce deviations if this duration isn't realized in practice. Lastly, the assumptions surrounding the efficiency of the PV system, especially the 15% panel efficiency and default performance ratio, could vary with the specifics of the actual PV panels installed. Note that is the minimum achievable based on literature and market available products. Therefore, the 48% is a safe and conservative result.

For future endeavours in this realm, it is important to consider a few enhancements. Utilizing more localized weather data for energy modelling could be a pivotal step in refining the accuracy of the predictions. This move would circumvent potential inaccuracies arising from distant weather data sources. Moreover, employing more advanced and detailed software could prove beneficial. Such tools might offer deeper insights by incorporating more intricate building aspects, thus providing a more holistic energy model. Given the proposed integration of the PV system, a detailed economic analysis is essential. Evaluating the economic viability and potential return on investment becomes even more crucial in the context where electricity for public buildings is economically very low cost in Qatar. A suggestion of improved building envelopes has also been provided, mentioning improved glazing and reduced U-value as key considerations. Delving deeper into other carbon-emitting facets of the building, especially concerning construction materials, could provide a broader perspective on the building's carbon footprint. Finally, with the potential of the building producing surplus energy, it would be prudent to explore energy storage solutions or mechanisms for energy sharing with neighbouring infrastructures.

In summary, Renad Academy's commitment to understanding its energy consumption patterns and carbon emissions is evident. While the emphasis on operational carbon is clear, the academy's approach to understanding embodied carbon is also commendable. With the data collected and analyzed, the institution is well-positioned to implement strategies that further its sustainability goals, setting a benchmark for similar institutions in the region.

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